International PtX Hub

On behalf of:
Federal Ministry
for the Environment, Climate Action,
Nature Conservation and Nuclear Safety
of the Federal Republic of Germany

IKI INTERNATIONAL CLIMATE INITIATIVE

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giz Deutsche Gesellschaft
für Internationale
Zusammenarbeit (GIZ) GmbH

REPUBLIC OF KENYA
MINISTRY OF ENERGY AND PETROLEUM
State Department for Petroleum

Pre-Feasibility Study for the Development of a Power-To-Liquid Project for Sustainable Aviation Fuels in Kenya

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Abbreviations

AEL	Alkaline Electrolysis
AFLH	Annual Full Load Hours
Al_2O_3	Aluminum Oxide
ASAL / AI	Arid and Semi-Arid Lands / Aridity Index
ASTM	American Society for Testing and Materials
BESS	Battery Energy Storage Systems
BtL	Biomass to Liquid
CAPEX	Capital Expenditure
CCS	Carbon Capture and Sequestration
CfDs	Contracts for Difference
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CSDR	Combined Steam and Dry Reforming
DAC / LT-DAC / HT-DAC	Direct Air Capture / Low Temperature Direct Air Capture / High Temperature Direct Air Capture
DESTW	Dandora Estate Sewage Treatment Works
DIN	Deutsches Institut für Normung (German Institute for Standardization)
ECA	Export Credit Agencies
EEA	European Economic Area
EIA	Environmental Impact Assessment
EoI	Expression of Interest
EPC	engineering, procurement, and construction
EPRA	Energy and Petroleum Regulatory Authority
ESG	Environmental, Social, and Governance

ESIA	Environmental and Social Impact Assessments
EU	European Union
EU ETS	EU Emissions Trading System
EUR/kWel	Euros per Kilowatt Electric
FEED	Front-End Engineering Design
FID	Final Investment Decision
FM / DM	Fresh Mass (FM) / Dry Matter
FOAK	First of a Kind
FRL	Fuel Readiness Level
FT / FT-SPK / FT-syncrude	Fischer-Tropsch / Fischer-Tropsch Synthetic Paraffinic Kerosene / Fischer-Tropsch Synthetic Crude Oil
GH_2	Green Hydrogen
GH_2-PCC	Green Hydrogen Program Coordination Committee
GHAK	Green Hydrogen Association of Kenya
GHG / GHF	Greenhouse Gas / Greenhouse Gas Factor
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GSE	Ground Support Equipment
GWh	Giga-Watt Hour
h/a	Hours per Annum
HEFA	Hydro Processed Esters and Fatty Acids
HTFT / LTFT	High-Temperature Fischer-Tropsch / Low-Temperature Fischer-Tropsch
IATA	International Air Transport Association
ICAO	Internation Civil Aviation Organization
IFIs	International Financial Institutions
IPC	Integrated Food Security Phase Classification
IRR	Internal Rate of Return

ISCC	International Sustainability and Carbon Certification
JKIA	Jomo Kenyatta International Airport
KAM	Kenya Association of Manufacturers
KCAA	Kenya Civil Aviation Authority
KEBS	Kenya Bureau of Standards
KEPSA	Kenya Private Sector Alliance
KEREA	Kenya Renewable Energy Association
KPC	Kenya Pipeline Company
kW / kWh / kWp	Kilowatt / Kilowatt-hour / Kilowatt-peak
LCOE	Levelized Cost of Electricity
LCOS	Levelized Cost of Storage
LCPDP	Least Cost Power Development Plan
LHV	Lower Heating Value
LTWP	Lake Turkana Wind Power Station
LULC	Land Use/Land Cover
MBA	Moi International Airport
MEP	Ministry of Energy and Petroleum
MOGD	Mobil Olefins to Gasoline and Distillate
MRV	Monitoring, Reporting, and Verification
MSW	Municipal Solid Waste
Mt	Metric tonne / Million tonne
Mt/a	Million Tonnes per Annum
$MtCO_2eq$	Million Tonnes of Carbon Dioxide Equivalent
MtJ	Methanol-to-Jet
MtO	Methanol-to-Olefins

MTP	Medium-Term Plans
MWLHV	Megawatt Based on Lower Heating Value
NCCAP	National Climate Change Action Plan
NDC	Nationally Determined Contribution
NEMA	National Environment Management Authority
NPV	Net Present Value
OH	Hydroxyl Group
OPEX	Operational Expenditures
PBGtM	Power-and-BioGas-to-Methanol
PBtL	Power-and-Biomass-to-Liquids
PEMEL	Proton Exchange Membrane Electrolysis
ppb	Parts per Billion
PPP	Public-Private Partnership
PSA	Pressure Swing Adsorption
PtL	Power-to-Liquid
PtX	Power-to-X
PV	Photovoltaic
RED	The Renewable Energy Directive
RFNBOs	Renewable Fuels of Non-Biological Origin
RSB	Roundtable on Sustainable Biomaterials
RWGS	Reverse Water Gas Shift
SAF	Sustainable Aviation Fuel
SAPO-34	Silico-Aluminophosphate-34
SCS	Sustainability Certification Scheme
SOEC	Solid Oxide Electrolyzer Cell
SOEL	Solid oxide Electrolysers

SOW	Statement of Work
SPV	Special Purpose Vehicle
Syngas	Synthesis Gas
t/a	Tonnes per Annum
TRL	Technology Readiness Level
UNIDO	United Nations Industrial Development Organization
UOP	Universal Oil Products
vol %	Volume Percent
VS	Volatile Solids
W / MW / MWth / MWe	Watt / Megawatt / Megawatt Thermal / Megawatt Electric
WACC	Weighted Average Cost of Capital
ZnO	Zinc Oxide
ZSM-5	Zeolite Socony Mobil–5

Executive Summary

This report presents an in-depth pre-feasibility study for the development of a Power-to-Liquid Sustainable Aviation Fuel (PtL SAF) production facility in Kenya, with a particular focus on the Methanol-to-Jet (MtJ) pathway. The study provides a comprehensive assessment of market potential, feedstock and energy supply, technology selection, regulatory and policy frameworks, technical feasibility, economic and financial viability, and a practical roadmap for project implementation. Its findings and recommendations are intended to guide decision-makers, policymakers, investors, and stakeholders interested in advancing Kenya's role in the global transition to sustainable aviation fuels.

Objectives and Scope

The principal objective of this report is to evaluate the preliminary feasibility of establishing a commercial-scale PtL SAF production plant in Kenya, leveraging the country's significant renewable energy resources and its strategic position as an aviation hub in East Africa. The scope encompasses:

- Market analysis of SAF demand and stakeholder landscape
- Assessment of local feedstock and renewable energy supply options
- Comparative review of SAF production technologies
- Analysis of Kenya's regulatory and policy environment
- Site-specific technical pre-feasibility study
- Economic and financial modeling
- Development of a phased implementation roadmap

The methodology integrates quantitative data from government and industry sources, technical benchmarks, stakeholder consultations, and international best practices.

Key Findings

Market Analysis. Kenya's aviation sector is expanding rapidly, with passenger volumes exceeding 8.6 million in 2023 and aviation fuel consumption gross estimate at 887 million litres in 2021. Demand for SAF is driven by international airlines, increasing regulatory pressure, and Kenya's commitment to climate goals. The market is influenced by global frameworks such as ICAO's CORSIA and the EU's RED III, EU ETS and ReFuelEU Aviation, which impose strict sustainability and traceability requirements for SAF. While SAF production cost estimates remain higher than conventional jet fuel (currently 3–10 times greater), technological advances and policy incentives are narrowing this gap. Kenya's abundant renewable energy resources along with its biomass feedstock and growing aviation traffic makes the country a promising candidate for SAF production and export with right incentives and investments.

Feedstock and Energy Supply. Kenya offers diverse renewable energy resources, including solar, wind, geothermal, and hydropower, with competitive levelized costs of electricity (LCOE) ranging from 0.03–0.13 €/kWh depending on the energy source and location. The country also has substantial biogas and sustainable organic material potential from agricultural and food industry by-products (e.g. cattle manure, cut flower waste), invasive weeds (e.g. water hyacinth) and municipal solid waste. The choice for carbon supply can be biogenic for the medium term and direct air capturing (DAC) of CO_2 for the long-term, considering the cost and readiness of technology.

In addition, the demand for water poses a risk since Kenya's total land area is classified as arid and semi-arid land. Thus, the demand could be met by seawater desalination. Finally, to ensure a continuous electricity supply, the integration of battery energy storage systems (BESS) is recommended, especially for PV-based electricity.

Technology and Process Selection. The production of syngas based fuels can be separated into three different pathways depending on the feedstock. The here proposed Power-and-Biomass-to-Liquid process (PBtL) combines the advantages of the relatively cheap carbon source biomass with a high carbon efficiency through the additional use of green hydrogen. Since the technology after the syngas production is identical with pure power-to-liquid (PtL) processes, PBtL can act as an enabler for the implementation PtL processes in the future. The study evaluates the process routes for the conversion of syngas into SAF: Fischer-Tropsch and Methanol-to-Jet (MtJ), recommending the MtJ route for its resilience towards a fluctuating amount of feedstock, higher degree of modularity, lower logistics costs and the production of a valuable intermediate with an already established market **(Table 0-1)**. The proposed PBtL plant configuration combines biogas reforming and electrolysis, requiring 32 MW of electricity and producing 21,900 tonnes of SAF annually via the MtJ process, alongside naphtha and heavy diesel co-products. Technology readiness is progressing, but pilot-scale demonstration is advised to validate process integration and performance under Kenyan conditions.

Regulatory and Policy Framework. Kenya's policy environment is supportive of renewable energy and climate mitigation, but specific SAF regulations and certification pathways are still evolving. Compliance with international sustainability standards (CORSIA, ASTM, ReFuel EU, RED II & III) is critical for market access and eligibility for carbon credits and create a coherent legal and economic framework favourable to the production and export of PtL SAF from Kenya. Licensing and permitting processes must be streamlined, and alignment with recognized sustainability certification schemes (e.g., ISCC, RSB) is recommended to facilitate export and investment.

Technology Pre-Feasibility. A suitable site assessment for three locations in Kenya (Olkaria, Nairobi and Mombasa) was conducted **(Table 0-2)**. These areas have been selected for their favorable site characteristics, namely proximity to renewable energy potential, land, and skilled labour availability, feedstock supply, grid infrastructure, water supply and proximity to the end user. Nairobi and Mombasa feature the two largest airports in Kenya while Olkaria exhibits the highest renewable energy potential. Conceptual process design confirms technical viability and compliance with environmental and sustainability requirements.

Table 0–1: Qualitative Comparison of the FT-Based and Methanol-Based Production Routes from CO_2 and H_2 (FT: Fischer-Tropsch, MeOH: Methanol)

			FT	MeOH
Technical aspects	Carbon efficiency	Total fuel	+	–
		Kerosene	–	+
	Energy efficiency	Total fuel	+	–
		Kerosene	–	+
Systemic aspects	Maturity	Process	o	o
		Fuel	+	–
	Flexibility	Feedstock	o	o
		Intermediate Products	–	+
		Operation	–	+
Economic aspects	Production costs	Total fuel	+	–
		Kerosene	–	+

inferior	neutral	superior
🟦	⬜	🟩

Table 0–2: Assessment of the Area Identification

Criteria	Olkaria	Nairobi	Mombasa
Renewable Energy Potential	+	0	-
Land Availability	+	-	0
Skilled Labour Availability	-	+	0
Feedstock Supply	-	+	0
Water Availability	-	0	+
Electricity Grid	+	0	-
Proximity of Potential SAF Off-takers	-	+	0
Transport Limitation	-	0	+

Disadvantageous Conditions	Neutral Conditions	Advantageous Conditions
🟦	⬜	🟩

Non-financial risks – including feedstock supply, technology integration, and market development – can be assessed with mitigation strategies such as long-term contracts, pilot projects and stakeholder engagement. Table 0–2 shows that Olkaria has the highest renewable energy potential, ample land and no grid constraints, but struggles to attract skilled labor and has the lowest water availability among the three sites. Nairobi has strong renewable energy potential, reliable local feedstocks (municipal solid waste, sewage), available skilled labor, good grid connection and transport links with access to three airports, but limited land and potential conflict between groundwater use for electrolysis and drinking-water supply. Mombasa's location on the coast enables water use from desalination and entails a major airport and seaport, offering off-taker potential.

Economic and Financial Analysis. The financial model estimates a levelized cost of the proposed PBtL SAF at 4,500 EUR/t, exceeding current market prices benchmarked for other SAF routes by 1,600–2,200 EUR/t.

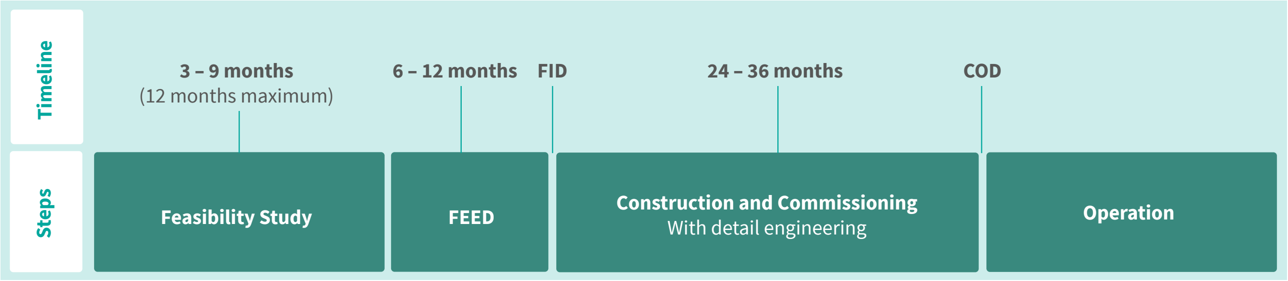
The gap between the estimated SAF and current market price indicate necessary support via government policy or premium SAF contracts will be required. Economic viability depends on achieving a SAF market premium (~30 % above conventional jet fuel), optimizing co-product revenues, and accessing concessional finance from development institutions (e.g., EIB, KfW, AfDB). Key risks include feedstock supply, technology integration, market development, and financing. Sensitivity analysis highlights feedstock costs, market pricing, and regulatory support as decisive factors for project returns.

Roadmap and Next Steps. The report outlines a structured roadmap for project development, advancing from pre-feasibility to Final Investment Decision (FID). Figure 0–1 shows the milestones and the estimated timeline until operation of the plant.

1. Expression of Interest (EoI): Submission to the Ministry of Energy and Petroleum, accompanied by a pre-feasibility study and identification of project partners, financing, and offtakers.
2. Feasibility Study: Comprehensive evaluation of site-specific feedstock, technical and economic viability, and alignment with national and international sustainability standards. Includes Environmental and Social Impact Assessment (ESIA) and securing certification under CORSIA-approved schemes.
3. Front-End Engineering Design (FEED) Study: Detailed technical plant design, finalization of feedstock and offtake agreements, comprehensive risk assessment, and preparation for permitting and land acquisition.
4. Final Investment Decision (FID): Consolidation of engineering, financial, and regulatory documentation to enable project financing and execution readiness.
5. Construction and Commissioning with detail engineering.
6. Commercial operation date (COD): Commissioning tests have been passed and plant starts to produce.
7. Operation of the plant.

Early and ongoing stakeholder engagement, policy advocacy, and pilot demonstrations are recommended to build market confidence and regulatory clarity.

Figure 0–1: Next Steps and Timeline of the Project



Introduction

The global aviation sector faces increasing pressure to decarbonise in line with international climate commitments. Sustainable Aviation Fuel (SAF), and in particular Power-to-Liquid (PtL) pathways based on renewable hydrogen and captured carbon dioxide, are emerging as a key lever to reduce greenhouse gas emissions in hard-to-abate aviation activities. Against this background, Kenya is well positioned to play a pioneering role in SAF production, thanks to its abundant renewable energy potential, established expertise in geothermal and other renewable technologies, and its strategic location as a regional aviation hub.

The Government of Kenya has demonstrated strong commitment to this transition through its Green Hydrogen Strategy and Roadmap (2023–2032), which identifies SAF as a priority product in the development of a national hydrogen economy. Complementary initiatives, including the National Action Plan for Aviation and the establishment of a National Steering Committee on SAF, further underscore Kenya's ambition to become a leader in the deployment of low-carbon fuels.

It should be noted that the hydro processed esters and fatty acids (HEFA)-based SAF pathway is not included in this prefeasibility study. In the current discussions and studies on SAF for Kenya, bio-based pathways such as the hydro processed esters and fatty acids (HEFA)-based SAF pathway are being discussed with great interest, indicating a significant potential. A preliminary assessment for Kenya has indicated that biomass-based SAF production via HEFA could already be economically competitive at the global average SAF price [8]. Although HEFA-based SAF production accounts for the largest share of SAF production in the global market and is expected to continue increasing in the near term, the sectoral discussion also includes the concern that sustainable availability of suitable feedstocks is inherently limited. Consequently, to meet the growing SAF demand necessary to achieve CO_2 reduction targets, the development of alternative production pathways is essential to broaden the range of feedstock options and ensure long-term scalability [9]. In this context, this study aims to complement the discussion and shining light onto the potential of PtL pathways for SAF in Kenya. It should be noted that the HEFA-based SAF pathway is not included in this prefeasibility study.

The purpose of the study is not only to determine the preliminary conditions for a viable SAF project but also to highlight transition pathways that combine biomass residues with renewable electricity in hybrid Power-and-Biomass-to-Liquids (PBtL) configurations. In doing so, it seeks to inform decision-makers, investors, and industry stakeholders about Kenya's potential to supply both domestic and export markets while meeting international sustainability and certification standards.

This prefeasibility study, commissioned under the International Power-to-X Dialogue Project and supported by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), provides a high-level technical and economic assessment of opportunities for developing a PtL SAF plant in Kenya. Building on earlier studies and recent policy initiatives, it evaluates market dynamics, feedstock and energy availability, technology options, regulatory frameworks, potential sites, and financial viability.

Ultimately, the results of this prefeasibility study are intended to support the Kenya's Ministry of Energy and Petroleum in implementing the national Green Hydrogen Strategy and to guide the next steps towards a full feasibility study and eventual project development.

1

Market Analysis

Douglas Liner and Francis Njoka

The market for Sustainable Aviation Fuel (SAF) in Kenya is driven mainly by the country's position as an international and regional aviation hub in East Africa, demand from the main international airlines including Kenya Airways, and government policy/international regulations regarding the shift to SAF. On the supply side, Kenya benefits from an abundance of renewable feedstock options ranging from sugarcane residues (bagasse), water hyacinth, and municipal solid waste among others as well as production opportunities.

The development of the Kenyan SAF market depends upon investments in transformation technology to collect, transform and deliver the necessary SAF quantities to satisfy aviation fuel demand. Current air traffic in Kenya is estimated at 8.6 million annual passengers in 2023 [1] while the most recent total aviation fuel consumption gross estimate in Kenya was 887 million litres in 2021 [2] SAF can satisfy a portion of this growing market in line with international regulations and commitments to blend SAF and aviation fuel.

The pricing of SAF in Kenya depends on several factors. The abundance of renewable energy sources and biomass feedstock is a positive factor, as is the potential for carbon credits from the national and international markets, however, the required investments in technology and infrastructure to produce, collect, process, transform and distribute the SAF will entail concerted organization, government support and costly up-front infrastructure costs. Currently, the production of SAF is estimated to cost anywhere from 3 to 10x the cost of conventional fuel although this multiple is falling with improvements in technology [3]. Given the right incentives, the SAF market has a strong potential to tap the growing demand for aviation fuel in Kenya and the region and serve as an example to other countries with abundant renewable energy sources and rising tourism/commercial aviation traffic.

The development and export of SAF in Kenya, particularly Power-to-Liquid (PtL) SAF, are strongly influenced by international and European regulations. Key frameworks include ICAO's CORSIA, which incentivizes airlines to use certified SAF for emissions reduction, and several European Union regulations such as RED III, ReFuelEU Aviation, and the EU Emissions Trading System. These regulations establish strict sustainability, traceability, and emissions reduction standards that Kenyan SAF producers must meet to access international and EU markets. Ensuring compliance with these global standards is crucial for attracting investment, securing offtake agreements with international airlines, and positioning Kenya as a credible supplier in the growing global SAF market.

1.1 Stakeholder Analysis

1.1.1 Description of Main Stakeholders in Kenyan SAF market

1.1.1.1 Demand Side

Table 1–1 : Summary Table: Aviation Fuel Demand in Kenya (2016)

Stakeholder Category	Entity/ Location	Annual Aviation Fuel Demand [4] (million litres)	% of Market	% of International Flights
1. Fuel Demand				
Nairobi	**JKIA**	**713**	**91 %**	**94.5 %**
Mombasa	Moi International Airport	60	8 %	5.5 %
Kisumu	Kisumu International Airport	7	0.8 %	0 %
Eldoret	Eldoret International Airport	4	0.5 %	0 %
	Sub-total	**783**	**100 %**	**100 %**
2. Airline Demand				
Kenya Airways	National carriers (all airports)	277	35 %	40 %
International Airlines	Various foreign carriers	414	53 %	60 %
Regional/Domestic	Various	92	12 %	0 %
	Sub-total	**783**	**100 %**	**100 %**
3. Flight Type				
International	All international carriers	691	88 %	100 %
Regional	Regional carriers	34	5 %	n/a
Domestic	Domestic carriers	58	7 %	n/a
	Sub-total	**783**	**100 %**	**100 %**

From a demand perspective, most aviation fuel (91 %) in Kenya is currently [5] uplifted at Jomo Kenyatta International Airport (JKIA) for international flights. Among the other national airports, Mombasa accounts for 8 % while Kisumu and Eldoret combined account for 1.3 %. Airline demand for aviation fuel is split between international airlines at 53 %, Kenyan Airlines, the

national carrier, at 35 % and domestic and regional airlines accounting for the remaining 12 %. Aviation fuel demand by flight type is overwhelmingly international at 88 %, while regional and domestic flights account for 5 % and 7 % respectively. Aside from airlines, there is some limited aviation fuel demand by ground service equipment companies (Kenyan Airways, Kenya Aerotech and others). Note that that reference data is from 2016 and that changes may have occurred since this period, however, the fundamental takeaway is that most aviation fuel is consumed at JKIA, by different international airlines, including Kenya Airlines for use on international flights. There is some demand by Kenyan Airlines and other carriers for use on regional and domestic flights.

Several international airlines currently serving JKIA have either regulatory or corporate commitments to SAF adoption by 2030.

International Airlines Commitments to SAF:

- Emirates: 3 million gallons (11.4 million litres) blended SAF supply deals 2024-2025
- Qatar Airways: Target 10 % SAF use by 2030
- British Airways: Target 10 % SAF use by 2030
- Turkish Airlines: Carbon Neutral by 2050 (introducing SAF)
- Kenya Airlines: Fly Carbon Net Zero by 2050 through partnership with International Air Transport Association (IATA)
- KLM: Member of SkyTeam global airline alliance with group SAF challenges and EU commitments (average of 2 % SAF fuel at EU airports by 2025)
- Air France: 10 % SAF use by 2030 and 63 % by 2050
- These commitments to SAF use, especially by Emirates, Qatar Airways, and British Airways given their traffic through JKIA, support SAF development in Kenya.

Table 1–2 : Place in Value Chain of Demand Side Stakeholders

Place in value chain	Stakeholder	Justification
Demand Side	Kenya Airways	Kenya Airways alone accounts for 40 % of aviation fuel demand for international flights. It can be an important anchor customer for SAF adoption locally.
	International Airlines	Several international airlines already have SAF commitments and regulatory-driven demand that make SAF introduction at JKIA economically viable.

1.1.1.2 Supply Side

The primary stakeholders involved in a future SAF market in Kenya includes several categories. The three main categories are producers/collectors, transformers and infrastructure providers.

Producers/collectors

As SAF can be derived from different feedstocks abundant in Kenya, there needs to first be a selection of feedstock (sugarcane (bagasse), water hyacinth, etc) or the municipal waste or other sources. The second step involves negotiating long-term supply contracts with the potential stakeholders that possess this feedstock.

Table 1–3 : Producers/Collectors Category

Category	Feedstock Type	Example Stakeholders
Municipal Waste	Municipal Solid Waste	County governments, municipal waste operators, e.g. Nairobi, Mombasa, Kisumu
Agricultural Residues	Sugarcane (Bagasse)	Sugar Mills, Farmer Cooperatives
Water Hyacinth	Aquatic Biomass	Lake Victoria Basin Commission (LVBC)

Biodiesel Producers/ Transformers

A specialized, commercial entity to transform the feedstock into certified SAF aviation fuel is required. Based on the feedstock choice, this entity will employ different processes to reach the required SAF standards. In terms of stakeholders, one could potentially choose an existing Biodiesel Producer in Kenya or establish a dedicated Greenfield project entity (which would most likely require more time and effort).

Table 1–4: Biodiesel Producers/ Transformers Category

Category	Example Stakeholders
Biodiesel Producers	Eco-Fuels Kenya, Nanyuki, Kenya Zijani, UCO Nairobi, Kenya
Greenfield Project Company	“Kenya SAF Conversion Ltd”

Infrastructure Providers

To supply JKIA with the certified SAF, one must rely on the exiting fuel supply and distribution networks in Kenya. These stakeholders already handle conventional aviation fuel supply in Kenya and would have to adapt the infrastructure to handle blended SAF. Currently, all jet fuel in Kenya is imported through the port of Mombasa and a strategic pipeline connects it to major airports [6]. The main stakeholders are:

Table 1–5: Infrastructure Providers

Category	Example Stakeholders
Fuel Supply	Total Kenya/ other fuel suppliers
Fuel Distribution (to JKIA and other airports)	Kenya Pipeline Company (KPC)

Finally, to support the development of SAF in Kenya, different Kenyan associations and research organizations may be contacted to identify the most promising feedstocks, and feasible conversion channels to SAF.

Table 1–6 : Place in Value Chain of Supply Side Stakeholder

Place in value chain	Stakeholder	Justification
Supply Side	County/Municipal governments (Nairobi, Mombasa, etc.)	Municipal Solid Waste feedstock
	Sugar mills, Farmer Cooperatives	Sugarcane (Bagasse) feedstock
	Lake Victoria Basin Commission	Water Hyacinth feedstock [7]
	Biodiesel Producers	Experience with renewable conversion, Kenyan market practices
	Greenfield Company	Specialized SAF technology option
	Total Kenya/ other fuel suppliers	Fuel supply infrastructure
	Kenya Pipeline Company (KPC)	Fuel Distribution to JKIA and other airports
	Kenya Agricultural and Livestock Research Organisation (KALRO)	A state corporation established to co-ordinate and advance agricultural research in Kenya. Can provide data and useful insights on potential crops and available quantities which can be used as feedstock for SAF production.
	Kenya Association of Hotel Keepers and Caterers (KAHC)	An association comprising various large hotels and resorts that can provide useful insights on the availability and potential quantities of waste oils from cooking as a possible source of SAF feedstock.

1.1.1.3 Government Ministries and Regulatory Bodies

Kenya has several line ministries and regulatory bodies that are involved with the development of SAF in the country. Indeed, different aspects of SAF impact transport, agriculture, environment and energy sectors, as examples. In practice, a dedicated steering committee, or sub-committee of existing climate change coordination entity would probably be required to oversee the development of SAF in Kenya according to existing laws, government policy and international agreements

1.1.1.4 Government Ministries and Regulatory Bodies

Kenya has several line ministries and regulatory bodies that are involved with the development of SAF in the country. Indeed, different aspects of SAF impact transport, agriculture, environment and energy sectors, as examples. In practice, a dedicated steering committee, or sub-committee of existing climate change coordination entity would probably be required to oversee the development of SAF in Kenya according to existing laws, government policy and international agreements.

Table 1–7 : Place in Value Chain of Government Ministries and Regulatory Bodies

Place in value chain	Stakeholder	Justification
	Government Bodies	
Regulatory Bodies	Ministry of Roads and Transport (State Department for Transport)	• Formulate policies with regards to aviation, including international aviation agreements • Formulate regulations and guidelines that operationalise laws relevant to/impacting on the SAF sector. Fuel procurement oversight. Biofuel strategy devilment and Steering Committee Secretariat. • Enforces the regulatory framework • Climate Change Act implementation; Environmental Standards
	Ministry of Energy and Petroleum	
	Ministry of Agriculture	
	Ministry of Environment and Natural Resources	
	Regulatory Authorities/Bodies	
	Kenya Civil Aviation Authority (KCAA)	• Regulates the sector and players in the sector Develops relevant guidelines that can impact on the SAF industry in Kenya Fuel Quality Certification, ASTM compliance verification • Fuel Pricing and licensing and market oversight
	Energy and Petroleum Regulatory Authority (EPRA)	
	Kenya Bureau of Standards	
	Energy Regulatory Commis-sion	

1.1.1.5 Government Ministries and Regulatory Bodies

Kenya has several line ministries and regulatory bodies that are involved with the development of SAF in the country. Indeed, different aspects of SAF impact transport, agriculture, environment and energy sectors, as examples. In practice, a dedicated steering committee, or sub-committee of existing climate change coordination entity would probably be required to oversee the development of SAF in Kenya according to existing laws, government policy and international agreements.

1.1.1.6 Supporting Institutions

Several stakeholders already operating in Kenya can support the institutional and commercial environment for the development of SAF. These include professional associations, academic institutions and international financial institutions. An indicative list of these supporting institutions is provided on the next page:

Table 1–8 : Place in Value Chain of Supporting Institutions

Place in value chain	**Stakeholder**	**Justification**
Supporting	International Financial Institutions: World Bank, African Development Bank, Green Climate Fund, UNIDO, GIZ, and others	Various programmes focussed on GH_2, and synergies could be harnessed to support SAF projects in Kenya. The World Bank is providing support to Kenya's green energy transition, via policy and renewable energy project support
	International/Regional entities: AU	Regional initiatives promote SAF development.
	Green Hydrogen Association of Kenya (GHAK)	The association brings together private stakeholders in Kenya within the GH_2 industry and can provide key insights on sector developments and the different private sector players operating in the industry.
	Kenya Private Sector Alliance (KEPSA) – Energy Sector Board	Hosts a Bioenergy sub-committee that played a key role in development of the Kenya's Bio-energy Strategy (2020 – 2027). Can provide key information on feedstock potential, suppliers and other key insights.
	Kenya Association of Manufacturers (KAM)	A private sector association of industry players in Kenya's manufacturing sector. Can provide good linkages to industries in the edible oils manufacturing sector.
	Kenya Renewable Energy Association (KEREA)	A non-profit organisation that hosts a digital Bioenergy Innovation Platform that fosters bioenergy development. Can be a good source of data/information about potential feedstock for SAF production and existing or ongoing innovations.
	Academic Institutions e.g. Strathmore University, possibly Jomo Kenyatta University and University of Nairobi	Potential source of information or data/ re-search and training activities/programmes relevant for/to SAF production in Kenya.

1.1.2 Stakeholder Mapping Charts

1.1.2.1 Value Chain

The following is a mapping of the main stakeholders with respect to the central value chain of SAF production in Kenya:

Figure 1–1 : Value Chain and Main Stakeholders

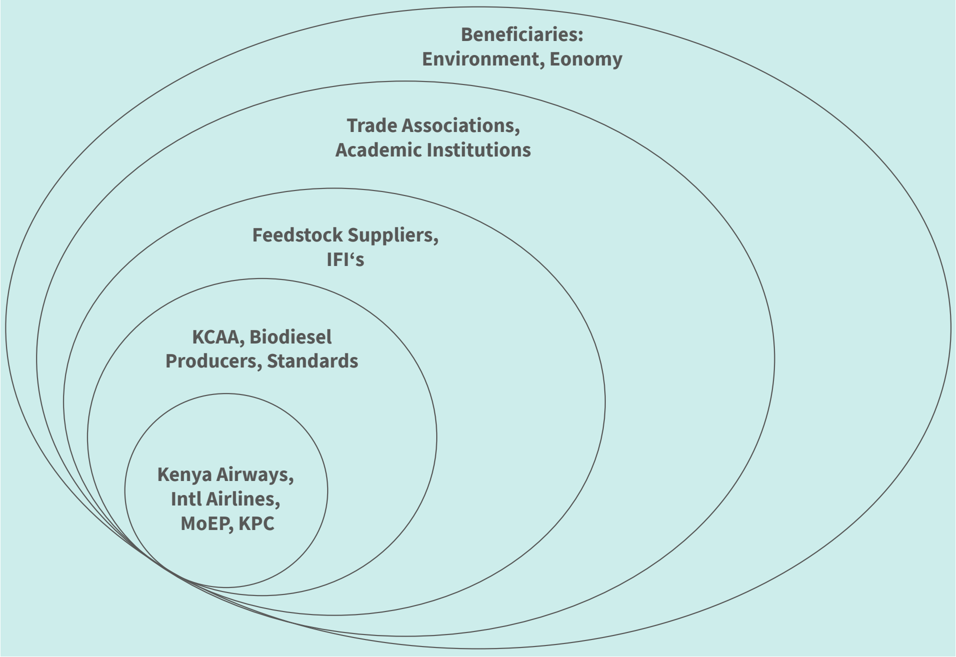
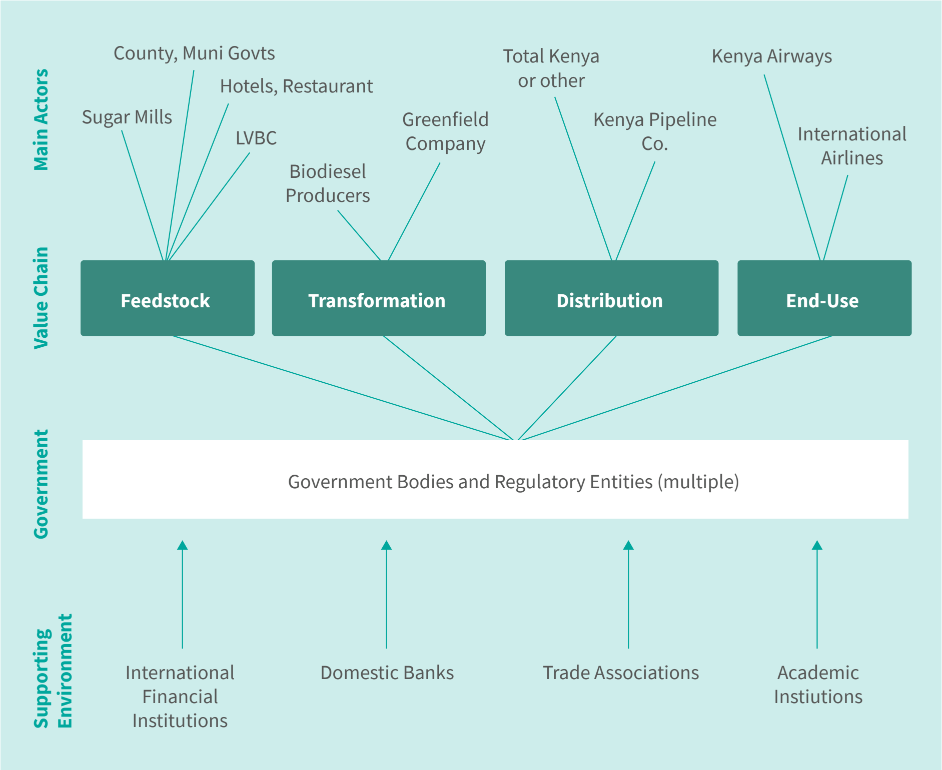


Figure 1–2 : Stakeholder Mapping: Core Decision Makers



1.1.3 Concentric Circles

The following is a stakeholder mapping of the main stakeholders in the SAF Development in Kenya. The central decision makers are at the core, followed by less important stakeholders towards the periphery. The last circle represents, generally, the end beneficiaries, the environment and the economy

1.2 SAF Demand Analysis

This analysis builds on the stakeholder analysis. **Table 1–1**: Aviation Fuel Demand in Kenya (2016) already presents the known salient points regarding the aviation fuel market in Kenya to identify the stakeholders from a demand perspective in the future SAF market. Based on these fundamentals, the future SAF market will likely be centred around international flights from JKIA in Nairobi, with the international airlines including Kenya Airways accounting for most of the demand. To the extent that SAF use is expanded domestically and regionally, it is possible that additional demand could come from other secondary airports, including Moi International Airport in Mombasa. Finally, SAF adoption and competitive pricing in Kenya could differentiate it from other East African airports and become a SAF refuelling hub for regional airline companies with SAF commitments.

1.2.1 Demand in Kenyan Airports

SAF Demand is likely to be concentrated at JKIA in Nairobi over the medium term. This stems from historical traffic patterns, the existence of supporting infrastructure and services (KPC and GSE companies) to support the strong international demand, as well as the regulatory push facing international airlines and Kenya Airways (CORSIA, EU and UK mandates). This concentration may also present an economic advantage since SAF fuel contracts can be negotiated with a small number of stakeholders as opposed to the situation with multiple sites and stakeholders a more diversified market.

Regarding Kenya’s secondary airports, Moi International Airport (MBA) already accounts for 8 % of the aviation fuel market. Though air traffic is limited compared to JKIA, MBA does have international connections which increase the demand for SAF. For example, in 2018, Qatar Airlines announced 4 x weekly direct flights to MBA, however this service was subsequently suspended during the Covid 19 pandemic. [8] Despite Qatar’s exit, service levels have returned close to pre-pandemic levels and different airlines have entered to fill the gap. In 2022, Condor airlines resumed 3 x weekly service to Frankfurt, while Ethiopian airlines began twice daily service to MBA in 2023. It should be noted that sugar cane (bagasse) production in Kenya is concentrated along the coastal areas.

Finally, SAF demand at other airports, Kisumu and Eldoret will remain limited in the medium term. Traffic to these airports is limited and is mainly domestic. To the extent that traffic increases to these destinations and Kenya Airways serves them, there could be a limited future demand for SAF at these sites.

1.2.1.1 Regional Demand (East Africa)

East African aviation fuel demand statistics and potential SAF demand can be extrapolated from OAG African Aviation Market Analysis statistics:

Table 1–9 : Estimated Regional Annual Aviation Fuel Demand (by Country) at JKIA

Origin Country	Flights to Kenya	Annual Fuel Demand (est.)
Tanzania	Air Tanzania, others (20 +/w)	15-20 million litres
Uganda	Uganda airlines/ others (15 +/w)	10-15 million litres
Rwanda	Rwandair (10 +/w)	8-12 million litres
Ethiopia	Ethiopian Airlines (25+/w)	25-30 million litres
Other EAC	Various (10+)	5-10 million litres
Total		**63-87 million litres**

Based on a hypothetical 10 % requirement for SAF by 2030, this would translate to an annual SAF demand of 6.3 to 8.7 million litres. This is of course based on the commitments of the different airlines. For the moment, a cursory review of East Africa airlines commitments related to SAF indicates:

- Ethiopian Airlines already uses a 30 % SAF blend with its Airbus A350-900 aircraft and has established SAF production facilities in Ethiopia.
- Rwandair is expanding connections to Kenya and has a sustainability focus, but no public SAF commitments.
- Uganda Air is committed to achieving net zero emissions by 2050, which may include the use of SAF.
- Air Tanzania is expanding its regional East African network but has no public SAF commitments.

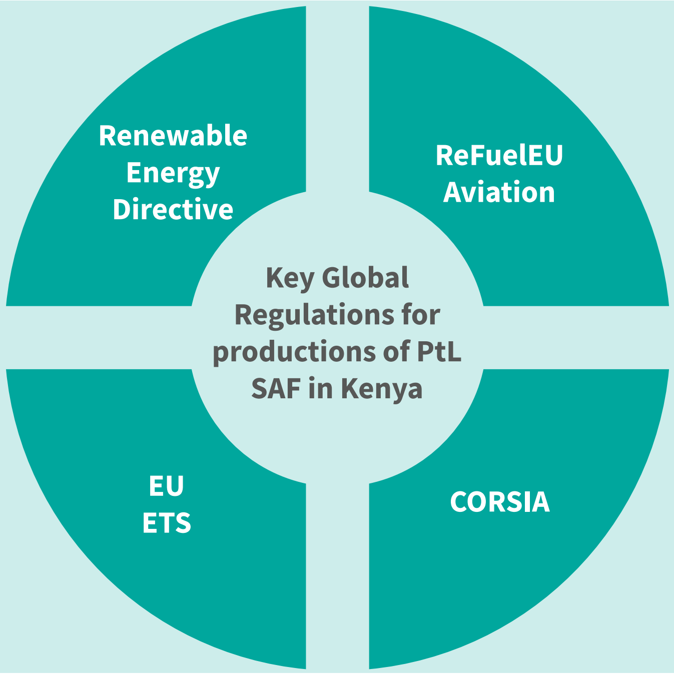
Finally, despite the fragmented appearance, the air traffic is projected to grow at 5 % annually in the region and there are initiatives to create a single regional aviation market, which could lead to a more consistent demand for SAF in the medium-long term. Kenya could position itself to deliver SAF in this growing market, although it may face competition from Ethiopia which has already launched different SAF initiatives.

1.3 International Market Driving Regulations for PtL SAF

This subchapter provides a high-level overview of market driving international regulations that are relevant to the present pre-feasibility study for PtL SAF production in Kenya. They key market driving international regulations for PtL SAF relevant to the present pre-feasibility comprise the following international and European regulations:

- The Carbon Offsetting and Reduction Scheme for International Aviation (“CORSIA”)[7]
- The Renewable Energy Directive (RED III)[8]
- Commission Delegated Regulation (EU) 2023/1184 that establishes common rules for the production of renewable liquid and gaseous transport fuels of non-biological origin [9]
- The ReFuelEU Aviation Regulation [10], and
- The EU Emissions Trading System (EU ETS)[11]

Figure 1–3 : Key Global Regulations for Production of PtL SAF in Kenya

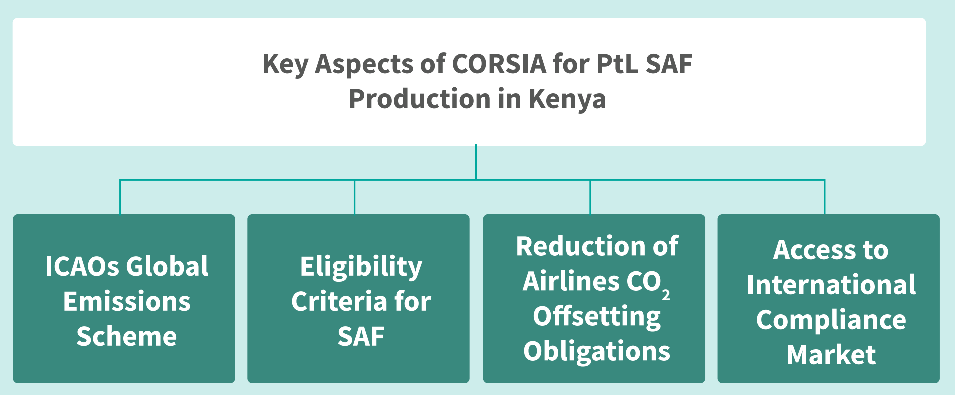


1.3.1 Key International Regulatory Framework for PtL SAF: ICAO CORSIA

The key global regulatory instrument that is relevant to the present pre-feasibility study on production of PtL SAF in Kenya is the Carbon Offsetting and Reduction Scheme for International Aviation ("CORSIA"). CORSIA is a multilateral market-based mechanism adopted by the Internation Civil Aviation Organization (ICAO) in 2016 that forms part of the Convention on International Civil Aviation (Chicago Convention) [12] and that aims to cap net CO_2 emissions from international aviation at 2019 levels.

CORSIA operates through a phased approach. While the initial pilot phase (2021–2023) and first phase (2024–2026) involve voluntary participation by States, the scheme becomes mandatory for most ICAO Member States from 2027 onward, subject to specified traffic volume thresholds. Participating aircraft operators are required to monitor, report, and verify their annual emissions from international flights and to offset any emissions exceeding the established baseline through the acquisition and surrender of eligible emissions units. However, in lieu of offsets, aircraft operators are entitled under the scheme to reduce their compliance obligations by using CORSIA-eligible Sustainable Aviation Fuels (SAF), provided these fuels meet the prescribed environmental and sustainability criteria.

Figure 1–4 : Key Aspects of CORSIA for PtL SAF Production in Kenya



Power-to-Liquid Sustainable Aviation Fuel (PtL SAF) qualifies as a CORSIA-eligible fuel if it is produced via an ICAO-approved fuel production pathway, demonstrates a minimum of 10 % lifecycle greenhouse gas (GHG) emissions reduction compared to conventional jet fuel, and is certified under an ICAO OCOA recognised sustainability certification scheme. Furthermore, the fuel must be supported by robust documentation within an ICAO-compliant monitoring, reporting, and verification (MRV) system, ensuring traceability of inputs, production processes, and emissions calculations.

In the context of this pre-feasibility study on PtL SAF production in Kenya, CORSIA holds significant strategic relevance. As a global compliance framework, it enables PtL SAF produced outside the European Union—including in developing economies such as Kenya—to access a growing international market for emissions-reducing aviation fuels. Airlines operating under CORSIA face direct financial incentives to procure SAF, thereby creating a demand driver that extends beyond regional regulations such as the EU's ReFuelEU Aviation and Emissions Trading System.

Ensuring CORSIA eligibility will be critical for securing offtake agreements with international carriers, improving project bankability, and ensuring regulatory credibility in export markets for SAF producers in Kenya. Early alignment with CORSIA's sustainability framework, including adherence to approved production pathways, and the use of recognized certification systems, is therefore an essential requirement for any developer of PtL SAF project in Kenya. from the early stages of technical design of the any promoter of a PtL SAF project in Kenya. Such alignment should be established and demonstrated from the earliest stages of project planning and development to ensure regulatory compliance, eligibility for international recognition, and market acceptance.

1.3.2 The EU Legal and Regulatory Framework for PtL SAF

As the European Union accelerates its transition toward climate neutrality, the demand for sustainable aviation fuels (SAF) in the EU —particularly synthetic fuels such as Power-to-Liquid (PtL) SAF — is expected to increase significantly in short- and medium term. For countries like Kenya with its abundant renewable energy potential this presents a unique strategic opportunity to position themselves as exporters of climate-compliant aviation fuels to the EU market. However, market access is contingent upon strict adherence to a complex legal and regulatory framework established by the European Union to ensure environmental integrity, traceability, and emissions reduction.

The key EU legal and regulatory relevant to the present pre-feasibility study is comprised by the following four interrelated and complementary legal instruments:

- The Renewable Energy Directive (RED III)
- Commission Delegated Regulation (EU) 2023/1184 establishing common rules for the production of renewable liquid and gaseous transport fuels of non-biological origin
- The ReFuelEU Aviation Regulation, and
- The EU Emissions Trading System (EU ETS)

Each of these instruments plays a distinct but complementary role. RED III establishes the sustainability and greenhouse gas (GHG) performance criteria that fuels must meet to be considered renewable. The ReFuelEU Aviation Regulation creates binding obligations for the use of SAF within the EU aviation sector, thereby generating demand. The EU ETS, meanwhile, provides a financial incentive for the use of certified SAF by treating it as zero-emission for compliance purposes. This text provides a comprehensive explanation of each of these instruments and analyses their relevance for the production and export of PtL SAF from Kenya.

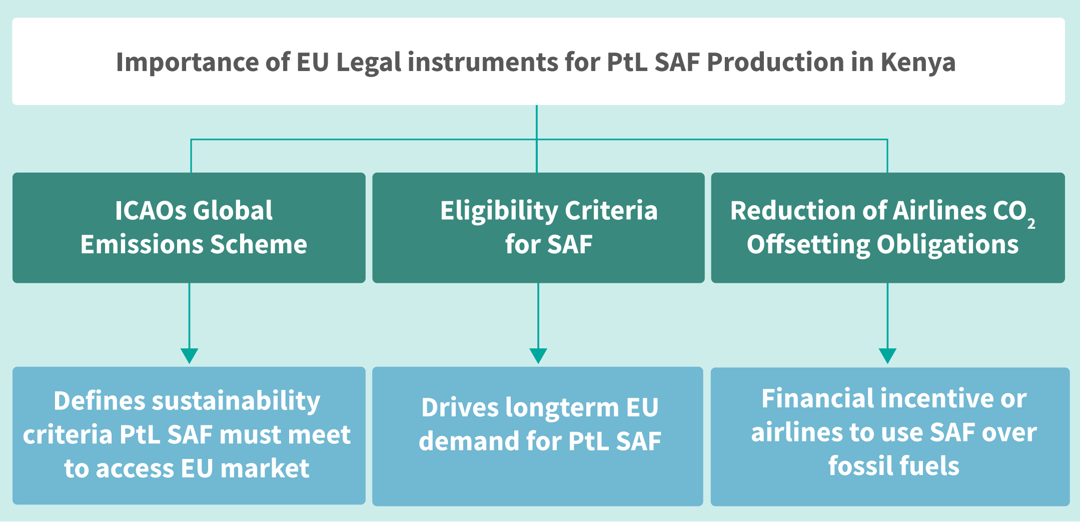


Figure 1–5 : Importance of EU Legal Instruments for PtL SAF Production in Kenya

1.3.2.1 Renewable Energy Directive (RED III)

The Renewable Energy Directive (Directive (EU) 2018/2001, as amended by Directive (EU) 2023/2413—RED III), presents the key EU legal framework for promoting energy from renewable sources across all sectors, including transport. Relevant to the present pre-feasibility study the RED III among others introduces rigorous sustainability and GHG reduction criteria that must be met for fuels to be classified as renewable and enable them to count towards the EU climate and energy targets.

Of particular relevance for PtL SAF is the Directive's definition and treatment of Renewable Fuels of Non-Biological Origin (RFNBOs), which include synthetic aviation fuels produced from renewable electricity and captured carbon dioxide. To qualify under RED III as RFNBO, PtL SAF must be produced using 100 % renewable electricity. The specific criteria for determining whether electricity used for the production of renewable liquid and gaseous transport fuels of non-biological origin can be considered fully renewable within the meaning of the RED III are set forth by the Commission Delegated Regulation (EU) 2023/1184 that establishes common rules for the production of renewable liquid and gaseous transport fuels of non-biological origin. In addition, PtL must achieve a minimum of GHG emissions saving of 70 % compared to fossil-derived aviation fuel and must be independently certified by an EU-recognised voluntary scheme such as for example the ISCC EU [9].

For PtL SAF produced in Kenya, the RED III thereby sets the regulatory conditions that must be met for any PtL SAF to be considered compliant within the EU. Without certification as renewable under RED III, PtL SAF produced in Kenya may not be marketed as renewable aviation fuel in the EU, nor would such fuels count towards fulfilling the obligations established under other EU climate instruments. The provision of the RED III are thus of key importance for PtL SAF produced in Kenya in terms of legal recognition and market eligibility in the EU.

1.3.2.2 ReFuelEU Aviation Regulation

The ReFuelEU Aviation Regulation (Regulation (EU) 2023/2405) presents the EU's sector-specific response to the challenge of decarbonising air transport. Relevant to the present pre-feasibility study the ReFuelEU Regulation among others establishes mandatory minimum shares of SAF that must be blended with conventional jet fuel at EU airports, beginning at 2 % in 2025 and increasing incrementally to 70 % by 2050 and introduces a sub-mandate specifically for synthetic aviation fuels, starting at 1.2 % by 2030 and gradually rising up to 35 % by 2050.

The ReFuelEU Regulation builds upon the definitions and sustainability criteria established in RED III. Only fuels that comply with RED III may be counted toward the ReFuelEU blending targets. As mentioned further above this includes the requirement that PtL SAF must originate from renewable electricity and be verifiably sustainable and traceable throughout the supply chain.

For Kenyan producers, the ReFuelEU Regulation is significant not merely because it enables market entry, but because it guarantees a stable and expanding demand for RED-compliant SAF. Whereas RED III determines whether a fuel is environmentally legitimate, ReFuelEU makes its use legally mandatory, transforming compliant PtL SAF into a tradable commodity within a growing regulated market.

1.3.2.3 EU Emissions Trading System (EU ETS)

The EU Emissions Trading System (EU ETS) (Directive 2003/87/EC and related amendments) is the European Union's principal carbon pricing mechanism, which applies to various sectors including aviation. Relevant to the present pre-feasibility study under the EU ETS, airlines operating intra-EU flights are obliged to hold allowances equivalent to their CO_2 emissions. However, fuels that meet the sustainability and GHG performance criteria set under the RED III are treated as having zero emissions for compliance purposes.

This means that the use of certified PtL SAF enables airlines to reduce their emissions liability, thereby lowering their demand for ETS allowances. This creates a direct financial incentive for airlines to source SAFs like PtL SAF and a competitive advantage for PtL SAF producers wishing to export their product to the EU. In this respect, certified PtL SAF meets the blending targets under the ReFuelEU Regulation.

At the same time airlines benefits from cost savings to airlines subject to ETS compliance. Thereby, PtL SAF provides both regulatory compliance and economic value to European carriers.

For Kenyan PtL SAF producers, the EU ETS is significant as it creates a financial incentive for EU airlines to use certified PtL SAF, thereby reducing their obligation to purchase emissions allowances. For Kenyan producers, this enhances the export potential for PtL SAF provided it complies with the outlined EU regulatory framework for SAFs.

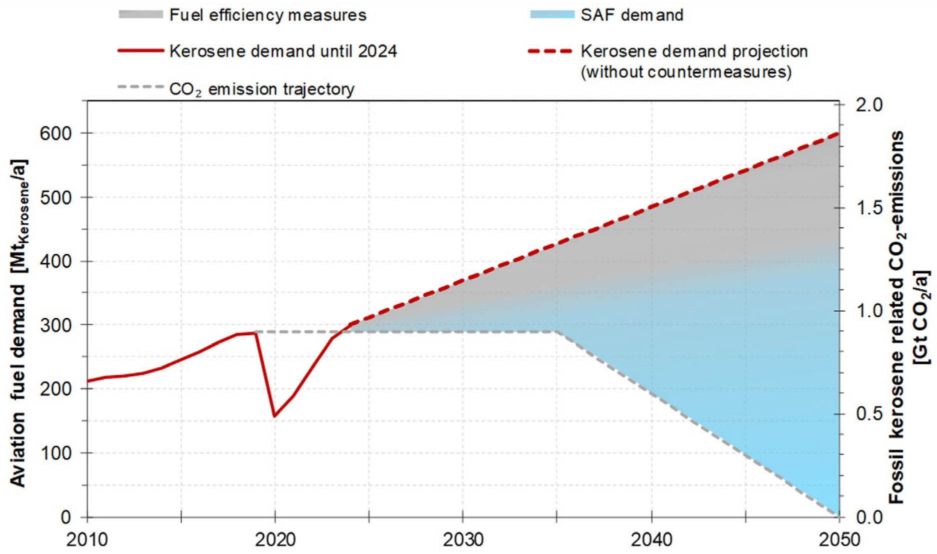
2

Assessment of feedstock and energy supply options in Kenya

**David Kretzschmar, Fabian Carels, Francis Njoka,
Prof. Martin Kaltschmitt and Dr. Stefan Bube**

The demand for Sustainable Aviation Fuel (SAF) is projected to increase in the future due to the growing demand for kerosene and the aviation sector's efforts to reduce the consumption for fossil fuels (defossilization) in line with the Net Zero targets set by the Paris Agreement [13]. Figure 2–1 illustrates the projected global increase in kerosene demand from 300 MtKerosene/a in 2024 to 600 MtKerosene/a in 2050, along with an estimated SAF demand exceeding 350 MtSAF/a by 2050.

Figure 2–1: Expected Global Kerosene and SAF Demand Until 2050 **[14]**



Kenya's National Climate Change Action Plan (NCCAP) 2023–2027 commits to the development of SAF by capacity building and to support the implementation of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) by reporting to the International Civil Aviation Organization (ICAO)[15]. In its study [16], ICAO highlighted that Kenya possesses several favourable conditions for establishing an indigenous SAF supply chain. These include the availability of bio residues as feedstock, strong governmental commitment to renewable energy, a stable policy and business support framework, feedstock co-benefits that help reduce production costs, and social advantages arising from public engagement and incentive-based waste collection strategies.

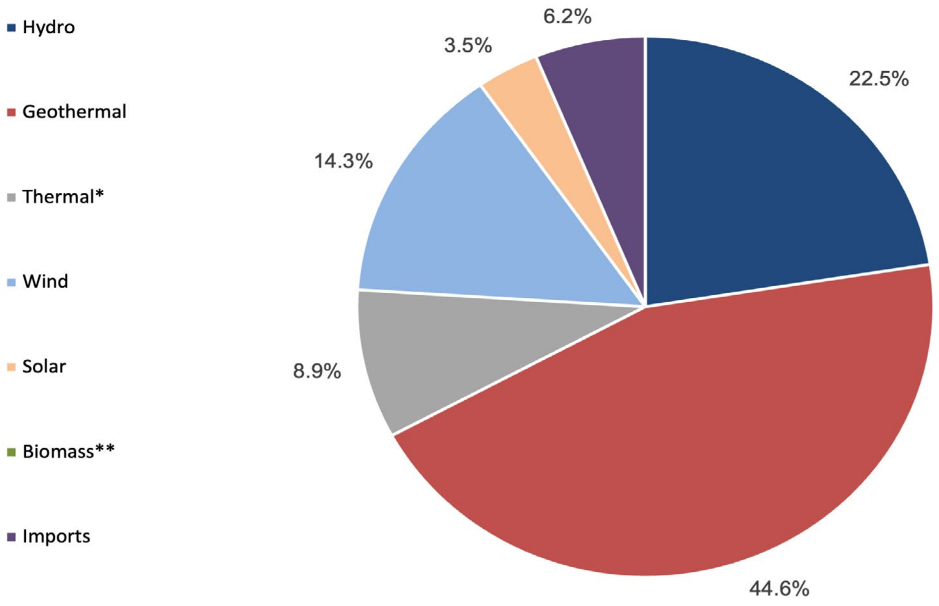
This report aims to provide an overview of the resources available for a domestic SAF production in Kenya. The focus is on the production of power-based kerosene (PtL) and processes that utilize both electricity and biomass (PBtL) as feedstocks. Accordingly, the renewable energy resources available in Kenya for the provision of green electricity are examined first.

Next, the potential for the provision of biomass, in particular biogenic waste streams, is analysed. Based on this, options for the supply of (sustainable) CO_2 needed for PtL SAF production will be discussed. Finally, the availability of water in Kenya is also considered.

2.1 Availability of Renewable Energy Sources

In the financial year 2023/24, renewable energy sources dominated the Kenyan electricity sector, accounting for over 91 % of total generation (including imports from Ethiopia and Uganda, which are primarily hydro power) [17]. The total generation – comprising both, off-grid and interconnected systems – amounts to around 6,805 GWh electricity delivered to the national grid, with hydro power and geothermal power together contributing more than 67 % of the generated energy (see Figure 2–2).

Figure 2–2: Percentage Share of Kenya's Total Electricity Generated, [18]



* Thermal: Fossil-based electricity production

** Biomass: Amounts to 0.21 GWh generated electricity, which is less than 0.05 % of the total 6,805 GWh of electricity generated

The Government of Kenya has set the target of generating 100 % of its electricity consumption from domestic renewable energy sources by 2035 [17]. This objective and the already high renewable share provide a strong foundation for further investments in renewable energy projects. The following sections examine the country's potential for solar, wind, hydro, and geothermal energy.

2.1.1 Solar Power Potential

As solar energy has recently become the fastest-growing energy source globally – with falling costs, rapidly increasing capacity additions, and widespread deployment – Kenya has a great opportunity to capitalize on its exceptional solar potential, illustrated in **Figure 8–1** (see Annex). Figure 8–1 represents the annual average totals of electricity produced from a 1 kW-peak grid-connected solar photovoltaic (PV) power plant, calculated over a 25-year weather period (1994-2018). It can be observed that the highest solar potential is located in the northwestern part of the country, with values exceeding 2,000 kWh/kWp in some areas. Overall, Kenya's solar potential is very high due to its proximity to the equator, with over 90 % of the country receiving more than 1,500 kWh/kWp. In comparison, for example, Germany's national average is approximately 1,080 kWh/kWp [19].

2.1.2 Wind Power Potential

Wind energy is deemed to be one of the most promising renewable energy sources due to its world-wide availability as well as its high level of technological development. Particularly in regions with strong and consistent wind resources (onshore) wind turbines can supply renewable electricity to low cost. Kenya is well-positioned to benefit from this development due to its favourable wind conditions in specific high-potential areas. Figure 8–2 provides an estimate of the mean wind power density as well as the mean wind speed at 100 m above surface level in Kenya. The mean wind power density is a measure of the available wind energy at a specific location, indicating the potential for electricity generation using wind turbines. The displayed wind maps are based on data from the weather period 1998–2017. In contrast to the solar power potential which is relatively evenly distributed across the country the regions with the highest mean wind power densities with above 1,000 W/m² (average wind speeds above 10 m/s) are found in the north of Kenya, especially around the Lake Turkana. The windiest locations here even achieve average energy densities of more than 2,000 W/m² (average wind speeds above 14 m/s).

With a total capacity of around 310 MW the Lake Turkana Wind Power Station (LTWP) located in Loiyangalani in Marsabit County is one of the largest operational wind farms in Africa.

The wind farm is connected to the Kenyan national grid via a 435 km long transmission line. Lake Turkana Wind Power Station achieves one of the highest annual capacity factors for wind power generation globally, consistently exceeding 50 % [22], [24]. Additional wind farms in Kenya include the Kipeto Wind Farm, with an installed capacity of approximately 100 MW, located in Kajiado County, and the Ngong Wind Farm, with an installed capacity of 25.5 MW, situated near Nairobi [25].

2.1.3 Hydro Power Potential

Hydro power remains one of the most widely utilized renewable energy sources globally, accounting for a significant share of electricity generation in many countries. It offers key advantages such as low operational emissions, high efficiency, and the ability to provide both baseload and flexible power to support grid stability. In Kenya, hydro power plays a significant role in the energy mix and, at 22.5 %, accounts for a significant proportion of the country's electricity generation. Large hydro power stations already in operation in Kenya can be identified from the Table 2–1.

Table 2–1: Large Hydro Power Stations in Kenya (Status: 2020), [26]

Hydro power Station	Commissioned Year	Capacity (MW)
Gitaru	1999	225
Kiambere	1988	165
Kindaruma	1968	72
Masinga	1981	50
Kamburu	1974	93
Sang´oro	2013	21
Sondu Miriu	2007	60
Turkwel	1991	106

Kenya's total economically viable hydro power potential is estimated at 1,500 - 1,700 MW, of which approximately 1,310 MW is suitable for projects of 30 MW or bigger. The country's hydrological sites have been categorized into five major geographical regions, each with distinct hydro power potential. The three largest river systems contribute significantly: the Tana River with an estimated potential of 570 – 800 MW, the Athi River with 80 - 90 MW, and the Ewaso Nyiro (also known as Ewaso Ng'iro River) with 145 – 155 MW.

Additionally, the Rift Valley region, including its network of smaller rivers, holds a potential of about 345 MW, while the Lake Victoria Basin – comprising rivers flowing between Lake Victoria and the Rift Valley – is estimated to offer 295 – 355 MW of hydro power potential (see **Figure 8–3**). [27], [28]

2.1.4 Geothermal Power Potential

Geothermal energy utilizes heat from the Earth's interior to generate electricity and is thus offering a form of renewable power that can provide consistent, baseload supply in geologically suitable regions. The geological conditions in Kenya are considered optimal due to the abundance of geothermal prospects located within the Kenyan Rift Valley. The country's geothermal power potential is estimated to range between 7,000 MW [29] and 10,000 MW [26].

Only 9 – 13 % of Kenya's estimated geothermal potential is currently being utilized, yet it already accounts for about 45 % of the country's electricity production (see **Figure 2–2**). The largest operational geothermal field is located in Olkaria, with an installed capacity of approximately 950 MW, distributed across seven subfields and supported by a total of around 300 drilled wells.

Additional exploited fields include Eburru, with an installed capacity of 2.4 MW, and Menengai, currently producing around 50 MW [29], [30].

To date, 19 geothermal prospect areas have been identified and investigated across the country of which 16 are situated in the Rift Valley region. One additional prospect is located in Homa Hills, in the western part of the country near Lake Victoria, one in Nyambene Ridges in the middle of the country and another in Mwananyamala, in the far south of Kenya (see **Figure 8–4**).

Complementing to Figure 8–4, Table 2–2 provides an overview of all geothermal prospects, including their potential capacity as well as the heat source and reservoir temperatures of each prospect. The number assigned to each geothermal prospect in Table 2–2 corresponds to the numbering in the **Figure 8–4**.

Table 2–2: Geothermal Fields and Their Potential Capacity in Kenya, Based on Information From Local Expert (KenGen)

No	Geothermal field	Potential Capacity	Source of Heat	Class according to temperature	Approx. reservoir temperature
1	Barrier	300 MWe – 750 MWe	volcanic complex	High-temperature	281 °C
2	Namarunu	255 MWe – 540 MWe	Pliocene shield volcano	High-temperature	-
3	Emuruangogolak	615 MWe – 865 MWe	Shield volcano	High-temperature	-
4	Silali	410 MWe – 1,025 MWe	Caldera volcano	High-temperature	281 °C
5	Paka	500 MWe	caldera volcano	High-temperature	-
6	Korosi	600 MWe	Korosi volcano	High-temperature	-
7	Lake Baringo	247 MWe -308 MWe	Deep dykes	Low-to medium	-
8	Arus Bogoria	247 MWe – 430 MWe	Intrusive.	Low-to medium	-
9	Nyambene Ridges	-	Shield volcano	Low-to medium	-
10	Menengai	1,200 MWe	caldera volcano	High-temperature	230 – 340 °C
11	Homa Hills	3-4 MWth	Intrusive	Low-to medium	-
12	Badlands	-	Intrusive	Low-to medium	-
13	Eburru	50 MWe	volcanic complex	High-temperature	Up to 280 °C

14	Olkaria	1,000 MWe	volcanic complex	High-temperature	Up to 340 °C
15	Longonot	520 MWe – 750 MWe	Caldera Volcano	High-temperature	-
16	Suswa	410 MWe – 680 MWe	Caldera volcano	High-temperature	-
17	Magadi	-	Intrusive	Low-to medium	-
18	Chyulu Hills	-	Intrusive	Low-to medium	-
19	Mwananyamala	5 – 6 MWth	Intrusive	Low-to medium	-

2.1.5 Summary of Power Generation from Renewable Energy Sources

Table 2–3 provides a summary of the key economic indicators of the relevant options for power generation based on renewable energy sources in Kenya. Additional assumptions regarding the financial parameters used for the calculation of the Levelized Cost of Electricity (LCOE) are presented in **Table 8–1** (Annex).

Table 2–3: Key Economic Indicators for Power Generation Renewable Sources in Kenya, [22],[23], [31]

Energy Source	CAPEX	OPEX	AFLH	LCOE
Solar	1,000 – 1,200 €/kW	2.0 %of CAPEX	1,500 - 2,000 h/a	0.043 – 0.057 €/kWh
Wind	1,250 – 1,700 €/kW	5.0 %of CAPEX	1,500 - 4,500 h/a*	0.027 – 0.133 €/kWh
Hydro power (>10 MW)	1,700 – 3,500 €/kW	2.2 %of CAPEX	3,000 - 6,800 h/a	0.027 – 0.061 €/kWh
Hydro power (<10 MW)	1,700 – 3,700 €/kW	2.6 %of CAPEX	4,500 - 5,700 h/a	0.047 – 0.059 €/kWh
Geothermal	3,700 – 5,200 €/kW	2.6 %of CAPEX	6,100 - 7,900 h/a	0.047 – 0.060 €/kWh

Electricity generation from solar energy via PV-systems exhibits a narrow range of LCOE, primarily due to the relatively uniform distribution of solar resources across the country. Only a few localized exceptions exist – such as in the southwest of Meru and the north of Kakamega – which are attributable to high mountains or mountain ranges. The challenges of solar power utilization for green hydrogen and PtL SAF production in Kenya include the relatively low AFLH compared to other renewable energy technologies in Kenya.

Additionally, a significant increase in PV capacity feeding into the public power grid could lead to grid congestion due to the high fluctuations of supply and limited electricity storage capabilities, unless appropriate mitigation measures are implemented.

To ensure a continuous electricity supply based on PV systems for an industrial-scale SAF production facility, the AFLH can be increased by integrating battery energy storage systems (BESS). This requires oversizing the PV-system and appropriately sizing the battery storage capacity. In recent years, battery costs have significantly declined – from approximately 1,400 €/kWh in 2015 [22] to 290 €/kWh in 2025 [32]. Currently, the levelized cost of storage (LCOS) for battery systems larger than 1 MW with one daily storage cycle ranges between 0.09 €/kWh and 0.11 €/kWh [24]. This could increase the effective electricity costs by a factor of 3 times compared to PV electricity without storage.

Across all renewable technologies considered, the lowest LCOE values are achieved by wind and large-scale hydropower (installations >10 MW), with reaching around 0.03 €/kWh. Both energy sources are highly site sensitive. While it is technically feasible to install wind turbines almost anywhere in the country – provided there are no structural or regulatory constraints – high wind potentials, and thus competitive cost of power generation, are limited to specific regions, such as the northern areas of Meru or the regions surrounding Lake Turkana. As a result, the range of LCOE values for wind power in Kenya is relatively wide. The main challenge for further implementation of wind power in Kenya is to transport the electricity generated in the wind-rich but sparsely populated north of the country to the more densely populated areas such as Nairobi or Mombasa. This would require additional transmission infrastructure. If wind energy is to be used for the production of green hydrogen/SAF, the respective plants could be erected near the areas with high wind potentials to limit the need for new electricity transmission lines. However, this would be accompanied by new challenges, supplying the plants with biomass/CO_2.

Hydro power utilization is generally limited to rivers with sufficiently high flow velocities and/or volumes. Large-scale hydropower plants require either major rivers or significant elevation drops to be economically viable. Such hydro power projects face challenges related to climate variability, seasonal fluctuations in water availability, and environmental impacts. Understanding these dynamics is essential for ensuring the sustainable development as well as grid integration of hydro power and its utilization for new applications such as green hydrogen/SAF production within Kenya. Small-scale hydropower systems (installations <10 MW) can utilize smaller rivers or segments of rivers, often with lower environmental impact compared to larger installations. However, due to their limited output, small hydropower plants are typically not suitable for energy-intensive industrial applications such as electrolysis for hydrogen production.

Geothermal power plants exhibit the highest AFLH among all renewable energy sources in Kenya. Due to their consistent and reliable output, they are particularly well-suited for baseload power generation and could also ensure high-capacity utilization of hydrogen and SAF production. At around 0.05 €/kWh, the LCOE of geothermal power generation is typically slightly higher than that of PV and onshore wind at favourable locations, but in combination with the high availability, it still enables an economically attractive electricity supply. The main challenges for geothermal energy utilization in Kenya, as in every other part of the world, include high upfront investment costs, exploration risks, and environmental considerations, all of which remain critical factors influencing the sector’s development. However, as Kenya leads geothermal power generation in Africa and ranks as the seventh-largest producer globally [29], the necessary technical expertise for successful implementation and further expansion is already available within the country. An overview of the main challenges and opportunities for the different options for renewable power generation is provided in Table 2–4.

Table 2–4 : Main Challenges and Opportunities for Renewable Power Generation in Kenya

Energy Source	Challenges	Opportunities
Solar - PV	• Low AFLH • High land use for power generation • Not suitable for baseload power generation	• Low investment cost • Further cost reductions expected • High flexibility in site selection
Wind	• Highly site sensitive • Few suitable sites • Additional transmission infrastructure could be required	• Low LCOE • High AFLH at specific locations
Hydro Power (>10 MW)	• Potential environmental impacts • Highly site sensitive to rivers	• Low LCOE • Suitability for baseload power generation • Longstanding technical experience
Geothermal	• High CAPEX • Extended planning and drilling durations • Exploration risk	• Suitability for baseload power generation • Reduced land use • High degree of expertise in Kenya

2.1.6 Land Availability for Power Generation

Land availability in Kenya is a crucial factor in determining suitable locations for the construction of renewable energy facilities – especially for solar and wind energy utilization as these technologies are typically featured with high specific space requirements. In principle, nature reserves and protected areas must be excluded from consideration. As illustrated in **Figure 8–5** (Annex), approximately 20 % of the Kenya's land area would be excluded from large-scale energy production for these reasons.

In addition, current land use must be taken into account when assessing the suitability of an area for renewable energy production. To analyze current land use, spatial layers derived from the Global Map of Land Use/Land Cover (LULC) [33] can be used. To avoid potential conflicts with food production and the need to preserve ecological diversity, agricultural land – here classified as Crops – and forests - here classified as Trees - must be excluded [34]. Additional exclusions are made due to technical and structural constraints, these include areas classified as Snow/Ice, Built-up Areas and Flooded Vegetation. Therefore, land types suitable for large-scale renewable energy production include Rangeland, defined as open areas covered predominantly by homogeneous grasses with little to no taller vegetation, and Bare Ground, which encompasses extensive regions of rock, soil, desert, or sand with very sparse or no vegetation throughout the year.

Beyond restrictions due to protected areas and land classifications, the topography must be taken into account when assessing the land availability for renewable energy generation. Kenya is characterized by numerous mountain ranges, particularly in the central and western parts of the country, such as the Kenya Highlands, the Aberdare Range, the Mount Kenya Massif, and the Mau Range. While elevation itself may be assessed differently depending on the technology (e.g., high plateaus can be favourable for wind farms as long as they are accessible), gentle slopes (slope gradient < 15 % [35]) are generally a prerequisite for the deployment of PV or wind power installations. As a result, areas with steep terrain must be excluded. **Figure 8–6** (Annex) illustrates the spatial distribution of the average slope gradient across Kenya. It becomes evident from Figure 8–6 (Annex) that regions extending from western to central Kenya are particularly affected by steep terrain. However, most of these areas would likely be excluded anyway due to their classification in the land cover dataset as well as their overlap with nature reserves and protected areas (see also **Figure 8–5** in Annex).

2.2 Biogas and Bio Residues Potential

In addition to electrical energy of renewable origin, the synthetic production of long-chain hydrocarbons as the most important component of SAF kerosene, inevitably requires a carbon source. Biomass is a particularly suitable source of renewable, non-fossil carbon. This biomass can be used in power-based SAF production either as a source of energy and carbon (Power-and-Biomass-to-Liquid, PBtL) or simply as a carbon source (Power-to-Liquid, PtL).

Biogas and bio residues are already utilized in Kenya as part of efforts to transition away from fossil fuels. Currently, approximately 2 MW of electricity are generated from biogas at the Gorge Farm Energy Park in Naivasha, representing the country's largest plant for biogas utilization [18]. In addition to the Gorge Farm Energy Park, several other commercially operated biogas plants exist in Kenya, although they are not connected to the national electricity grid. Table 2–5 provides an overview of these installations. The total installed biogas capacity in the country is reported to be 113.8 MW for the year 2023/24 [18].Furthermore, there are approximately 20,000 installed smaller biogas units in the country, most of which have been implemented under the Kenya Biogas Partnership Programme since 2021 [38]. The majority of these systems are used for domestic energy purposes, such as cooking and typically have volumes ranging between 3 and 16 m^3.

Table 2–5: Commercial Biogas Plants Installed in Kenya (Status: 2018), **[37], [38], [39]**

County	Name	Capacity [kW]
Naivasha	Gorge Farm Energy Park	2,000
Dagoretti	Dagoretti Slaughterhouse	30
Isinya	P. J. Dave Flower Farms Ltd (PPP)	100
Keekonyoike	Keekonyoike Slaughterhouse	20
Kericho	James Finlay Ltd	160
Kilifi	Pine Power Ltd	150
Naivasha	Bio-joule Kenya	340
Simbi Roses	Ereka Holdings Ltd (PPP)	55

To avoid competition between SAF production and food production – especially in a country where 13 % of the population (2.8 million people) are facing high acute food insecurity (IPC Phase 3 or above) and are in urgent need of assistance [40] – organic residue streams should be prioritized as sources of biogenic carbon. This also ensures compliance with the ReFuelEU Aviation Regulation (Recital 23 [41]) and the CORSIA framework (Sustainability Criterion 14.1 [42]).

The eligible organic residue streams in Kenya can be classified into four categories:

1. Agricultural residues
2. Food industry by-products
3. Municipal solid waste (MSW), and
4. Invasive weeds.

An overview of the recorded organic residue streams is provided in Table 2–6. The invasive weeds are not included in the table, as the quantity of invasive weeds available in Kenya has not yet been systematically assessed. However, the types of invasive weeds that could be considered for biogas production in Kenya will be discussed later in the text.

Table 2–6: Main Organic Residue Streams in Kenya, [34], [43], [44], [45], [46], [47], [48]

Resource	Residue streams [Mt/a]	Dry matter* [%]	Dry matter [Mt/a]
Agricultural			
Maize stover	2.2	29	0.62
Banana stems	1.1	5	0.05
Cattle manure	189	8	15.12
Poultry manure	82	55	45.10
Pig manure	11	4	0.44
Food Industry			
Sisal pulp	0.62	2	0.01
Coffee pulp and processing waste	0.11	29	0.03
Slaughterhouse waste	0.06	21	0.01
Sugar filter cake	0.19	90	0.17

Post-Consumer (MSW)			
Cereal food waste (excluding beer)	2.2	88	1.9
Fruit waste	1.5	12	0.2
Vegetables, oil	1.4	29	0.4

*Dry matter (%) refers to the portion of a substance that remains after all water has been removed

The recorded agricultural residues from major crop groups (maize stover and banana stems) amounted to a total of 3.3 Mt in 2023. Annual manure production is estimated at 282 Mt, of which approximately two-thirds (189 Mt) is cattle manure. Waste from the food industry has only limited potential, contributing approximately 0.98 Mt/a. Kenya generates an estimated 22,000 t of post-consumer waste per day, amounting to approximately 8 Mt/a [43]. The MSW attributable to the three largest biogenic residue streams amounts to approximately 6.7 Mt/a, as shown in Table 2–6.

Of the organic residue streams tracked, a total of around 295 million tons is generated annually in Kenya, of which over 65 million tons are in the form of dry matter. Approximately two-thirds of this dry matter is attributable to poultry manure.

Table 2–7: Biogas Potential of Selected Biomass Resources, [34], [43], [44], [45], [46], [47], [48]

Resource	Volatile Solids* [% of dry matter]	Methane yield [m3 per ton of Volatile Solids]	Methane yield [mln m3 per year]
Agricultural			
Maize stover	97	288	173
Banana Stems	4	13	0.03
Cattle manure	82	192	2,380
Poultry manure	75	277	9,370
Pig manure	86	355	134
Food Industry			
Sisal pulp	82	330	2.7
Coffee pulp and processing waste	91	244	6.7
Slaughterhouse waste	80	560	4.5

Sugar filter cake	97	262	43
Post-Consumer (MSW)			
Cereal food waste (excluding beer)	93	265	468
Fruit waste	80	516	83
Vegetables, oils	78	425	133

* Volatile Solids (VS) refers to the portion of a substance total solids that is organic and can be volatilized or burned off at high temperatures.

The methane yields from the main organic residue streams analysed in Kenya are presented in Table 2–7, expressed in specific as well as absolute terms. It serves as an example of the potential output when converting different types of biomasses into a carbon-based energy carrier.

The biogas potential of the assessed feedstocks ranges from 13 m^3 methane per ton VS for banana residues to 560 m^3 methane per ton VS for Slaughterhouse waste. The VS content of these feedstocks varies significantly, from as low as 0.2 % in banana residues to over 90 % in maize stover and cereal food waste. Within the biogenic waste streams recorded here, the majority of the potential annual methane yield is projected to originate from poultry manure, contributing approximately 73 % to the total potential. Only 8 % of the potential methane yield could be generated from biogenic waste sources other than animal manure, with the category of post-consumer waste showing the second largest potential.

Information on the spatial distribution of biogenic residue streams in Kenya is currently not available for open access. However, against the background of the land cover classification shown in **Figure 8–5** (Annex), it can be assumed that the majority of agricultural residue streams and post-consumer wastes are generated in the densely populated and intensively farmed west of the country, particularly in the Lake Victoria area and in the greater Nairobi area.

Another way to align carbon supply for SAF production in Kenya with the CORSIA framework and the ReFuelEU Aviation Regulation is through the use of invasive plant species. One of them is the water hyacinth occurring in the Lake Victoria, which originates from South America and is believed to have entered the lake from Rwanda via the Kagera River, probably in the 1980s. Since then, the hyacinth has spread prolifically due to a lack of natural predators, favourable temperature conditions, and abundant nutrients resulting from increased pollution in the lake. The negative economic impacts of this weed in seven African countries have been estimated at between USD 20 and 50 million per year.[48]

Fresh water hyacinth exhibits an average dry matter content of approximately 0.25 %, with volatile solids accounting for about 71 % of the dry matter. Anaerobic digestion over a 60-day retention period yields approximately 101 m^3 of methane per ton of volatile solids [49], equivalent to 67.4 kg/tVS [50].

The first commercial hyacinth-to-energy project is already underway. The UK-based firm Equinox Energy Capital, together with Thika Way Investments, is reported to be constructing a 39 MW hyacinth-to-energy plant in Homa Bay. The project is expected to commence commercial operations by 2027 [51].

2.3 CO_2 Sourcing Options

For the production of power-based SAF, CO_2 is a critical feedstock in all conversion processes that do not use biomass as carbon source (so called Biomass-to-Liquid pathway (BtL) or Power-and-Biomass-to-Liquid pathway (PBtL)). Thus, securing a reliable and sustainable CO_2 supply is a fundamental prerequisite for any SAF production based on PtL pathway.

In general, there are three primary sources for supplying CO_2 to a PtL SAF plant:

1. Fossil-based point sources, such as emissions from cement or ammonia plants;
2. Biogenic point sources, such as ethanol or biogas production facilities; and
3. Direct Air Capture (DAC), where CO_2 is extracted directly from the ambient atmosphere.

Each option differs significantly in terms of technical maturity, cost, carbon intensity, and long-term sustainability.

Fossil CO_2 point sources are currently the most cost-effective and technically mature option. Next to coal- or natural gas-fired power plants, these include process-related emissions from the cement and chemical sectors, where CO_2 is released as an unavoidable by-product. In Kenya, the cement industry is particularly relevant in this context, with several large-scale plants (e.g., plants of Bamburi Cement in Nairobi and Mombasa) that could potentially serve as CO_2 suppliers. However, using fossil CO_2 does not support a closed carbon cycle and results in a net increase in atmospheric CO_2 once the SAF is combusted. Additionally, reliance on fossil CO_2 sources may cause a lock-in effect, creating long-term dependency on carbon emissions from fossil point sources may delay or hinder the transition to a CO_2 neutral economy. Therefore, if climate neutrality is to be achieved, fossil CO_2 can only be used for the production of SAF in a transitional phase. This is, for example, reflected by the current EU legislation (Renewable Energy Directive II/III, RED II/III), which allows the utilization of certain fossil CO_2 sources until 2041 – provided that the corresponding CO_2 source is subject to a carbon pricing system.

Biogenic CO_2 point sources, in contrast, can contribute to a near-closed carbon cycle when the biomass is sustainably sourced. Facilities such as plants for upgrading biogas to biomethane, bioethanol plants, and pulp and paper mills offer concentrated CO_2 streams with relatively low capture costs. In Kenya, the existing potential for utilization of bioenergy – especially biogas and agro-industrial residues (see Chapter 2.2) – may offer viable biogenic CO_2 supply options. However, it must be taken into account that suitable point sources for biogenic CO_2 are currently only available to a very limited extent in Kenya. Even the previously mentioned 2 MW biogas facility at Gorge Farm Energy Park in Naivasha would likely not provide sufficient amounts of CO_2 to supply a commercial PtL SAF plant. Accordingly, it can be assumed that new plants for bioenergy use (e.g., biogas plants) and the corresponding infrastructure for the collection of biogenic waste streams must be established to ensure an adequate supply of biogenic CO_2.

Direct Air Capture (DAC) draws CO_2 directly from the atmosphere and thus enables a fully closed carbon cycle – provided that renewable energy is used to power the process. Due to the relatively low concentration of CO_2 in ambient air, with a global average of 410 ppm [52], the associated capture costs are significantly higher compared to CO_2 from point sources (70 – 90 €/tCO_2 [53] compared to at least 200 €/tCO_2 and up to 600 €/tCO_2 depending on the DAC technology and energy cost [53], [54]). The DAC technology has not yet been commercialized on a large scale. Even if substantial reductions in CAPEX are expected over the next few years, DAC systems are likely to remain capital- and energy-intensive in the medium term. It can therefore be assumed that, also in the long term, CO_2 will only be available from DAC plants at significantly higher costs compared to fossil or biogenic point sources.

In the context of power-based SAF production in Kenya, the choice of the source for CO_2 supply should be guided by considerations of local availability, cost-effectiveness, and long-term climate compatibility. If the SAF is intended for export to the EU, then the EU Renewable Energy Directive (RED II/III) and its delegated regulations apply. These frameworks mandate that CO_2 used for SAF production must originate from non-fossil sources such as DAC or biogenic processes, with only temporary allowances for the use of unavoidable industrial fossil CO_2 emissions (and the necessity to implement a carbon pricing system). Even if the SAF is consumed domestically or exported outside the EU, aligning with such sustainability criteria is advisable to ensure future compatibility with international carbon markets and climate targets.

For example, also the International Civil Aviation Organization (ICAO) points out to the great importance of non-fossil CO_2 for the production of PtL SAF [55]. Taking into account the high costs of DAC technology, the identification and exploitation of biogenic CO_2 sources is particularly important for the medium-term ramp-up of SAF production. Nevertheless, as the first DAC plants are already being commissioned in Kenya with plans for future scale-up, in the long term, there is also a certain potential for the use of DAC to provide CO_2 for SAF production. Projects such as Hummingbird by Octavia and Jacaranda by Sirona Technologies demonstrate that Kenya offers highly favourable conditions for the successful deployment of DAC technologies. These include a high share of renewable energy – available even for baseload supply through geothermal power plant operators as well as the potential use of waste heat, and supportive government for project developers [56], [57].

2.4 Water Availability

The production of power-based SAF goes hand in hand with a substantial demand for purified water, mainly needed for green hydrogen production via water electrolysis. According to Criterion 4.1 of the CORSIA Sustainability Criteria, production of SAF must ensure that “operational practices are implemented to maintain or enhance water quality” [42]. In this context, it is essential to verify that water resources are sufficiently available to avoid overexploitation. The aridity index of the respective regions in Kenya serves as a critical indicator for assessing water availability (see Figure 8–7 in Annex).

It becomes evident that over 80 % of Kenya’s total land area is classified as arid and semi-arid land (ASAL, $0 < AI < 0.65$) and is regarded as being at risk of desertification [59]. Consequently, water scarcity poses a serious challenge, particularly in the arid and semi-arid areas of the country. To avoid potential conflicts over water resources with local communities and to comply with the CORSIA Sustainability Criteria, the water demand associated with electrolysis should be met by seawater desalination where possible - especially in the long term, aiming at upscaling PtL SAF production. Additionally, by oversizing the desalination facilities, an added benefit can be created for local populations, who could gain access to the surplus freshwater. However, environmental risks may arise if the brine residues from desalination are not properly managed. [60]

Stoichiometrically, in electrolysis 9 kg of water are required to produce 1 kg of hydrogen. In practice, however, water consumption is typically higher, ranging from approximately 10 to 22 kg of water per kilogram of hydrogen produced [61], [62]. The overall water-production costs for the electrolysis of hydrogen account for only about 1 – 5 % of the total green hydrogen production costs, even if seawater desalination is applied with water production cost of approximately 2.5 – 3.5 €/m^3 (without transportation) [61]. This would account for an even smaller share in the production of PtL SAF. Accordingly, the provision of water by means of seawater desalination usually does not represent a significant economic burden for SAF production. The transport of water incurs a surcharge of 2 €/m^3 for every 100 km of distance travelled and for each 1000 m of elevation gained [63]. Nevertheless, water transport remains comparatively inexpensive relative to the transport of other resources, such as hydrogen, whose transport can be approximately 5 to 10 times more costly [64].

3

Technology and process selection to produce SAF

David Kretzschmar, Fabian Carels, Prof. Martin Kaltschmitt and Dr. Stefan Bube

3.1 Process and Technology Overview for SAF Production

Sustainable Aviation Fuels (SAF) are defined under the ReFuelEU Aviation regulation with reference to the Renewable Energy Directive III (RED III) and the CORSIA framework. They define various sustainability criteria, which vary depending on the type of feedstock and power source used [70], [71], [72]. For commercial use, SAF must be certified according to ASTM D7566. Currently, eleven conversion processes are approved, allowing the blending of up to 50 % SAF into conventional (fossil fuel-based) jet fuel. Today, SAF is produced from various biogenic feedstocks, including mainly waste oils and fats, but also to a minor amount municipal and agricultural waste, and non-food biomass. Additionally, kerosene-type SAF can be synthesized from carbon dioxide (CO_2) of non-fossil origin and green hydrogen (H_2) produced by electrolysis via synthetic intermediates such as methanol or synthetic crude oil and further downstream processing.

The synthetic production of kerosene-type SAF can utilize various energy and carbon sources processed within several pathways using different technologies [70]. Power-based SAF production (also known as Power to Liquid, PtL) typically uses synthesis gas-based processes with subsequent conversion steps to form the required molecules. Synthetic SAF production can also be based on various sustainable biomass feedstocks, including waste oils and fats, municipal and agricultural waste, and non-food biomass (also known as Biomass to Liquid, BtL) [71]. Additionally, hybrid processes that combine power- and biomass-based approaches are possible and considered promising based on current knowledge (also known as Power and Biomass to Liquid, PBtL) [76].

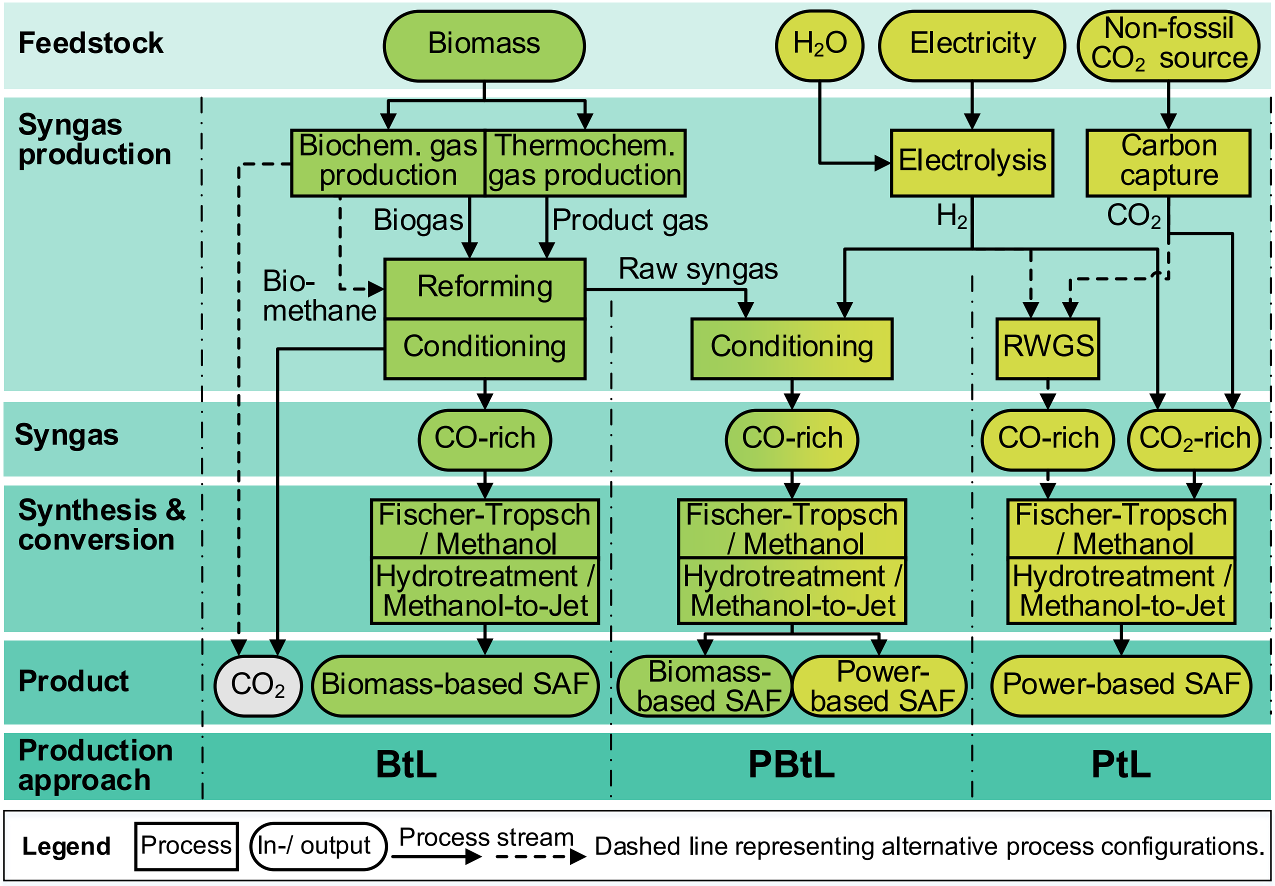
The following sections present the various production pathways and conversion processes. It is important to distinguish the production pathways, which are categorized into BtL, PtL, and PBtL, and the synthesis and conversion processes, which will primarily focus on the technological approach for converting the feedstocks into kerosene. Within the production of power-based kerosene (PtL or PBtL), synthesis and conversion routes can generally be divided into Fischer-Tropsch (FT)-based kerosene production – also known as FT Synthetic Paraffinic Kerosene (FT-SPK) production – as well as methanol-based kerosene production – commonly known as Methanol-to-Jet (MtJ).

3.1.1 Overview of SAF Production Pathways

Figure 3–1 illustrates the three production pathways for synthetic SAF production; i.e. SAF, which is produced from synthesis gas via thermochemical synthesis reactions. Overall, the various SAF production pathways differ primarily in the production of the synthesis gas (syngas) and the type of feedstock used. Syngas refers to mixtures of gaseous components of varying composition that serve as feedstock for chemical synthesis in corresponding processes. Depending on the targeted synthesis reaction, syngas can contain different reactants in specific concentrations and mixing ratios. In the context of this report, the term syngas specifically refers to gas mixtures based on H_2 and CO_2 or CO_2 that are employed in the syntheses under consideration. For further distinction, syngas is categorized into CO-rich and CO_2-rich syngas.

Figure 3–1 is the hydro processed esters and fatty acids (HEFA)-based SAF pathway. A preliminary assessment for Kenya has indicated that the biomass-based SAF production via HEFA could already be economically competitive at the global average SAF price [77]. Although HEFA-based SAF production accounts for the largest share of SAF production in the global market and is expected to continue increasing in the near term, the sustainable availability of suitable feedstocks is inherently limited. Consequently, to meet the growing SAF demand necessary to achieve CO_2 reduction targets, the development of alternative production pathways is essential to broaden the range of feedstock options and ensure long-term scalability [78].

Figure 3–1: Overview of the SAF Production Pathways BtL, PBtL and PtL, Based on [14]



The BtL pathway (left) converts biogenic feedstocks into kerosene-range hydrocarbons, whereby the chemical energy bound in SAF comes exclusively from biomass.

The PBtL pathway is designed around technologies that convert biomass into synthesis gas. The PBtL approach integrates additional electricity-derived H_2 from electrolysis directly into the biomass conversion process, compensating for the H_2 deficit in the syngas and avoiding CO_2 release during syngas conditioning. This enhances carbon utilization efficiency and reduces the overall hydrogen demand [76].

The PtL pathway utilizes only H_2 produced from renewable electricity via water electrolysis combined with CO_2 from non-fossil sources as feedstock to produce SAF. This pathway allows decoupling SAF production from biomass availability and enables flexible CO_2 sourcing options.

The synthesis routes for converting syngas into kerosene which will be looked into in this report are methanol-based and Fischer-Tropsch-based kerosene production pathway. In each case, the targeted product is kerosene-type SAF. The following chapters will comprehensively describe the associated process steps.

3.1.2 Syngas Production

As mentioned above, the PtL, BtL and PBtL pathways differ primarily in the syngas provision. Thereby, syngas production is always designed to generate a gas mixture with a composition suitable for downstream fuel synthesis. The syngas production approach is strongly influenced by the characteristics of the feedstock and the downstream synthesis technologies employed. The subsequent sections provide a detailed overview of the various syngas production pathways and technologies involved.

3.1.2.1 Biomass-Based Syngas Production

Biomass-based syngas production involves converting organic materials, such as bio residues or organic waste, through multiple steps including biomass-conversion into a light gas followed by gas reforming and/or conditioning into syngas. The generated syngas mainly consists of H_2, CO, and CO_2, with their relative ratios depending on the synthesis requirements.

Key conversion technologies for initial gas production are biochemical anaerobic digestion, producing biogas, and thermochemical gasification, producing a so-called product gas (see Fehler! Verweisquelle konnte nicht gefunden werden. [75].

Biochemical gas production via anaerobic digestion is a mature technology used for the stepwise decomposition of wet organic matter under anaerobic conditions by microbial consortia. Operating predominantly under mesophilic temperatures (~37 °C), it offers a favourable compromise between biogas yield and energy demand. The process generates biogas, mainly composed of methane (CH_4) and CO_2, but also includes impurities – particularly sulphur compounds – which necessitate purification prior to downstream conversion processes. The selection of gas cleaning methods depends on the utilized biomass and the required quality of the biogas respectively syngas. Anaerobic digestion is particularly suited for the treatment of high-moisture waste streams such as sewage sludge, food waste, and manure, making it an attractive option for decentralized waste-to-energy systems [80].

Thermochemical gas production via gasification is a high-temperature process (700–1,500 °C) used to convert dry, solid biomass – particularly lignocellulosic materials – into a so-called product gas primarily consisting of H_2, CO, CO_2, and light hydrocarbons. The resulting gas composition is influenced by the biomass type, gasification method, and choice of oxidizing agent (typically oxygen or steam). Compared to the anaerobic digestion, gasification enables higher syngas yields but requires dry input materials and involves greater technical complexity. In addition, due to the formation of contaminants such as particulates, tars, alkali metals, and heteroatom compounds, thorough gas cleaning is necessary prior to downstream processing.

In order for the gas mixture produced during gas generation to be subsequently used in catalyst-based processes, thorough gas cleaning (i.e., removal of potential catalyst poisons) is required. In particular, sulphur and halogen compounds must, depending on the catalyst applied, be reduced to concentrations in the parts per billion (ppb) range. For small-scale plants, technically simple methods such as adsorption on activated carbon filters may be advantageous, whereas large-scale processes typically employ regenerable adsorbents or absorbents integrated in more complex cleaning trains. Well-established techniques include adsorption processes (e.g., desulphurization via iron hydroxide or zinc oxide) as well as physical and chemical absorption/washing methods, particularly suited for high gas volumes with elevated impurity levels. It should be emphasized, however, that the choice of the appropriate gas cleaning technology is primarily determined by the initial gas composition, the specific catalyst requirements, and the boundary conditions at the production site (capacity, available energy sources).

After the gas production, reforming processes have to be employed to convert the hydrocarbon-rich gas mixtures – common in both, anaerobic digestion and biomass gasification – into a raw syngas with a composition close to the requirements of the downstream synthesis. Reforming aims to increase the H_2 and CO content through partial or full oxidation of hydrocarbons with oxidizing agents such as steam (H_2O), oxygen (O_2), or CO_2, typically at temperatures above 700 °C in the presence of a catalyst. Some examples of reforming processes are briefly described below [75].

Steam reforming is a well-established, highly endothermic process where hydrocarbons (e.g., CH_4) react with H_2O, producing raw syngas with a high H:C ratio. It requires external heat input and is catalyzed by nickel-based materials (e.g., Ni/Al_2O_3) at temperatures above 800 °C. By today, it is the most common reforming process [83].

Partial oxidation is an exothermic process using sub-stoichiometric amounts of O_2, eliminating the need for external heating. While it can be operated without catalysts at >1,000 °C, catalysed processes enable lower-temperature operation. However, the resulting raw syngas typically has a relatively low H:C ratio. Usually, it is only used after the thermochemical gasification [83].

Dry reforming utilizes CO_2 to convert hydrocarbons in an endothermic reaction to H_2 and CO, over nickel-based catalysts. Although it is suitable for CO_2-rich feedstocks like biogas, challenges such as coke formation and catalyst degradation limit its industrial viability. The H:C ratio of the product gas is typically low, requiring further syngas conditioning [83].

Reforming processes play a key role in natural gas–based syngas production and have been applied at industrial scale for decades, making them fully technologically mature. In contrast, the reforming of CO_2-rich gases, such as biogas, or the reverse water–gas shift reaction are processes that have only relatively recently found application in biomass- or electricity-based synthesis routes. The fundamental technological principles (reactor design, heat management, etc.) are available based on established reforming technologies; however, large-scale implementations for these specific, novel applications are still lacking. Consequently, the assessment of the technology readiness level (TRL; see "Systemic aspects" below) spans a relatively wide range, from TRL 5 to 8, depending on the available data, the process configuration, and the chosen feedstock. Technology providers include established companies with experience in conventional fossil-based production (e.g., Topsoe, Thyssenkrupp Uhde, Johnson Matthey, Air Liquide) as well as newer firms specialized in green technologies (e.g., HYCO1, GTI ENERGY, WS Reformer, Caloric).

Syngas conditioning refers to the further adjustment of the raw syngas from the reforming step to meet specific synthesis requirements (specifically the ratio of H_2, CO and CO_2). Syngas produced from biomass typically shows a H_2 deficit. Additional H_2 can be generated internally through the water-gas shift reaction, which converts CO and H_2O into CO_2 and H_2. Conditioning can also include CO_2 separation to optimize the syngas ratio, enhance reactant partial pressures, and reduce volume flows for downstream synthesis [84].

3.1.2.2 Power-Based Syngas Production

Power-based syngas production fundamentally differs from biomass-based routes by utilizing H_2O and CO_2 as feedstocks, with renewable electricity as the primary energy source. Core processes include water electrolysis to generate H_2 and carbon capture from non-fossil sources to supply CO_2. Depending on the downstream synthesis, power-based syngas production might also include the reduction of CO_2 to CO via e.g., the reverse water-gas shift (RWGS) reaction [85].

Electrolysis converts electrical energy into chemical energy by splitting H_2O into H_2 and O_2, achievable at various temperature levels through low-temperature or high-temperature electrolysis. Low-temperature electrolysis (<100 °C) operates exothermically and requires cooling to manage ohmic losses within the cell. The primary technologies are proton exchange membrane electrolysis (PEMEL) and alkaline electrolysis (AEL), achieving stack efficiencies up to 68 % (based on electricity input and the lower heating value (LHV) of H_2). AEL is the most mature technology, whereas PEMEL offers superior load flexibility, favouring its use with intermittent renewable energy sources. High-temperature electrolysis uses electrical and thermal energy for H_2O splitting, making this method particularly attractive when waste heat >100 °C is available. Solid oxide electrolysers (SOEL) are employed for this process, and co-electrolysis of CO_2 and H_2O can directly produce syngas. However, the low technological maturity of SOEL presents substantial technical and economic challenges for large-scale commercialization of high-temperature electrolysis at the time.

CO_2 capture can target gas streams with elevated CO_2 concentrations from point sources (3–100 vol% [88]) or the atmosphere. Due to the high dilution of CO_2 in the atmosphere (~0.041 vol% in 2021 [89]) direct air capture (DAC) systems require substantially more energy and construction efforts compared to capturing CO_2 from point sources. Non fossil CO_2 point sources include biomass-processing facilities such as anaerobic digestion plants and alcoholic fermentation units [88].

For carbon capture from point source, amine scrubbing, a chemisorption process, is the most established method, achieving capture rates above 90% and CO_2 purities exceeding 99 vol%. The desorption step (dissolution of the CO_2 from the amine) is energy-intensive, requiring thermal energy at temperatures between 100 and 140 °C. Physical absorption processes such as Rectisol and Selexol are suited for gas streams with high CO_2 partial pressures and operate under elevated pressures. Alternative methods include membrane separation and pressure swing adsorption (PSA), though these typically result in CO_2 purities below 99 vol%, making them less favourable for syngas production. [88], [90]

Direct air capture (DAC) technologies are classified into low-temperature DAC (LT-DAC) and high-temperature DAC (HT-DAC). LT-DAC, based on solid amine sorbents for binding CO_2, is the more mature technology but requires higher overall energy input compared to HT-DAC. HT-DAC technologies use aqueous potassium hydroxide (KOH) or sodium hydroxide (NaOH) solutions with CO_2 desorption at temperatures above 800 °C, while LT-DAC operates at 100–120 °C [91]. DAC processes can be powered by heat, electricity, or a combination of both. Due to the low CO_2 concentration in the atmosphere, DAC technologies are technically complex and are expected to remain significantly more expensive than point source CO_2 capture [88], [92], [93].

The RWGS reaction is carried out in a reactor which operates at pressures ranging from 1 to 30 bar and temperatures between 700 and 1,000 °C to achieve sufficient CO generation [94], [95].

$$\mathrm{CO_2 + H_2 \leftrightharpoons CO + H_2O} \qquad \Delta H_{\mathrm{R\,(298\,K)}} = 42\ \mathrm{kJ/mol} \qquad \text{Eq. 1}$$

The high-temperature heat demand of the endothermic reaction can be supplied by fuel combustion, like typically applied in fossil fuel processing systems. However, in the context of electricity-based production, heating using electrical energy appears to be more efficient and in line with the PtL approach. Catalysts based on nickel or noble metals are commonly used to facilitate the reaction [96].

3.1.2.3 Hybrid Power- and Biomass- Based Syngas Production

Hybrid power- and biomass-based syngas production integrates biomass-derived raw syngas with H_2 from electrolysis to balance the H_2 deficit in the syngas Figure 3–1. This approach eliminates the need for water-gas shift and CO_2 removal, at least if additional technologies for CO_2 reduction can be applied, in order to increase the hydrogen content internally. All technologies involved in hybrid syngas production are described above. A major advantage of the hybrid route is that the valuable biogenic carbon within the biomass can be fully utilized and almost completely converted into the targeted synthesis product [76].

3.1.3 Synthesis and Conversion

The aim of the synthesis and conversion step is to produce kerosene from the syngas. The involved processes can be differentiated into the Fischer-Tropsch (FT)-based and methanol-based SAF production route, regardless of the syngas production pathway (BtL, PtL or PBtL). Both process routes have been under discussion for several years especially regarding their application for synthetic kerosene production [76], [85], [94]. The following sections will examine both process routes in greater detail.

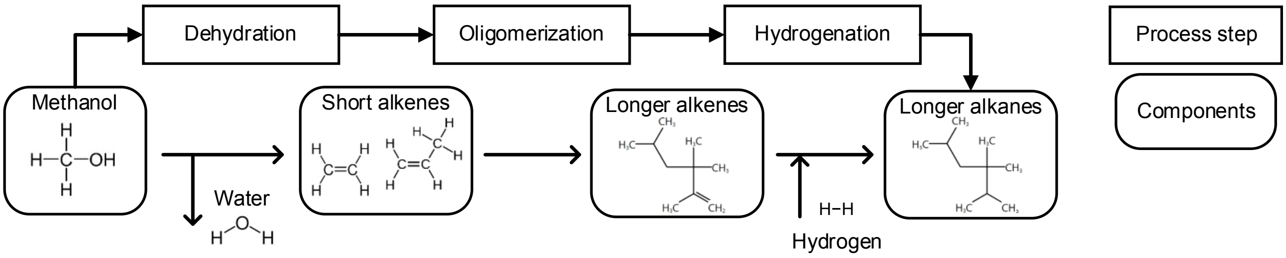
3.1.3.1 Fischer-Tropsch-Based SAF Production

The FT synthesis converting a CO-rich syngas is a well-established technology, with commercial applications dating back to the 1930s [97]. Nowadays, FT synthesis is used on a large industrial scale to produce synthetic liquid fuels (e.g., gasoline and diesel) based on coal and natural gas. The direct conversion of CO_2 within an CO_2-rich syngas into long-chain hydrocarbons is currently technically still in a research status since CO_2 behaves inert under most catalysts commercially used for long chain hydrocarbon production [98]. Thus, power-based kerosene-type SAF production via the FT route requires CO_2 reduction to CO upstream of the synthesis reactor. Therefore, CO_2 contained in the syngas must first be reduced to CO to generate a gas composition for subsequent FT synthesis. Whether CO_2 must be separated from CO-rich synthesis gas or can remain as an inert gas component depends on the specific design of the FT synthesis; various concepts are offered by technology providers.

Low-temperature Fischer-Tropsch (LTFT) is the most commonly used process for producing long-chain hydrocarbons, which are the main components of kerosene. In comparison the high-temperature Fischer-Tropsch (HTFT) yields shorter hydrocarbons in the synthesis product, which would require completely different and potentially more complex processing to produce significant shares of kerosene. The reaction is strongly exothermic, and the properties of the hydrocarbon molecules produced are primarily influenced by the catalyst type, the syngas composition, and the reactor operating conditions such as temperature and pressure [99]. Iron (Fe) and cobalt (Co) are commonly used catalysts, with cobalt preferred due to its higher activity and superior conversion efficiency, particularly for production of long-chain hydrocarbons [100]. Typical operating conditions range from 200 to 240 °C and 20 to 45 bar, achieving per-pass conversions of 60 to 85 % [98].

The LTFT synthesis produces a mixture of long-chain hydrocarbons, commonly referred to as FT-syncrude. This intermediate product requires further upgrading and refining to obtain fuels with properties equivalent to conventional fossil-based jet fuel, ensuring compatibility with ASTM certification, and thus, existing aircraft engines and infrastructure (i.e., drop-in capability). In the refining process, hydrocarbons heavier than kerosene are broken down into lighter fractions partly suitable for kerosene via hydrocracking. Furthermore, hydrogenation and fractionation steps are required, during which the FT-derived hydrocarbon mixture is saturated with hydrogen to improve long-term stability of the molecules and the SAF share is separated from lighter and heavier fractions. [101]

Figure 3–2: Basic Conversion Steps for Methanol to Jet (MtJ) within SAF Production Processes



Hydrocracking is a catalytic upgrading process used to convert heavy FT-syncrude fractions, especially waxes, into fuel-range hydrocarbons. It combines cracking and isomerization under elevated pressure and temperature, improving product properties such as cold flow behaviour. Process conditions, catalyst design, and chain length influence selectivity and yield, with shape-selective zeolites enhancing control over the product distribution. [101]

Hydrogenation and fractionation are critical steps in the upgrading of FT-based SAF to ensure molecular stability and prevent reactions of unsaturated hydrocarbons during storage and transport. Hydrogenation is performed under elevated pressure with metal catalysts (Ni, Pt, Pd) and excess hydrogen to fully saturate olefins, followed by rectification to separate the hydrocarbon mixture into defined fuel fractions. [75], [101]

The primary product yield of the FT-based SAF production route consists of naphtha, kerosene and potentially diesel. Hydrocarbons heavier than the kerosene fraction (C18+), such as compounds within the diesel range, can be recycled back to the hydrocracking process step to enhance the overall yield of naphtha and kerosene fractions.

A selection of technology providers for the Fischer–Tropsch route includes Topsoe and Sasol (also operating as Zaffra), Shell, Johnson Matthey in collaboration with BP, and Technip in partnership with Axens, as well as Ineratec, which is specialized in decentralized plant concepts. Methanol-Based SAF Production

Methanol-based SAF production starts with methanol synthesis, before the subsequent Methanol to Jet (MtJ) process takes place. The complete production process, from syngas over methanol to kerosene, is described in the following sections.

Methanol synthesis is an exothermic process typically conducted at 200–300 °C and 40–100 bar. The formation of methanol proceeds via two main reactions (Eq. 2 and Eq. 3). Accordingly, both CO and CO_2-rich synthesis gases can be converted directly into methanol. Today, methanol produced from CO-rich syngas of fossil origin – primarily coal and natural gas – is widely used as a feedstock for the production of various chemicals, including paints and plastics. It is also utilized as a fuel blending component, particularly in China.

$$\mathrm{CO} + 2\,\mathrm{H_2} \rightleftharpoons \mathrm{CH_3OH} \qquad \Delta H_{\mathrm{R}\,(298\,\mathrm{K})} = -90.8\ \mathrm{kJ/mol} \qquad \text{Eq. 2}$$

$$\mathrm{CO_2} + 3\,\mathrm{H_2} \rightleftharpoons \mathrm{CH_3OH} + \mathrm{H_2O} \qquad \Delta H_{\mathrm{R}\,(298\,\mathrm{K})} = -49.2\ \mathrm{kJ/mol} \qquad \text{Eq. 3}$$

In comparison to conventional CO-based synthesis, the direct use of CO_2 exhibits a lower conversion rate (<85 % CO-rich syngas, < 45 % CO_2-rich syngas), while achieving a slightly higher selectivity (>99.0 % CO-rich syngas, >99.9 % CO_2-rich syngas) [72]. Both reactions are exothermic, typically requiring reactors with external cooling. After synthesis, the methanol–water mixture produced must undergo distillation, resulting in an additional thermal energy demand. By using heat integration this demand can partly be covered by the heat released during methanol synthesis.

A reference plant in Iceland with a capacity of 4,000 t/a has demonstrated renewable methanol production from H_2 and CO_2 at a (semi-)commercial scale since 2011. More recently, two significantly larger CO_2-based methanol synthesis plants have been commissioned in China. While the feedstock in these facilities are derived from fossil resources, it shows the feasibility of the process. [102]

Figure 3–2 illustrates the process steps of the Methanol to Jet (MtJ) process. Commercially available technologies for converting methanol into fuels include the Mobil Olefins to Gasoline and Distillate (MOGD) process and the MtSynfuel process developed by Lurgi (now Air Liquide). However, none of these processes are currently optimized specifically for SAF production, but historically rather developed for gasoline and diesel production.

The MtJ process starts with the dehydration of methanol to short alkenes (light olefins) also known as Methanol-to-Olefins (MtO) process [103]. During this dehydration, the hydroxyl group (OH) is removed from methanol, producing water and alkenes in the C2 to C5 range. Low temperatures and pressures thermodynamically favour the exothermic reaction, yet methanol dehydration requires significant activation energy, necessitating temperatures above 350 °C and the use of catalysts to achieve complete conversion [75].

Most commercial MtO processes operate at approximately 400 °C and pressures below 5 bar [104]. Common catalysts include protonated ZSM-5 and SAPO-34 zeolites [75], [104]. Main by-products are coke deposits on the catalyst, short-chain alkanes, and CO_2, which can be removed before further olefin processing [105]. Currently, MtO is primarily used to produce methylene and propylene as alternatives to olefins from naphtha cracking. However, for subsequent oligomerization, propene and butene are more advantageous as starting materials for producing hydrocarbon fuels like kerosene, since less chain-linking reactions are required to reach the desired chain length [75].

Within a subsequent oligomerization step the alkenes produced in the MtO process are linked to form longer hydrocarbons within the chain-length contained in the kerosene (molecular length C9 to C16). As illustrated in Figure 3–2, new, longer-chain molecules are built up from monomers such as butene and propylene, whereby the reaction – depending on the catalyst and process conditions – tends to yield more branched or more linear hydrocarbons. The reaction is exothermic and volume-reducing, thus, favoured at high pressures and low temperatures. However, depending on the catalyst, temperatures above 100 °C are required to overcome the respective activation energy [106]. Commercial oligomerization is currently focused on the conversion of C_2 to C_4 olefins into gasoline-range hydrocarbons (C4 – C12) [106].

For oligomerization within SAF production, acidic catalysts are considered as particularly suitable, as they additionally promote aromatic formation. Shape-selective acidic zeolites are extensively studied as catalysts, allowing for controlled conversion of olefin mixtures into branched (i.e., iso-alkane-rich) kerosene and diesel fractions [106].

Remaining light olefins in the gasoline range can be recycled to the oligomerization stage to enhance the overall kerosene yield. Moreover, the combination of sequential oligomerization steps can further increase the kerosene fraction [107].

The final process steps, hydrogenation and fractionation of the oligomerization products can be conducted similarly to the processing of FT-syncrude (see Fischer-Tropsch-Based SAF). Compared to FT-syncrude, a higher hydrogen demand is required due to the feedstock consisting of a pure olefin mixture. Additionally, the hydrocarbons may present greater challenges during hydrogenation because they are typically more branched than the FT products. As in the FT-based SAF production, separating the different product fractions from each other can be performed via rectification [106].

In contrast to the FT-based route, the methanol-based SAF production route does not allow the recycling of heavier hydrocarbons (C18+) for conversion into lighter molecules without applying additional process steps; since the fraction of C18+ and their respective chain length is much lower compared to waxes from FT synthesis, usually no hydrocracking is considered within the pathway. As a result, the product fractions are in the naphtha, kerosene, and diesel range.

A selection of technology providers for the methanol-to-jet route includes ExxonMobil, Topsoe as well as Honeywell UOP with Johnson Matthey. CAC Engineering as well as Thyssenkrupp Uhde with BASF are also involved in developing the route.

3.2 Comparison of Methanol- and Fischer-Tropsch-Based SAF Production Route

In the following chapter, the FT-based and methanol-based production route are systematically compared with respect to their technical, systemic, and economical aspects. The comparative analysis aims to highlight the respective advantages, limitations, and potential roles of each process within the context of SAF production. The comparison focuses on the power-based SAF production (PtL), while aspects that change within hybrid production (PBtL) are also discussed.

3.2.1.Technical Aspects

In this section, the methanol- and FT-based routes are evaluated with respect to their technical performance, with a particular emphasis on carbon efficiency and energy efficiency of the overall fuel / SAF production. By analysing these key performance indicators, the assessment aims to provide a technical comparison of the respective strengths and limitations of each conversion process.

3.2.1.1 Carbon Efficiency

Carbon of non-fossil origin is typically a limited resource in PtL and PBtL production, since the availability of biogenic carbon is often constrained by the local biomass or CO_2 potential, while the extraction of CO_2 from the atmosphere requires considerable effort. As a result, its provision can be a significant factor for the plant capacity, the overall energy demand and thus, the cost of SAF production [94], [108]. To minimize the overall carbon demand, it is crucial to achieve a high share of carbon bind to the final product ($\dot{C}_{\text{Product}}$) relative to the amount of carbon fed into the SAF production process ($\dot{C}_{\text{Feed}}$). Maximizing carbon efficiency ($\eta_{\text{C,Product}}$) is essential, especially when the supply is costly or when carbon availability is the limiting factor for scaling. The carbon efficiency can be calculated by Eq. 4.

$$\eta_C = \frac{\dot{C}_{Product}}{\dot{C}_{Feed}} \qquad \text{Eq. 4}$$

η_C: Carbon efficiency [-].
$\dot{C}$: Carbon flow [mol/s].

Assuming recycling of light gases (mainly methane) and unconverted syngas, the FT-based route achieves near-complete conversion of the carbon to fuels, with overall carbon efficiencies ranging from 98 % to 99 % across all end products, including kerosene, and naphtha [94], [108]. However, this requires that the entire production chain be implemented at a single location. Losses are minimal and primarily attributed to purge gas venting in the synthesis loop. In contrast, the methanol-based process shows slightly lower overall carbon efficiencies of 75 to 92 % [94], [108], within purely power-based production (converting from H_2 and CO_2). Carbon losses arise primarily from purge gases in the oligomerization stage, due to the accumulation of light alkanes and the absence of reforming and hydrocracking steps, which limits recycling options. However, within a PBtL approach, purge gases might be recycled for reforming into syngas, increasing the overall carbon efficiency up to ca. 99 %.

When considering only the production of the kerosene fraction, higher carbon efficiency is expected for the methanol-based production, as more selective production of the kerosene fraction can be reasonably anticipated [94].

Overall, especially in purely power-based production, the FT route benefits from integrated hydrocracking and RWGS reactions, enabling comprehensive carbon utilization by converting non-fuel fractions in the product stream back into syngas or directly into fuels, while the methanol-based route lacks such integrated conversion options, resulting in higher carbon and hydrogen losses. On the other hand, the methanol-based route enables more selective kerosene production, facilitated by efficient oligomerization and the direct recycling of short-chain olefins [94].

3.2.1.2 Energy Efficiency

Energy efficiency is a key parameter in the production of SAF, especially for power-based production where electricity is one of the major cost factors. Maximizing energy efficiency reduces resource consumption and improves the economic viability.

The energy efficiency can be determined using Eq. 5, which defines it as the ratio of the energy content (based on the higher heating value, HHV of the product stream ($\dot{m}_{Product}$) to the total energy input. The latter includes the HHV of the feed (HHV_{Feed}) multiplied by the feed stream ($\dot{m}_{Feed}$) plus the electricity demand (P_{el}) and any additional thermal energy required for the process (Q_{th}).

$$\eta_{e,\ Product} = \frac{\dot{m}_{Product} \cdot \mathrm{HHV}_{Product}}{\dot{m}_{Feed} \cdot \mathrm{HHV}_{Feed} + P_{el} + \dot{Q}_{th}} \qquad \text{Eq. 5}$$

$\eta_{e,Product}$: Energy Efficiency [-]
$\dot{m}$: Product-/Feedstock Flow [kg/d]

HHV: Higher Heating Value [MJ/kg]
P_{el}: Electricity Demand [MJ/d]
$\dot{Q}_{th}$: Thermal Energy Demand [MJ/d]

When considering all energy flows, it becomes evident that the electrolyser accounts in both production routes for 70–90 % of the total process energy demand, depending on the assumed electrolyser efficiency and potential process integration [94], [108]. If a direct air capture (DAC) unit is included for CO_2 supply, it can contribute an additional ~20 % to the overall energy demand [108]. Starting from H_2 and CO_2, the thermodynamic maximum energy efficiency of both routes, can be cited as 77 % HVV [94]. Technical investigations of both process routes indicate that, considering the individual process steps and associated losses, the FT-based route achieves a higher total fuel energy efficiency of 63 – 70 % HHV, due to the higher total fuel yield. In contrast, the methanol-based SAF production shows slightly lower total fuel energy efficiencies of 54 – 67 % HHV but achieves higher kerosene-specific energy efficiencies (44 – 65 % HHV vs. 38–54 % HHV in the FT-based process) [94].

Thermodynamically, the methanol-based route is advantageous, as it relies entirely on exothermic reactions and does not require supply of high-temperature heat. In contrast, the FT-based route involves significant heat input at a high temperature level for the reverse water–gas shift (RWGS) reaction, whose heat release is partially recovered in the low-temperature Fischer–Tropsch (LTFT) synthesis. In addition, partial heat recovery is achieved via the gas recycling of the FT-based process. [94]

Both synthesis routes are relatively efficient compared to their thermodynamic limits, while upstream processes such as water electrolysis and CO_2 capture substantially reduce overall system efficiency – by up to 25 %. This reduction depends largely on the performance of the electrolyser, hydrogen losses and the nature of the CO_2 source, whether it is pure already (100 vol % CO_2), from a point source (3 – 99 vol % CO_2 [88]) or captured from the ambient air via DAC [94].

3.2.2 Systemic Aspects

The systemic aspects of the process routes can be reflected by the overall technological maturity and the overall flexibility.

The maturity of the entire process chain is either constrained by the technology with the lowest Technology Readiness Level (TRL), as this may represent a potential bottleneck, or by the integration of the individual process steps, especially within highly integrated process concepts. The individual process technologies can be evaluated based on their TRL, using the scale proposed by the IEA, which ranges from TRL 1 (concept) to TRL 11 (fully mature technology) [109]. In addition, the Fuel Readiness Level (FRL) provides insight into the progress of regulatory approval and the extent to which the fuel process is approaching commercial deployment. The FRL scale ranges from 1 (basic principles observed and reported) to 9 (production capability established) [110]. An overview of all TRLs and FRLs is provided in Figure 8 8 (Annex).

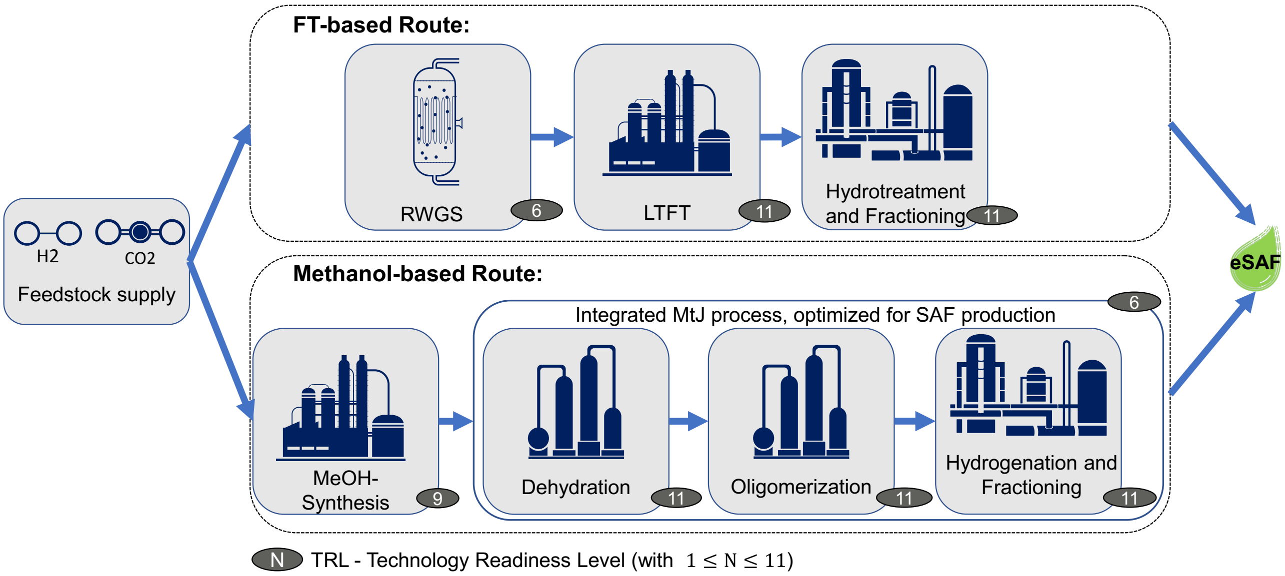
The flexibility can be assessed from a logistical standpoint, considering the variability of feedstock and intermediate products, as well as from an operational perspective.

3.2.2.1 Maturity

Figure 3–3 provides an overview of the TRL levels for the main technologies of both process routes. The synthesis and downstream steps of the FT-based route, such as LTFT synthesis, have reached full technological maturity (TRL 11). The TRL of the overall process is limited by the TRL of the RWGS step and thus also by the pending demonstration of the overall process chain [109], [111]. Given the limited number of research, demonstration plants and the absence of commercial reactors, the TRL of RWGS reactors is currently estimated to be around 6 (large prototypes) [85], [112].

The RWGS reaction plays a crucial role in syngas conditioning by converting captured CO_2 into CO, serving as a key intermediate step. Although direct CO_2 utilization in FT synthesis is being explored, it remains in the early stages of development. Co-electrolysis via Solid Oxide Electrolyser Cell (SOEC) technology presents an alternative to RWGS reactors, but it is also at a low TRL, with companies such as Sunfire only recently completing a pilot plant for SOEC-based syngas production (TRL 5, pilot plant) [113].

Figure 3–3: TRLs of the Technologies of Fischer-Tropsch (FT)-Based and Methanol (MeOH)-Based SAF Production Routes from H_2 and CO_2, based on [14], [109]



The methanol-based route involves five main steps: methanol synthesis, dehydration, oligomerization, hydrogenation, and fractionation. While these unit operations are individually well-established and have been commercially applied for decades in the production of chemical intermediates, their integration into a complete pathway for jet fuel synthesis based on methanol is relatively recent [113]. The SAFari project represents one of the most advanced initiatives in the development of the MtJ process chain. The project aims to reach TRL 5 – corresponding to a large-scale prototype in a relevant environment – by 2024, with further scaling to TRL 7, denoting a fully integrated demonstration system, anticipated by 2028 [114]. Since similar concepts for gasoline or distillate production have already been successfully demonstrated commercially by various technology providers, the overall chain for kerosene production is classified at a TRL of approximately 6. It should be noted, however, that there are considerable differences in the assessment of TRL within the field, as no complete and publicly available data basis exists and the definition of TRL is not entirely unambiguous.

In the case of the FT route, the RWGS reaction represents the TRL-limiting technology. For syngas production from biomass (BtL and PBtL) via reforming processes, the RWGS step can potentially be omitted, as a CO-rich syngas is already generated. In this case, the overall TRL of the process chain may be higher than for purely electricity-based production, provided that the upstream syngas generation exhibits a higher level of technological maturity.

Processes routes to produce SAF are subject to evaluation and certification by the standard organization American Society for Testing and Materials (ASTM) International. From a regulatory and certification perspective, the FT-based SAF production process has been approved under ASTM D7566 Annex A1, permitting blending with conventional Jet A/A-1 fuel at concentrations of up to 50 % by volume.

In contrast, the MtJ pathway is currently undergoing evaluation by ASTM (as of July 2025). Among others, ExxonMobil is acting as a principal technology developer for the MtJ process within the certification framework [74]. Accordingly, the methanol-based process is currently estimated to be at FRL 6, whereas the FT-based process is moving toward the start-up of first commercial facilities (FRL 7–8), reflecting its more advanced stage of regulatory and commercial maturity [115].

3.2.2.2 Flexibility

Since both, the FT and methanol-based process, can utilize the same feedstock for syngas production, no significant distinction can be made between the two routes in terms of feedstock flexibility. Both processes are capable of converting either biomass-derived syngas (H_2, CO and CO_2) or power-based syngas (H_2 and CO_2) into SAF. Notably with the PtL pathway, both technologies are largely independent of feedstock location and transport. Hydrogen can be produced at virtually any site, provided sufficient water and renewable electricity can be supplied to the facility.

Methanol and FT-syncrude represent the respective intermediate products of the two SAF production routes. Methanol is an established bulk chemical that is routinely transported, e.g., by ship, and handled in global trade. A large number of ports worldwide possess methanol storage infrastructure, with additional facilities under development to support growing demand [109]. The transport of the liquid FT-syncrude fraction can largely rely on existing infrastructure and regulatory frameworks originally developed for conventional petroleum products which are broadly compatible with FT-syncrude. However, the transportation and storage of the heavy wax fractions, typically part of the FT-syncrude, poses an additional challenge and cannot be carried out via the conventional petroleum infrastructure without additional measures [116]. Additionally, a significant disadvantage of FT-syncrude is the environmental risk associated with spills. In the event of accidents at sea or within protected water areas, FT syncrude, just like fossil crude oil, can cause severe and long-lasting damage to marine ecosystems due to its persistence and toxicity. In contrast, methanol – although classified as a water pollutant – is readily biodegradable and poses a substantially lower long-term risk to aquatic organisms [117]. Consequently, the transportation of FT-syncrude is generally more expensive, driven by higher insurance premiums and more stringent regulatory requirements compared to methanol [116]. Therefore, methanol is generally regarded as a more logistically flexible intermediate product. Given the easier logistics for methanol transport compared to syncrude and the higher degree of process integration between up- and downstream processes within power-based production in the FT route, the methanol route can be more easily separated from the downstream SAF production. This facilitates greater potential for geographic decoupling and modular deployment of methanol-based SAF production compared to FT-based route [94].

In terms of operational flexibility of the synthesis plants, the methanol-based route demonstrates a clear advantage. This is primarily due to the methanol synthesis reactor's ability to flexibly respond to variations in the quantity of the feed stream, enabled by the adjustable recycling quantity of unconverted syngas. In contrast, this flexibility is limited in most commercially available FT-reactors, as the per-pass conversion is significantly higher, and the syncrude composition is significantly influenced by the residence time [94].

3.2.3 Economic Aspects

This chapter provides a qualitative, high-level cost comparison between methanol-based and FT-based process routes. The explanations and specified values refer to the PtL pathway. The comparison aims to highlight the economic advantages and disadvantages of each process. The insights are largely the result of the previously described distinctions in terms of carbon and energy efficiency. Thus, the analysis distinguishes between the total fuel cost – including potential revenues from by-products like diesel or naphtha – and the net production cost of kerosene, excluding any by-product revenues.

In general, the expected SAF production costs for PtL pathways range between 3,000 and 9,000 €2023/tSAF for the commercial implementation of large-scale plants (Nth-of-a-kind) [108], [118]. The supply costs of green H_2 and CO_2, as main upstream feedstocks, significantly influence the overall kerosene production costs in both process routes; therefore, fluctuations in feedstock prices result in the considerable cost variability. Notably, CO_2 prices reflecting the current investment costs and energy demands of DAC systems can nearly double the kerosene production costs compared to scenarios utilizing (biogenic) CO_2 from concentrated point sources [108], [118].

When revenues from by-products such as diesel and naphtha are factored into the cost calculation, the FT-based route produces kerosene at approximately 8 15 % lower costs than the methanol-based route [108], [118]. However, excluding these by-products from the cost calculation reverses the comparison: in this case, the methanol route shows a cost advantage of around 3 8 % [85], [118]. This is primarily due to the higher selectivity of the methanol-based route toward kerosene, resulting in fewer by-products and a greater yield of the target product. It can therefore be concluded that the economic viability of power-based SAF production depends largely on H_2 and CO_2 supply costs. Costs associated to the installation, operation and maintenance of the conversion plant have a significantly lower impact on the kerosene production costs. Since feedstock supply is the main cost factor, conversion efficiency and product selectivity are essential. If the market value of the target product kerosene significantly exceeds the value of the by-products, naphtha and diesel, the methanol-pathway might become economically more attractive due to the expected higher kerosene selectivity [118].

3.2.4 Summary and Qualitative Evaluation

Table 3–1: Qualitative Comparison of the FT-Based and Methanol-Based Production Routes from CO_2 and H_2(FT: Fischer-Tropsch, MeOH: Methanol)

			FT	**MeOH**
Technical aspects	Carbon efficiency	Total fuel	+	–*
		Kerosene	–	+
	Energy efficiency	Total fuel	+	–*
		Kerosene	–	+
Systemic aspects	Maturity	Process	o**	o
		Fuel	+	–
	Flexibility	Feedstock	o	o
		Intermediate Products	–	+
		Operation	–	+
Economic aspects	Production costs	Total fuel	+	–
		Kerosene	–	+

inferior	neutral	superior
🟦	⬜	🟨

* More favourable assessment in the PBtL pathway due to the extended recycling option for purge gases enabled by the syngas reformer.

** More favourable assessment in the PBtL pathway due to higher technological maturity when operated with a CO-rich synthesis gas, as the RWGS reactor – responsible for the lowest TRL – can be avoided.

Technical Aspects

The FT-based SAF production route is characterized by high overall carbon utilization and energy efficiency, enabled by effective recycling of heavy hydrocarbons (C18+) and unconverted intermediates. It is particularly well suited for applications targeting a broad fuel slate, including kerosene, diesel, and naphtha, within a fully integrated process design. In contrast, the methanol-based route demonstrates higher selectivity toward hydrocarbons in the kerosene range, making it advantageous in scenarios where a highly targeted SAF production is desired. Additionally, the methanol-based process relies predominantly on exothermic reactions and avoids the need for high-temperature heat input, thereby facilitating thermal integration and reducing process complexity.

Systemic Aspects

Both process routes exhibit similar feedstock flexibility, as they are based on renewable H_2 and captured CO_2 (PtL pathway) or renewable H_2 and a carbon-containing synthesis gas of biogenic origin (PBtL pathway). In the PtL pathway, both the FT-based and the methanol-based routes can operate entirely by using renewable electricity as the sole energy source for producing their feedstocks, H_2 (electrolysis) and CO_2 (e.g., DAC, sustainable point source), as well as for all other process steps. From a logistics perspective, methanol is cheaper and environmentally safer to transport and therefore offers greater flexibility in terms of decoupling the sites for synthesis of the intermediate products and final kerosene production. In terms of technological maturity both process routes are in the same range of TRL. While the technological maturity of the FT route is primarily limited by the implementation of the reverse water-gas shift (RWGS) reaction, the methanol route's main bottleneck lies in the full integration of the process steps- with individually hight TRL levels - for converting methanol into jet fuel (MtJ). However, the FT-based route within the PBtL pathway demonstrates in comparison to the methanol-based route a higher technological maturity when operated with a CO-rich synthesis gas, as the RWGS reactor – responsible for the lowest TRL – can be avoided. Moreover, the FT-based route offers a clear advantage in terms of FRL, as its process is already certified under ASTM D7566 for blending kerosene produced via FT synthesis with conventional jet fuels. Conversely, the methanol-based process is still undergoing regulatory approval and is at a lower FRL, despite relying on long-established process steps. With regard to operational flexibility, the methanol route exhibits an advantage due to its lower thermal inertia and higher syngas recycle rate, enabling better responsiveness to fluctuating feedstock quantity.

Economic Aspects

From an economic perspective, the methanol-based process generally offers a slight cost advantage, when by-product revenues are excluded and only SAF is considered as saleable product. This is due to its higher selectivity for kerosene-ranged hydrocarbons and the resulting reduced reliance on co-product valorisation. In contrast, the FT-based process shows a higher sensitivity to by-product revenues, stemming from its lower product selectivity. Therefore, if a market value comparable to the SAF is attributed to the by-products (mainly diesel and naphtha), the FT-based route has slight economic advantages due to its higher overall fuel efficiency (in terms of energy and carbon). H_2 and CO_2 supply costs are major cost drivers for both processes. Sourcing CO_2 from the ambient air via DAC systems significantly increases overall production costs compared to the use of CO_2 from point source.

3.3 Assessment of Production Pathway and Route for SAF Production

This chapter aims to provide a qualitative decision making aid to determine the most suitable process configuration for SAF production, comparing the PtL and PBtL pathways as well as methanol-based and Fischer–Tropsch-based production routes. The evaluation is based on various external influencing factors. The objective is to present a structured overview and analysis to support a well-founded decision regarding the optimal production route and pathway.

3.3.1 Pathway Decision – PtL, BtL, or PBtL?

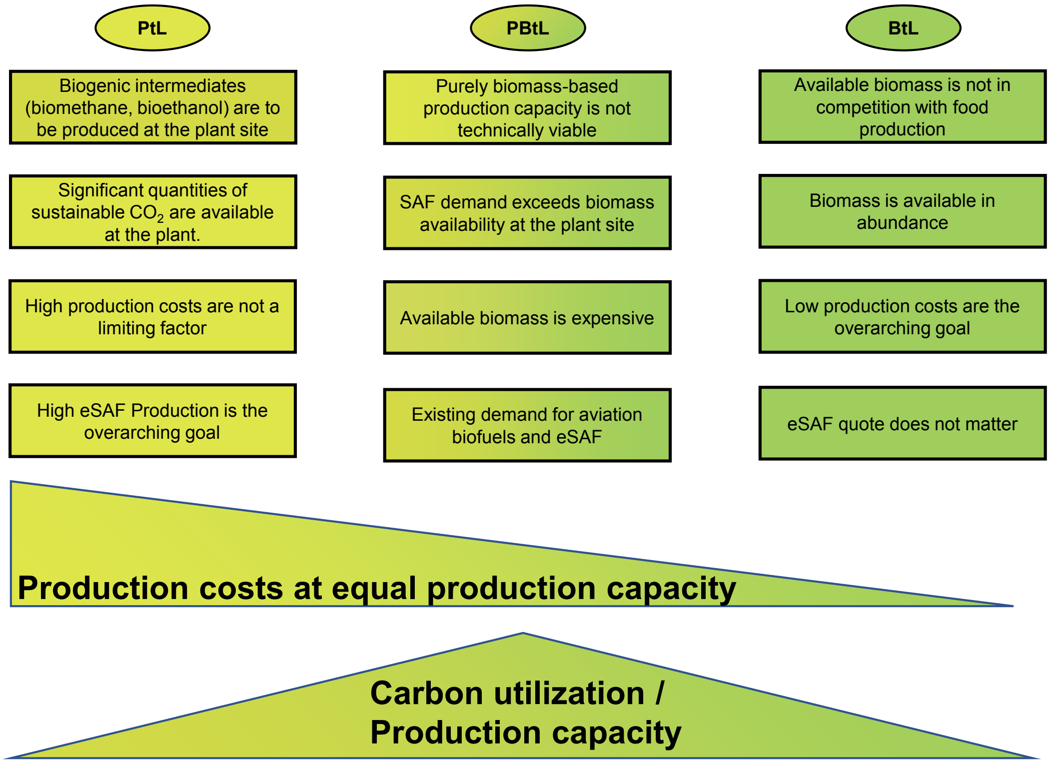
Figure 3–4 presents decisive decision criteria for the PtL, PBtL, and BtL pathways, indicating under which criteria each production pathway is more suitable.

Within the BtL pathway, biomass serves as the sole material and energy feedstock, apart from minor processing energy requirements. To address the intrinsic hydrogen deficit of most biomasses (or biomass-derived intermediates), a substantial share of carbon must be removed during conversion into kerosene. This reduces the attainable fuel yield from a given biomass potential. However, since the BtL pathway does not rely on power-derived H_2 – which remains costly – it currently represents the lowest-cost production route, provided that sufficient suitable biomass is locally available. If minimising production costs constitutes the primary objective of SAF deployment, regardless of whether the fuel is of biogenic or electricity-based origin, BtL may be considered the most favourable pathway.

In contrast to BtL, the PtL pathway relies exclusively on CO_2 as a carbon source, which may originate from biomass utilisation, direct air capture (DAC), or other CO_2 point sources recognised as sustainable under regulatory frameworks. From an energetic perspective, electricity constitutes the sole input, providing both the final energy content of the fuel and the energy required for processing. Since CO_2 is fully oxidised, all oxygen atoms must be removed via H_2, necessitating large quantities of electrolytic hydrogen. Given the high cost of hydrogen production through electrolysis, the PtL pathway represents the most expensive option. Consequently, PtL is mainly relevant in contexts where biomass availability is limited, or where CO_2 streams from processes such as ethanol or biomethane production can be valorised for eSAF generation.

The PBtL pathway integrates electricity-derived H_2 to overcome the hydrogen deficit of biomass without discarding valuable carbon, thereby maximising the production capacity from a given biomass input. As biomass itself contributes part of the hydrogen and is not fully oxidised during syngas generation, PBtL requires significantly less additional electrical energy compared to PtL. This translates into lower production costs relative to the PtL pathway. Although SAF from PBtL is expected to be more costly than purely biomass-derived SAF due to the expense of H_2 production, lower biomass demand and economies of scale may narrow this cost differential. Thus, compared to separate BtL and PtL production, PBtL is inherently advantageous due to the aforementioned synergies.

Figure 3–4: Decision Criteria for the PtL, PBtL, or BtL Production Pathways



3.3.2 Process Route Decision – Fischer-Tropsch or Methanol?

In contrast to the comparison between the production pathways, the decision-making process for selecting a specific production route (Fischer–Tropsch-based vs. methanol-based) cannot be broken down into a straightforward decision tree. This is due to the fact that the selection between production routes depends on multiple independent factors and complex evaluations. The table provides an overview of the most important decision-relevant conditions and indicates which factor supports the respective route. For a fluctuating feedstock flow rate, the methanol-based process offers clear advantages, as a larger portion of the syngas can be recycled after methanol synthesis. This allows for partial compensation of feedstock fluctuations over

time. In contrast, such flexibility is not feasible in the Fischer–Tropsch (FT)-based pathway, because the reaction and thus the product output is significantly more sensitive to changes in production conditions. Furthermore, the intermediate product methanol can not only be converted into fuels for the mobility sector but also be utilized to defossilize various industrial applications, such as a precursor for chemicals and plastics production. On the other hand, the use of FT-syncrude is limited to fuel production to a much greater extent. Furthermore, the methanol-based production route offers a higher degree of modularity, as the two main process steps – methanol synthesis and MtJ process – can be more easily separated and operated independently.

Additionally, methanol has lower transport-related environmental and safety risks compared to FT-syncrude, resulting in lower logistics costs. On the other hand, although the FT-based route is slightly less selective towards kerosene production, it is more efficient overall.

Thus, if the valorisation of by-products such as naphtha and diesel is possible, the FT-based pathway becomes more economically attractive [118]. Additionally, in the case of an immediately planned project launch, the FT-based pathway is preferable, as it has already been certified for jet fuel production under ASTM standards. This is especially to for PBtL pathway, since then (without RWGS) the TRL of the FT-based production clearly exceeds the maturity of the methanol-pathway.

Table 3–2: Process Selection Factors for Fischer–Tropsch-Based or Methanol-Based Production Route

Factor	Decision-relevant conditions	Production Route
Feedstock flow quantity	Fluctuating	Methanol-based
	(nearly) Constant	Both
Selling intermediate products in other sectors	Intended	Methanol-based
	Not intended	Both
Geographical separation of process steps	Intended	Methanol-based
	Not intended	Both
By-product revenue	Possible	FT-based
	Not Possible	Methanol-based
Project start	Immediately	FT-based
	At a later date	Both

3.3.3 Final Consideration of Process Route and Pathway Selection

To make a well-founded pathway and process route selection, it is essential to consider all the factors outlined in **Figure 3–4** and **Table 3–2**, while also defining individual priorities. A key aspect before initiating construction is the decision on the primary feedstock, including its geographic limitations, the potential for integration of the intermediate product (FT-syncrude and methanol) into other industrial sectors, the possibility of by-product valorisation and the scheduled project start.

4

Regulatory and policy framework

Jian Bani and Louise Mathu

The legal framework for PtL SAF production and export in Kenya is shaped by both international and national requirements. As SAF is still an emerging sector, compliance extends across energy, environmental, aviation, climate change, and sustainability standards. Meeting these obligations is essential not only for securing approvals within Kenya but also for ensuring that PtL SAF qualifies under global schemes and can be exported to international markets, including the EU.

This chapter reviews the main international and national regulations relevant to PtL SAF, outlines the sustainability criteria set by ICAO's CORSIA scheme and EU law, highlights available support instruments that may facilitate project development, and details the licensing requirements for establishing and operating a PtL facility in Kenya.

4.1 National and International Regulations Relevant PtL SAF Production and Export in Kenya

This section provides a high-level overview of the national and international policies and regulations relevant to export of PtL SAF produced in Kenya to the EU. At international level key regulations relevant project comprise the ICAO Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), the ReFuelEU Regulation, the EU Renewable Energy Directive, and the EU ETS. At national level, whereas Kenya to date does not have specific policies or regulations for PtL SAF, the Kenya Vision 2030, the National Green Hydrogen Strategy and Roadmap and the Kenya Energy Act 2019 set forth the general regulatory conditions for green hydrogen production in Kenya that also apply for PtL SAF production, including the scope of licenses, permits and approvals required under national law to execute PtL SAF projects in Kenya.

4.1.1 International Regulations

ICOA CORSIA

The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), developed under the auspices of the International Civil Aviation Organization (ICAO), is a global market-based mechanism aimed at stabilising net CO_2 emissions from international aviation at 2020 levels by requiring operators to offset emissions growth through the purchase of eligible carbon credits or the use of CORSIA-eligible Sustainable Aviation Fuels (SAF).

CORSIA is relevant to PtL SAF produced in Kenya, insofar as it provides a compliance-based pathway for reducing airlines' offsetting obligations through the use of SAF that meets the scheme's lifecycle greenhouse gas (GHG) performance thresholds and sustainability criteria. SAF must achieve a minimum 10 % reduction in lifecycle GHG emissions relative to the ICAO baseline. PtL fuels derived from renewable electricity and sustainable carbon sources typically achieve higher reductions, making them highly advantageous under the scheme.

To be recognised as CORSIA-eligible, SAF must be certified under a CORSIA-approved Sustainability Certification Scheme (SCS), such as ISCC CORSIA [120] or RSB CORSIA [121] or another eligible certification scheme, and must comply with ICAO's prescribed sustainability criteria. [122] Furthermore, CORSIA requires the use of a chain of custody system to ensure traceability and prevent double counting of sustainability characteristics along the supply chain.

While CORSIA and its certification framework are distinct from other regional regulatory schemes, compliance with CORSIA is only relevant where SAF is intended for use on international routes covered by the scheme. It does not apply where SAF is used exclusively within jurisdictions governed by separate emissions reduction frameworks, such as for example the European Union's Emissions Trading System (EU ETS), which have their own binding sustainability and compliance requirements.

CORSIA currently applies to international flights between participating States during its pilot phase (2021–2023) and first implementation phase (2024–2026) and will become mandatory for most ICAO Member States from 2027 onward, subject to defined exemptions for certain developing countries and low-volume emitters. Kenya's participation in the CORSIA scheme implies that PtL SAF produced domestically in Kenya is eligible for recognition towards the compliance obligations of aircraft operators subject to CORSIA, irrespective of the operator's State of registry or the geographic origin of the fuel supply.

In conclusion, CORSIA provides a globally recognised framework for the deployment of sustainable aviation fuels, offering PtL SAF producers in Kenya access to an international compliance-driven market, subject to adherence with ICAO's sustainability, lifecycle emissions, and certification requirements.

Re-FuelEU Regulation

The RefuelEU Aviation Regulation (Regulation (EU) 2023/2405) is a key legal instrument under the EU's Fit for 55 climate package, aimed at reducing greenhouse gas emissions from aviation in line with the EU's 2030 and 2050 climate targets. It imposes legally binding obligations on aircraft operators and aviation fuel suppliers to increase the use of Sustainable Aviation Fuels (SAF), including Power-to-Liquid (PtL) synthetic fuels, within the EU.

While the Regulation applies within the EU, it has extraterritorial implications for SAF producers in third countries such as Kenya, who wish to access the EU market. It creates a long-term, predictable demand for SAF, provided the fuel meets the regulatory criteria.

Under Article 4, the Regulation sets minimum SAF blending mandates for aviation fuel supplied at EU airports, starting at 2 % in 2025 and rising to 70 % by 2050. A dedicated sub-mandate for synthetic aviation fuels—which includes PtL SAF—starts at 1.2 % in 2030, increasing to 35 % by 2050. These quotas ensure that a defined and growing share of aviation fuel must come from renewable sources, creating a stable market for certified SAF producers.

To be eligible, SAF must comply with the sustainability and lifecycle greenhouse gas savings criteria established in the Renewable Energy Directive (RED II/III). For PtL SAF, this includes achieving at least 70 % GHG emissions savings compared to fossil jet fuel and using renewable electricity that meets strict requirements under RED Article 27(3), including additionality, temporal correlation, and geographical correlation—unless the production is entirely off-grid. The CO_2 feedstock must be non-biogenic, typically sourced from direct air capture (DAC) or industrial point sources.

Compliance must be demonstrated through independent certification by a voluntary scheme recognised by the European Commission under Article 30 of RED. Accepted schemes—such as ISCC EU [123] or RSB EU RED [124]—verify the sustainability, traceability, and emissions performance of the fuel. Certification is a legal requirement for SAF to be counted toward the blending mandates and to qualify for the EU market.

The Regulation currently requires that SAF be physically supplied at Union airports. All SAF volumes used for compliance must be verifiably blended and delivered at the point of uplift.

Aircraft operators and fuel suppliers are subject to monitoring, reporting, and verification (MRV) obligations under Articles 8–10 of the Regulation. This includes mandatory annual reporting on SAF quantities and characteristics, independent verification of sustainability declarations, and record-keeping for regulatory audits. Non-compliance may lead to financial penalties and the exclusion of non-compliant fuel from the quotas.

In conclusion, the RefuelEU Aviation Regulation sets a clear, enforceable legal framework for the uptake of SAF within the EU. For PtL SAF producers in Kenya, it offers long-term market certainty, but access is conditional on full compliance with EU sustainability and certification standards. The Regulation does not currently provide alternative compliance mechanisms such as book-and-claim, so physical delivery and certification remain essential for participation in the EU SAF market.

EU Renewable Energy Directive

The Renewable Energy Directive- comprising Directive (EU) 2018/2001 („RED II“) and its amending Directive (EU) 2023/2413 („RED III“) - establishes the primary legal framework for promoting energy from renewable sources across all sectors of the EU economy, including the transport sector. It is directly relevant to the development of PtL SAF production facilities in Kenya, with the aim of exporting such fuels to the EU aviation market. Compliance with RED II/III is a legal prerequisite for SAF to be recognised as renewable within the EU and to count toward climate and energy targets, including those established under the RefuelEU Aviation Regulation (Regulation (EU) 2023/2405).

Of particular relevance to PtL SAF is RED II/III’s definition and regulatory treatment of Renewable Fuels of Non-Biological Origin (RFNBOs). These are defined in Article 2(36) REDII/III as liquid or gaseous transport fuels not derived from biomass, whose energy content is entirely derived from renewable sources. PtL SAF produced using hydrogen derived from renewable electricity and non-biological CO_2, such as from industrial point sources or direct air capture, falls within this legal category—provided all sustainability and emissions performance requirements are met.

To qualify as an RFNBO under RED II/III, PtL SAF must be produced using 100 % renewable electricity. Article 27(3) RED II/III, as further elaborated in Commission Delegated Regulations (EU) 2023/1184 and 2023/1185, sets specific criteria for determining whether the electricity used in production can be considered renewable under EU law. For grid-connected installations, compliance requires:

- Additionality: electricity must come from new renewable generation capacity,
- Temporal correlation: alignment between electricity generation and use, moving toward hourly matching by 2030, and
- Geographical correlation: electricity must be sourced from the same bidding zone or directly connected.

However, off-grid PtL SAF facilities powered entirely by dedicated renewable energy sources (e.g. solar, wind, or geothermal) are exempt from correlation requirements.

This creates a strategic opportunity for Kenya to leverage its abundant renewable energy resources through co-located or captive power configurations.

Under Article 29a RED II/III, RFNBOs must also demonstrate a minimum 70 % reduction in lifecycle greenhouse gas (GHG) emissions compared to conventional fossil-derived aviation fuel. Compliance with this threshold is mandatory for the fuel to be legally classified as renewable and to count toward EU climate targets.

With respect to the CO_2 required for PtL SAF production, RED II/III does not prescribe specific eligible sources. Article 25(2) simply stipulates that the CO_2 must not be of biological origin and that the fuel must be produced with renewable electricity. In practice, however, only certain sources—such as CO_2 captured from industrial point sources or through direct air capture (DAC)—are capable of meeting the necessary greenhouse gas (GHG) performance thresholds and obtaining certification. Although other CO_2 sources are not expressly excluded, their use may undermine lifecycle GHG performance and thereby jeopardize the fuel’s eligibility.

In addition, all RFNBOs, including PtL SAF, must be independently certified by a voluntary scheme recognised by the European Commission under Article 30 RED II/III. Approved schemes, such as ISCC EU [123] or RSB EU RED [124], verify compliance with sustainability criteria, lifecycle emissions performance, traceability, and mass balance requirements. Without such certification, PtL SAF produced in Kenya cannot be marketed as renewable aviation fuel in the EU, nor can it be used to fulfil obligations under instruments like RefuelEU.

In conclusion, RED II/III sets out the legal conditions, technical benchmarks, and certification requirements that PtL SAF produced in Kenya must comply with to access and compete in the EU aviation fuel market. The Directive governs the eligibility of fuels as renewable, mandates GHG performance thresholds, and establishes strict criteria for electricity sourcing and CO_2 inputs. Alignment with RED II/III is thus essential for legal recognition, market eligibility, and long-term bankability of PtL SAF exports to the European Union.

The EU Emission Trading System (EU ETS)

The European Union Emissions Trading System (EU ETS) constitutes the principal market-based mechanism established under Union law for the cost-effective reduction of greenhouse gas (GHG) emissions. It operates through a cap-and-trade framework, pursuant to Directive 2003/87/EC [127], as most recently amended by Directive (EU) 2023/959, and applies to emissions from a range of sectors, including aviation.

The EU ETS is directly relevant to the prospective export of Power-to-Liquid (PtL) Sustainable Aviation Fuel (SAF) from Kenya to the European Union, as SAF that meets the applicable sustainability and greenhouse gas savings criteria is treated as zero-rated for emissions compliance purposes. This legal classification—provided under Article 3c of Directive 2003/87/EC in conjunction with the Renewable Energy Directive III - exempts qualifying SAF from the obligation to surrender EU ETS allowances, thereby generating a commercial and regulatory incentive for aircraft operators to procure and use SAF, including from third countries such as Kenya.

Pursuant to the EU ETS, all intra-European Economic Area (EEA) flights, and selected international departures, fall under emissions monitoring obligations. Operators must monitor, report, and verify (MRV) their emissions annually and surrender one allowance per tonne of verified CO_2 emitted. The ongoing phase-out of free allowances—25 % reduction in 2024, 50 % in 2025, and full auctioning from 2026—further increases the cost of fossil fuel usage and enhances the relative value of SAF in the emissions compliance strategy of airlines.

In support of early SAF deployment, the amended EU ETS establishes a dedicated reserve of 20 million allowances between 2024 and 2030 to compensate operators for the cost differential between fossil kerosene and eligible SAF. The level of cost compensation is differentiated by fuel type: 95 % for renewable fuels of non-biological origin (PtL); 70 % for advanced biofuels; and 50 % for other SAF. These allowances are allocated annually, based on verified SAF use, and administered in accordance with procedures defined by the European Commission.

Airlines must submit SAF usage data by 31 March; the Commission publishes fuel price benchmarks by 31 May; and competent authorities allocate allowances by 31 August.

Eligibility for such regulatory incentives is contingent upon full compliance with the sustainability and lifecycle GHG performance criteria set out in RED III. For PtL fuels, a minimum lifecycle emissions reduction of 70 % is required relative to the fossil comparator. Compliance must be demonstrated through participation in a recognised voluntary certification scheme and the use of a legally compliant mass balance system or equivalent chain of custody method. The legal basis for these requirements is set out in Article 30 of RED III and further specified in Commission Implementing Regulation (EU) 2022/996 [126], which governs the traceability and verification obligations applicable to economic operators.

Producers of PtL SAF in Kenya must therefore ensure robust documentation, third-party verification, and traceability across the supply chain, including emissions associated with feedstock sourcing, processing, and delivery to final use points in the EU. Only SAF that meets these criteria may be treated as zero-emission under the ETS and be eligible for allowance-based compensation.

As already outlined, in addition to the ETS framework, the ReFuelEU Aviation Regulation introduces binding SAF blending mandates and a specific sub-target for synthetic aviation fuels (including PtL). While a detailed analysis of these obligations has been outlined further above, it should be reiterated that the Regulation establishes a legally binding and progressively increasing demand for SAF and synthetic fuels at EU airports, thereby complementing the EU ETS by reinforcing long-term market certainty for SAF producers and exporters.

In conclusion, the EU ETS, together with the Renewable Energy Directive and supported by the ReFuelEU Aviation Regulation, creates a coherent legal and economic framework favourable to the production and export of PtL SAF from Kenya.

Full regulatory compliance is essential for market access and for the realisation of the emissions and financial incentives established under Union law.

4.1.2 National Regulations

As mentioned earlier in this chapter, Kenya does not have a particular policy on PtL SAF. However, within the existing broader regulatory framework comprising policies, strategies and action plans, acts of parliament and regulations, there are provisions that support the proposal to develop a pilot PtL SAF plant in the country. PtL SAF development cuts across three main sectors, energy, transport and environment/climate change. This section will therefore highlight the key and relevant aspects of the regulatory framework across these sectors that relate to or have implications for PtL SAF development in Kenya.

Kenya Vision 2030

Vision 2030 is Kenya's development blueprint spanning the years 2008 to 2030. Energy is identified as one of the enablers of the country's development under the economic pillar, with the exploitation of renewable energy mentioned as an important component for the energy sector. The Vision is implemented in successive five-year Medium-Term Plans with the country currently in the fourth such plan, MTP IV that covers the period 2023-2027. MTP IV clusters development under five key priorities sectors, two of which are particularly relevant for this study – infrastructure and environment and natural resources sectors.

- Under the infrastructure sector, the plan proposes promoting the development of energy generation by increasing investments in green energy citing geothermal, wind, solar and hydro. Alternative energy technologies such as the development of green hydrogen is also mentioned.
- The Environment and Natural Resources sector highlights several aspects with the one most relevant being the sustainable exploitation of natural resources. Targeted interventions mentioned include climate change mitigation and reduction of greenhouse gas emissions (GHF Reduction in GHG emissions is an important component given Kenya's commitment to reduce emissions in the aviation sector.

Energy Sector Regulatory Framework

National Energy Policy, 2018

PtL SAF development in Kenya falls primarily under the energy sector whose development is currently guided by the National Energy Policy 2018. The policy identifies biofuels and hydrogen derived from renewable resources as among the resources that can supply Kenya's present energy needs as well as those of the future in a sustainable way. It captures some of the requirements for the development of biofuels such as bio-ethanol feed stocks with sugarcane and sweet sorghum as the main feedstock for ethanol and jatropha, castor and other vegetable crops such as coconut, croton and cotton seed for biodiesel.

The policy highlights several challenges that face the development of bio-fuels such as; insufficient feed-stocks to produce biofuels for blending; limited research data/information for the use and sustainable production of biofuel; insufficient legal and institutional framework to support sustainable generation, utilisation, production, distribution, supply and use of liquid biofuels; the threat of competition over land use that could lead to food insecurity; reliance on rain fed, slow maturing feed-stock for biofuels and inadequate research and development on alternative biofuel feed-stocks and technologies; lack of knowledge among the stakeholders on the importance of biofuels for complementing energy needs in the country and competing uses of the ethanol.

To facilitate the development of biofuels, the policy proposes research and development, review of the regulatory framework, collaboration among various stakeholders to ensure efficient land use for biofuel feedstock, food production and other human needs.

Planning for electricity expansion in the country is another important aspect of the policy with regard to PtL SAF production because of the Additionality requirement in the EU's Renewable Energy Directive. Additionality requires that after 2028, hydrogen used in PtL synthesis is to be produced from new generation capacity and not drawn from existing capacity.

Power planning in Kenya is guided by a twenty-year Least Cost Power Development Plan (LCPDP) to facilitate decision-making in power generation development and transmission capacity for the country in the medium to long term. The plan is updated every two years. The latest version of the LCPDP was adopted in June 2024 and covers the period 2024 to 2023. In view of the country's plan to develop PtL SAF that could possibly be obtained from green hydrogen derivatives, it would be important that updates of the LCPDP take into account future plans for electricity production that comply with the EUs Additionality requirement after 2028.

Draft Energy Policy (2025-2034)

The Government of Kenya through the Ministry of Energy and Petroleum has reviewed the National Energy Policy 2018 and developed a draft National Energy Policy 2025 – 2034. The reasons for the review are to, among others, accelerate the harnessing of renewable energy sources and adoption of emerging technologies. The proposed new policy is yet to be adopted but has been through the main stages required for adoption, including a validation forum with sector stakeholders. In anticipation of its expected adoption, it is therefore important to highlight relevant provisions that relate to SAFs in Kenya.

The draft policy cites Kenya's goal to halve CO_2 emissions from the aviation sector by 2050 in line with the international aviation industry's climate change targets. It also identifies SAF derived from bioenergy and green hydrogen as transformative solutions to decarbonize the industry. Several challenges that need to be addressed are captured; low production of biofuel feed-stocks due to lack of awareness and markets; lack of refining infrastructure, technical expertise and research in SAFs; advanced conversion technologies for converting biomass to jet fuel being locally unavailable; inadequate legal and institutional framework to support sustainable development of SAFs; and investment costs for achieving commercial viability are high. The global requirement for decarbonisation in the aviation industry including certification and standards for fuel and vast renewable energy potential for SAF production however present opportunities for its development in Kenya.

In the draft policy the Government undertakes to, in the next five years, develop a framework for oversight and coordination of SAF production; facilitate research and development to scale up the use of biofuels and green hydrogen; strengthen international partnerships to align with global climate goals and technology advancements and establish policies to integrate sustainable fuels into national energy strategies.

The Energy Act, 2019

This is the main law or Act of Parliament that governs Kenya's energy sector. It provides for the promotion and development of renewable energy technologies which include biomass, biodiesel and bioethanol, solar, wind, hydropower and municipal waste. It provides for the use of fast maturing trees for energy production including biofuels and the establishment of commercial woodlots. The Rural Electrification and Renewable Energy Corporation is the state energy agency conferred with the responsibility of managing, in collaboration with other agencies, the use of renewable energy and technologies such as biodiesel and bioethanol.

The Act identifies some functions of County Governments relevant for PtL SAF production such as physical planning for solar and wind farms, municipal waste dumpsites and plantations for the production of bio-energy feedstock.

Green Hydrogen Strategy and Roadmap for Kenya

The Green Hydrogen Strategy and Roadmap highlights that that green hydrogen derivatives can play and important role in decarbonising the aviation sector through the use of SAF. The level of readiness for the country to do so is however stated to be rather low. Establishment of a regulatory framework is a critical pillar in mitigating certain risks to adequately facilitate development of derivatives that can be used for SAF.

Kenya's Guidelines on Green Hydrogen and Its Derivatives

These Guidelines were published by the Energy and Petroleum Regulatory Authority (EPRA) in May 2024 and provide guidance on sustainability criteria for green hydrogen and its derivatives. In addition, they also highlight relevant statutory requirements, standards and a monitoring mechanism for projects under development

The Guidelines identify synthetic fuels, that includes SAFs, as some of the derivative products of green hydrogen and sustainably sourced carbon dioxide in a process powered by renewable energy. The regulatory steps to be complied with by a developer desiring to establish a facility handling green hydrogen and its derivatives are provided. These steps are summarised as follows:

- Expression of Interest (EoI): A developer is to submit an EoI to the Ministry of Energy and Petroleum. The application should be accompanied by a pre-feasibility study report which should provide details of the intended project location; size of land; source of electricity for the electrolyser and renewable energy technology; source of water; capacity of the electrolyser in MW; source of financing for the project; project partners; potential infrastructure requirements such as transmission lines and proposed off-takers.
- The Green Hydrogen Program Coordination Committee (GH2–PCC) reviews recommendations from a Green Hydrogen Secretariat (housed at the Ministry of Energy and Petroleum) and approves or rejects EoI applications within a period of 60 days. GH2-PCC is a multisectoral committee comprising government ministries and relevant state agencies, private sector and civil society. It provides strategic leadership, monitors and evaluates the progress of green hydrogen projects among other functions.
- Where the EoI is approved, a developer is to progress to a full feasibility study within 24 months of EoI approval and submit it to the GH2-PCC for approval. The feasibility study is to contain, as a minumum, a resource assessment, technical feasibility, and environmental and social impact assessment; a project financing and proposed green hydrogen off-taker/transformation plan; a risk management plan and an implementation plan.
- The GH2-PCC reviews the feasibility study and approves or rejects it within 60 days of its submission.

Following approval of the feasibility study, a developer is required to obtain other licensing/regulatory approvals. These are highlighted in greater detail in part of this chapter.

The Guidelines highlight certain incentives that are available to developers interested in establishing projects in Kenya. These incentives are not specific to SAF production projects in Kenya but form part of a wider national framework to attract investment and encourage the establishment of industries in the country

- Export Processing Zones (EPZs): EPZs are defined in the Export Processing Zones Act, Cap 517 as a designated part of Kenya where any goods introduced are generally regarded, in so far as import duties and taxes are concerned, as being outside the customs territory but are duly restricted by controlled access... and enjoy certain other benefits. Some of the incentives available in EPZs include a 10-year tax holiday; perpetual exemption on duty and value-added tax (VAT) on machinery and raw materials; operation under a single license; perpetual exemption from stamp duty; a 10-year withholding tax holiday; 25 % corporate tax after expiration of the first 10-year tax holiday; 100 % investment deduction allowance over 20 years and no exchange controls.

- Special Economic Zones (SEZs) – These are areas designated as such by the Government of Kenya pursuant to the Special Economic Zones Act, Cap 517A. The purpose of SEZs is to promote global and local investment and facilitate the development of an enabling environment for such investments. SEZs that are relevant for SAF project development in Kenya are industrial parks. An industrial park is defined in this Act as an area with integrated infrastructure to facilitate the needs of manufacturing and processing industries. There are currently 3 public and 15 private SEZs which benefit from several incentives: imported goods fully exempt from VAT, excise duty, import duty and import declaration fee; zero-rated VAT for local supplies; 10-year tax holiday; 10 % corporate tax for the first 10 years, 15 % corporate tax for the next 10 years and 30 %; corporate tax for subsequent years; operation under a single license; perpetual exemption of stamp duty; preferential rates for withholding tax at 5 % on interest, management and royalties; 100 % investment deduction allowance over 20 years; and access to special electricity tariffs.

Prospective developers of SAF projects could explore the possibility of establishing production plants in an EPZ or SEZ in order to benefit from the incentives available in these areas.

Bioenergy Strategy (2020 – 2027) and Bioenergy Strategy Action Plan 2023

The Bioenergy Strategy was launched in November 2020 with the objective of promoting the sustainable production, distribution and utilisation of bioenergy as a clean source of energy. The Action Plan captures the specific activities to be implemented to achieve the Strategy. The Strategy highlights challenges such as competition for land between energy crops and food crops, insufficient supplies from the sugar industry due to the low prices offered and lack of standards and regulations. Proper land use planning, intercropping with food crops and effective delivery and co-ordination mechanisms under the Ministry of Energy are cited as ways these challenges could be addressed. Innovation Platforms are mentioned as being key to implementing the aspirations of the Strategy. Innovation Platforms which are organised in thematic areas are defined as safe spaces for stakeholder learning and change with champions proposed to advocate for each theme. The potential uses of renewable carbon, particularly from biomass waste as envisaged in the proposed SAF pilot plant project and SAFs themselves are not captured in the Strategy. These are notable gaps that could be highlighted and brought to the attention. of the National Bioenergy Committee (domiciled at the Ministry of Energy and Petroleum) in the SAF stakeholder engagement process to draw attention to the potential for PtL SAF production in Kenya.

Transport Sector Regulatory Framework

Updated Integrated National Transport Policy, 2024

This policy recognises that the transport sector is one of the largest emitters of the GHGs and the role of SAF to reduce these emissions. It emphasises the need for Kenya to comply with national and international legal requirements that include; development of a framework for aviation environment protection including the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA); supporting coordination between the aviation stakeholders and environment experts to enhance expertise and promoting knowledge sharing and harmonization of positions on issues of environment protection. Development of capacity in terms of personnel, technology and encouraging production and deployment of alternative sources of fuels including SAF is also mentioned.

Action Plan for CO_2 Emissions Reduction in the Aviation Sector (2022–2028)

The Aviation Industry Action Plan sets an ambitious goal to reduce GHG emissions from both domestic and international operations, which is expected to contribute to both global efforts to minimize aviation's carbon footprint and achievement of Kenya's Nationally Determined Contribution (NDC) target.

It identifies SAF as one of several measures that is expected to have the greatest environmental benefits on the aviation industry. Development of a Sustainable Biofuels Policy that includes SAF is captured as one of the actions that Kenya will undertake to facilitate SAF development. The Ministry of Energy will take lead on implementing several actions:

- Start pilot projects for utilization of green hydrogen for ground and aviation services
- Undertake full feasibility study(s) for take-off of green hydrogen
- Start pilot projects for production of Sustainable Aviation Fuels (SAFs)
- Review of the Ministry of Energy Bioenergy Strategy
- Review the SAF standards to ensure consistent product quality
- Conduct training and capacity building

In addition, the Action Plan reports that the Government is developing a comprehensive renewable fuels strategy primarily focused on on-road transportation including aviation with five key elements:

- A regulation to establish minimum biofuels content for ethanol and diesel
- Programs to support farmer participation in the industry
- A production incentive to stimulate domestic production
- Encourage the use of ethanol from the sugar industries
- Initiatives to support next generation technologies

The Action Plan sets out concrete steps and actions that are planned or are being undertaken by the Government of Kenya to support SAF development. This provides confidence for the planned PtL SAF pilot project and impetus for the development of a more robust and specific regulatory framework for SAF in Kenya.

Civil Aviation Act, 2013, Civil Aviation (Amendment) Act, 2016 and Draft Civil Aviation (Carbon Offsetting and Reduction Scheme for International Aviation) Regulations, 2024 (CORSIA Regulations)

The Aviation Act itself does not contain substantive provisions on PtL SAF production but proposed regulations as subsidiary legislation under it - Draft CORSIA Regulations have however been prepared pursuant to Section 82 of the Civil Aviation Act 2013. This section empowers the Cabinet Secretary in the Ministry of Roads and Transport to make regulations, such as the draft CORSIA regulations, to facilitate the operationalisation of CORSIA in Kenya. The regulations are yet to be adopted but they have undergone several steps in the regulation adoption process and could become part of the aviation sector's regulatory framework in the not-too-distant future, which is why they are highlighted in this chapter.

The general objective of the regulations is to promote consistent implementation of the technical requirements for the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). The specific objectives are to:

- Provide guidelines for monitoring, reporting and verification of an aeroplane operator's CO_2 emissions
- Provide guidelines on an aeroplane operator's CO_2 offsetting requirements
- Provide relevant applicability requirements to an aeroplane operator engaged in international air navigation
- Provide for developing and maintaining the CO_2 emission registry for the purpose of implanting CORSIA
- Ensuring that Kenya complies with existing national and international regulations, guidelines and standards on climate change mitigation and adaptation in the aviation sector.

Environment Sector Regulatory Framework

Kenya’s Nationally Determined Contribution (NDC) pursuant to the Paris Agreement

At the international level, Kenya submitted its Second NDC for the period 2021-2035 on the 30th of April 2025. The country’s mitigation target towards fulfilment of its obligations under the Paris Agreement is to endeavor to abate her GHG emissions by 35 % by 2035 relative to the BAU scenario of 215 $MtCO_2eq$ in 2035, leading to the abatement of 75.25 $MtCO_2eq$. The NDC indicates that this mitigation goal will be achieved through the promotion of some key priority mitigation initiatives including increased renewable energy generation in the national grid, towards 100 % by 2035 so as to enable adoption of clean efficient energy use for transport industry and overall greening of the transport sector. Aviation is not mentioned specifically but it forms part of part of Kenya’s transport sector which therefore implies that the commitment on mitigation measures extends to actions for the aviation sector, such as the adoption of PtL SAF.

The Climate Change Act, 2016

This key piece of legislation provides for a regulatory framework for enhanced response to climate change and mechanisms and measures to achieve low carbon climate development in Kenya. The Act mandates that state departments and national government public entities integrate the climate change action plans and other implementation projections; report on sectoral GHG emissions for the national inventory and regularly review the performance of climate change functions through sectoral mandates.

The Kenya Civil Aviation Authority (KCAA), the regulatory body for the aviation sector, which is a public entity, therefore has obligations under the sectoral mandate of the Ministry of Roads and Transport under which it falls. The Act further provides that climate change obligations may also be placed on private entities which would be required to report on the performance of these duties. These obligations could therefore extend to Kenya’s national airline, Kenya Airways, other Kenyan aircraft carriers and other entities involved in the PtL SAF value chain.

National Climate Change Action Plan (NCCAP) III (2023-2027)

The Climate Change Act mandates the formulation of a National Climate Change Action Plan that presents detailed priority actions that Kenya will embark on to address climate change. The Plan is reviewed every five years with the current version covering the period 2023-2027. Energy and Transport are captured under Climate Change Priority 7 with planned actions being to increase generation of electricity from renewable energy sources in a climate resilient manner and encouraging low-carbon technologies in the aviation sector. The plan further sets expected results such as a policy and regulatory framework for emerging technologies such as green hydrogen to be developed by 30th June 2028. By the same period expected actions for the aviation sector include the implementation of CORSIA in Kenya and development of SAF with lower life cycle CO_2 emissions.

The Climate Change (Carbon Market) Regulations, 2024

These regulations adopted in 2024 provide a framework for implementation of carbon projects and create incentives to support GHG emissions reduction and removal targets in line with Kenya’s Nationally Determined Contribution. The regulations require that each transaction in a carbon project result in additional reduction or removal of GHGs and that reported mitigation outcomes are accounted for in tonnes of carbon dioxide equivalent. Project proponents desiring to engage in a carbon project is to apply to the Designated National Authority under the regulations (National Environment Management Authority, NEMA) for approval of the carbon project. Where the proposed PtL SAF project is proposed to be registered as a carbon project, the procedures to be followed would need to be followed as prescribed in these regulations.

From the foregoing review of Kenya's regulatory framework, it is clear that despite the lack of a specific policy or law on SAF in Kenya, the existing framework is fairly sufficient to support PtL SAF development initiatives such as the proposed pilot project. This proposed pilot project aligns with and supports the country's goal of decarbonising it's aviation industry through adoption of SAF.

4.2 Sustainability Criteria

This subchapter identifies sustainability criteria that should be taken into consideration for producing PtL Sustainable Aviation Fuel (SAF) in Kenya and exporting it to the European Union (EU) and globally. Producers operating within the Kenyan jurisdiction and intending to access international SAF markets must ensure that their production practices conform to both (a) globally recognized sustainability standards under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), administered by the International Civil Aviation Organization (ICAO), and (b) the binding sustainability requirements imposed by European Union legislation, particularly those set forth in Directive (EU) 2018/2001 (RED II), Regulation (EU) 2023/2405 (ReFuelEU Aviation), and related delegated regulations.

4.2.1 Sustainability Criteria under ICAO's CORSIA Scheme

The ICAO framework sets out fourteen (14) sustainability criteria for SAF to be eligible for CORSIA crediting. The following analysis identifies those criteria to the degree that they may be relevant for PtL SAF production:

- **CORSIA SAF Sustainability Criterion 1 – Reduction of Greenhouse Gas Emissions:** CORSIA SAF Sustainability Criterion 1 concerns the reduction of greenhouse gas emissions. This criterion requires that CORSIA-eligible SAF must result in net greenhouse gas emissions that are at least ten percent (10 %) lower, on a full life cycle basis, than the baseline emissions for conventional fossil-derived jet fuel. For PtL SAF, this necessitates the exclusive use of renewable electricity and low-carbon CO_2 sources to satisfy lifecycle accounting methodologies.
- **CORSIA SAF Sustainability Criterion 2 – Protection of Carbon Stock:** CORSIA SAF Sustainability Criterion 2 concerns the protection of carbon stock. While not directly applicable, this criterion compliance with this criteria requires to ensure that PtL SAF production sites do not involve the conversion of areas with high biogenic carbon stock, such as forests or wetlands.
- **CORSIA SAF Sustainability Criterion 3 – Permanence of GHG Emissions Reduction:** CORSIA SAF Sustainability Criterion 3 concerns the permanence of greenhouse gas emissions reductions. This criterion only applies if carbon capture and sequestration (CCS) is used in PtL SAF production. In such cases, compliance requires ensuring that captured carbon remains permanently stored, with measures for monitoring, mitigation, and leakage prevention in place.
- **CORSIA SAF Sustainability Criterion 4 – Protection and Sustainable use of Water Resources:** CORSIA SAF Sustainability Criterion 4 concerns the protection and sustainable use of water resources. This criterion requires that producers must demonstrate that water used—particularly in the electrolysis process—is sourced and managed in a manner that maintains or enhances water quality and does not result in the depletion of surface or groundwater resources beyond natural replenishment rates.
- *CORSIA SAF Sustainability Criterion 6 – Protection of Air Quality:* CORSIA SAF Sustainability Criterion 6 concerns the Protection of Air Quality.

This criterion requires that PtL SAF production must be operated to minimize emissions that may adversely impact air quality. This includes ensuring that emissions from electrolysis units, synthesis reactors, or combustion processes comply with applicable air emission standards and are subject to continuous monitoring.

- CORSIA SAF Sustainability Criterion 7 - Conservation of Biodiversity and Ecosystems: CORSIA SAF Sustainability Criterion 7 concerns the conservation of biodiversity and ecosystems services. PtL SAF production facilities must not be established in areas designated for biodiversity protection or known for critical ecosystem services, unless it can be demonstrated that such operations do not undermine the conservation objectives of the area. This is particularly pertinent during the project siting phase.

- CORSIA SAF Sustainability Criterion 8 - Waste and Chemical Management: CORSIA SAF Sustainability Criterion 8 concerns waste and chemical management. Producers must implement operational controls to ensure that any waste products and chemicals used during the production process - including catalysts, solvents, and fuel intermediates - are safely stored, handled, and disposed of in accordance with best environmental practices and legal requirements.
- CORSIA SAF Sustainability Criterion 10 - Human and Labour Rights: CORSIA SAF Sustainability Criterion 10 concerns the protection of human and labour rights.
- All stages of PtL SAF production must respect internationally recognized human rights and labour standards, including the prohibition of forced labour, the right to safe working conditions, and non-discriminatory employment practices, in conformity with ILO (International Labour Organization) conventions.
- CORSIA SAF Sustainability Criterion 11 - Land Use Rights and Tenure: CORSIA SAF Sustainability Criterion 11 concerns land use rights and tenure. Although PtL SAF does not require large-scale land occupation, the rights of local landholders—including customary and indigenous rights—must be respected. Land acquisition for facility construction must be based on lawful tenure, free, prior, and informed consent where applicable, and documented through verifiable processes.
- CORSIA SAF Sustainability Criterion 12 – Water Use Rights: CORSIA SAF Sustainability Criterion 12 concerns water use rights. Production of PtL SAF must not infringe upon the formal or customary water use rights of indigenous peoples or local communities. Equitable access and non-discriminatory allocation must be ensured for shared water resources.
- CORSIA SAF Sustainability Criterion 13 - Local and Social Development: CORSIA SAF Sustainability Criterion 13 concerns local and social development. Whereas compliance with this criterion is not mandatory, PtL SAF producers are encouraged to take actions that contribute positively to the socio-economic development of communities in regions of poverty. This may include local employment, skills transfer, and infrastructure development.

4.2.2 Sustainability Criteria under European Union Law

For PtL SAF to be eligible for import and market entry to the EU, compliance with the following legal provisions is mandatory:

- Greenhouse Gas Savings Threshold: PtL SAF must achieve at least seventy percent (70 %) greenhouse gas emissions savings relative to the fossil comparator, as specified in RED II, Annex V.
- Renewable Electricity Source for Hydrogen: Hydrogen used in PtL synthesis must be produced from renewable electricity sources. This must comply with the conditions outlined in Delegated Regulation (EU) 2023/1184, including:
    - Temporal correlation (alignment of hydrogen production and renewable electricity generation).
    - Geographical correlation (proximity between electricity source and electrolyser).
    - Additionality (post-2028, renewable electricity must come from new generation capacity).
- Carbon Dioxide Source Requirements: CO_2 used must originate from:
    - Direct air capture (DAC), or
    - Industrial point sources where emissions would otherwise be released into the atmosphere and are non-biogenic in origin.

- Certification and Traceability: Sustainability claims must be verified under an EU-recognized voluntary scheme (e.g. ISCC, RSB), which must maintain auditable records and provide full traceability of inputs, emissions, and outputs in accordance with Articles 25–30 of RED II.
- Environmental and Water Use Considerations: Although the EU does not impose standalone water criteria for PtL, environmental permits must address any significant water use in electrolysis, especially in areas where water stress is documented.

National Sustainability Criteria

Kenya's Guidelines on Green Hydrogen and Its Derivatives capture sustainability criteria that borrows elements of the CORSIA Sustainability Criteria. The specific aspects in the Guidelines are:

- Source of electricity - Electricity for green hydrogen production may be sourced from a captive renewable energy plant which may or may not be grid tied. Where a captive power plant is grid tied, EPRA is to validate energy measurements to verify that only renewable energy produced by the plant was used in the process of electrolysis. Energy attribute certificates or renewable energy certificates may also be used to confirm this requirement has been met. Where electricity is supplied from the grid, at least 80 % of the electricity supplied to the electrolyser should be renewable energy, based on the previous calendar year's electricity mix. The grid intensity should be below 64.8 gCO_2/kWh, also based on the previous year's electricity mix.

Where power is wheeled using the grid, the developer must demonstrate that the plant was not contracted for the grid at the time the electrolyser was being commissioned. The electricity used by the electrolyser in such an arrangement must be generated in the same period when the renewable energy plant is operational.

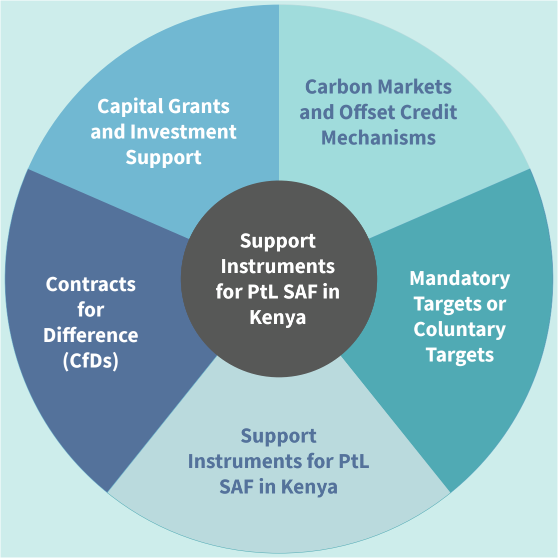
- Water resource: Developers are to optimise water use and avoid using freshwater in sites with water stress and reduce risk associated with water stress.
- Land: Developers are encouraged to use non-arable land or areas with minimal environmental and ecological impacts.
- Local communities: Developers are required to engage with the seek project acceptance from local communities and also endeavour to improve the standard of living of affected communities.

This national sustainability criteria is evidently quite limited relative to what is provided in the CORSIA sustainability criteria. SAFs produced in Kenya that are to gain access to international markets would be required to meet CORSIA requirements.

4.3 Support Instruments for PtL SAF

This section provides a high-level overview of potential key support instruments available to promote the production of PtL SAF in Kenya. Potential support instruments comprise capital grants and investment support, carbon Markets and carbon offset credit mechanisms, mandatory blending targets or voluntary targets, tax credits or production-based incentives, and Contracts for Difference (CfDs). Whereas not all instruments present feasible short-term options to for Kenya at this time, it is recommendable to consider introducing a combination of strategically selected support instrument in the medium-term. Such an approach would facilitate the effective deployment of PtL SAF and other types of SAF in Kenya, consistent with national climate goals and industrial development objectives.

Figure 4–1 : Support Instruments for PtL SAF in Kenya



Capital Grants and Investment Support

Capital grants offer direct public or donor financing to cover a portion of the upfront costs associated with establishing PtL SAF production facilities, including electrolysis units, CO_2 capture systems, and fuel synthesis infrastructure. Such grants can be expected to contribute to lower the initial financial barrier by de-risking private sector investment, thereby contributing to incentivise pilot projects and mobilise additional private sector investment. Additionally, grants can be conditioned on technology transfer, skills development, and environmental safeguards, aligning with Kenya's sustainable policy objectives. For Kenya capital grants funded through entities such as the Green Climate Fund or through international multilateral or bilateral partnerships present a feasible instrument to support the deployment of PtL SAF in short-term. In this respect, Kenya has substantial experience with capital grants in the energy sector, particularly through partnerships with bilateral donors, multilateral development banks, and climate finance mechanisms. This experience makes capital grants a well-understood and legally feasible tool for supporting early-stage clean energy technologies such as PtL SAF.

Carbon Markets and Offset Credit Mechanisms

Carbon markets present another potential instrument to support the deployment of PtL in Kenya. Carbon markets would enable producers to monetize emissions reductions through certified carbon credits. These credits could be traded on compliance markets comparable to international schemes like the EU ETS or on voluntary carbon markets. However, this option is not regarded as realistic for Kenya in short-term this stage as no adequate regulatory framework for certification of carbon credits PtL SAF is in place and institutional experience is limited. However, in the medium-term Kenya could with international assistance develop the enabling regulatory framework and build the necessary capacity for certifying PtL SAF credits.

Mandatory and Voluntary Blending Targets

Mandatory blending targets could present another potential instrument to support the deployment of PtL in Kenya. Mandatory blending targets would oblige fuel suppliers to include a defined percentage of SAF within aviation fuel.

Blending targets may include technology-specific targets for different types of SAF, including for PtL SAF. The European Union presents a good example for this approach through the RefuelEU Aviation Regulation, which includes mandatory SAF and technology specific blending targets, including specific targets for PtL SAF. However, while mandatory targets are effective at driving market demand and providing investment certainty, mandatory blending targets are not regarded as a realistic support instrument for the deployment of PtL SAF in Kenya in the short-term. In this respect, Kenya presently has limited domestic SAF production and a robust enabling legal framework for certification of SAF and enforcement of compliance with national mandatory national targets is not in place. However, whereas mandatory blending targets would thus only be a medium-term option, voluntary blending targets could present a feasible short-term alternative to mandatory blending targets. Voluntary blending targets could be embedded in national and potentially regional climate policy instruments and strategies. This approach would signal political commitment to the deployment of SAF while allowing time to develop domestic production capacity and policy infrastructure. In addition, it would serve as soft regulatory support instrument for promoting the deployment of SAF including PtL SAF in Kenya in the short-term and help to prepare the ground for the introduction of mandatory SAF blending targets in the medium-term.

Tax credits or Production-Based Incentives

Tax credits or production-based incentives could present another potential instrument to support the deployment of PtL SAF in Kenya. Tax credits would contribute to reduce the tax burden of PtL SAF producers in Kenya's tax liability based on the volume or emissions performance of fuel produced. Production-based incentives would provide performance-based cash transfers to PtL SAF producers. The policy goal of both would be to lower the productions costs of PtL SAF, thereby contributing to improve the competitiveness of PtL SAF vis a vis fossil aviation fuel. However, whereas tax credits and production-based incentives can be a very effective instrument for supporting PtL SAF and other types of SAF, this instrument is not regarded as a recommendable option for Kenya in the short-term given that presently no verification system that is required to verify the tax credits or production of SAF is in place. Nevertheless, whereas Tax credits and production-based incentives do not present a feasible support instruments to promote the deployment of PtL SAF in Kenya in the short-term it should be considered to form part of the future combination of strategically selected support instruments in the medium-term.

Contracts for Difference (CfDs)

Contracts for Difference (CfDs) could present another potential instrument to support the deployment of PtL SAF in Kenya. Under CfDs the public sector would guarantee the producer a minimum price for SAF over a specified period of time. If the market price would fall below this agreed price, the public entity would be obliged to compensate the producer. On the other hand, if the market price would rise above the agreed price, the producer would be obliged to return the difference. This model would provide long-term revenue stability for PtL SAF producers and thereby making potential projects bankable by removing exposure to price volatility. However, whereas CfDs could present a very effective instrument to support the deployment of PtL SAF, CfDs do not present a feasible short-term option for Kenya. In this respect CfDs are highly complex in terms of price benchmarking and require enforceable long-term public contracts, and guaranteed access to public funds to cover potential liabilities. These requirements may exceed the current legal and administrative capabilities of Kenya's public sector. Nevertheless, whereas CfDs do not present a feasible support instrument to promote the deployment of PtL SAF in Kenya in the short-term it should be considered to form part of the future combination of strategically selected support instruments in the medium-term.

4.4 Licensing Requirements

PtL SAF production cuts across various sectors in Kenya, therefore several licensing requirements would need to be fulfilled to facilitate development and actual construction of the proposed PtL plant. This section summarises the required permits or licences.

This list may however not be fully exhaustive because PtL SAF is still in the nascent stages of development and the country's regulatory framework on SAF may propose additional licensing requirements as the framework develops and continues to evolve. Every effort has however been made to identify, within the regulatory framework as it is at present, the licences/authorisations to be obtained and entities from which they are to be obtained.

Kenya's Guidelines on Green Hydrogen and Its Derivatives l

PtL SAF development falls within the mandate of the Ministry of Energy and Petroleum that develops Kenya's energy policy. The Action Plan for CO_2 Emissions Reduction in the Aviation Sector (2022-2028) identifies the Ministry as the lead on pilot projects for production of SAF and review of SAF standards. The Energy and Petroleum Regulatory Authority (EPRA) is the energy sector regulator. Its functions include regulating the production, conversion, distribution, marketing and use of renewable energy and the production, conversion, distribution, supply, marketing and use of renewable energy. [127] EPRA developed the Guidelines to guide project developers and users of green hydrogen and its derivatives such as SAFs. A developer intending to produce green hydrogen and its derivatives such as SAF, is required to first submit an EoI to the Ministry of Energy and Petroleum. Approval of the EoI and a feasibility study thereafter are pre-requisites to proceeding with obtaining other licences/regulatory approvals in order to progress with development of a SAF pilot project. **l Management and Co-ordination Act, 1999 (incorporating several amendments and the Environmental Management and Co-ordination (Amendment) Act).**

This is the main law governing environmental matters in Kenya. A key requirement to be complied with is the conduct of an environmental impact assessment study for projects such as the proposed PtL SAF facility [128]. The Act provides that a project proponent shall before proceeding to finance, commence, proceeding with or carrying out a project undertake an environmental impact assessment (EIA) study and prepare a report to be submitted to the National Environmental Management Authority (NEMA). If the EIA report is approved, NEMA issues an EIA license.

Other relevant regulations under this Act to be complied with include:

- Environmental (Impact Assessment and Audit) Regulations 2003;
- Environmental Management and Co-ordination (Waste Management) Regulations, 2006;
- Environmental Management and Coordination (Water Quality) Regulation, 2006;
- Environmental Management and Coordination, Conservation of Biological Diversity Regulations, 2006
- Environmental Management and Coordination (Noise and Excessive Vibration Pollution) (Control) Regulations, 2009

County Government Act, 2012

Counties are Kenya's devolved units of administration totalling 47 in number. Each county has developed its own licensing requirements for operations taking place in its administrative jurisdiction. Some of these that are relevant to the proposed project include those pertaining to construction activities and waste management – waste being a potential feedstock. Therefore, depending on the particular county in which the PtL SAF plant is to be located, it would be prudent to confirm what specific authorisations may be required from the particular county government.

The Physical Land Use and Planning Act, No. 13 of 2019 and The Land Act, No. 6 of 2012

Under the Physical Land Use and Planning Act, counties are empowered to approve land developments that are to take place within their administrative jurisdiction. An applicant for a development permission is to provide documents, plans and particulars as may be required to indicate the purpose of the proposed development [129].

The Land Act applies to contracts over land, leases for land and certain administrative aspects relating to public land. The physical location and status of the land where the PtL SAF facility will be sited will determine what provisions of this Act may be applicable.

National Construction Authority Act 2011 and National Construction Authority Regulations, 2014

The National Construction Authority, established under the Act is mandated under the regulations (subsidiary legislation under the Act) to register all construction works, contracts or projects located on public or private land. The application for registration is to be made before the commencement of the construction works. [130]

Water Act, No. 43 of 2016

The use of any water resources is also subject to the provisions of the Water Act. Permits for use of water would be required. [131] The Water Resource Management Rules, 2007 are subsidiary legislation that that require compliance on the use of resources IN Kenya.

Wildlife Conservation and Management Act, No. 47 of 2013.

Should the site of the project be in a location designated as a national park, the approval of the Kenya Wildlife Service (KWS) will be required.

The Occupational and Safety and Health Act, No. 15 of 2007

This Act prescribes for safe working conditions for workers in addition to prescribing the safe handling and use of any machinery and chemicals that may be used in a workplace.

The Civil Aviation Act, No 21 of 2013 and The Civil Aviation (Amendment) Act, 2016

The Kenya Civil Aviation Authority (KCAA) is the mandated regulator for Kenya’s aviation industry. KCAA is responsible for the safety, security, economic and technical regulation of civil aviation [132] which includes airports. It is also responsible for implementing and enforcing treaties to which Kenya is a party. [133] The establishment of any PtL SAF handling facilities at any of Kenya’s airports would therefore require the approval of KCAA.

The Climate Change Act, 2016 and The Climate Change (Carbon Markets) Regulations, 2024

The Carbon Markets Regulations are subsidiary legislation under the Climate Change Act. Where the PtL SAF pilot project is to be considered as a carbon project, registration is required under the Regulations. Registration is undertaken by the Designated National Authority which is the National Environment Management Authority (NEMA). Registers are to be maintained for all carbon projects in energy, transport and waste among others. The proposed PtL SAF pilot plant potentially cuts across all these 3 sectors; therefore, registration may be required in each respective register. [134]

5

Technology pre-feasibility study for a selected area

David Kretzschmar, Fabian Carels, Prof. Martin Kaltschmitt and Dr. Stefan Bube

The preliminary assessment of the feasibility of a SAF production plant within this study encompasses several core aspects. First, the identified areas of interest are evaluated against key criteria, with particular emphasis on the local availability of feedstocks, namely electricity of renewable origin, sustainable carbon sources, and water. In addition, further requirements such as sufficient land, skilled labour, and infrastructure must be met. The pre-feasibility study also comprises the presentation of the preferred conceptual process design, including the main mass and energy flows, which can in turn be assessed in relation to feedstock availability. Furthermore, the analysis addresses compliance with, and positioning within, existing sustainability criteria for SAF. Finally, the assessment includes an evaluation of non-financial risks.

5.1 Area Identification for the SAF Plant in Kenya

This chapter examines three pre-selected locations in Kenya – Nairobi, Olkaria, and Mombasa – based on their favourable site characteristics for a potential SAF production plant. These three locations are hereafter referred to as areas of interest. The analysis focuses on the specific attributes of each location, including the potential for renewable energy, land and skilled labour availability, biogenic (carbon) feedstock as well as limitations related to infrastructure constraints. For all areas of interest ownership structures and relevant political and regulatory frameworks must be clarified in advance.

5.1.1 Renewable Energy Potential

The renewable energy potential has already been examined in the Assessment of Feedstock and Energy Supply Options (Chapter 2). In the context of SAF production, renewable energy is considered to refer to electricity derived from solar, geothermal, wind, or hydropower sources. Biomass, by contrast, is addressed separately in this study, primarily as a material (carbon) feedstock. Since the solar energy potential is consistently very high throughout Kenya, no significant distinction is made between the three areas of interest (for a more detailed overview see Chapter 2). Therefore, all areas of interest are considered suitable for using photovoltaic (PV) systems as a means of electricity generation. **Figure 8–9** (Annex) presents a summary of the wind, geothermal and hydro power energy potentials for the respective areas of interests.

High-quality geothermal energy sources are concentrated in and around Olkaria (see Figure 8–9 in Annex). These renewable energy sources are of particular interest, as they can potentially supply both the electricity and thermal energy demands - partially or even entirely - of SAF production, which was already discussed in Chapter 2.

Favourable wind conditions are found approximately 50 km west of Nairobi. In addition, the Athi River flows from the south to the east of the metropolitan region and offers a theoretical potential for hydropower generation. About 75 km north of Nairobi, and about 100 km east of Olkaria, the Tana River presents further hydropower potential.

In contrast, Mombasa (bottom right of Figure 8–9 in Annex) lacks both high wind energy potential or rivers suitable for hydropower in its immediate surroundings. Apart from solar energy, the only nearby renewable resource is a geothermal prospect at Mwananyamala located approximately 60 km to the southwest.

5.1.2 Land, and Skilled Labour Availability

This subsection provides a summary of land availability based on the Assessment of Feedstock and Energy Supply Options for the three areas of interest. The objective is to identify potential sites for the SAF production facility and the possible renewable energy systems for electricity supply. Additionally, the potential for the settlement of skilled labour, is assessed. Information on land cover classification, protected zones and areas with slopes exceeding 15° within the three areas of interest can be derived from Figure 8–10.

The analysis indicates that, compared to Nairobi and Mombasa, Olkaria has the largest amount of available rangeland, which could be suitable for the construction of large industrial complexes and/or PV solar parks. However, compared to Nairobi and Mombasa, Olkaria has the lowest availability of residential areas for the settlement of skilled labour. The nearest larger city is Naivasha, with around 355,000 inhabitants, located approximately 30 km northeast of the geothermal prospects (see Figure 8–9 in Annex). on the eastern side of Lake Naivasha.

The metropolitan area of Nairobi has a population of 5.8 million [138] and represents the largest urban centre among the three locations. Consequently, the settlement of skilled labour would present comparatively minimal challenges. In addition, agricultural regions located north of Nairobi could contribute bio-residues, particularly if an organized collection network is implemented. Large contiguous land areas suitable for industrial complexes are mainly located in the western parts of Nairobi.

Mombasa is the second-largest city in Kenya, with a population of approximately 1.6 million [138]. The settlement of skilled labour in and around Mombasa is feasible due to its urban infrastructure and population size. Additionally, sufficient land is available in the surrounding area to accommodate potential industrial complexes.

5.1.3 Feedstock Supply

Potential feedstocks include agricultural residues from crops cultivated in the southwestern and northern areas surrounding Olkaria. In particular, cut flowers are extensively grown in the Naivasha region and residues from this production could serve as an additional feedstock option for biogas production [139]. Furthermore, CO_2 release from geothermal vents in Olkaria are available and may be utilized as a carbon source in PtL processes for SAF production [140]. However, the regulatory framework regarding the utilization of geothermal CO_2 sources remains unclear. Consequently, under the ReFuelEU Aviation Regulation and the Renewable Energy Directive (RED), there is uncertainty as to whether this PtL Process would be recognized as SAF [141], [142]

As a potential feedstock option in Nairobi, municipal solid waste (MSW) can be supplied for the SAF production facility, provided that a sustainable municipal waste management system is in place, an objective already outlined in Kenya’s Second Nationally Determined Contribution (NDC) [143]. Wastewater from the Dandora Estate Sewage Treatment Works (DESTW), the second-largest facility of its kind in Africa, could additionally serve as a feedstock for biogas production [144]. Furthermore, cut flower residues from the Limuru and Thika regions in the vicinity of Nairobi represent another viable biomass source for biogas production [139].

Similar to the Nairobi metropolitan region, Mombasa, as a major city with a population in the millions, also has the potential to utilize MSW as a feedstock option for SAF production under comparable conditions. An alternative or an additional feedstock source could be wastewater from the Kipevu Sewage Treatment Plant [145]. In contrast to Olkaria and the Nairobi region, the availability of residues from cut flower and from crops as a feedstock source in the Mombasa region is limited.

5.1.4 Water Availability

Water availability in Kenya is significantly constrained by the country's large proportion of arid land. **Figure 8–11** (Annex) presents a classification of the Aridity Index for the three areas of interest.

Based on the Aridity Index, only the Nairobi region appears suitable for utilizing groundwater for electrolysis. However, caution is warranted, as the high population density in and around Nairobi results in significant demand for drinking water.

In contrast, Mombasa's location directly at the Indian Ocean makes it well-suited for the implementation of a seawater desalination plant. Provided that a sustainable solution for brine management is established, desalination represents a more sustainable and higher-value water supply option than the use of groundwater.

Olkaria is situated within an ASAL region, where local water resources are insufficient. Lake Naivasha, a freshwater lake situated north of Olkaria supports the local population of around one million with freshwater and is also critical for Kenya's flower industry in the near vicinity [146]. Using the lake for additional purposes could lead to competition with these users. In ASAL regions it is generally advisable to avoid reliance on lakes as a water source, in order to mitigate risks of declining water levels and deteriorating water quality.

Consequently, the water required for electrolysis must be sourced externally and transported to the facility to ensure a reliable supply. When considering the transport of water for electrolysis, it should be noted that Olkaria is the most distant of the three areas of interest from seawater resources for potential desalination. In addition, its location in a high-altitude and mountainous region makes transportation logistically complex and cost intensive.

5.1.5 Infrastructure Limitation

Infrastructure limitations primarily arise from the connection to the electricity grid the highway network and trough the proximity of potential off takers. **Figure 8–12** (Annex) illustrates Kenya's high-voltage transmission network, the highway network, airports and the locations of existing renewable power generation installations above one MW.

The high-voltage transmission grid passes through all three areas of interest, making grid connection feasible for all sites without significant issues. Of particular importance is the 400 kV high-voltage line running past Olkaria towards Ethiopia, which enhances grid capacity in the region. Existing power plants in Olkaria include four geothermal power stations. Transportation to and from Olkaria poses the greatest logistical challenge; although highways run along its periphery, none traverse the area directly. Additionally, Olkaria lacks proximity to major airports in contrast to the other two locations.

In the wind-rich regions southwest of Nairobi (**Figure 8–9** in Annex), the Kipeto Wind Park and Ngong Wind Farm are operational. South of Nairobi next to the highway, a 1.5 MW rooftop solar power plant operated by Kapa Oil Refineries Ltd. is located. Nairobi is notably well connected to potential SAF off takers, as it hosts three airports: Jomo Kenyatta International Airport, Moi Air Base (military airbase), and Wilson Airport. The highway network for road transport of SAF is well developed in and around Nairobi.

Mombasa features the second-largest airport in Kenya, Moi International Airport, after Jomo Kenyatta International. Transportation to and within Mombasa is expected to be comparatively straightforward. Furthermore, Mombasa's direct access to the Indian Ocean renders it particularly advantageous for the shipment of construction and technical components.

5.1.6 Assessment of the Area Identification

A qualitative assessment of all described criteria is presented in **Table 5–1**. The assessment serves solely to compare the three locations of interest and does not constitute a general classification.

The results indicate that, compared to the other locations, Olkaria exhibits the highest renewable energy potential and faces no electricity grid constraints, while offering high land availability. However, Olkaria shows a problem of settling skilled labours in the area and the lowest water availability among the three areas of interest. The feedstock supply for biogas production is associated with high uncertainty, since the availability of crops and cut flowers fluctuates considerably with harvest seasons, drought periods, and the impacts of climate change. In addition, the use of CO_2 from geothermal sources for SAF production remains legally uncertain. Furthermore, transportation to and from Olkaria is comparatively disadvantageous, as highways do not pass directly through the area and it is the most distant location from a seaport, increasing the complexity of transporting technical components. The nearest potential airports that could serve as SAF off takers are located in Nairobi, approximately 70 km southeast of Olkaria.

Nairobi has considerable renewable energy potential, with the Athi River to the south and high wind resources in the east. Feedstock supply in Nairobi can be reliably secured from MSW and sewage treatment plants by the densely populated region. Additionally cut flower residues can be used in the near vicinity of Nairobi. The settlement of skilled labour in the metropolitan area is readily achievable. However, land availability is limited. Nairobi benefits from a good connection to the high-voltage grid and hosts two existing grid-connected wind farms in the eastern area. Additionally, the north-western part of Nairobi is not located within an ASAL region, making groundwater extraction for electrolysis feasible. However, this directly competes with Nairobi's drinking water supply. The highway network passes directly through Nairobi, enabling the transport of SAF by road as well as the delivery of technical components for the production facility from e.g., seaports in Mombasa. Potential off takers in Nairobi include three airports, one military and two passenger airports, providing advantageous market access.

Mombasa is located directly adjacent to the Indian Ocean, making it an ideal location for seawater desalination for the water supply for electrolysis. As the second-largest city in Kenya, feedstock supply can be supplied through MSW and biogas from the Kipevu Sewage Treatment Plant, and the settlement of skilled labour is also feasible. However, this urban density slightly limits land availability. Compared to other locations, the renewable energy resources in and around Mombasa are the poorest, with the exception of solar energy. Although Mombasa is well connected to the high-voltage grid, there are no feasible renewable energy installations in its immediate vicinity. Mombasa has potential SAF off-takers due to hosting the second-largest airport in Kenya and possesses the most favourable logistics infrastructure for importing technical components by being sea connected.

Table 5–1: Assessment of the Area Identification

Criteria	Olkaria	Nairobi	Mombasa
Renewable Energy Potential	+	0	-
Land Availability	+	-	0
Skilled Labour Availability	-	+	0
Feedstock Supply	-	+	0
Water Availability	-	0	+
Electricity Grid	+	0	-
Proximity of Potential SAF Off-takers	-	+	0*
Transport Limitation	-	0	+

Disadvantageous Conditions 🟦

Neutral Conditions ⬜

Advantageous Conditions 🟩

* When considering exports to the EU, Mombasa exhibits among the most favourable off-take characteristics.

5.2 Conceptual Process Design of the SAF Plant in Kenya

Within the scope of this study, SAF production is examined with a focus on the use of electricity from renewable sources. For the design of a viable plant concept, however, consideration of local boundary conditions as well as compliance with external requirements is crucial. The most favourable sites are characterized by substantial potential for "green" electricity and biomass suitable for biogas production. Based on these conditions, both a pure PtL concept – utilizing biogenic CO_2 captured from the biogas – and a hybrid PBtL concept – making use of the entire biogas stream (CH4 and CO_2) – are possible. Taking into account economy-of-scale effects the hybrid PBtL concept is advantageous over BtL (CH4 utilization) and PtL (CO_2 utilization), as it enables higher SAF production from the same, potentially limited, amount of biomass, respectively biogas.

With regard to the technological route, the combination of methanol production followed by further processing via Methanol-to-Jet has been selected. Compared to the Fischer–Tropsch route, this offers two project-specific advantages:

- Stepwise implementation of process sections. Methanol production can be planned, constructed, and commissioned as an initial step as methanol itself is already a valuable product. Once the methanol-to-jet (MtJ) process has reached sufficient technological maturity, i.e., technology providers can offer guarantees at acceptable conditions, and ASTM certification of the MtJ route has been achieved, the implementation of the MtJ facility can subsequently be realized in a time-staggered manner.

- Higher production flexibility. Since methanol as well as light olefins are generated as intermediates in the methanol route, the facility can respond more flexibly to potential market fluctuations or demand uncertainties. In Kenya, the cost of methanol supply is significantly higher than, for example, in the EU, which may render domestic production competitive despite higher production costs.

For a more detailed comparison of BtL, PtL and PBtL, as well as a comparison of the methanol-to-jet and Fischer–Tropsch routes, see Technology and Process Selection to produce SAF (Chapter 3).

The technical plant concept is presented below in a generic manner, based on the overarching concept previously described (PBtL via the methanol route). Accordingly, the provision of biogas and electricity is defined as the interface between site conditions and the plant concept. The description of the plant layout as well as the mass and energy flows are therefore considering biogas and electricity as given inputs. The supply of biogas and electricity may, in turn, be based on different locally available resources depending on the plant location. From a process engineering perspective, the separation of biogas supply from biogas processing is acceptable, as there is little potential for integration between the respective plant sections. Integration opportunities are limited to the use of waste heat for digester heating and the use of pure O_2 (from electrolysis) for biological pre-desulfurization in the fermenter; however, the impact of these factors on the overall energy demand of the facility is considered rather minor. Moreover, a decoupled approach enables local optimization of biogas supply, potentially through multiple decentralized digestion units and a biogas network; such optimized provision must be evaluated in a later project phase, taking into account the specific local boundary conditions. Fine purification of biogas (i.e., the removal of potential catalyst poisons, in particular sulphur- or halogen-containing compounds) strongly depends on the type of biomass used as well as on catalyst requirements specified by the respective technology providers. In addition to the nature of impurities and the required purity levels, plant capacity is a decisive factor. For large gas volumes that can be processed centrally at industrial sites, technically more sophisticated purification concepts may be techno-economically advantageous, offering cost benefits compared to decentralized purification solutions. In this context, economies of scale as well as the availability of auxiliary energy sources (e.g., waste heat) play an important role.

While technically simple but operationally cost-intensive adsorption processes (primarily activated carbon filters) are particularly suitable for decentralized purification steps, centralized plants can typically employ regenerable adsorbers (e.g., ZnO) and various washing (absorption) processes, which are also commonly used in conventional natural gas-based syngas production. A pre-desulfurization of the biogas (biological desulfurization), as is already common practice in many biogas plants today, should therefore be carried out at the biogas facility, whereas fine purification appears advantageous at the centralized methanol synthesis site. An assessment of the biogas supply, based on the locally available potential feedstock options and their related biogas potential, is presented at the end of this chapter.

According to the stepwise implementation approach described above, both process sections (methanol production and MtJ) are described individually, with pure methanol the connecting element. Thus, local separation of the process stages is also theoretically possible. Possible integration potentials for optimized/integrated SAF production are discussed and quantified in terms of SAF production increase.

The subsequent sections present a comprehensive plant layout in conjunction with detailed mass and energy balance assessments, thereby providing an integrated basis for the technical and economic evaluation of the proposed facility.

5.2.1 Plant Layout

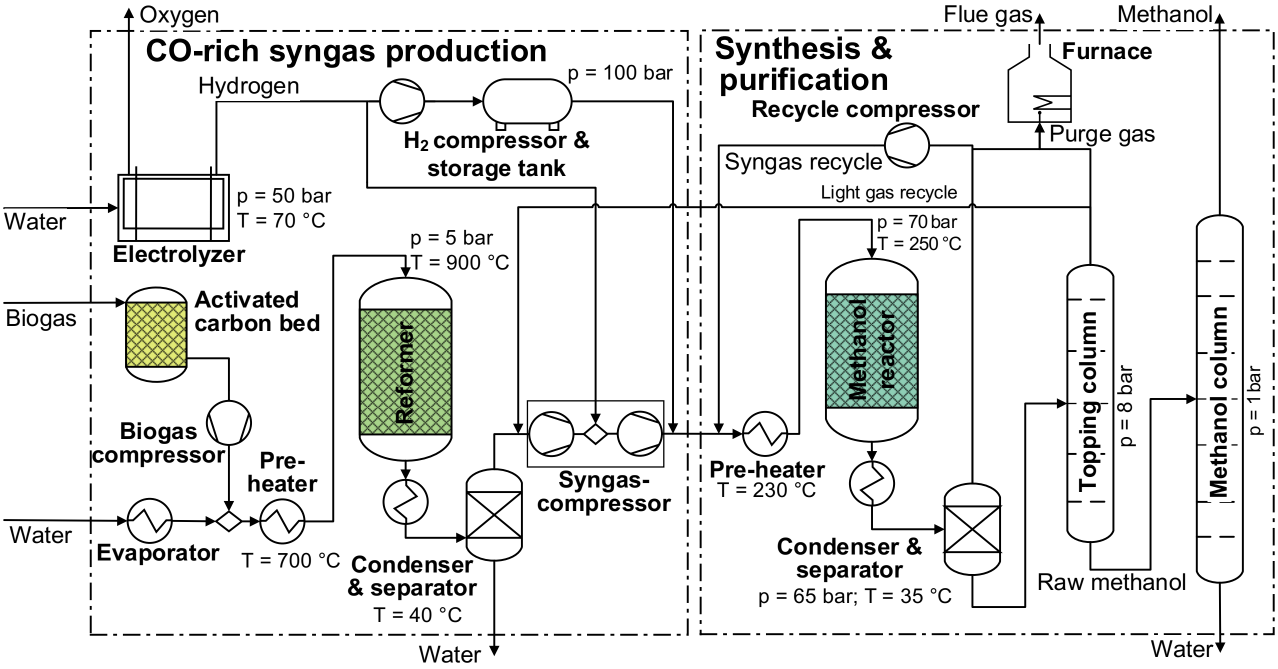
The provisioned biogas follows requisite conditioning and is conveyed to the methanol synthesis unit. The produced intermediate methanol is then processed via the MtJ pathway, comprising sequential dehydration, oligomerization, hydrogenation, and fractionation stages, which collectively yield SAF as the principal output.

Methanol production. The overall plant layout of the methanol synthesis, including the assumed process parameters, is shown in Figure 5–1. The methanol production utilizes dried and cleaned biogas consisting of approximately 60 % methane and 40 % CO_2. Impurities like sulphur-, halogen- and nitrogen-containing compounds must be removed beforehand. Various options are available depending on the biomass and plant size (see above). As an example, the process flow diagram includes an activated carbon filter, which – depending on the type of activated carbon used – can remove sulphur as well as halogen compounds and other contaminants without having a significant impact on the mass and energy balances of the process.

However, the optimal combination of purification processes must be determined during the basic engineering phase, based on the exact biogas compositions and catalyst requirements. The purified biogas is then preheated and mixed with steam to be fed into the reformer (combined steam and dry reforming (CSDR), also known as bi-reforming). High reactor temperatures (around 900 °C) are essential to reach sufficient CH_4 and CO_2 conversion into CO an H_2 within reforming, resulting a CO-rich raw syngas (for a more detailed consideration, see chapter 3). Heat provision is assumed to be mainly via electrical heating while high temperature heat from purge gas combustion can partly be integrated. The steam reforming of biogas in an electrically heated reactor is technically challenging but has already been successfully demonstrated at a technically relevant scale [147]. The gas mixture leaving the reformer is cooled to remove residual water. Afterwards, the gas is compressed in multiple stages, mixed with light gases (mainly CO_2) from the purification process, and conditioned with H_2 from water electrolysis.

The required amount of H_2 storage capacity and the sizing of the electrolyser represent an optimization problem that depends on the volatility/ temporal availability of renewable energy at the H_2 production site. This aspect is not further addressed in the present discussion and must be considered once the electricity supply framework has been defined. The conditioned CO-rich syngas is preheated and converted into methanol in the methanol reactor. The resulting methanol–water mixture is cooled and separated from gaseous components (unconverted syngas and light by-products like dimethyl ether or methyl formate). The main fraction of the gas stream is recycled directly to the reactor feed, while a minor fraction is purged to avoid the accumulation of inert components (mainly CH_4 and N_2). The liquid methanol–water mixture undergoes a two-stage purification. In the first "topping" column, light components (mainly CO_2) are removed at the column head. In the second distillation column, water and heavy by-products like higher alcohols are separated from methanol.

Figure 5–1: Methanol Production Plant Layout for Power- and Biogas- Based Production with Operating Conditions, according to [148]



Methanol-to-Jet. The overall process flow diagram of the MtJ process, including the process parameters, is shown in Figure 5–2 (methanol-to-olefins (MtO)) and **Figure 5–3** (oligomerization and upgrading). The synthesized pure methanol is subsequently fed into the MtJ process. The specific configuration of the MtJ process – particularly with respect to the chain length of the olefins produced in the methanol-to-olefins (MtO) step and the oligomerization technology applied – depends on the selected technology provider. The following outlines one possible implementation approach. The methanol is preheated and introduced into the MtO reactor, where raw olefins are produced. The MtO Process is designed on the basis of the UOP/Norsk Hydro MtO technology [149]. The olefin stream is directed to a water separation column and subsequently washed with caustic soda to remove CO_2. The separated olefin stream is then dried over a molecular sieve and, after compression and preheating, given into the oligomerization reactor. The reactor operates under process conditions of 150 – 300 °C and 40 – 100 bars.

The product stream from the oligomerization reactor is cooled and goes into a separator, where light hydrocarbons (mainly alkanes which behave almost inert within oligomerization) are removed from the remaining products. A distillation column further separates light gases and naphtha from higher olefins. The light gases are largely recycled back to the oligomerization reactor, while a small purge stream is withdrawn to prevent the accumulation of alkanes. The heavier fraction from the distillation column is subsequently mixed with hydrogen from water electrolysis and hydrogenated in a dedicated reactor to produce saturated hydrocarbons. Excess hydrogen is separated by cooling and recycled back into the process. The saturated hydrocarbons are then separated by carbon chain length in two distillation columns. In the first column, kerosene is obtained at the column head. The remaining longer-chain hydrocarbons are fractionated in a second column into a diesel fraction at the top and a heavier wax fraction at the bottom.

Figure 5–2: Methanol to Olefins (MTO) Process Step for the Methanol-to-Jet Plant Layout with Operating Conditions, According to [150]

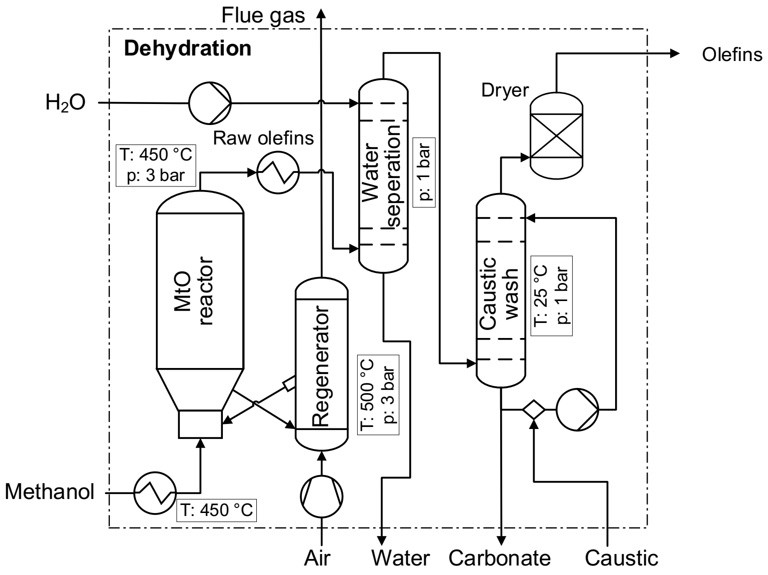
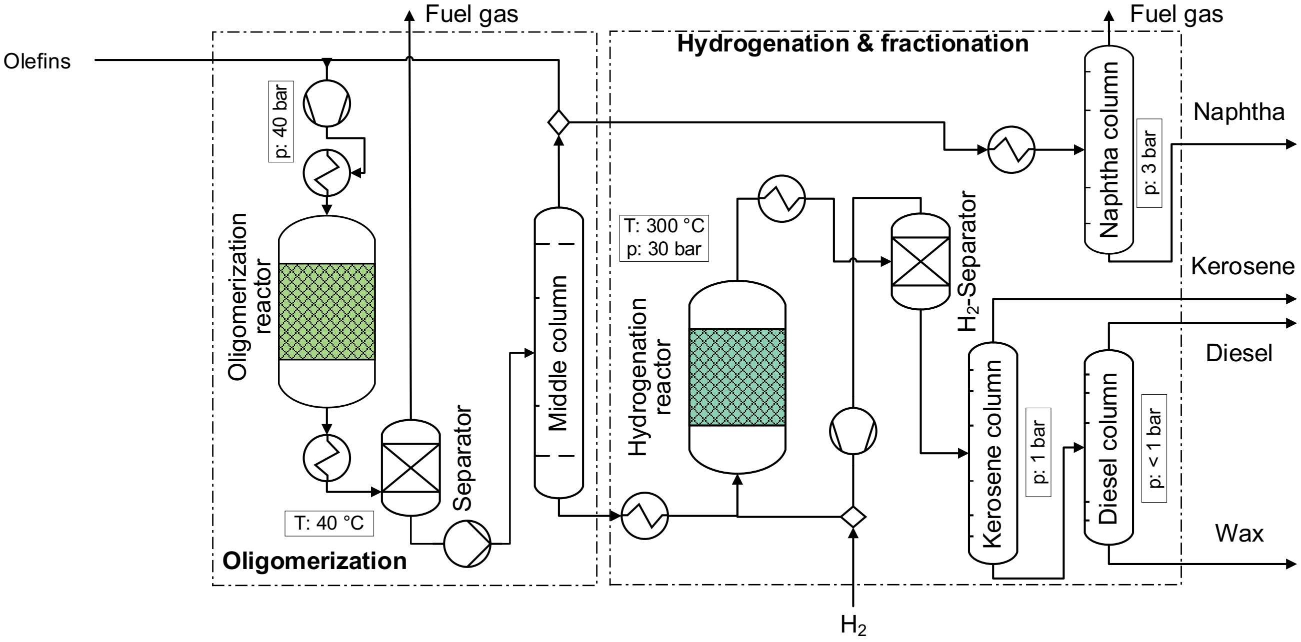


Figure 5–3: Oligomerization, Hydrogenation & Fractioning Process Steps for the Methanol to Jet Plant Layout with Operating Conditions, According to **[150]**



5.2.2 Mass and Energy Balances for the SAF Plant

Figure 5–4 depicts the main mass and power flows of the presented process concept. The annual SAF production of the plant is designed to supply ca. 2 % of Kenya's projected 2030 kerosene demand for international aviation. Considering a plant capacity utilization of 90 %, the nominal production is 21.900 t/a, respectively 2.78 tSAF/h. Biogas serves as the main material input for methanol, respectively SAF production. The biogas is assumed to be a mixture of CH_4 and CO_2 with a molar ratio of 1.5, diluted with 1 % N_2 and saturated with H_2O (at 10 °C). The biogas demand at norm conditions is around 2.2 m^3N/kgSAF, referring to 7.5 t/h. The biogas also serves as the main energy input (36 MWLHV), while the electricity demand (without considering re-electrification of waste heat) lies around 32 MW. It has to be noted that the biogas composition is a decisive factor for the overall electricity demand (especially electrolysis) and the share of biomass- and electricity-based product [148].

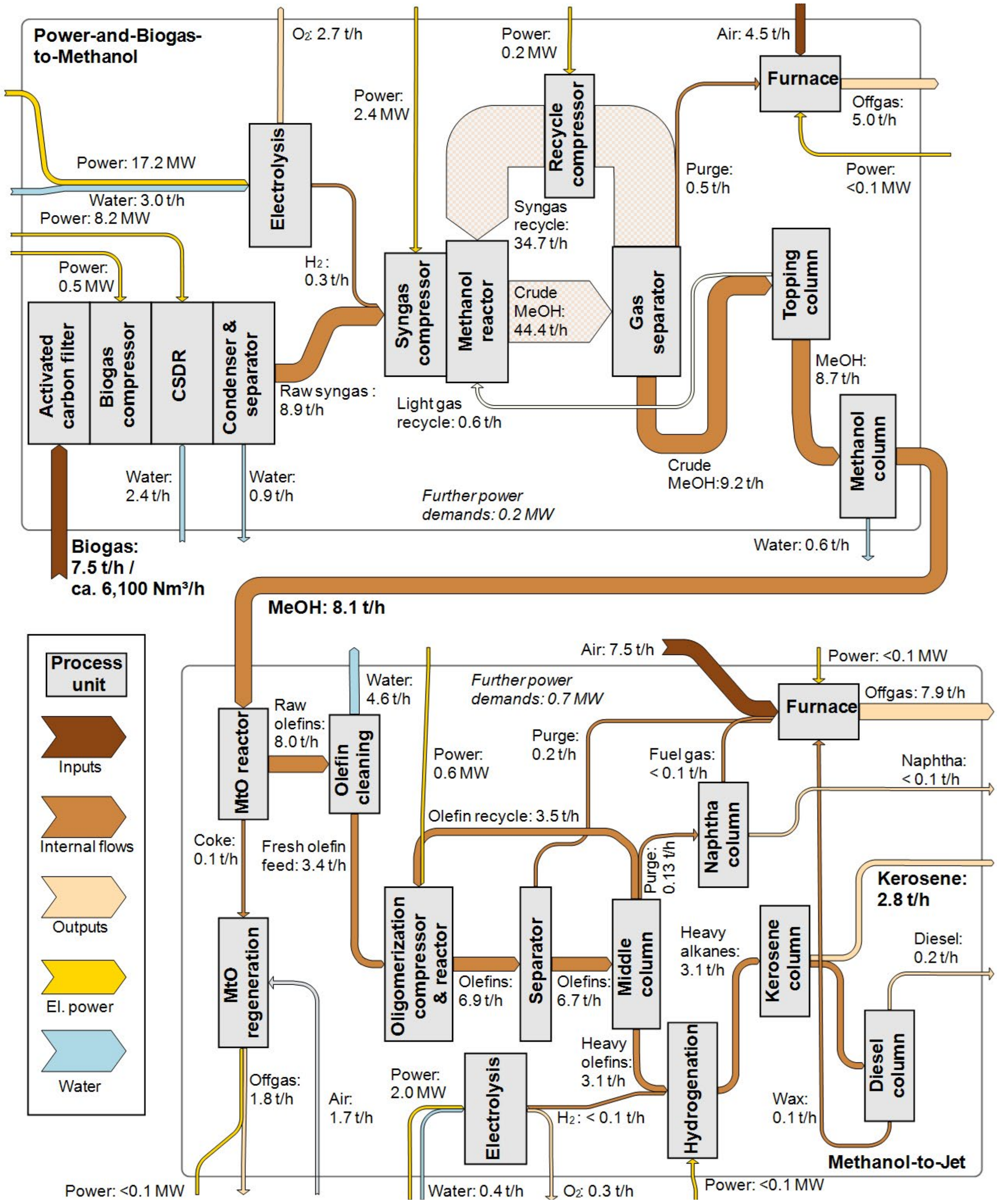
The overall heat demand highly depends on the overall heat integration, and thus, also on the integration of the process sections as well as their load management. The primary heat sources can be identified as the exothermic reactors of the methanol synthesis and the MtJ process. These can be utilized in particular to cover the heat demand of product separation (rectification). An exception is biogas reforming, which, due to its high temperature-level requirements, can only make use of waste heat from purge gas combustion and must additionally be externally heated. Overall, it can be stated, that in both process sections (methanol production and MtJ) the main heat demands can be satisfied through heat integration and the electricity-based heating already considered within the shown process flows. On the other hand, excess heat from exothermic processes could be used for electricity production or steam driven compression to decrease the external electricity demand; the extend is limited to provide energy in the order of magnitude of overall compression and pumps demands [151].

At the assumed biogas composition, the specific electricity-demand is dominated by the electrolysis and heating of the CSDR. The further electricity demands relate to the compression of gas streams, mainly biogas and synthesis gas. Since the MtJ process section, in comparison to methanol production, involves significantly lower mass and particularly volumetric flows, and consists exclusively of exothermic reactions, it requires substantially less electricity. The highest electricity demand is required for olefin compression within the oligomerization.

The methanol demand for SAF production is approximately 2.9 tMeOH/t of SAF. For each ton of SAF, the outlined process generates about 0.03 t of naphtha and 0.07 t of heavy diesel as by-products. Thus, the kerosene share within the total fuel product is expected to be around 90 %. The total electricity demand of the plant is around 32 MW, of which roughly 29 MW are attributable to methanol production. Integration of the process units could potentially allow the recycling of naphtha and purge streams from the MtJ unit into the CSDR. This could increase kerosene production by about 10 % (total of ca. 3.1 tSAF/h) at the same biogas input, with naphtha as a by-product being entirely eliminated. However, such integration would need to be incorporated into the basic engineering of the methanol plant from the outset, as it would affect internal flows as well as reforming requirements. Furthermore, it would increase the absolute electricity and heat demand, since less purge gas would remain available for thermal utilization.

The share of bioSAF and eSAF in the overall product can be calculated by means of energy allocation. According to European regulation (Renewable Energy Directive), this requires relating the contribution of electrical and biogenic (LHV) energy incorporated into the chemical energy of the product to the total of both inputs. The definition of the system boundary, as well as the treatment of electrically heated endothermic processes, is critical in this context. If the system boundary includes the electricity used for hydrogen production and for reformer heating, the share of eSAF amounts to approximately 43 %. However, if H_2 (LHV) is used instead of electricity as the basis for calculation (i.e., under a modified system boundary), and electrical heating is not considered (uncertain to what extent it may be included), the eSAF share decreases to around 26 %. As this allocation may have a significant impact on the economic value of SAF, the issue must be clarified with the relevant certification bodies in the course of further project planning.

Figure 5–4: Main Mass and Power Flows of the Process Concepts



5.2.3 Different Feedstock Supply for Biogas Production

The following section provides a detailed assessment of feedstock options for biogas production through anaerobic digestion of MSW, from sewage treatment plants, and cut-flower residues. An additional option in Olkaria is the utilization of CO_2 from geothermal power plants; however, the legal eligibility for its use as eSAF feedstock has not yet been proven. The addition of CO_2 to biogas reforming (within the technical limits of the reformer) or directly into the syngas is generally feasible, provided that the resulting hydrogen deficit is compensated by additional hydrogen from electrolysis. It should be noted, however, that this also affects the design of the synthesis loop as well as methanol purification. The exclusive use of CO_2 would result in a shift from a PBtL process to a PtL process. The integration of additional CO_2 is thus possible both within the PBGtM concept (provided it is accounted for in the overall process design) and in pure PtM concepts, in which the methanol can subsequently be supplied to the MtJ unit.

MSW as feedstock requires to be collected and transported to a local waste treatment facility. At this stage, the material undergoes pre-treatment involving the removal of non-organic fractions and recyclable components to homogenise the feedstock, as well as shredding and pre-composting [152]. Given that MSW composition exhibits significant regional variability on a global scale, the present pre-feasibility study adopts the representative composition for Nairobi, as summarized in Table 5–2, as the basis for subsequent biogas production at all considered locations in Kenya.

Table 5–2: Waste Fraction of Total Municipal Solid Waste (MSW) Stream, [153]

Waste Fraction	%-Generated from Total
Organic	50-70
Plastic	20
Paper	10
Medical waste	1
Metal	2

After pre-treatment, the organic fraction of MSW is subjected to anaerobic digestion for biogas production. The composition and the resulting biogas potential are presented in Table 5–3. As even minor impurities, such as heavy metals, can negatively affect the biogas yield, the potential indicated in should be regarded only as an approximate order of magnitude.

Table 5–3: Composition of Municipal Solid Waste (MSW) and the Resulting Biogas Potential, [139], [152], [154]

Composition	Unit
Organic fraction [% of fresh mass (FM)]	60a
Dry Matter (DM) [% of organic fraction]	40
Volatile Solids (VS) [% DM]	85

Biogas Potential	Unit
Biogas potential of VS [m^3 N/tVS]	400
Biogas potential of FM [m^3 N/tFM]b	82

[a] Represents the mean value from Table 5–2 / b) FM refers to MSW prior to pre-treatment

While the biogas potential based on fresh mass (FM) indicates the potential including the water content, the VS-based potential considers only the dry matter fraction, excluding the ash that remains after combustion. Consequently, a biogas potential of 82 m^3N/tFM can be considered. For a SAF production of 21,900 t/a, the required biogas demand is around 48 Mio. m^3N/a. This translates to a demand of ca. 590,000 tMSW/a MSW, assuming a methane content of 60 % and 40 % CO_2 [139], [152]. The available quantities of MSW for the two metropolitan regions, Nairobi and Mombasa, are presented in Table 5–4, along with their current share of collected waste, as well as the proportion required from the collected waste to support SAF production.

Table 5–4: Waste Generation in Nairobi and Mombasa for Potential Biogas Production, [155]

Name of Town	Nairobi	Mombasa	Olkaria
Estimated Waste (t/a)	876,000	803,000	-
Waste Collected [%]	80	65	-
Biogas Potential from Waste Collected [Mio. m^3N/a]	57.5	42.8	-
SAF production potential (t/a)	26,200	19,500	Feasible[a]

[a] Feasible with transport of MSW from Nairobi (and Naivasha) to Olkaria

The table highlights that the current MSW collection rates are barely sufficient for Nairobi and insufficient for Mombasa to provide the required feedstock for the targeted SAF production capacity. However considering higher waste collection rates and the projected population growth in Kenya, MSW might enable the required biogas production in Mombasa and even more feasibly in Nairobi in the future [153]. For Olkaria the demand of 21,900 t/a SAF could be feasible with the transport of MSW or the generated biogas from Nairobi (100 km by truck) and Naivasha (40 km by truck) to the PBtL plant. However, transporting MSW (by truck) or biogas (by pipeline) would result in additional costs.

Another option for biogas provision is the anaerobic digestion of cut flower residues. Cut flowers are part of Kenya's horticultural exports, which represent the country's largest source of export revenue [139]. The typical composition of roses, as well as the associated biogas potential, is presented in Table 5–5.

Table 5–5: Composition of Cut Flower Residues and the Resulting Biogas Potential, [139], [156]

Composition	**Unit**
Dry Matter (DM) [% of FM]	27
Volatile Solids (VS) [% DM]	92
Biogas potential	**Unit**
Biogas potential of VS [m^3/tVS]	300
Biogas potential of FM [m^3/tFM]	90

From the table, a biogas potential of 90 m^3/t of cut-flowers residues can be derived. Based on the assumed requirement of ca. 48 Mio. m^3N, this translates into a demand of 540,000 t/a of cut-flower residues. In 2023, a total of 111,000 t of cut flowers were exported [157]. Assuming that approximately one-third remains as residues [139], this corresponds to a potential of 37,000 t, yielding about 3.4 Mio. m^3N/a of biogas. This amount would cover only 7 % of the total biogas demand of the assumed PBtL plant, with an assumed methane content of 60 % and a CO_2 content of 40 % [139], [156].

An additional option for biogas production is the utilization of sewage sludge from wastewater treatment plants. Sewage sludge can be processed to recover solids, organic matter, and nutrients such as phosphorus and nitrogen for use as fertilizers. Following further treatment, the sludge can be fed into an anaerobic digester to generate biogas. The biogas potential, expressed relative to the inlet flow to the treatment plant, is approximately 0.04 m^3N/m^3 [158], [159] although this value strongly depends on the volatile solids content of the wastewater. Table 5–6 provides an overview of the biogas potentials of the sewage treatment plants in Nairobi and Mombasa, assuming a methane content of 60 % and CO_2 content of 40 % [159].

Table 5–6: Sewage Treatment Plants in Nairobi and Mombasa for potential Biogas Production, [144], [145]

Location and Name of Sewage Treatment Plant	**Nairobi (Dandora)**	**Mombasa (Kipevu)**	**Olkaria**
Max. Inlet Flow (m^3/d)	80,000	17,100	-
Biogas Potential [Mio. m^3N/a]	1.2	0.3	-
SAF production potential [t/a]	550	140	Not feasible

It becomes evident that the biogas potential of both sewage treatment plants is by far insufficient to meet the biogas demand. The analysis indicates that a combination of several organic waste streams is preferable to cover the required biogas demand. The highest potential is associated with MSW. In the capital Nairobi MSW would already provide an adequate supply for the required biogas demand for SAF production of 21.900 t/a. Moreover, with expected population growth the MSW generation is expected to increase further in the coming years, thereby enhancing the available potential.

5.3 Environment & Sustainability Requirements

This section defines various environmental and sustainability requirements for the production of SAF in Kenya. At the global level, the baseline requirements for SAF are specified under the CORSIA Eligible Fuel framework. For potential future exports to the European Union, or for prospective collaborations, compliance with the ReFuelEU Aviation criteria will be required.

5.3.1 CORSIA Sustainability Criteria for CORSIA Eligible Fuels

CORSIA is an internationally recognized carbon reduction scheme for aviation, defined by ICAO. The primary objective of CORSIA is to achieve carbon-neutral growth from 2020, with the long-term goal of reaching net-zero carbon emissions in the aviation sector by 2050 [160]. As of June 2025, there are 14 environmental criteria that SAF must meet to be able to get certified under CORSIA. These criteria are summarized in Table 5–7. All criteria must be demonstrated through a recognized certification system.

Table 5–7: CORSIA Eligible Fuels Sustainability Criteria, [161]

Theme	Criteria
1. Greenhouse Gases (GHG)	10 % life cycle Emission reduction of CORSIA SAF compared to fossil fuel-based aviation fuel.
2. Carbon Stock	2.1 Excludes biomass for CORSIA SAF from land ore aquatic ecosystems hat was primary forest, wetlands, peat lands, coral reefs, kelp forests, seagrass meadows, estuaries, tidal salt marshes or mangrove forests or contributes to degradation of the carbon stock in primary forests, wetlands, peat lands, coral reefs, kelp forests, seagrass meadows, estuaries, tidal salt marshes or mangrove forests. 2.2 Direct land use change (DLUC) emissions will be calculated and compared to the default induced land use change (ILUC) emissions, with the higher value integrated into the life cycle emissions of SAF.
3. GHG Reduction Permanence	Operational practices will be established to monitor, mitigate, and compensate for any instances of non-permanence in CCS activities.
4. Water	4.1 Operational practices will be implemented to maintain or enhance water quality and 4.2 to use water efficiently and to avoid the depletion of surface or groundwater resources beyond replenishment capacities

5. Soil	Best management practices in agriculture and forestry will be applied to maintain or improve soil health
6. Air	Air pollution emissions will be limited
7. Conservation	7.1 CORSIA SAF cannot be produced from biomass sourced in state-protected areas valued for biodiversity, conservation, or ecosystem services, unless it's proven that such production does not harm the protection goals. 7.2 Feedstock with low invasive risk will be chosen, and controls will be implemented to prevent the uncontrolled spread of alien species and modified microorganisms. 7.3 Operational practices will be implemented to prevent negative impacts on state-protected areas with high biodiversity, conservation value, or ecosystem services.
8. Waste and Chemicals	8.1 Operational practices will ensure responsible storage, handling, and disposal of waste and chemicals, 8.2 limit pesticide use through science-based methods and 8.3 prevent and mitigate damage from accidental releases of fossil fuels and chemicals
9. Seismic and Vibrational Impacts	Operational practices will be implemented to minimize seismic impacts from surface, subsurface, and underwater activities
10. Human and labour rights	CORSIA SAF production will respect human and labour rights.
11. Land use rights and land use	CORSIA SAF production will respect existing land rights and land use rights including indigenous peoples' rights, both formal and informal
12. Water use rights	CORSIA SAF production will respect the existing water use rights of local and indigenous communities
13. Local and social development	CORSIA SAF production aims to improve socioeconomic conditions in impoverished regions impacted by its operations.
14. Food security	CORSIA SAF production will aim to improve local food security for stakeholders in food-insecure regions affected by its operations.

5.3.2 ReFuelEU Aviation – RED II/III

The ReFuelEU Aviation regulation, also known as Regulation (EU) 2023/2405, together with the Renewable Energy Directive II/III (RED II/III), known as the Directive (EU) 2023/2413 amending the Directive (EU) 2018/2001, represents the primary regulatory framework defining the requirements and application of SAF in European air traffic. To this end, from 2025 onwards, a minimum SAF blending share of 2 % at EU airports is mandated, progressively increasing to a 70 % SAF share across all EU airports by 2050, with synthetic aviation fuels comprising 35 % of the total SAF volume [141]. A more detailed allocation of quotas, according to the specific SAF definitions and year, is presented in Table 5–8.

For potential exports of SAF to the European Union, as well as for eligibility for EU funding or participation in EU market mechanisms, compliance with the applicable laws and definitions for SAF production is mandatory. Such compliance must be demonstrated through a recognized certification system. **Table 5–9** summarizes various definitions within ReFuelEU Aviation and RED II/III, detailing feedstocks and their associated sustainability criteria. For a more detailed description of all non-fossil fuel categories in EU legislation, see [162] and for general information on PtX projects, see [163].

Table 5–8: ReFuelEU Aviation Superior Quotas of total kerosine demand, **[141]**

Superior Quotas		
Fuel	Definition	Quote
Sustainable Aviation Fuel (SAF)	Synthetic Aviation Fuels/ Renewable hydrogen for aviation, Aviation Biofuels, Recycled Carbon aviation fuels	2025 share of 2 % SAF 2030 share of 6 % SAF 2035 share of 20 % SAF 2040 share of 34 % SAF 2045 share of 42 % SAF 2050 share of 70 % SAF
Synthetic Aviation Fuels	Synthetic Aviation Fuels, Synthetic low-carbon aviation fuels	2030 share of 0.7 % Synthetic Aviation Fuels 2035 share of 5 % Synthetic Aviation Fuels 2040 share of 10 % Synthetic Aviation Fuels 2045 share of 15 % Synthetic Aviation Fuels 2050 share of 35 % Synthetic Aviation Fuels

Table 5–9: SAF Definitions and Requirements in EU Regulations, [141], [142]

Superior Quotas			
Fuel	Definition	Feedstock	Sustainability criteria

Synthetic Aviation Fuels/ Renewable hydrogen for aviation	According to RED II/III: Renewable fuels of non-biological origin (RFNBO) [a]	Renewable energy sources other than biomass	Power supply criteria and GHG emission threshold (70 % reduction); (see Article 29a Directive (EU) 2018/2001, Delegated Regulation (EU) 2023/1184 and Delegated Regulation (EU) 2023/1185)
Aviation Biofuels	According to RED II/III: Advanced biofuels [a]	Directive (EU) 2018/2001 Part A of Annex IX	Sustainability criteria and GHG emission threshold for biofuels, bioliquids and biomass fuels; (see Article 29 Directive (EU) 2018/2001)
	According to RED II/III: Biofuels	Directive (EU) 2018/2001 Part B of Annex IX	
	According to RED II/III: Biofuels [b]	Biomass not produced of the Directive (EU) 2018/2001 Part B of Annex IX with the exception of biofuels produced from “food and feed crops”	
Recycled Carbon aviation fuels	According to RED II/III: Recycled carbon fuels	solid waste streams of non-renewable origin which are not suitable for material recovery in accordance with Article 4 of Directive 2008/98/EC Waste processing gas and exhaust gas of non-renewable origin which are produced as an unavoidable and unintentional consequence of the production process in industrial installations	GHG emission threshold (70 % reduction); (see Article 29a Directive (EU) 2018/2001)
Eligible SAF till 2035 (by Article 4 ReFuelEU Aviation)			
Synthetic low-carbon aviation fuels/ Low-carbon hydrogen for aviation	Within ReFuelEU Aviation; Calculation methodology according to RED II/III	non-fossil non-renewable low-carbon hydrogen	Power supply criteria and GHG emission threshold (70 % reduction); (see Article 3 REGULATION (EU) 2023/2405)

[a] Non-aviation specific quota in RED III, 1 % in 2025 and 5.5 % of which a share of least 1 % should be Renewable fuels of non-biological origin in 2030 for the Transport Sector

[b] Maximum of 3 % of aviation fuels of complying with the minimum shares of SAF defined in ReFuelEU Aviation

5.3.3 Assessment of the Environment & Sustainability Requirements

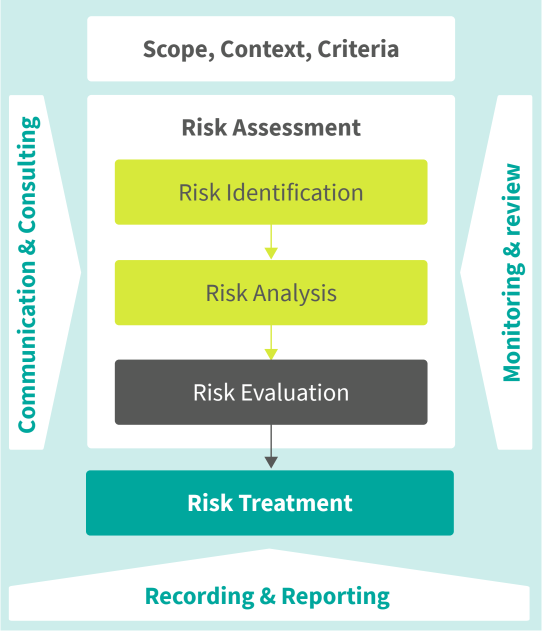
Within the described plant concept, the regulatory frameworks (CORSIA Eligible Fuels and the EU Regulations) can be fulfilled. However biomass and electricity supply must ensure compliance with the applicable sustainability criteria (according to CORSIA Eligible Fuel and RED II/III, see Table 5–7, Table 5–9 and [162]). In addition, the electricity sourcing criteria under the two Delegated Acts – COMMISSION DELEGATED REGULATION (EU) 2023/1184 and COMMISSION DELEGATED REGULATION (EU) 2023/1185 – must also apply. For a comprehensive overview of the power supply criteria and carbon sourcing options, see [162]. When MSW and sewage sludge from wastewater treatment plants are utilized, multiple CORSIA eligibility criteria are inherently satisfied, such as (2) Carbon Stock, (5) Soil, (7) Conservation, and (14) Food Security. Under ReFuelEU Aviation, with reference to the RED II/III, the biomass fraction of MSW and sewage sludge are feedstocks for advanced biofuel (in accordance with RED II/III Part A Annex IX). If the supply of electricity (in particular for electrolysis) complies with the electricity sourcing criteria of the RED (for the production of renewable fuel of non-biological origin (RFNBO)), an additional share of the SAF can be classified as synthetic aviation fuel (in accordance with RED II/III Article 29a). The respective fuel fractions (advanced biofuel and synthetic aviation fuel) are allocated according to the energy inputs.

Another important factor is the procurement of sufficient water for electrolysis. It must be ensured that hydrogen production complies with the CORSIA Eligible Fuels requirement on (4) water, meaning that water quality must be maintained or enhanced, and the depletion of surface or groundwater must be prevented. Consequently, water sourcing in ASAL regions must be strictly avoided. In addition, all (12) water use rights in Kenya must be respected.

5.4 Non-Financial Risk Assessment

Risk management has gained increasing importance in recent years and is now an essential component of frameworks such as the Environmental, Social, and Governance (ESG) criteria. To identify and address risks, the risk management framework outlined in DIN ISO 31000:2018-10 can be applied. The practical implementation of the risk management process requires six iterative steps, as illustrated in Figure 5–5.

Figure 5–5: Risk Management Process, based on DIN ISO 31000:2018-10



The following section focuses on the assessment of key non-financial risks and potential treatment options (highlighted in red in Figure 5–5), primarily operational risks and other significant risk categories, applied to the before mentioned scenario settings. These risks are evaluated in the context of available risk treatment options. Examples of risk mitigation strategies are provided, excluding cases involving risk retention, complete risk avoidance, or intentional increasing the risk for potential higher profits. These options can only be selected in accordance with the company- or project-specific risk management framework.

Consequently, the risk treatment measures considered here are limited to:

- Removing the risk source;
- Changing the likelihood;
- Changing the consequences;
- Sharing the risk (e.g., through contracts, buying insurance)

5.4.1 Operational Risks

Operational risks are risks that arise from internal processes, systems, or human factors. The following sections present examples of operational risks specifically related to the construction and operation of a SAF production facility, along with potential risk treatment options.

Risks could arise from supply chain disruptions during the construction phase, caused by delays or failures of technical components. Since these components are not manufactured in Kenya, they must be imported from abroad. To mitigate potential supply failures, Export Credit Agencies (ECA´s) can act as insurers to hedge the risk. Additionally, it is essential to evaluate and compare export companies from various perspectives in advance, in order to minimize the risk of supply disruptions.

Further risks arise during operation due to interruptions in feedstock supply streams. A decline in feedstock availability may lead to production shutdowns, potentially resulting in the failure to meet contractual SAF delivery commitments. To mitigate this risk, the feedstock supply should be diversified across multiple suppliers, adequate feedstock storage capacity should be established to buffer short-term shortages, and technology resilient to fluctuations in feedstock quantities should be implemented. This risk is further mitigated by the described Conceptual Process Design of the SAF Plant in Kenya, which features a separate setup between the methanol production unit and the MtJ unit. In order to utilize diverse feedstock sources, biogas production must be specifically adapted to the respective feedstock.

Consequently, either biogas from several geographically dispersed digesters must be transported to a central methanol production unit, or multiple methanol production units must be constructed, each designed to process the respective biogas feedstock. A centralized methanol production process is advantageous in that economies of scale substantially reduce the specific capital costs of methanol synthesis. The same effect applies, albeit to a somewhat lesser extent, to biogas production itself. On the other hand, such centralization requires either extensive transportation of the feedstock biomass or the development of a dedicated biogas pipeline network. By contrast, methanol can be transported relatively easily and at comparatively low cost. The utilization of MSW as a feedstock further reduces the risk of interruptions in feedstock supply streams, as MSW represents a relatively constant year-round supply stream that is largely independent of weather conditions or extreme weather events. This stands in contrast to other biomass residues, which are susceptible to significant fluctuations, for example during periods of drought.

Operational risks can also result from low TRLs. Technologies with lower TRLs are often not yet optimized for robust industrial-scale operation, leading to reduced efficient as well as increased frequency and duration of maintenance periods. Furthermore, technologies at lower TRLs typically have a limited number of suppliers, which may lead to dependencies, particularly concerning the availability of spare parts. A thorough pre-selection and evaluation of both the technologies and their manufacturers can facilitate the identification of solutions that are better suited for reliable industrial-scale processes. The separation of plant concepts, as outlined in the Conceptual Process Design of the SAF Plant in Kenya further reduces operational risks associated with low TRLs. Since methanol production is already a mature process, the production and commercialization of methanol as an intermediate product can commence first. Construction of the MtJ process plant can be postponed until the technology has reached sufficient maturity and kerosene from MtJ reached ASTM approval.

In current industrial operations, IT risks frequently arise in the form of data breaches, system disruptions, or ransomware attacks. Such incidents can lead to partial or complete shutdowns of the SAF production. These risks can be mitigated by implementing up to date and robust IT security systems, conducting employee awareness programs and providing regular IT-security trainings.

Human errors frequently cause injuries, damages, operational failures, or, in the worst cases, fatalities. To minimize these risks, a comprehensive security awareness management program is essential. This includes trainings and sensitization measures, appropriate safety equipment, regular audits, an open feedback culture, and technical support or automation to help reduce human error-related risks.

Another operational risk arises from a shortage of skilled labour. This can lead to considerable project delays, reduced operational efficiency, increased error rates, and higher costs due to the need to recruit external experts and their relocation near the construction site. To mitigate these risks, effective and timely workforce planning as well as talent acquisition, continuous training, development programs in Kenya, the provision of attractive working conditions, and a high degree of automation are applicable strategies.

5.4.2 Other significant risks

Other significant risks can mainly arise from reputational risks and strategic risks. Examples related to the construction and operation of a SAF production facility, as well as potential risk treatment options, are examined in the following section.

Reputational risks are caused by negative public perception of a project. In the context of SAF production facility construction and operation, such risks may arise due to factors like extensive freshwater usage, land rights disputes with local communities, construction in or near protected natural areas, noise pollution close to residential buildings, or competition with agricultural production.

This risk can be mitigated through thorough environmental and stakeholder analyses, proactive communication and engagement with all stakeholders, positive public relations efforts, and collaboration with political actors and other involved community members in Kenya.

Strategic risks result from subsequent changes in political and regulatory frameworks during the project lifecycle, as well as potential misestimations of SAF supply and demand. To mitigate this risk, close cooperation with potential off takers such as airports and political stakeholders in Kenya is advisable.

Additionally, creating a diverse portfolio of off-takers, supported by a cross-border or even global transportation infrastructure, helps to reduce dependency and increase resilience. This risk can also be mitigated through the considered production pathway with methanol as a separate intermediate product. In the event of a loss of SAF off takers in Kenya, the intermediate product methanol could still be marketed, thereby maintaining revenue streams and reducing exposure to local demand fluctuations of SAF.

6

Economic and financial analysis

Douglas Liner

6.1 Key Summary

This economic and financial analysis follows the earlier chapters in the Prefeasibility Study for Power-to-Liquid production in Kenya. It builds on the technical pre-feasibility study completed in Chapter 5 and translates these engineering specifications and process designs into a framework for economic and financial analyses and, by extension, investment decision making.

Integration with Technical Estimates. Chapter 5 establishes the technical foundation for a net 21,900 t/a SAF production facility using the Methanol to Jet (MtJ) pathway, with key technical parameters that shape the economic analysis:

Main technical parameters:

- Plant configuration: Power-Biomass-to-Liquids (PBtL) process combining biogas reforming with electrolysis
- Energy requirements: 32 MW total electricity demand (29 MW for methanol production and 3 MW for MtJ conversion)
- Material Balance: 2.9 tonnes methanol input per tonne SAF output, with co-products of naphtha (0.03 t/t SAF) and heavy diesel (0.07 t/t SAF).
- Feedstock Specification: 7.5 t/h biogas consumption at 60 % CH_4/40 60 % CO_2 composition
- Capacity Utilization: 90 % plant availability (8,000 operating hours/a)

6.1.1 Major Assumptions and Methodological Limitations:

Technical Assumptions: The economic and financial analysis builds on the following technical parameters:

- Technological Pathway: Methanol-to-Jet (PBtL) process with established conversion ratios
- Plant Design: Based on proven industrial processes with define mass/energy balances
- Operational Performance: 90 % capacity factor reflecting industrial best practices (21,900 t/a net)
- Location-Specific Factors: Kenya-specific conditions for utilities, labor and logistics

Economic and Financial Assumptions:

- Project Lifetime: 20 years operational project.
- Discount rate: 8 % weighted average cost of capital is initially assumed (reflecting Kenya’s infrastructure risk profile). Alternatively, government bond rate adjusted for inflation.
- Base Year: 2025 pricing with real adjustments.

- Currency: Analysis conducted in EUR with USD/KES conversions where applicable
- Financing structure: (to be defined – preliminary assumption of 70 % debt/ 30 % equity based on prior Kenya experience). Implies higher return requirements due to higher equity %.

Methodological Limitations:

- Estimation approach: High-level benchmarking rather than detailed bottom-up engineering estimates.
- Cost accuracy: +/- 30 % accuracy typical for pre-feasibility stage analysis
- Market Analysis: No long-term price forecasting included (as per SOW)
- Scenario Complexity: Detailed multi-parameter scenario analysis excluded by SOW.
- Risk Modeling: High level qualitative risk assessment only.

Key Data Sources and Validation:

- Industry and academic literature and peer-reviewed studies for technology benchmarking
- Similar SAF project cost data for scaling factor validation
- Kenya-specific utility and feedstock pricing from government sources
- International SAF market pricing from aviation industry reports

6.1.2 Investment Recommendations

Critical Success Factors Identified:

1. Feedstock Cost Management: Securing biogas supply at < 200 EUR/MWh is essential for project viability.
2. SAF Product Market Premium: Achieving sustainable pricing premium of approximately 30 % above conventional jet fuel. The SAF product price includes premium for potential carbon credits to avoid double counting.
3. Levelized Cost Gap: The current financial model estimates a levelized cost for the SAF product at 4,583 EUR/t which exceeds current pricing estimates for SAF conservative and base case scenarios as per **Table 6–21** by 1,600 to 2,200 EUR/t, and indicates necessary support via government policy or premium SAF contracts.
4. Co-product Revenue Optimization: Effective monetization of naphtha and heavy diesel by-products
5. Financing Strategy: Access to concessional (EIB, KfW, AfDB, etc) development finance to improve project returns.
6. Regulatory Certainty: Confirmation of CORSIA eligibility and certification pathways.

Key Risk Identification and Mitigation Strategies

1. Feedstock Supply Risk: Develop long-term biogas supply agreements or alternative feedstock strategies
2. Technology Integration Risk: Conduct pilot-scale demonstration of combined PBtL process
3. Market Development Risk: Secure preliminary offtake agreements with regional airlines
4. Financing Risk: Engage with development finance institutions early in project development process.

6.2 Introduction and Methodology

6.2.1 Analysis Framework

This Economic and Financial Analysis is based on a high-level estimation approach as opposed to a bottom-up approach. This analysis employs industry benchmarking and scaling factor methodologies consistent with pre-feasibility study standards. Cost estimates are derived from peer-reviewed literature, similar project data, and established chemical engineering cost estimation techniques, providing accuracy levels appropriate for investment decision making at this project stage (+/-30 % typical range).

Cost Allocation Methodology: The proposed financial model will allocate costs between the primary product (SAF from PBtL) and co-products (naphtha and heavy diesel) based on mass allocation principles. Since SAF represents 91 % of the product output by mass, most of the costs are attributed to SAF production while co-product revenues provide additional project value.

Key Limitations: The following limitations of the proposed high-level approach are listed here to avoid any misconceptions related to this methodology and its outputs:

- High-level estimates only, without detailed engineering breakdowns
- Scaling factors applied from different project sizes and contexts
- No long-term price forecasting (as per SOW)
- Qualitative risk assessment approach only

6.2.2 Data Sources and References

The following data sources and references were used as inputs to the economic and financial analysis.

Primary Technical Data Sources

- Chapter 5 Technology Pre-feasibility Study mass and energy balances.
- Chapter 5 Process flow diagrams and equipment specifications.
- Kenya-specific utility and infrastructure requirements. For example, in lieu of more specific data, the financial cost analysis uses 0.063 EUR/kWh for grid electricity based on Kenya’s Commercial and Industrial C1 3 tariff category (effective Jan 2022). A lower rate may apply if other RE electricity supply options are available, this has not been confirmed.

Cost Benchmarking Sources:

- Industry literature for PEM electrolysis systems (1,400 EUR/ kWel)
- Peer-reviewed studies on methanol and MtJ production costs
- Similar SAF product project cost data for validation
- Kenya-specific utility rates and feedstock pricing

Economic Parameters:

- Kenyan industrial electricity tariffs and infrastructure costs
- International SAF market pricing and regulatory frameworks
- Development finance market conditions for infrastructure projects

6.3 Capital Expenditure (CAPEX) Analysis

6.3.1 Major Plant Investment Components

The CAPEX analysis is directly taken from the technical specifications established in Chapter 5, using industry benchmarking and scaling factors to estimate the major investment components to arrive at the net 21,900 t/a PBtL plant for SAF production in Kenya. As this is a first of kind system in Kenya, the estimates are conservative. The following tables summarize the CAPEX by major system:

Table 6–1: CAPEX Estimations by the Major System Components

System component	Capacity/ Scale	Unit Cost Benchmark	Scaling Factor	Estimated Capex (EUR K)	Source/ Reference
Electrolysis System	32 MW	1,400 EUR/ kWel	-	35,000	Industry literature [170]
H2 Storage	-	-	-	11,000	[171]
Methanol Production	8.1 t/h methanol	160 EUR/t annual capacity	0.65	51,000	Scaled from 860 kg/h benchmark [171]
Methanol-to-Jet Unit	21,900 t/a SAF	180 EUR M for 100 kt/a	0.65	59,000	Scaled from benchmark. Net output [170]
Supporting Infrastructure	Plant-wide	25 % of process equipment	-	28,000	Industry standard [172]
Installation and EPC	Total equipment	50 % of equipment cost	-	69,000	Standard EPC markup [173]
Contingency	Total project	15 % of installed cost	-	62,000	Pre-feasibility standard [172]
Total Estimated CAPEX	-	-	-	315,000	-

Table 6–2: Electrolysis System Breakdown with the Related Costs (32 MW Total)

Component	Specification	Unit Cost	Total Cost (EUR K)	Notes
PEM Electrolyzer Stack	32 MW capacity	1,400 EUR/ kWel	34,944	Including installation [170]
Hydrogen storage	72 hours capacity	Included in electrolyzer cost	10,800	Standard industrial practice [171]
Compression system	30 bar operating pressure	Included in electrolyzer cost	-	Integrated system [170]
Power Electronics	32 MW capacity	Included in electrolyzer cost	-	Balance of Plant [170]

Table 6–3: Methanol Production Unit Scaling Calculation and Method [171]

Parameter	Benchmark Case	Project Case	Scaling Method	Result
Production Rate	860 kg/h	8,100 kg/h	Power law scaling	Scale factor: 9.42
Annual Capital Cost	160 EUR/t methanol	-	Scale factor 0.65	
Equipment Lifetime	20 years	20 years	Annuity conversion	51 EUR M

Table 6–4: Supporting Infrastructure Cost Estimates [172]

Infrastructure Category	Basis for Estimate	Estimated Cost (EUR K)	Notes
Biogas Conditioning & Storage	7.5 t/h biogas capacity	8.5	Includes purification systems
Electrical Infrastructure	32 MW grid connection	6.2	Substation and distribution

Water Treatment System	2.5-3.5 EUR/m3 desalination	4.8	Including pipeline transport
Control & Instrumentation	3 % of process equipment	3.8	DCS and safety systems
Buildings & Site Preparation	Kenya construction costs	1.8	Administration and maintenance
Sub-total		**27,723**	

6.3.2 Installation and Engineering Costs

Table 6–5: EPC and Project Development Cost Estimates [173]

Cost Category	Percentage of Equipment	Estimated Cost (EUR K)	Rationale
Engineering & Design	15 % of equipment cost	23,400	Standard chemical plant
Procurement & Logistics	10 % of equipment cost	15,600	Kenya import/transport
Construction and Installation	25 % of equipment cost	39,000	Local labor and materials
Commissioning & Startup	5 % of equipment cost	7,800	Integrated system testing
Project Development	8 % of equipment cost	12,500	Permitting, financing, etc.
Total EPC & Development	**~63 % of equipment**	**69,000**	

6.3.3 CAPEX Summary and Benchmarking

Table 6–6: Total CAPEX Summary by Category (Preliminary)

Major Category	Amount (EUR K)	Percentage of Total	EUR/t Annual Capacity
Process Equipment	184	~58 %	8,400
Installation & EPC	69	~22 %	3,150
Contingency	62	~20 %	2,830

TOTAL PROJECT CAPEX	315	100 %	14,430
Working Capital	47 (15 % of CAPEX approx.)	-	2,150
Total Investment Required	**363**		**16,580**

6.4 Operational Expenditure (OPEX) Analysis

6.4.1 Fixed Operating Costs

The OPEX analysis quantifies the estimated annual operating costs for the SAF product facility using PBtL process based on the technical parameters from Chapter 5 and Kenya-specific cost data for utilities, feedstock and labor.

Table 6–7: Annual Fixed OPEX Calculation Summary

Cost Category	Calculation Basis	Annual Cost EUR K	% of Total OPEX	Notes
Maintenance & Repairs	3.5-5 % of respective CAPEX	TBD	~25 %	Equipment-specific rates [171, 174]
Operating Labor	24 operators x 4,910 EUR/month	1.5	~8 %	Including supervision [175]
Administration & Overhead	60 % of (Labor + Maintenance)	TBD	~15 %	Standard chemical plant [172]
Insurance & Property Tax	3.2 % of total CAPEX	TBD	~12 %	Kenya standard rates
[171]				
Laboratory & Quality Control	15 % of labor costs	0.2	~1 %	SAF certification requirements (ASTM D7566, CORSIA)
TOTAL FIXED OPEX		**25,022**	**~60 %**	

Table 6–8: Maintenance Cost Breakdown by System

System	**Capex (EUR K)**	**Maintenance Rate**	**Annual Maintenance** (EUR K)	**Notes**
Electrolysis System	35,000	3.5 % per annum	1,225	PEM-specific rate [174]
Methanol Production	51,000	5.0 % per annum	2,550	Chemical process standard [171]
Methanol-to-Jet Unit	59,000	5.0 % per annum	2,950	Downstream processing [171]
Supporting Infostructure	28,000	3.0 % per annum	840	Utilities and storage [172]
H2 Storage	11,000	2.0 % per annum	220	Low maintenance [171]
Total Annual Maintenance			**7,785**	

Table 6–9: Operating Labor Requirements and Costs [175]

Position Category	**Number of Staff**	**Monthly Salary (EUR)**	**Annual Cost (EUR K)**	**Notes**
Plant Operators (Shifts)	16	4,910	941	4 shifts with 4 operators
Maintenance Technicians	4	5,200	249	Specialized skills
Laboratory Staff	2	4,500	108	Quality control
Supervision/ Management	2	6,500	156	Plant management
Subtotal Direct Labor	24		1,451	
Non-wage Costs (28 %)				Social security, benefits
Total Labor Costs			**1,861**	

6.4.2 Variable Operating Costs

Table 6–10: Annual Variable OPEX Calculation Summary

Cost Category	**Consumption Rate**	**Unit Price**	**Annual Cost (EUR K)**	**% of Total OPEX**	**Notes**
Biogas Feedstock	7.5 t/h x 8,000 h	120 EUR/MWh (LHV)		~45 %	MSW-based pricing [171]
Grid Electricity	Process consumption	0.063 EUR/kWh		~15 %	Kenya industrial rate [176]
Process Water	Electrolysis + cooling	3.2 EUR/m3		~5 %	Desalinated water [177]
Chemicals & Catalysts	Process requirements	Industry standard		~4 %	Replacement schedule [173]
Transport & Logistics	Product distribution	Kenya rates		~2 %	To distribution points
TOTAL VARIABLE OPEX			43,333	~70 %	
TOTAL VARIABLE OPEX			43,333	~70 %	

Table 6–11: Biogas Feedstock Cost Calculations

Parameter	**Value**	**Unit**	**Notes**
Biogas Consumption Rate		t/h	From Chapter 5 mass balance
Annual Operating Hours	8,000	h/a	90 % capacity factor [171]
Total Annual Biogas	60,000	h/a	
Biogas LHV	22	MWh/t	60 % CH4, 40 % CO_2
Total Energy Content	**1,320,000**	**MWh/a**	
Unit Price Range	**150-230 EUR/MWh**		**MSW feedstock in Kenya [171]**

Annual Cost Range	**198-304 EUR M**	**Primary cost driver [171]**
Base Case (190 EUR/ MWh)	**250.80 M EUR M**	

Table 6–12: Electricity Consumption and Cost Calculations [176]

Application	Power (MW)	hour per annum	Energy (MWh/a)	Cost (EUR/ MWh)	Annual Cost (EUR K)
Electrolysis (included in biogas)	29.0	-	-	-	-
MtJ Process Equipment	2.5	8,00	20,000	63	1,260
Auxiliaries & Utilities	0.5	8,760	4,380	63	276
Total Electricity Cost			**24,380**		**13,252 EUR K**

Table 6–13: Water Consumption and Cost Calculations [177]

Application	Rate (m3/h)	h/a	Annual Volume (m3)	Unit Cost (EUR/m3)	Annual Cost (EUR K)
Electrolysis Process	14 L/kg H2 produced	8,000	11,200	3.2	35
Cooling Water (Makeup)	2.5	8,000	20,000	3.2	63
General Plant Use	1.0	8,760	8,760	3.2	28
Total Water Cost			**39,960**		**126**

6.4.3 Total Annual OPEX Summary

Table 6–14: Annual Opex Calculation Summary (90 % Capacity Factor)

Category	Annual Cost (EUR K)	Cost per Tonne SAF (EUR/t)	Percentage of Total
Fixed OPEX	25,022	1,143	
Maintenance & Repairs	8,154	372	~25 %
Labor & Admin	6,754	308	~8 %
Insurance & Other	10,133	463	~7 %
Variable OPEX	43,333	1,979	
Biogas Feedstock	29,039	1,326	~50 %
Electricity	13,252	605	~3 %
Water	73	3	~2 %
Chemicals	689	31	
Transport & Logistics	280	13	
TOTAL ANNUAL OPEX	**66,355**	**3,122**	**100 %**

Table 6–15: Impact of Capacity Factor on OPEX Calculations **[171]**

Capacity Factor	Annual Production (t)	Fixed OPEX per tonne (EUR/t)	Variable OPEX per tonne (EUR/t)	Total OPEX per tonne (EUR/t)
70 %	15,330	1,633	1,979	3,612
80 %	17,520	1,429	1,979	3,408
90 % (Base)	**21,900**	**1,143**	**1,979**	**3,122**
95 %	23,178	1,080	1,979	3,059

6.5 Revenue Model Analysis

The Revenue model for the SAF product facility is based on a multi-product approach that maximizes value from the primary SAF product output while also generating revenue from co-products (naphtha and heavy diesel). This chapter quantifies the revenue streams and establishes pricing assumptions for financial modeling which reflects the premium nature of the SAF product and the regulatory frameworks that support the transition to SAF use.

6.5.1 Primary Product Revenue

6.5.1.1 SAF Market Pricing Framework

The SAF product market operates within a complex pricing environment where SAF currently commands significant premiums over conventional jet fuel due to its environmental benefits and regulatory compliance value. The pricing variability is significant – both for conventional fuel, but particularly for SAF. Some representative examples of SAF product pricing [25] [118] in different markets include:

Table 6–16: Comparison of Conventional Jet Fuel Prices, SAF Premium Costs and Total SAF Prices across International and Regional Market Segments (2025)

Market Segment	Conventional Jet Fuel (EUR/t)	SAF Premium (EUR/t)	Total SAF price (EUR/t)	Notes
International Benchmark	680–850	1,700–3,000	2,390–3,800	CORISA-eligible markets [178]
EU Market (ReFuelEU)	725–900	2,100–3,400	2,850–4,300	Mandatory blending requirements [182]
East Africa Regional	640–800	1,280–2,130	1,900–2,900	Emerging market premium
Kenya Domestic	680–850	1,020–1,700	1,700–2550	Local aviation market

Based on the earlier Chapter 1, Demand Analysis, the main characteristics of the Kenya Aviation Market include:

- **Total Aviation Fuel Consumption:** ~650,000 t/a (13 % of total petroleum products
- **International Flights:** ~75 % of consumption (focus for CORSIA compliance)
- **Jomo Kenyatta International Airport (JKIA):** Is the main airport in Kenya and 4th largest in Sub-Saharan Africa
- **Key Airlines:** Kenya Airways (national carrier), 30+ international airlines
- **EU/UK Flight Routes:** Significant portion require CORSIA-eligible fuel by 2025

The market potential for the SAF product is based on current consumption and pending or future regulatory/voluntary market characteristics for different segments. Taken together, the different segments total to as much as 186,875 t/a (roughly 1/3 of current consumption) for up to 824 EUR M in value. Note, the proposed technical project is based on a net production of 21,900 t/a of SAF product output which represents 12 % of the total potential market.

Table 6–17: Kenya Sustainable Aviation Fuel Market Potential & Revenue Opportunity

Market Segment	Current Annual Volume Aviation Fuel (t)	SAF potential (%)	Target Volume (t)	Revenue Opportunity (EUR M)
EU/UK Routes	195,000	50 %	97,500	234-439
CORSIA International	292,500	25 %	73,125	165-329
Regional/ Domestic	162,500	10 %	16,250	33-56
Total Potential Market	**650,000**	**29 %**	**186,875**	**432-824**

6.5.1.2 Certification and Sustainability Premiums

The proposed project PBtL product pathway is eligible for CORSIA certification, which provides access to international aviation markets with mandatory sustainability requirements. This potential certification provides several benefits:

Table 6–18: Benefits of CORSIA Compliance

Certification Benefit	Value Driver	Quantified Impact	Notes
Market Access	EU/UK route compliance	1,000-2,000/t premium	Mandatory for International Routes
GHG reduction	70 % + emission reduction vs. fossil	CORSIA credit value	Minimum 10 % reduction required
Carbon Avoidance	~3.2 tCO_2/tSAF	25-100 EUR/tCO_2 carbon value	Based on voluntary carbon markets
Sustainability Certification	14-criteria compliance	Premium market positioning	Non-compliance – market exclusion

In addition to CORSIA, SAF produced in the proposed plant may also qualify for EU export markets. The SAF produced may meet the ReFuelEU Aviation requirement for synthetic aviation fuel and qualify for the premium EU SAF market.

6.5.2 Co-Product Revenue Streams

The Methanol-to-Jet process generates valuable co-products that provide additional revenue streams and improve the overall financial and economic returns for the proposed project.

6.5.2.1 By-product Valorization

Based on the mass balance from Chapter 5, the proposed PBtL plant will produce significant quantities of naphtha and heavy diesel in addition to the main SAF production.

Table 6–19: Annual Co-Product Production Rate and Estimated Revenue [179, 180]

Co-product	Production Rate (t/tSAF)	Annual Production (t)	Unit Price (EUR/t)	Annual Revenue (EUR M)	% of Total Revenue
Naphtha	0.03	657	450-650	0.3-0.4	1-2 %
Heavy Diesel	0.07	1,533	600-800	0.9-1.2	3-5 %
Total Co-Products	**0.10**	**2,190**		**1.2-1.6**	**4-7 %**

These two co-products can be sold within the Kenyan domestic market with quality premiums. Current local demand and market pricing in Kenya for these two co-products suggests:

Naphtha Market (657 t/a)

- Primary use: Petrochemical feedstock, solvent applications
- Local demand: >50,000 t/a (mainly imports)
- Market position: Premium synthetic naphtha can command 10-20 % premium
- Offtake strategy: Long-term contracts with petrochemical companies

Heavy Diesel Market (1,533 t/a)

- Primary use: Industrial applications, marine fuel, power generation
- Local demand: >200,000 t/a
- Market position: Clean synthetic diesel with superior properties
- Offtake strategy: Industrial users, marine sector, premium diesel market

6.5.2.2 Carbon Credit Opportunities

The proposed project also generates significant carbon emission reductions that can be monetized through different carbon markets – both voluntary and compliance mechanisms:

Table 6–20: Carbon Credit Revenue Potential by Source

Carbon Credit	**Production Rate (t/tSAF)**	**Annual Production (t)**	**Unit Price (EUR/t)**	**Annual Revenue (EUR M)**
Source	Emission Reduction (tCO_2/a)	Price Range (EUR/tCO_2)	Annual Revenue (EUR M)	Notes
SAF vs. Fossil Jet Fuel	70,230	25-100	1.8-7.0	3.2 $tCO_2/tSAF$ displaced
[181]				
Biogas Utilization	15,000	15-50	0.2-0.8	MSW diversion from landfill [182]
Renewable Electricity	12,000	20-60	0.2-0.7	Grid displacement effect
TOTAL CARBON CREDITS	**97,230**	**20-70**	**2.2-8.5**	**Voluntary carbon market**

Carbon Market Development

Voluntary Carbon Market (VCM):

- Current Pricing: 20-70 EUR/tCO_2 for aviation sector credits.
- Quality Premium: 20-50 % for co-benefits (waste management, renewable energy).
- Certification Standards : Verra, VCS, Gold Standard, etc.
- Buyer Profile: Airlines, corporates with net zero commitments.

Compliance Market Potential:

- Kenya Carbon Tax: Under development, potential for 5–15 EUR/tCO_2 value.
- International Article 6 (Paris Agreement): Future potential for international carbon trading.
- Regional Carbon Markets: East Africa Initiatives under discussion.

6.5.2.3 Carbon Credit Account and CORSIA Compliance Consideration

The proposed PBtL project can potentially generate significant carbon credits as presented above; however, there are issues concerning double counting between CORSIA compliance markets and carbon markets. When the SAF product is sold to airlines for CORSIA compliance, the embedded carbon reduction value cannot simultaneously be sold as separate carbon credits to other buyers, as this would constitute double counting under international carbon counting frameworks. To avoid this potential double counting, the economic and financial analysis includes any potential carbon credit value in the premium price paid for the SAF product. For example, a value of 179 EUR/t

SAF based on 3.58 tCO_2/tSAF at 50 EUR/tCO_2 is embedded within the SAF premium pricing rather than monetized in separate carbon credit sales. This approach:

- Eliminates double counting compliance risk,
- Simplifies the revenue model and carbon accounting calculations

The SAF Product Revenue Model therefore incorporates potential carbon credit values into the SAF product pricing. The conservative and base case scenarios reflect SAF product pricing of 2,347 EUR/t (conservative) and 2,947 EUR/t (base case). There are currently no separate carbon credit revenues.

6.5.3 Revenue Model Scenarios

The Revenue Model forecasts constant volume sales of SAF and co-products in Kenya under three basic scenarios: conservative, base case and optimistic pricing. The rationales behind the different scenarios are explained below:

Conservative Scenario:

This scenario undershoots the pricing assumptions made earlier in this chapter. This can happen due to slow government or regulatory action.

- Limited SAF product premium due to slow regulatory adoption.
- Standard co-product pricing without any premiums for quality.
- Risk factors: Delayed CORSIA implementation, economic downturn/stagnation.

Base case Scenario:

This scenario reflects the earlier assumptions made in this chapter and assumes a gradual transition to SAF products without any major impediments.

- Moderate SAF premium reflecting steady market development.
- Co-product pricing includes some quality premiums.
- Assumptions: Normal market development, stable regulatory environment.

Optimistic scenario:

This scenario anticipates a strong environment for SAF transition due mainly to regulatory pressure and positive market development.

- High SAF product premium driving by strict regulatory enforcement
- Co-products are sold at premium prices

Drivers: Accelerated net-zero commitments by corporate clients, etc., carbon price increases

The following table summarizes the revenue forecasts for the SAF product and co-products under the different scenarios.

Table 6–21: SAF and Co-product Revenue by Conservative, Base Case and Optimistic Scenarios (EUR M/a) [178-181]

Revenue Stream	**Conservative**	**Base Case**	**Optimistic**	**Key Assumptions**
SAF Sales (21,900 t)				
Unit Price (EUR/t)	2,347	2,947	3,500	Market development price
Annual Revenue	43.7	54.9	65.2	Primary revenue driver
Co-Products				
-Naphtha + Diesel	1.1	1.3	1.5	Local market premiums
Carbon Credits				
-VCM				Carbon price (TBD)
TOTAL ANNUAL REVENUE	**44.9**	**56.1**	**66.4**	
Revenue (tSAF)	2,413	3,013	3.566	All-in revenue – before costs, tax, etc.

6.5.3.1 Market Penetration Strategy

The Revenue Model relies primarily on SAF product sales to Airlines (domestic Kenya Airways, and international KLM, British Air, Lufthansa, etc.) and to a lesser extent on Fuel Distributors and Corporate Buyers. The contract terms are for illustrative purposes only and need to be confirmed with Kenyan practices, particularly the possibility of direct sales to Airlines. Co-products are sold via existing channels to petrochemical companies (naphtha) and industrial, marine and fuel distributors (heavy diesel).

Table 6–22: SAF Market Penetration Strategy and Revenue Security by Segment

Market Segment	Volume (t)	Strategy	Contract Terms	Revenue Security
Airlines (Direct)	15,000	Long-term offtake agreements	5–10	
year terms	High			
Fuel Distributors	5,000	Supply contracts	3–5-year terms	Medium-High
Corporate Buyers	1,900	SAF certificates/ credits	Spot + contract	Medium
TOTAL SAF	**21,900**	**Mixed**	**7-year average**	**Medium-High**

Contract Structure:

- Take-or-Pay Agreements: 80 % of SAF product volume under long-term contracts.
- Price Adjustment Mechanisms: Annual adjustments linked to fossil fuel pricing.
- Sustainability Premiums: Fixed premiums with inflation adjustments.

The Revenue Model also assumes moderate real price escalations for the SAF product and co-products based on current market conditions in Kenya and near-term regulatory developments.

Pricing Escalation Assumptions

- SAF Product Pricing: 2-3 % annual real escalation reflecting carbon pricing trends.
- Co-products: 1-2 % annual escalation with oil price correlation.
- Carbon credits: 5-10 % annual escalation reflecting supply /demand dynamics.

6.5.3.2 Revenue Model Validation

To cross-check the Revenue Model, a quick benchmarking exercise with other SAF product markets provides context. Based on this comparison, the pricing assumptions for SAF product pricing in Kenya is slightly lower than that practiced in in Nordic countries. Other comparisons, particularly those including Ethiopia, which is currently embarking on a SAF product program, would be instructive when this data is publicly available.

Table 6–23: Comparative Analysis of Planned International SAF Project Pricing.

Project/ Region	Technology	SAF Price (EUR/t)	Revenue/	Revenue Security
Capacity	Notes	Long-term offtake agreements	5–10	
Nordic Electrofuels	Power-to-Liquids	3,200 -4,500	High premium	EU market, strong policy support
Norsk				
e-Fuel	Power-to-Liquids	2,800-3,500	Medium premium	Norway, early development
Proposed SAF Project in Kenya	Power-Biomass-to-Liquids	2,347-3,500	Market competitive	East Africa, emerging market

6.6 Financial Viability Assessment

6.6.1 Financial Model Structure

The financial viability assessment employs a 20-year discounted cash-flow model that integrates the technical specifications from Chapter 5 with market-based pricing assumptions from the Revenue Model. The model structure follows best practices for infrastructure project evaluation, incorporating base case analysis and sensitivity testing.

The financial model is based on the timing required to design and implement the SAF production plant in Kenya using the PBtL process. The cash flow projections begin with a construction period in 2027, followed by commercial operations commencing in 2028.

The financial analysis assumes a nominal capacity of 24,333 t/a with a 90 % capacity factor resulting in a net production of 21,900 t/a of SAF. All costs and revenues are expressed in 2025 EUR prices with escalation factors (in the Inputs section) applied throughout the project lifetime.

Assumptions made in the financial model inputs reflect the challenging first of a kind (FOAK) characteristic of a SAF production site in Kenya. Currently there are no similar technologies in Kenya that can be used as a reference, therefore conservative estimates are used. The weighted average cost of capital (WACC) of 8 % reflects Kenya’s infrastructure risk profile, which incorporates both emerging market premium and the innovative nature of the technology. Alternatively, a WACC calculation involving the inflation adjusted yield on Kenyan government bonds could be also used, if deemed more appropriate. The model employs straight-line depreciation over the 20-year asset life and assumes a 30 % corporate tax rate consistent with Kenyan fiscal policy.

For the moment, no specific financing structure is incorporated, although typically in Kenya this could by a 70/30 debt/equity structure for green field investments.

6.6.2 Base Case Financial Performance

The base case financial analysis reveals the significant economic challenges that are characteristic of new technologies in emerging markets. The financial model assumes conservative pricing which reflects current market conditions without optimistic policy support. Under these conditions, the proposed SAF production project generates an annual deficit of 12.3 EUR M between revenues of 56.1 EUR M and operating expenses of 68.4 EUR M.

The current negative Net Present Value of 423.6 EUR M over the project's 20-year duration indicates that current returns do not cover the significant CAPEX and OPEX costs of the investment. The Return on Investment of -8.2 % demonstrates that the project fails to meet basic commercial investment criteria, requiring approximately 562 EUR/t additional SAF price premium to achieve operational break-even.

The levelized cost calculation for the proposed SAF project provides another metric for comparison. According to the current cost estimates (CAPEX and OPEX) over the 20-year life, the levelized cost of SAF is 4,583/t and of methanol is 1,176/t (using the mass conversion). The cost SAF at 4,583 EUR/t significantly exceeds the 2,347-2,947 EUR/t assumed price range of other SAF types. This highlights the substantial cost gap that can be addressed through policy support or premium market pricing. This cost estimate for SAF indicates that even the 3,500 EUR/t optimistic SAF pricing scenario would still require additional support to achieve full cost recovery.

These initial results are not uncommon for FOAK project economic evaluations with new technologies and markets. Some instructive results from the analysis show that 73 % of the operating deficit stems from the premium cost associated with new technology deployment, such as higher maintenance costs, specialized labor requirements and training, and uncertain feedstock pricing. For the latter, feedstock represents 50 % of total operating expenses, making biogas pricing the most critical factor for the viability of this SAF project in Kenya. This underscores the point for all renewable energy projects that securing adequate feedstock supply contracts and pricing mechanisms will be fundamental to achieving a feasible project.

6.6.3 Investment Metrics in Context

The Base Case projected financial performance, on the surface, is not encouraging as the combined annual costs of the SAF facility (CAPEX +OPEX) outweigh the annual revenue streams assumed for SAF and it is co-products. Strictly speaking from a traditional commercial perspective, the proposed project is not feasible: however, this situation aligns with the initial results obtained with other clean energy technologies in the pioneering stages (for example, wind or solar power). These technologies require supportive policies and time to improve efficiency, performance and commercial viability.

The proposed SAF production project in Kenya can be seen as a strategic investment that includes technology development, market creation and positioning of Kenya as a regional leader in SAF. The learning curve benefits captured through this FOAK deployment could enable other, similar plants to achieve commercial viability while generating significant technical expertise within Kenya's emerging green economy. In addition, support can be provided to Kenyan banking institutions to understand the risks associated with the SAF production.

6.7 Sensitivity Analysis

6.7.1 Critical Parameter Identification

The sensitivity analysis of the proposed SAF production project in Kenya examines the financial performance across key variables to identify those parameters which have the largest impact. This analysis assesses movements in a single variable while holding others constant and also scenario-based analyses that consider combinations of parameter changes.

The sensitivity analysis reveals that SAF pricing represents a key influential factor affecting project returns. An initial inspection reveals that SAF price variations have approximately 3 times the impact of production volume changes and five times the impact of CAPEX variations. This sensitivity reflects the project's high fixed cost structure, where even modest revenue improvements translate directly into enhanced profitability due to operating leverage effects.

6.7.2 SAF Pricing Sensitivity Analysis

SAF pricing sensitivity demonstrates the project's potential for dramatically improved economic outcomes under supportive market conditions. The existing Revenue Model assumes pricing for SAF products with reference to existing markets in the EU- although a new market in East Africa might have different dynamics. The break-even analysis indicates that SAF prices of 2,909 EUR/t would eliminate the annual operating deficit, which represents a 562 EUR/t premium above current conservative pricing assumptions.

The Base Case scenario assumes a SAF product price of 2,947 EUR/t, slightly above the operational break-even, but still requires a higher price and/or additional support to cover the CAPEX payments (assuming no financing costs, for the moment). The Optimistic SAF pricing scenario of 3,500 EUR/t generates positive operating cash flows of approximately 3,500 EUR/t, which demonstrates the SAF project's viability under favorable pricing conditions.

The SAF product pricing sensitivity analysis reveals that each 100 EUR/t increase in SAF pricing improves the project's NPV by approximately 44 EUR M, which highlights the critical importance of premium off-take agreements (with airlines) and supportive policy frameworks (with possible subsidies or support).

6.7.3 Production Volume and Operational Efficiency

Varying the volume of the SAF production reveals the scale effects in chemical processing facilities. Operating at a higher 95 % capacity factor, instead of the assumed 90 %, improves revenues by 2.7 EUR M while adding minimal variable costs, resulting in nearly equivalent operating profit improvement. On the other hand, if the capacity factor drops to 85 %, then the project economics react more negatively due to the high fixed cost structure. Indeed, each percentage point drop in capacity utilization drops operating margins by 0.9 EUR M/a, which is more sensitive than the upside gains in capacity utilization. This again demonstrates the importance of reliable feedstock supply contracts and carefully managed operations to avoid extended downtime.

6.8 Conclusions and Recommendations

6.8.1 Financial Viability Assessment Summary

The economic and financial analysis of the proposed SAF product project in Kenya using PBtL technology is currently not feasible based on the current CAPEX and OPEX estimates and SAF product pricing assumptions. Nevertheless, these results are typical for a FOAK clean energy project in an emerging market like Kenya. Under current SAF market conditions and conservative pricing assumptions, the project faces significant challenges – with operational costs exceeding annual revenue. The Base Case pricing scenario improves operational profitability but still does not cover the CAPEX outlays. The most optimistic scenario, at 3,500 EUR/t SAF pricing does improve the overall financial viability but still returns -9 % Internal Rate of Return.

6.8.1.1 Current Economic Reality

The Base Case financial analysis shows an annual operating deficit of 12.3 EUR M, with operating expenses (68.4 EUR M) substantially exceeding combined SAF and co-product revenues of (56.1 EUR M). The project's NPV of -423.6 EUR M and negative 8.2 ROI reflect the economics of new technologies in emerging markets. On a commercial basis, the project therefore does not currently pass typical investment criteria – e.g. an IRR of at least 15 % (or substantially more if including financing costs). Premium SAF pricing contracts or policy support (subsidies) from the government could alleviate this economic performance.

6.8.1.2 Break-Even Requirements

The proposed SAF project currently requires either 12.3 EUR M/a in operating support or an additional 562 EUR/t SAF premium above conservative SAF pricing assumptions (2,347 EUR/t) to achieve just operational break-even. This translates to an overall break-even price of approximately 3,121 EUR/t, which while substantial, remains within the high range of premium SAF markets in developed markets.

6.8.1.3 Strategic Positioning

Despite the negative commercial returns, the project proposed SAF project represents the potential for a strategic technology investment that allows Kenya to become a regional leader in SAF. The facility can potentially serve as a technology platform for other EAC counties. Indeed, there is competition from Ethiopia which has recently announced policies supportive of SAF production. Finally, the possibility of relatively stable offtake agreements with Kenya Airways and international airlines assures a broad base or floor to the SAF market development.

6.8.1.4 First of a Kind Economics

The financial analysis reveals that approximately 73 % of the operating deficit stems from first of a kind premiums that typically occur in new markets with untested or unproven technologies. High maintenance costs, specialized labor and sub-optimal capacity are all characteristic. Once the technology is proven and risks managed, it is possible that OPEX and CAPEX could by reduced significantly which would create conditions for a more mature SAF market in East Africa.

6.8.2 Strategic Recommendations

As explained above, the proposed SAF project presents several potential strategic advantages, but currently faces economic challenges. To address these weaknesses there are three areas that could be tested and discussed with potential stakeholders:

6.8.2.1 Government Support Strategy

The SAF product project using PTtL technology as currently configured and operating within with a non-existing SAF product market, faces serious economic challenges. The financial model indicates that at least 12.3 EUR M is required annually for the proposed project to break-even operationally. This can be achieved by tax credits, direct subsidies, or favorable SAF premium pricing. Overall, this level of support is modest compared to other clean energy initiatives and could represent a strategic investment in Kenya's future international or regional role in SAF.

6.8.2.2 Development Finance

The proposed SAF product project using PBtL technology can potentially secure project financing from international financing institutions. Although these institutions have a variety of programmes and financing products, a 30 % CAPEX grant, for example, would substantially improve the economics of this project. The IFI's have a track record of supporting innovative clean energy projects in emerging markets, particularly those that contribute to regional technology platform potential.

6.8.2.3 Premium Offtake Agreements

Finally, as indicated earlier, the proposed SAF product project using PBtL technology is highly sensitive to SAF product pricing due to its high fixed cost structure. Favorable long-term contracts with international airlines that require CORSIA-eligible fuel would be a key support to the project. Given the current aviation fuel demand in Kenya, the proposed project's 21,900 t of SAF only represents 12 % of Kenya's potential SAF market – which provides substantial room for premium pricing agreements with Kenya Airways and other international carriers.

7

Roadmap and next steps

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7.1 Roadmap Scope

This chapter presents a structured roadmap for the realization of a Power-and-Biomass-to-Liquid (PBtL) plant for SAF production via the methanol pathway in Kenya, building directly upon the findings of the preceding pre-feasibility assessment. The primary objective of the roadmap is to outline the steps required to advance the project to the Final Investment Decision (FID) stage, thereby providing a practical reference framework for prospective developers. The approach builds on the outcomes the previous chapters such as site evaluations, technology pathway analyses, and financial break-even considerations, forming a comprehensive basis for subsequent project development activities.

The roadmap is organized around the main phases of the Feasibility Study and the Front-End Engineering Design (FEED) Study. Each phase is characterized by specific technical, commercial, and regulatory milestones that must be achieved to progress from pre-feasibility assessment to investment readiness. Key tasks include the development of robust concepts for all technical and logistical aspects, site- and feedstock-specific risk assessments, engagement with biomass residues and power suppliers, definition of technological configurations, and the negotiation of offtake agreements. In parallel, the roadmap addresses the need for detailed techno-economic modelling, investor identification, and the preparation of documentation required by both authorities and stakeholders. A central component of the roadmap is the integration of permitting and sustainability certification requirements, which are essential for regulatory compliance and market access.

The chapter outlines the administrative processes relevant to the Kenyan context, including timelines, responsible entities, and applicable legislation.

Additionally, the roadmap emphasizes alignment with international sustainability frameworks, notably the CORSIA eligibility criteria, and highlights the importance of early engagement with recognized certification schemes such as ISCC and RSB. Through this structured approach, the roadmap provides a clear pathway for translating pre-feasibility findings into actionable project development steps, thereby supporting the realization of a bankable and sustainable PBtL facility for SAF production via Methanol as intermediate product in Kenya.

7.2 Expression of Interest to the Ministry of Energy and Petroleum

As outlined in Kenya’s Guidelines on Green Hydrogen and its Derivatives (hereafter Guidelines), issued by the Energy and Petroleum Regulatory Authority on May 2024 [167], the developer will need to submit an Expression of Interest (EoI) to the Ministry of Energy and Petroleum (MoEP). The EoI is approved by the Green Hydrogen Program Coordination Committee (GH2-PCC) and the MEP will communicate the outcome of the application within 60 days of receiving the EoI.

The EoI specified in the Guidelines should be accompanied by a pre-feasibility study report, the minimum requirements of which are aligned with the present study. In addition to the contents of this report, the Developer should clarify the intended location of the project -this report provides several options-, and further secure its financing, partners, and off-takers.

Once the EoI result is communicated by the MEP, the developer shall progress to conduct a detailed feasibility study within 24 months.

7.3 Feasibility Study

The Feasibility Study constitutes a critical phase in the advancement of the project, building directly on the outcomes of the preceding pre-feasibility assessment. At this stage, the project developer undertakes a comprehensive evaluation of site-specific feedstock availability, engages with potential biomass and power suppliers, and consults with technology providers and prospective offtakers. This process is also designed to address the economic viability gap identified in Chapter 6 by facilitating the identification of suitable financing instruments, including opportunities from International Financial Institutions (IFIs), governmental subsidies, and the establishment of memoranda of understanding with offtakers. The Feasibility Study is structured around the achievement of several key milestones:

- Project consortium established
- Site of plant and target product finally determined
- Technical feasibility proven
- Economic viability proven
- FEED-Study budged secured

The Feasibility Study should be in line with the contents of Table 7–1 of the above-mentioned Guidelines.

To this end, the study encompasses a series of targeted tasks, including detailed feedstock and site assessments at shortlisted locations, consultations with engineering, procurement, and construction (EPC) partners, definition of the operating concept, and the assessment of target markets and sustainability frameworks.

The table below summarises the different tasks and results of the Feasibility Study.

Table 7–1: Specific tasks for the Feasibility Study

	Site/Feedstock	**Technology**	**Revenue/**	**Revenue Security**
Feasibility Study (based on report/pre-feasibility study)	Task: • Site specific feedstock evaluation • Consultation with potential biomass suppliers • Consultation with potential power suppliers • Final site assessment (Mombasa, Nairobi or Olkaria)	Task: • Consultation of potential technology provider/ Engineering, Procurement, and Construction (EPC) • Definition of potential operating concept	Task: • Product target market assessment • Consultation of potential off-taker • Screening of sustainability regulatory framework	Task: • Economic modelling (including results of Feedstock, Technology and Market)
	Result: • Quality, quantity and cost of potential feedstock • Biomass supply concept • Power supply concept • Water supply concept • Final selection of site	Result: • Technical consortium • Revised technology and operation concept in accordance with technology provider • Revised mass and energy balances	Result: • Definition of final product (Methanol and/or SAF) • Selection of target markets	Result: • Economic viability • Production cost • Investment volume • Revenue

With the approval of the EoI application, and in parallel to the Feasibility Study, the Guidelines request the conduct of the Environmental and Social Impact Assessment, which should be submitted to the National Environment Management Authority as per the Environmental (Impact Assessment And Audit) Regulations, 2003 – Regulations 18 and 23 and the Environmental Management and Co-ordination Act, 1999 Section 58 and the Second Schedule to the Act.A central consideration throughout the Feasibility Study is alignment with both national regulatory requirements

and international sustainability standards, particularly (CORSIA) as well as ASTM. This is, from today's perspective, essential for securing offtake agreements (which could also include off-takers from chemical industry, e.g., if methanol is (partly) the target product) and enhancing project bankability.

To achieve this, the project must obtain certification under a CORSIA-approved Sustainability Certification Scheme (SCS). Currently only the International Sustainability and Carbon Certification (ISCC), the Roundtable on Sustainable Biomaterials (RSB) and ClassNK are approved by the ICAO for this purpose [168]. Both schemes follow a similar process, by which the projects will apply and be audited by an independent certification body. Early engagement with the relevant certification body is recommended to ensure that all processes, from feedstock selection to audit preparation, are compliant with the applicable criteria. In later stages of the project development, it is recommended to contact the selected SCS to receive guidance and ensure preparation for the audit. In the process of selecting the most suitable SCS, different criteria, such as feedstock assessed (ISCC, for example, only accepts providing certifications for CORSIA processes using waste and residues and agricultural biomass), as well as availability of the certification bodies (ISCC's certification bodies are more widely present around the world), must be considered.

An example of the certification process under RSB would include the following steps:

Figure 7–1: RSB Certification Steps

For more information on the sustainability criteria for CORSIA, which was already highlighted in Chapter 4, please refer to ICAO's Corsia Sustainability Criteria for CORSIA Eligible Fuels [169].

7.4 FEED Study

Upon the decision to advance the PBtL project beyond the feasibility phase, the initiation of the Front-End Engineering Design Study marks a pivotal step towards investment readiness. The primary objective of the FEED Study is to consolidate and refine the technical, commercial, and regulatory decisions established during the feasibility stage, thereby enabling the project developer to finalize all key parameters necessary for the FID.

The FEED Study encompasses a comprehensive number of activities, including basic engineering for the plant, the validation of technical plant design, and the confirmation of feedstock supply concepts. At this stage, the project developer engages in detailed negotiations with technology suppliers, biomass residues and power providers, and product off takers, with the aim of securing binding agreements in principle. In parallel, a thorough risk assessment is conducted in accordance with the established risk management plan, and all technical standards and specifications required for project execution are defined.

Designs and suitability of the material for synthetic fuel production, storage, transport, metering, handling and dispensing equipment shall be approved by a professional or consulting engineer registered under the Engineers Act, 2011.

By the end of this stage, the project should have achieved the following milestones:

- Final, verified concepts for technical plant design and for feedstock supply
- Risk assessments are in compliance with the risk management plan
- Potential investors are identified, consulted and informed
- Viable feedstock, technology and off-take agreements are negotiated
- Local stakeholders and local communities are involved
- Compliance and authorization requirements are fulfilled

Table 7–2: Specific tasks for the FEED study

	Site/Feedstock	**Technology**	**Revenue/**	**Revenue Security**
Feasibility Study (based on report/pre-feasibility study)	• Task: • Feedstock and site-specific risk assessment • Negotiate with biomass suppliers • Negotiate with power suppliers • Permits, and Environmental/ Safety Assessment • Prepare for land acquisition • Ongoing stakeholder engagement	• Task: • Technical risk assessment • Request for proposals from technology suppliers • Basic engineering	• Task: • Market risk assessment • Negotiate with product off-takers	• Task: • Financial risk assessment • Preparation of CAPEX and OPEX estimates based on agreement with feedstock and technology suppliers • Identification of investors • Preparation of documentation for authorities and investors
	Result: • Identified feedstock and site-specific risks and mitigation measures • Agreement in principle for contracts with power and biomass suppliers	Result: • Identified technical risks and mitigation measures • Execution-ready basic design (for EPC) • Technical standards and specifications for project execution	Result: • Identified market risks and mitigation measures • Agreement in principle for contracts with product off-takers	Result: • Identified financial risks and mitigation measures • Detailed cost and schedule estimates • Techno-economic and financial decision-making basis for investors
Final Investment Decision (FID)				

In addition, the FEED Study initiates site-specific administrative processes, including land acquisition, permitting, and environmental and social impact assessments (ESIA), all of which must comply with national regulations and are of particular importance for de-risking the project from an international developer's perspective.

The following table defines a list of administrative processes that are applicable to the development of a PBtL plant in Kenya. It defines the process, its description, responsible entity that serves as counterpart for the process, approximate timeline for the process, and the relevant legislation:

Table 7–3: List of Administrative Procedure

Administrative Procedure	Entity Responsible	Legislation
Environmental and Social Impact Assessment License (ESIA)	National Environment Management Authority	Environmental Management and Coordination Act, 1999 (Environmental (Impact Assessment and Audit)
Certificate of Conformity to applicable standards At present, Kenya does not have a particular standard for SAF. The main applicable standards for green hydrogen however are: 1. KS ISO 14687:2019 – Hydrogen fuel – Product specification. 2. KS 2340-1:2011: Hydrogen – Specification Part 1: Industrial hydrogen. 3. KS 2340-2:2011: Hydrogen - Specification - Part 2: High purity hydrogen	Kenya Bureau of Standards	KEBS applicable product/process standard
Calibration Certificate This Certificate is required for measuring instruments, storage tanks and tanks that may be mounted on any trailer which may transport GH2 and synthetic fuels such as SAF.	Ministry of Investment, Trade and Industry, Department of Weights and Measures	The Standards Act (Cap 496)
Work place/Plant Compliance Certificates relating to: Businesses are required to provide for the safety, health and welfare of workers and all persons lawfully present at workplaces. Before any premises is occupied as a workplace or plant, a developer will be required to ensure the premises is registered with the Director of Occupational Safety and Health Services	Ministry of Labour and Social Protection (Directorate of Occupational Safety and Health Services	Occupational Safety and Health Act, 2007(OSHA)

Construction Permit All construction works, contracts or projects either in the public or private sector are required to be registered with the National Construction Authority. The application is to be made before the commencement of construction works.	National Construction Authority	National Construction Act, Cap 118
Water Permit Use of water from a water source requires a permit issued by the Water Resources Authority. The application for a permit is to be undertaken by the owner of the land on which the water use is to take place or with the consent of the land endorsed on the application – where the applicant does not own the land.	Water Resources Authority	The Water Act 2016
Application to the Carbon Registry Where a developer desires to have the SAF pilot recognized as a carbon project recognized in Kenya, the project is to be registered as such with the National Registrar of the National Carbon Registry	National Environment Management Authority (as the Designated National Authority)	The Climate Change (Carbon Markets) Regulations, 2024
Land acquisition consultation with National Land Commission The ministry responsible for land and/or the relevant county government to verify the legal status of the land.	National Land Commission	Land Act, 2012
Land Registration After the feasibility study is approved, processes relating to the acquisition land where the pilot plant is to be located can proceed. The land may be leased or purchased as may be deemed most appropriate with registration of the transfer of land to the developer or registration of the lease, as the case may be.	Ministry of Lands	Land Registration Act, 2012, section 37

Change of User Where there is a change in land use from other uses to industrial application, a Change of User is required	County Government where the project will be located (either Nairobi, Nakuru or Mombasa Counties which have been identified as potential project sites)	Physical Land Use and Planning Act, Cap 303, Section 55 and Third Schedule
Electricity Supply Agreement Where electricity is drawn directly from the national grid, an electricity supply agreement with the distribution company would suffice.	Distribution Company	The Energy (Electricity Licensing Regulations) 2012

In addition to the highlighted administrative processes, in order to undertake the SAF pilot project, a developer may wish to register an SPV as is typically done for development of projects. Registration of an SPV is recommended after approval of the Feasibility Study by the Ministry of Energy and Petroleum as pe the Guidelines. This way, any permits/licenses/approvals given by the relevant government entities are issued in the name of the SPV for consistency and uniformity in the name appearing on the authorizations issued by relevant authorities.

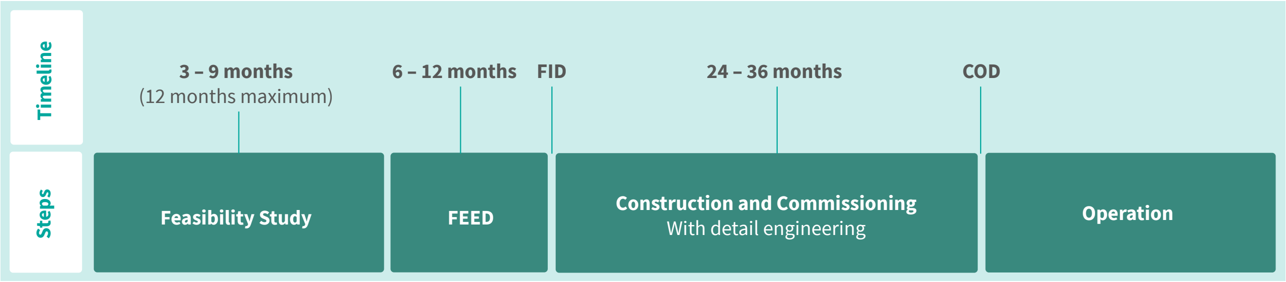
The process of registering an SPV entails registration of a limited company with the Business Registration Service. The process is undertaken through the e-Citizen platform (brs.ecitizen.go.ke). To register an SPV, the following documents are/information is required; proposed name of the SPV (3 options are to be provided); proposed directors, shareholders and their contact information (email addresses, phone contacts, digital photographs and copies of identification documents - or corporate registration documents where the shareholders are corporate entities); business objectives; registered office and tax registration details (for Kenyan citizens). The registration process can be completed within 7 days.

7.5 Conclusion

In conclusion, the next steps to undertake are those defined within the application process and requirements outlined in the Guidelines on Green Hydrogen and its Derivatives published by EPRA in 2024 [167]. The Feasibility Study establishes the foundational technical, commercial, and regulatory parameters necessary for the advancement of the PBtL project in Kenya. Through rigorous site-specific assessments, stakeholder consultations, and economic modelling, as proposed in the previous chapter, the study confirms the project's technical feasibility, economic viability, and alignment with both national and international sustainability frameworks, including CORSIA requirements. The concurring formation of a project consortium, the refinement of the operating concept, and the establishment of preliminary agreements with suppliers and off takers collectively position the project for further development. The systematic approach adopted during this phase ensures that the subsequent FEED Study can proceed on a robust analytical basis, with key risks identified and mitigation measures in place.

The completion of the FEED Study represents a critical transition from project definition to execution readiness. By consolidating technical plant design, finalizing feedstock and offtake agreements, and conducting comprehensive risk assessments, the FEED phase provides the detailed engineering and financial information required for informed investment decision-making. Furthermore, the initiation of permitting, land acquisition, and stakeholder engagement processes ensures compliance with national regulations and addresses key considerations for project bankability and risk mitigation. With all compliance and authorization requirements fulfilled, the outcomes of the FEED Study form the basis for a Final Investment Decision (FID), enabling the PBtL project to move towards the construction and commissioning phase. The date the commissioning tests are passed and the plant starts to generate the product, is called the commercial operations date (COD). From that day on, the plant is in operation.

Figure 7–2: Next Steps and Timeline of the Project



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8 Appendix

8.1 Geographic and Financial Data for Renewable Energy Potential Assessment

Figure 8–1: Long-term Annual PV Potential of Kenya, [20], [21]

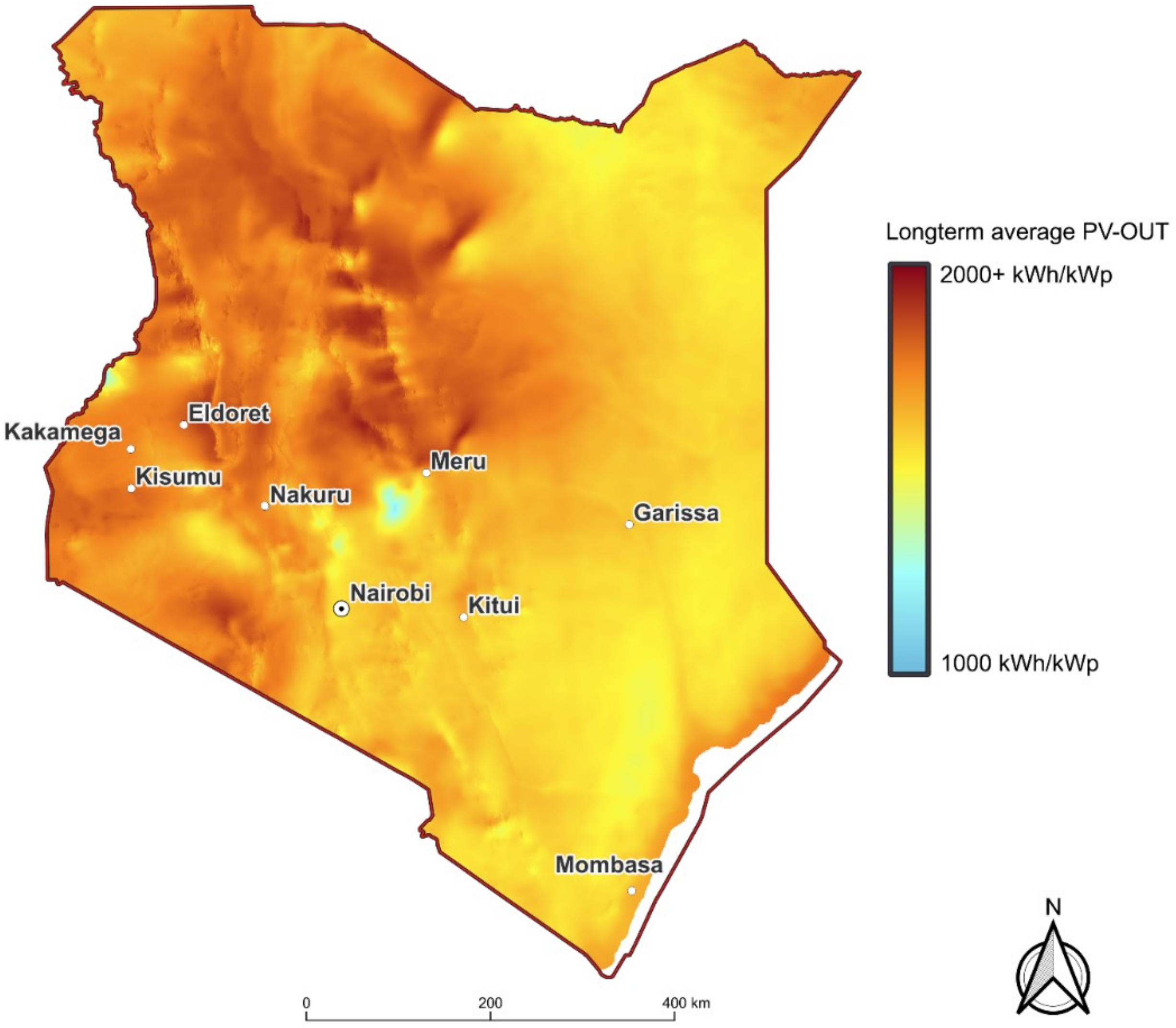


Figure 8–2: Mean Wind Power Density and Speed in Kenya, [20], [65]

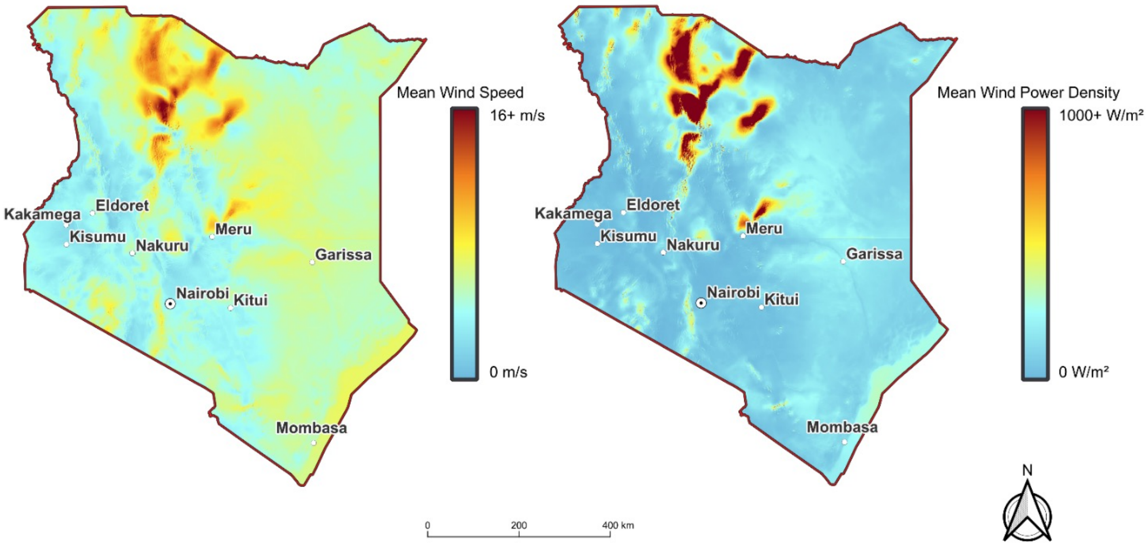


Figure 8–3: The Major Geographical Regions with High Potential for Hydro Power Utilization, [20]

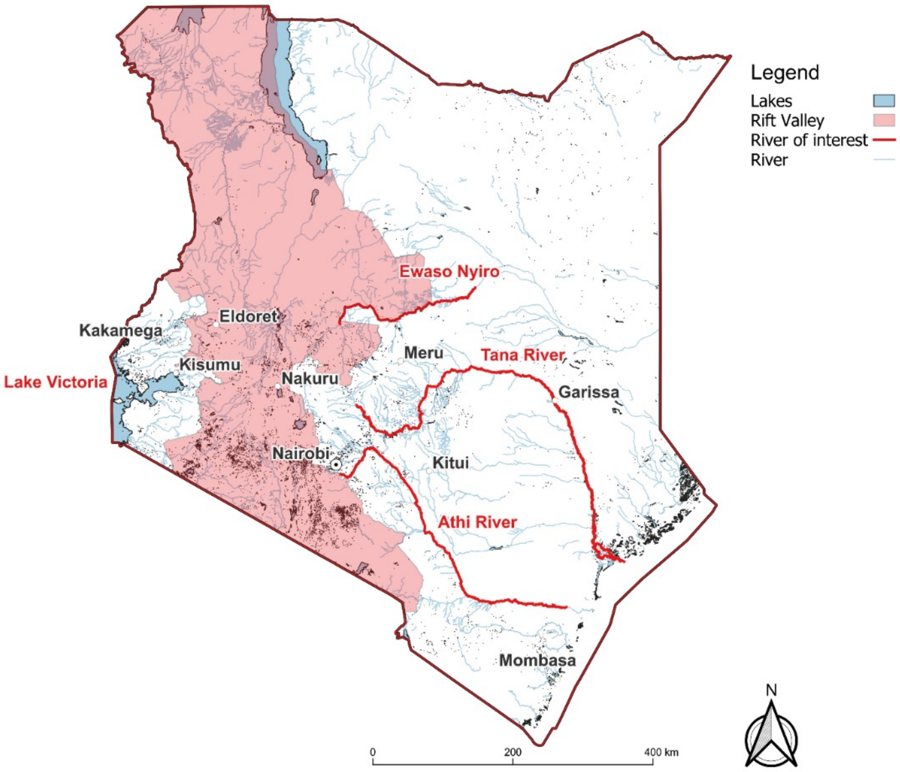


Figure 8–4: Geothermal Prospects and Existing Geothermal Power Plants in Kenya, [20], [30]

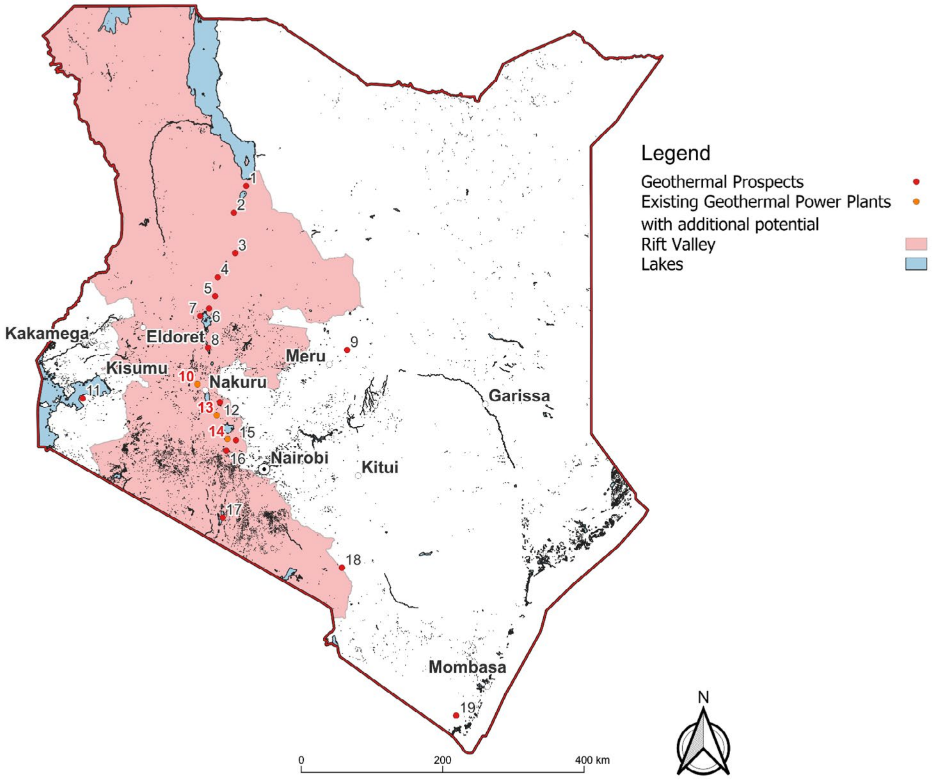


Figure 8–5: Land Cover Classification in Kenya, [20], [33]

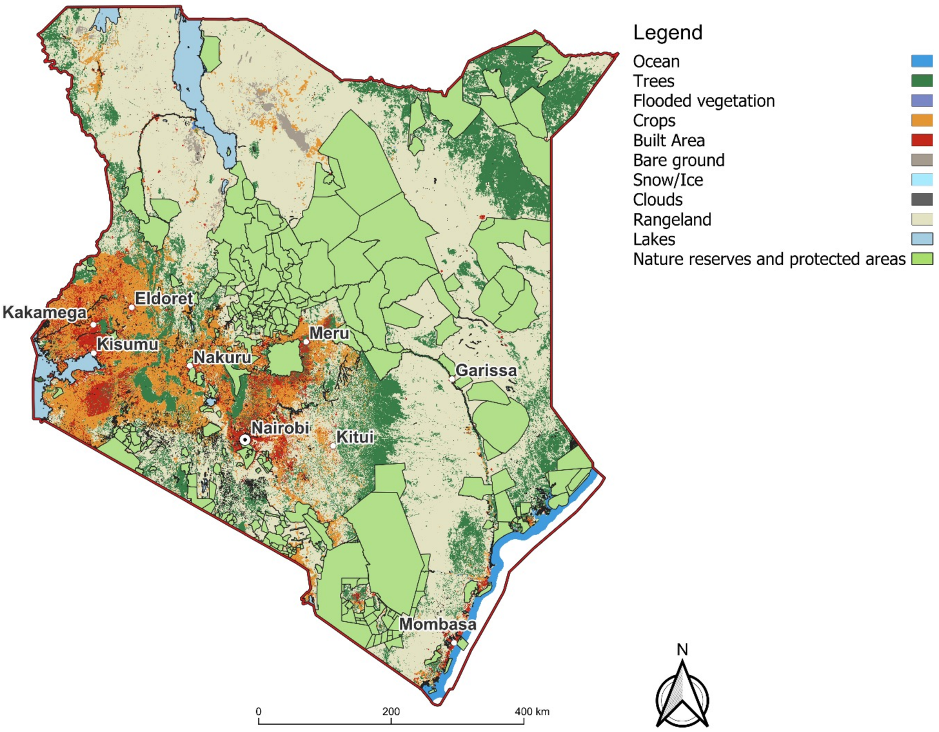


Figure 8–6: Average Slope Gradient of Kenya, [20], [36]

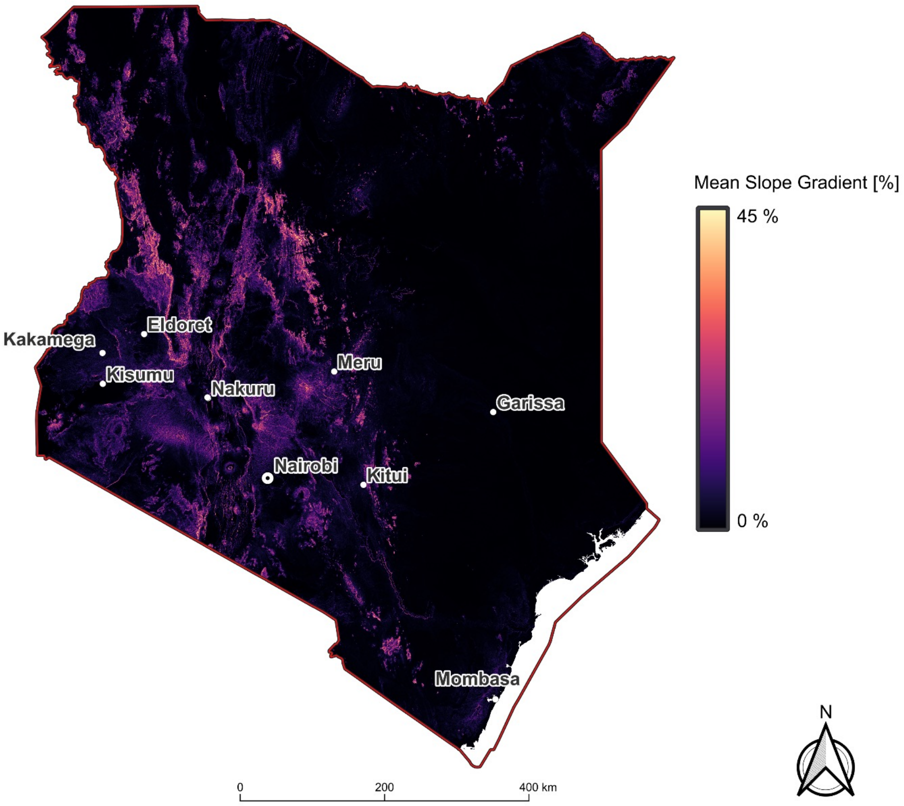


Figure 8–7: Aridity Index in Kenya, [20], [68]

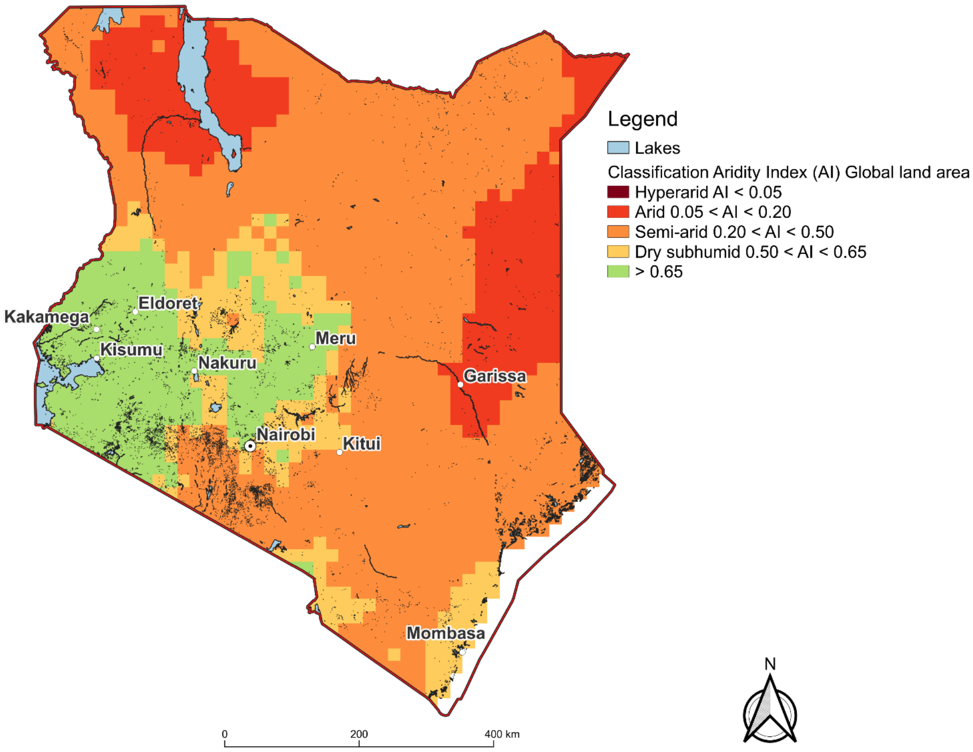


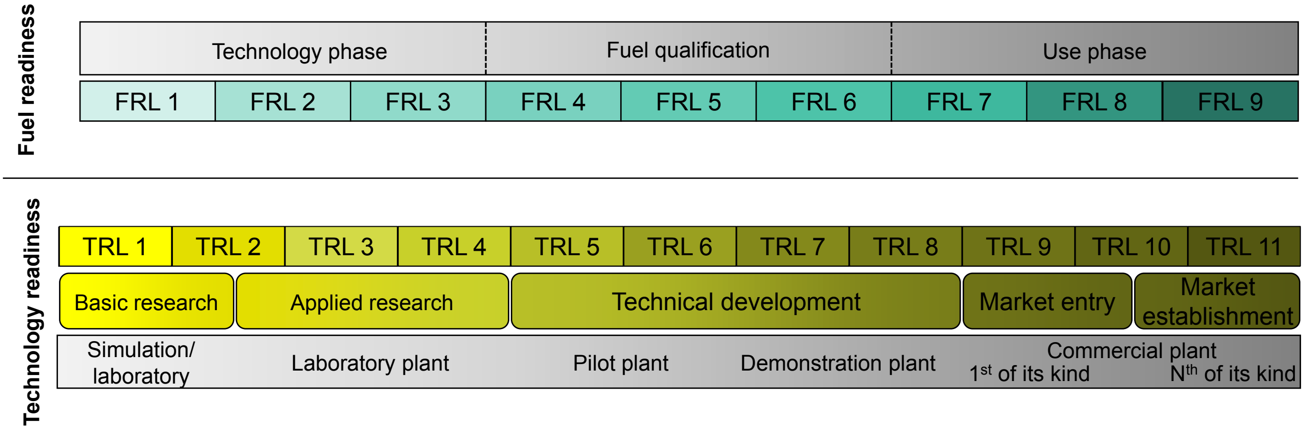
Table 8–1: Assumptions for the Financial Parameters Used for the LCOE Calculation, [66], [67], [68], [69]

Parameter	Assumption	Unit
Weighted Average Cost of Capital (WACC)*	10	%
Inflation (INFL)	4	%
EUR/USD exchange rate	1.17	-

*WACC) is assumed under the de-risking effect of offtake guarantees provided by European governments. All other assumptions are based on the mean values for Africa reported in the literature.

8.2 Technology and Fuel Readiness Level

Figure 8–8: Technology Readiness Level (TRL) and Fuel Readiness Level (FRL), based on [119]



8.3 Infrastructure, Land, and Water Availability for Renewable Energy and SAF Production

Figure 8–9: Renewable Energy Potential in Olkaria, Nairobi and Mombasa, (for the geothermal Prospect Numbers see the chapter for the Technology and Process Selection to produce SAF) [161], [162], [163]

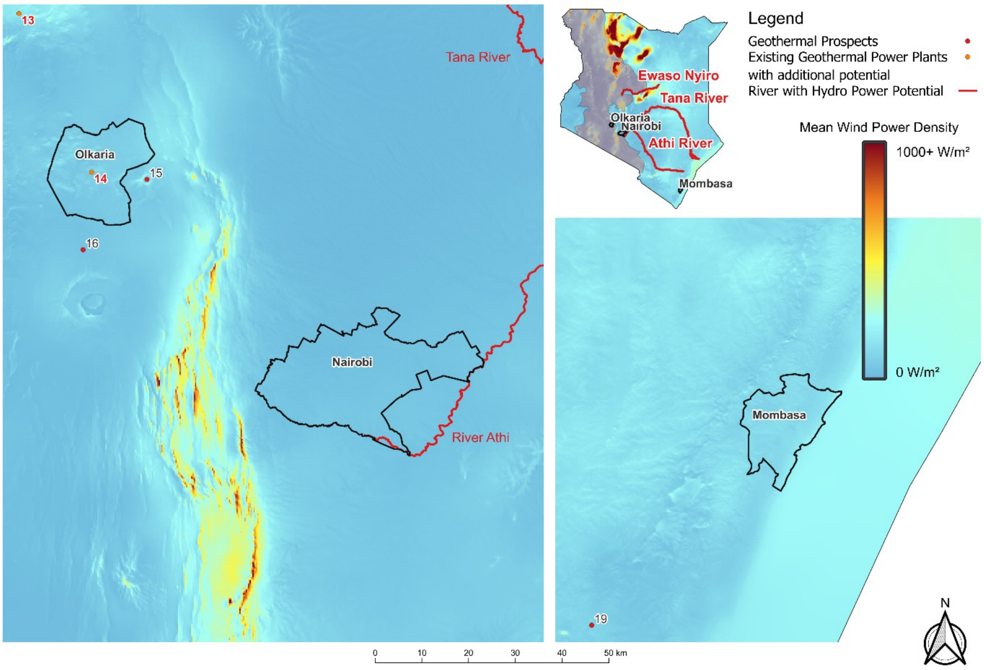


Figure 8–10: Land Availability for SAF Production and Renewable Energy, [161], [164], [165]

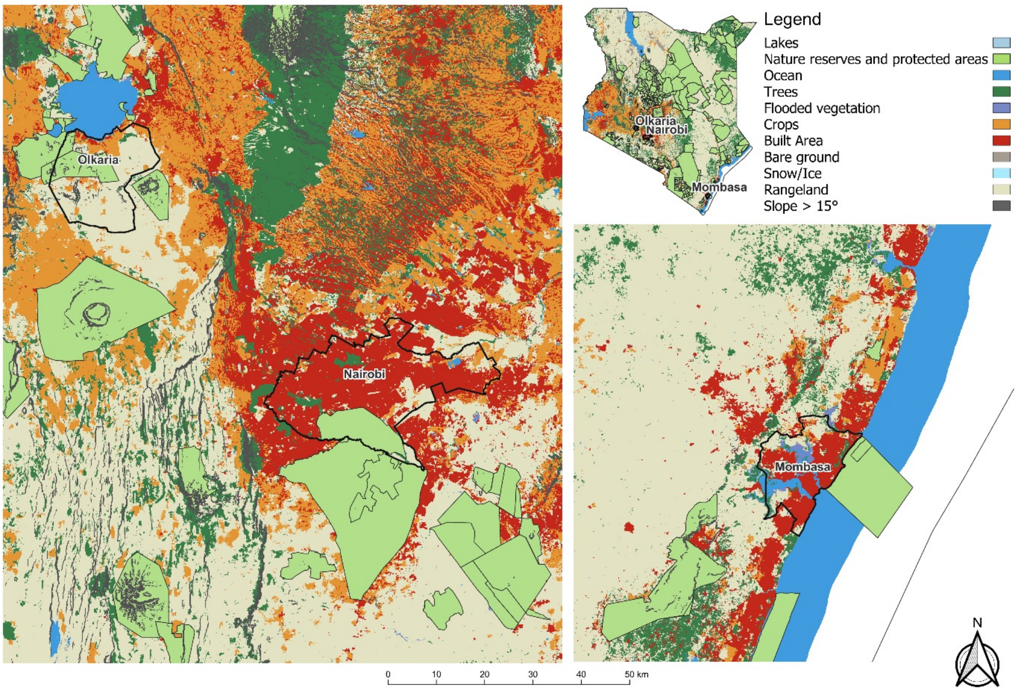


Figure 8–11: Water Availability at Areas of Interest, [161], [166]

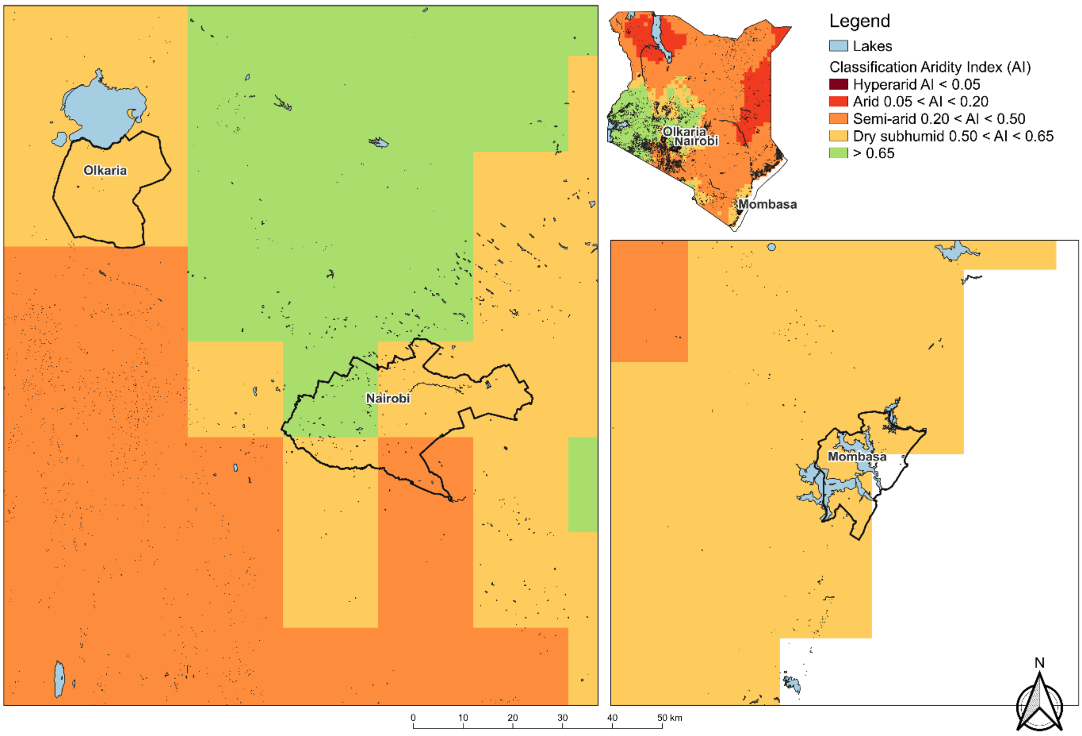
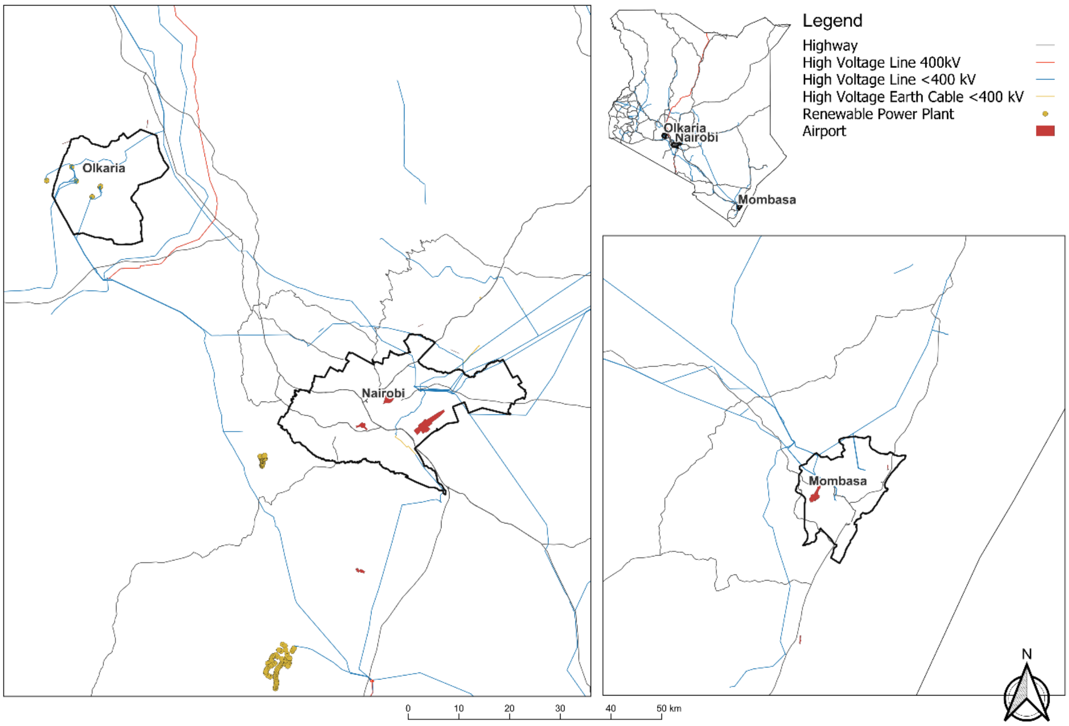


Figure 8–12: Infrastructure Limitations for the Areas of Interest, [161]



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