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ETHIOPIA

FEASIBILITY STUDY ON THE USE OF SUSTAINABLE AVIATION FUELS

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FOREWORD

In June 2022, on the 50-year anniversary of the Stockholm Convention, the International Civil Aviation Organization (ICAO) launched the Assistance, Capacity-building, and Training for Sustainable Aviation Fuels (ACT-SAF) programme to aid developing states in their transition to cleaner energy for aviation.

Later in 2022, the 41st ICAO Assembly adopted a long-term global aspirational goal (LTAG) for international civil aviation: collectively targeting net-zero carbon emissions by 2050, as a contribution to global climate action in line with the objectives of the UNFCCC Paris Agreement. The ICAO Assembly, through Resolution A41-21, emphasized the need for targeted support to developing states, including enhanced access to financial resources, technology transfer, and capacity-building initiatives.

With the adoption at the 3rd ICAO Conference on Aviation Alternative Fuels (CAAF/3) in November 2023 of the ICAO Global Framework for Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuels (LCAF) and other Aviation Cleaner Energies, ICAO and its Member States have agreed to strive to achieve a collective global aspirational Vision to reduce CO_2 emissions in international aviation by 5 per cent by 2030 through the use of SAF, LCAF and other aviation cleaner energies (compared to zero cleaner energy use).

The Vision has four building blocks, the third of which is implementation support. It expresses the importance of support for developing countries and states with particular needs, to be addressed through the ACT-SAF programme. This should be a robust and substantial capacity-building and implementation support programme designed to assist states, to foster partnerships and collaboration on SAF initiatives under ICAO's coordination and to serve as a global platform for knowledge exchange. In Resolution A42-21 the 42nd ICAO Assembly resolves to achieve this Vision and requests the ICAO Council to continue to implement the ACT-SAF Programme to support the global scale-up in development and deployment of SAF, LCAF and other aviation cleaner energies.

Since 2013, the European Union has funded successive capacity building efforts through the two phases of the ICAO Assistance Project. In total, 24 ICAO Member States in Africa and the Caribbean were assisted, including the development of seven feasibility studies on the use of SAF by 2023. In the margins of the 41st ICAO Assembly, the EU and ICAO signed a Declaration of Intent to fund a new EUR 1.6 million initiative to continue cooperation to address climate change and to reduce the environmental impact of international aviation through the promotion of SAF within the ICAO ACT-SAF Programme. The action is aimed at delivering SAF feasibility studies in ten selected ICAO Member States, in addition to assistance provided by the EU directly through EASA.

Ethiopia is one of the ten selected ICAO Member States. This feasibility study assesses the potential for producing and utilizing sustainable drop-in Sustainable Aviation Fuel (SAF) in Ethiopia, ensuring alignment with the environmental and socio-economic sustainability criteria in ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). It follows the guidelines set out in the ICAO *Template for Feasibility Studies on Sustainable Aviation Fuels* and *Guide for Feasibility Studies on Sustainable Aviation Fuels* (Version 1, July 2023).[1]

[1] https://www.icao.int/act-saf

ACKNOWLEDGEMENTS

This feasibility study would not have been possible without the invaluable engagement and leadership of Ethiopia Civil Aviation Authority.

We acknowledge the instrumental role of the many national stakeholders who have contributed to the development of this work by providing valuable information and guidance to identify SAF potential in the country. The authors express their gratitude to all stakeholders and the technical Committee which was established by the Ethiopian Civil Aviation Authority (ECAA) and particularly to the following ones with whom information exchange meetings were held: Environment Protection Authority (EPA), Ethiopian Institute of Agricultural Research (EIAR), Ministry of Agriculture (MoA), Ethiopian Petroleum Supply Enterprise (EPSE), Ethiopian Airlines, Ethiopian Sugar Industry Group, Ethiopian Mineral and Biofuel Corporation, Zoscales Partners, and 54 Capital amongst others. Their expertise has significantly enriched the analysis and recommendations presented in this document.

SCOPE AND METHODOLOGY

This feasibility study assesses the potential for producing and utilizing drop-in Sustainable Aviation Fuel (SAF) in Ethiopia, ensuring alignment with ICAO CORSIA environmental and socio-economic sustainability criteria. It follows the guidelines set by the ICAO *Template for Feasibility Studies on Sustainable Aviation Fuels* and *Guide for Feasibility Studies on Sustainable Aviation Fuels*. The study begins with an overview of Ethiopia's specific context, highlighting factors that may influence SAF development and deployment. Based on this, it identifies potential SAF production pathways, evaluates the required implementation support and financing, and concludes with a proposal of action plan to be considered by the State, aligned with national policies to advance these pathways.

The feedstock analysis undertaken in the present feasibility study is intended to complement, and not replicate, significant work that has already been undertaken regarding the feasibility of SAF feedstocks and SAF production in Ethiopia, notably WWF South Africa and IIASA (2019), RSB (2021) and RSB (2022). Together, these studies have covered key areas of interest, including agricultural land availability; preliminary evaluations of the potential of key feedstocks and technologies to realize SAF production in Ethiopia; the availability of industrial and logistic infrastructure; and they provide a broad understanding of the policy and regulatory contexts of relevance to renewable and low carbon fuels for the aviation sector. A preliminary assessment carried on at the initiation of this study, identified the opportunity to undertake a "deep dive" with further collection and analysis of data to provide a higher resolution understanding of the availability and quality of key feedstocks for SAF production.

The findings of the pre-feasibility study were discussed during a kick-off workshop that included the national SAF technical committee and various stakeholders. During this workshop, participants reviewed previous studies, including the current national SAF roadmap. The objective was to decide whether to conduct a further assessment of feedstock or to proceed directly to a business implementation study. The stakeholders recommended conducting a more detailed assessment of selected feedstocks before initiating the business implementation study and reached a consensus on which feedstocks the study should focus on. As a result, the scope of the study was defined based on the guidance provided by the state.

EXECUTIVE SUMMARY

BACKGROUND

As part of its mandate to facilitate the civil aviation sector's access to renewable energy across member states, ICAO is supporting the completion of studies to assess the feasibility to adopt sustainable aviation fuel (SAF), as defined under CORSIA. These feasibility studies aim to assess the capacity to produce SAF, considering feedstock requirements, technology, and infrastructure, along with the corresponding fuel demand.

Ethiopia's aviation sector is an important driver of economic activity in Africa, anchored by Ethiopian Airlines – the continent's largest carrier by passenger and freight volumes. The government's long-term strategies, including the Climate Resilient Green Economy (CRGE) framework, the Long-Term Low Emission and Climate Resilient Development Strategy (LT-LEDS), and the forthcoming revised Biofuel Strategy, set ambitious decarbonisation goals for transport and energy, including specific SAF blending targets (5% by 2030, 10% by 2035).

Ethiopia has significant agricultural, waste, and renewable energy resources that could support SAF production. This report builds on the insights provided by prior studies investigating the feasibility of feedstocks for SAF production. Based on findings of a pre-feasibility review of prior studies, and with agreement of Ethiopia SAF stakeholders, here we undertake a "deep-dive" with further collection and analysis of data for key feedstocks – Brassica carinata, sugarcane molasses, municipal solid waste (MSW) castor seed, and electricity-based fuels – assessing their availability, sustainability, and economic potential. Key factors are considered, including current and projected future availability of feedstock, competition with other uses, technology readiness, environmental and social sustainability effects, and potential for financial viability. The study also evaluates implementation support, financing needs, and policy alignment. A forward-looking Action Plan summarizes recommended updates to Ethiopia's SAF Roadmap, including suggestions for near- and medium-term actions to support future SAF implementation.

KEY FINDINGS

The availability of diverse feedstocks presents both opportunities and challenges for SAF production in Ethiopia:

- Brassica carinata offers promising potential as a non-food oilseed feedstock for HEFA SAF production, with possible large-scale cultivation in rotation with existing crops. However, achieving competitive yields requires improved seed varieties, agronomic expertise, and planning for supply chain to aggregate large quantities of feedstock.
- Sugarcane molasses is a viable ATJ feedstock but is in high demand for other uses (beverages, ethanol, animal feed). Planned expansion of domestic sugar production would increase molasses supply, with potential to support modest production of ethanol as a SAF feedstock.
- Municipal solid waste could supply a portion of SAF feedstock needs while reducing methane emissions from current waste management. However, data gaps, limited waste separation, and competing waste-to-energy applications must be addressed.
- Electricity-based fuels (power-to-liquids) could leverage Ethiopia's renewable energy potential, but near-term deployment is constrained by current generation capacity, the need to prioritize household and industrial energy access, and the high relative cost of e-SAF relative to conventional kerosene and HEFA fuels.

- Castor seed has niche potential in specific regions, though commercial viability depends on overcoming agronomic and processing constraints.

Achieving viable SAF production in Ethiopia will require coordinated action across feedstock development, technology deployment, infrastructure, policy, and financing. Critical success factors are summarized in Table ES.1.

Table ES.1. Critical Success Factors for Achieving SAF Production in Ethiopia.

Factor	Requirements
Create implementation plan to facilitate SAF production in the country	Implementation plan will translate existing strategies (SAF Roadmap, 2021; Biofuel Strategy, 2025) into action, through collaboration by policymakers, investors, and innovators
Create scalable and sustainable supply chains	Expand crop trials for key feedstocks, including on less productive and marginal lands to improve evidence base. Agricultural sector modelling is needed to assess scalability of feedstock production within sustainable agricultural systems.
Innovate crop varieties, management practices, and processing to maximize value	Improve economic viability of oilseed crops for SAF through improved crop management and valorisation of byproducts including seed cake.
Create market conditions to encourage SAF production and uptake	Review policy and regulatory options to encourage investment in SAF value chain, with clarity on their effectiveness and potential to deliver socio-economic net benefits.
Use Green Hydrogen Strategy to underpin longer-term opportunities for e-SAF	Leverage near- and medium-term opportunities provided by Hydrogen Strategy, such as for green ammonia production, as a means of developing in-country expertise and infrastructure to support future hydrogen applications including e-SAF.
Ethiopian Airlines as a SAF off-taker	The planned expansion of Ethiopian Airlines fleet and destinations will entail rising jet fuel demand, making it a natural off-taker for domestic SAF production.

POLICY IMPLICATIONS

SAF development in Ethiopia will be shaped by the interaction of policies across multiple sectors, including agriculture, waste management, energy, transport, and trade. Current strategies already set an enabling context, while the forthcoming Biofuel Strategy proposes blending targets specific to SAF. Together, these initiatives provide a strong policy foundation for SAF, but their successful implementation will depend on how they address resource competition, infrastructure readiness, and market conditions.

Feedstock availability and competing uses will be a key factor in determining the role SAF can play in future. Non-food oilseeds (Brassica carinata, castor), sugarcane molasses, municipal solid waste, and renewable electricity have been identified as potential contributors, but these all have current or potential competing uses in other sectors. How competing demands are managed will influence both the scale and sustainability of SAF production. Ensuring that SAF deployment complements, rather than competes with, existing objectives for food security, waste management, and energy access will be essential to success.

SAF production currently entails higher costs than conventional jet fuel, meaning that market demand is unlikely to emerge without supportive policy measures. The potential costs of incentives and mandates must be assessed, ensuring alignment with climate change and green growth goals and balancing with the wider potential socio-economic benefits of developing a domestic SAF industry.

OPPORTUNITIES AND CHALLENGES

Key opportunities and challenges related to SAF production are summarized in Table ES.2.

Table ES.2. Summary of opportunities and challenges facing SAF production in Ethiopia.

Strengths	• Strong government commitment to low-carbon development, including specific support for SAF in the revised Biofuel Strategy • Significant potential for agricultural feedstocks, including rotational and intercropping of non-edible oilseed crops • Established ethanol production capacity, with potential growth in production aligned to planned expansion of domestic sugar sector • Abundant renewable energy resources with potential for low-cost renewable electricity generation • Ethiopia's strategic position as a major African aviation hub with growing fuel demand
Weaknesses	• Lack of refining, blending and certification capacity within the country • Limited technical/agronomic data on key feedstocks and scalability • High production costs for some feedstocks relative to global benchmarks • Fragmented and underdeveloped supply chains and processing infrastructure • Skills and institutional capacity gaps across agriculture, refining, and certification
Opportunities	• Alignment with existing initiatives to expand domestic sugar sector and thereby increase molasses availability for ethanol production • Waste-to-SAF aligns with urban waste management and climate goals • Green hydrogen and ammonia initiatives can build expertise and infrastructure for future e-SAF production • Potential to position as an early-mover SAF hub in Africa • International finance could be tapped for SAF value chain development
Threats	• Competition for feedstocks with food, feed, energy and export markets • Global SAF cost competitiveness – Ethiopian SAF may struggle against cheaper imports • Risk of unsustainable land use change if crop feedstocks expand without safeguards • Technological uncertainty for less mature pathways (MSW gasification, e-SAF)

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ABBREVIATIONS

AACMA	Addis Ababa Cleansing Management Agency
ACT-SAF	Assistance, Capacity-building and Training for Sustainable Aviation Fuels
AfCFTA	African Continental Free Trade Area
AfDB	African Development Bank
AFRAA	African Airlines Association
ATJ	Alcohol-to-Jet
CAAF	Conference on Aviation Alternative Fuels
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CRGE	Climate Resilient Green Economy
DBE	Development Bank of Ethiopia
EC	European Commission
ECAA	Ethiopian Civil Aviation Authority
ECRC	Environment and Climate Research Center
EDRI	Ethiopia Development Research Institute
EEP	Ethiopian Electric Power
EIAR	Ethiopia Institute for Agriculture Research
EIB	European Investment Bank
EIC	Ethiopian Investment Commission
EIH	Ethiopian Investment Holdings
EPA	Environmental Protection Authority
EPSE	Ethiopia Petroleum Supply Enterprise
ETB	Ethiopian Birr
FDI	Foreign Direct Investment
FDRE	Federal Democratic Republic of Ethiopia
FT	Fischer-Tropsch
GCF	Green Climate Fund
GDP	Gross Domestic Product
GHG	Green House Gas
GTP	Growth and Transformation Plan
HEFA	Hydroprocessed esters and fatty acids
HTL	Hydrothermal liquefaction

HVO	Hydrotreated vegetable oil
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICT	Information and Communication Technology
IIASA	International Institute for Applied Systems Analysis
KPI	Key Performance Indicator
LT-LEDS	Long Term Low Emissions Development Strategy
MoA	Ministry of Agriculture
MoF	Ministry of Finance
MoPD	Ministry of Planning and Development
MoTL	Ministry of Transport and Logistics
MoWE	Ministry of Water and Energy
MSP	Minimum fuel Selling Price
MSW	Municipal Solid Waste
NDC	National Determined Contribution
N-SEDS	National Sustainable Energy Development Strategy
NZE	Net Zero Emissions
RED	Renewable Energy Directive
RPK	Revenue Passenger Kilometres
SAF	Sustainable Aviation Fuel
SNNP	Southern Nations, Nationalities, and Peoples' Region
STI	Science, Technology, and Innovation
SWOT	Strengths, Weaknesses, Opportunities, Threads
TCI	Total Capital Investment
TRL	Technology Readiness Level
UCO	Used Cooking Oil
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar

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SECTION 1. STATE-SPECIFIC INFORMATION

1.1 GEOGRAPHY & CLIMATE

Ethiopia is a landlocked country in northeast Africa, bordered to the north by Eritrea, to the east by Djibouti and Somalia, to the south by Kenya, and to the west by Sudan and South Sudan. Climatically, Ethiopia has three distinct regions: alpine vegetated cool zones; temperate Woina zones where much of the population resides; and hot Qola zone (World Bank, 2021). Mean annual temperatures range from 15-20 °C are present in the temperate zones, with higher temperatures of 25-30°C in the Qola zone (Alhamshry et al., 2019). Rainfall amounts are highly variable across the country, exceeding 2,000 mm/year in the Abay and Baro-Akobo regions, but far lower in arid regions in the country's east and northeast (Berhanu et al., 2014). Overall Ethiopia covers a land area of 1,104,300 km^2, of which approximately 36% is utilized for agriculture including arable land for crops and managed pastureland, and 12% is forest cover. The most recent land use map available for Ethiopia is from 2013 (see Figure 1) (Bekele et al., 2019), however, it does not account for more recent land use changes. Importantly, Ethiopia's Green Legacy Initiative, which aims to address land degradation and restore ecological function in degraded landscapes, has successfully led to the planting of over 35 billion seedlings between 2019 and 2024 (Green Legacy Initiative, 2025). Further discussion of land use in the agricultural sector in Ethiopia can be found in 1.5.

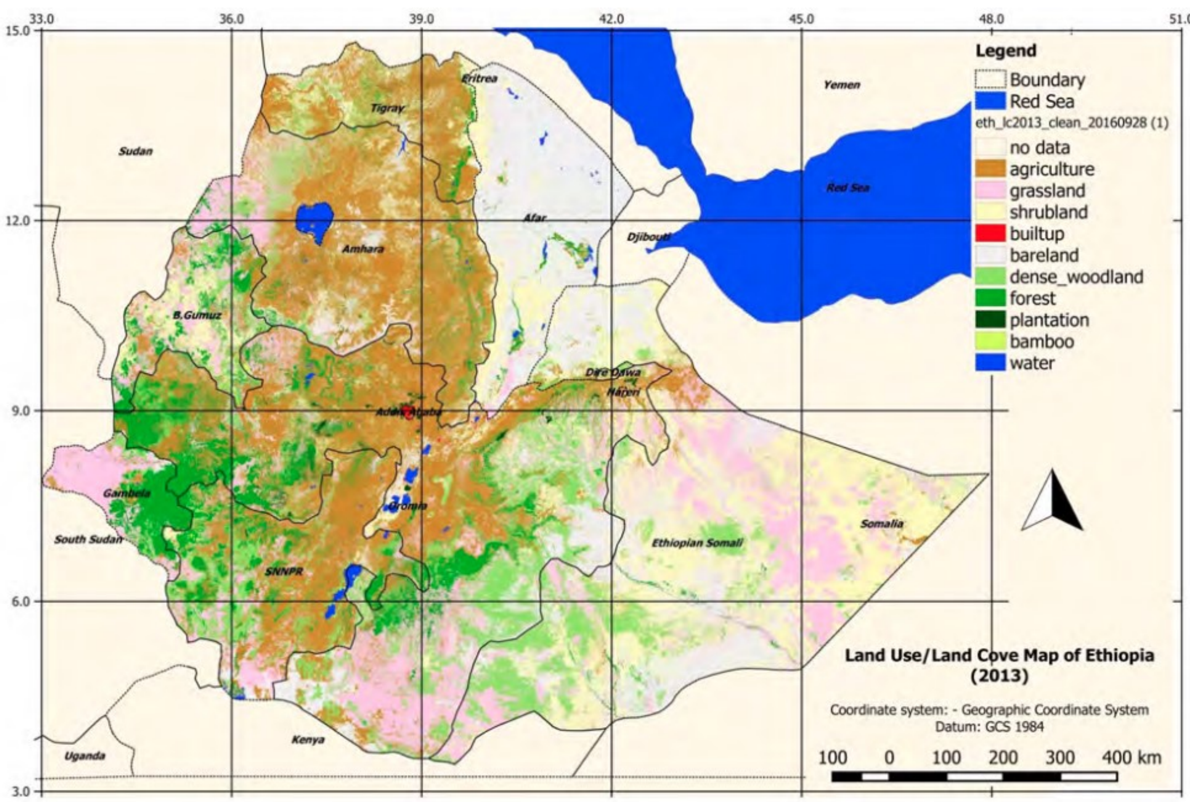


Figure 1. Land use types and land cover in Ethiopia. From Bekele et al. (2019).

1.2 TRADE AND GOVERNANCE

The Federal Republic of Ethiopia operates under a federal government structure, consisting of nine autonomous regional governments and two city administrations. The highest executive authority lies with the Prime Minister and the Council of Ministers.

In terms of trade, Ethiopia's primary exports include agricultural goods such as coffee, tea, sesame, oil seeds, as well as minerals like gold. The country is currently undergoing reforms, particularly in its trade policies and framework. The home-grown economic reform policy is seen as a potential game changer, aimed at reducing trade barriers. Additionally, Ethiopia is in the process of joining the World Trade Organization (WTO), a move that is expected to open new markets. Negotiations are ongoing, with the government anticipating accession to the WTO in March 2026. The African Continental Free Trade Area (AfCFTA) is also a regional agreement that is expected to strengthen trade within the continent.

In July 2024, Ethiopia devalued its currency as part of a significant policy shift from a government-controlled to a market-based foreign exchange system, which is part of a broader macroeconomic policy reform initiated by the new government.

1.2.1 Stakeholder roles on SAF development and deployment

SAF development is inherently cross-sectoral, spanning agriculture, energy, transport, waste management, climate change mitigation, finance, and international trade. Success in Ethiopia will therefore depend on broad participation and collaboration across government ministries, state-owned enterprises, research institutions, private investors, and development partners (see Table 1). Engaging this wide spectrum of stakeholders is essential to mobilize feedstock supply chains and ensure that SAF pathways are aligned with national priorities for food security, renewable energy access, economic growth, and climate resilience.

Ethiopia has established in late 2019 a steering committee co-chaired by the Ministry of Transport and Logistics (MoTL) and the Ministry of Water and Energy (MoWE). This committee is responsible for overseeing the development and deployment of Sustainable Aviation Fuel (SAF) within the country. Its primary goal is to provide direction for policy instruments and recommendations to the government regarding SAF initiatives. The committee includes representatives from the Environment Protection Authority, the Ministry of Agriculture, the Ministry of Foreign Affairs, the Ministry of Finance, and the Ministry of Water and Energy. Additionally, it is supported by a Technical Committee led by the Ethiopian Civil Aviation Authority (ECAA) and consisting of representatives from various research institutes, Ethiopian Airlines, and academic institutions.

The main role of the Technical Committee is to provide technical support for the development and deployment of Sustainable Aviation Fuel (SAF) in Ethiopia. Its objectives include offering evidence-based knowledge, serving as a resource for the steering committee, and providing insights to assist in decision-making regarding SAF development in the country. The Technical Committee has held its initial meetings and developed a Terms of Reference aimed at creating an implementation plan. Additionally, the committee will devise mechanisms to conduct detailed studies on feedstock assessments and lead the revision of the existing SAF roadmap (ECAA Draft ToR, 2024).

Table 1. Summary of key stakeholder groups and actors.

Government ministries and agencies	• Ministry of Transport and Logistics (MoTL) • Ministry of Water and Energy (MoWE) • Ministry of Agriculture (MoA) • Ministry of Finance (MoF)

	• Ministry of Foreign Affairs (MoFA) • Environmental Protection Authority (EPA) • Ethiopian Civil Aviation Authority (ECAA) • Ethiopian Petroleum Supply Enterprise (EPSE) • Ethiopian Investment Holding (EIH) • Development Bank of Ethiopia (DBE)
State-owned enterprises and sectoral groups	• Ethiopian Airlines • Ethiopian Sugar Industry Group • Ethiopian Mineral and Biofuel Corporation
Academic and research institutions	• Ethiopian Institute of Agricultural research (EIAR) • Addis Ababa University, Jimma University, Ethiopian Aviation University • Other agricultural and technical universities engaged in feedstock research and development
Private sector/investors	• Agribusinesses • Oilseed processors • Logistics companies • Fuel suppliers

1.2.2 The Ethiopian SAF roadmap

The Ethiopian SAF roadmap was developed by Roundtable for Sustainable Biomaterials (RSB) and published in October 2018, financed by a grant from the Boeing Company. It is split into the following three phases (as illustrated in Figure 2):

1. Establish an enabling policy and regulatory environment (2021–2023).
2. Demonstrate the potential and ensure an open economy (2024–2028).
3. Forward-looking plan (2029–2030).

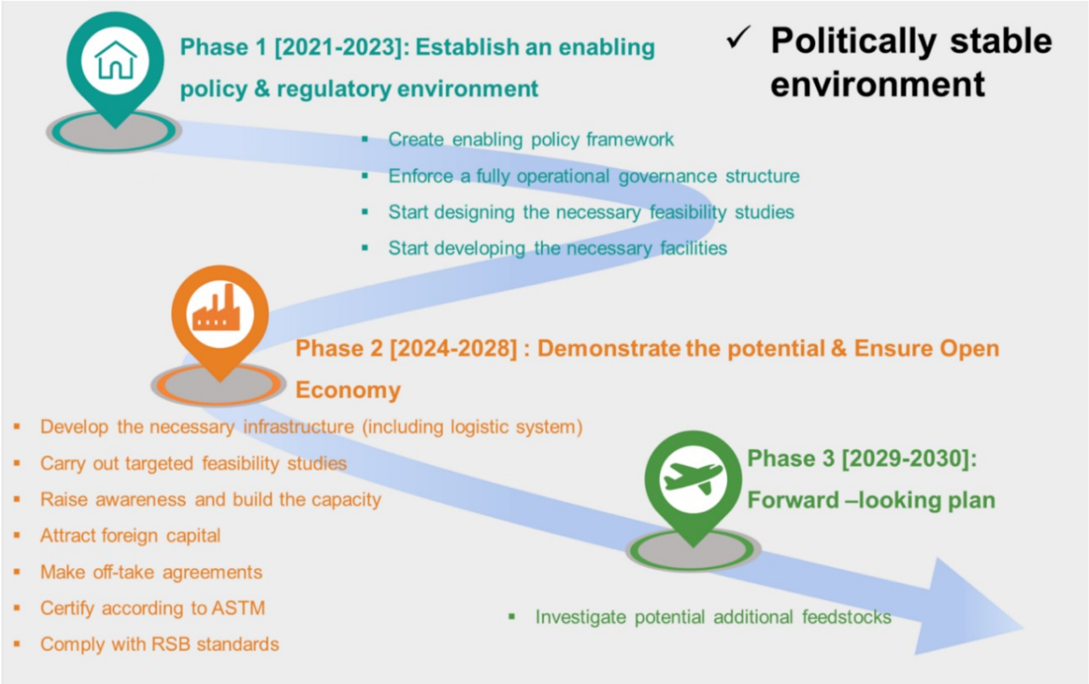


Figure 2. Ethiopia SAF Roadmap Overview. From RSB (2021).

1.3 DEMOGRAPHICS

Ethiopia has a population of 128.7 million, growing at an annual rate of 2.6% (World Bank, 2025a). The population is largely rural, comprising 76.8% of total population (FAOSTAT, 2025a), and is expected to remain a largely rural country (over 50%) by 2050 (OECD, 2020). The median age is 19.1 years (United Nations, 2025), in line with the African median of 18.6 but younger than the global median of 30 years.

The aviation sector plays an important role in Ethiopia's economy and employment. Approximately 19,800 people are directly employed in aviation, generating USD 89.6 million of economic output (IATA, 2025). Across the wider supply chain, employee spending and tourism, activities arising from the aviation sector contribute 527,400 jobs and USD 2.0 billion in economic activity (IATA, 2025). The aviation sector is an important mode of transport, supporting domestic and import/export supply chains, and enabling 1.4 million international and 3.1 million domestic passenger departures per year (IATA, 2025).

The social impact of future SAF feedstock production in Ethiopia could be significant in terms of providing overall socio-economic benefits. These benefits include job creation, rural development, increased income for smallholder farmers, and improvements in infrastructure. Given that agriculture is the major economic sector in Ethiopia, the production of biobased feedstock is likely to enhance the livelihoods of rural and agricultural households. It also enables smallholder farmers to diversify their crops, creating new opportunities for income. Furthermore, certain energy crops are being cultivated on marginal lands, which helps rehabilitate degraded land for productive use.

1.4 VULNERABILITY TO CLIMATE CHANGE

The agricultural sector is the main source of greenhouse gas (GHG) emissions in Ethiopia, producing approximately 80% of domestic emissions (FAO, 2024). At the same time, Ethiopian agriculture is particularly vulnerable due to its relatively low adaptive capacity to deal with droughts and floods, rainfall variability, and pest invasions (FAO, 2024). The Ethiopia National Adaptation Plan (FDRE, 2019a) outlines strategies for adaptation in agriculture and other vulnerable sectors. The NAP state ambitions to improve resilience and enhance food security through agricultural productivity, including the use of resistant and tolerant crop varieties, increasing use of organic fertilizers, appropriate mechanization, monitoring for pests and diseases, increasing water availability, and using appropriate technologies for improved soil and water conservation.

Additional objectives of the NAP include enhancing renewable power generation, introducing sustainable transport systems, creating adaptive industrial systems with efficient logistics and formal finance institutions across the value chain. Developing efficient value chain and marketing systems with improved resilience for agricultural and forestry products are also part of its scope.

Climate vulnerabilities are also present in Ethiopia's energy sector, in particular due to strong reliance on rainfall-fed hydroelectric electricity generation (see 1.6). While changes in rainfall risk negatively impacting the capacity factor of hydroelectric facilities on average across Africa, model outputs suggest that Ethiopia's hydroelectricity output potential could moderately increase under a warming climate (IEA, 2020).

1.4.1 Ethiopia's Long-Term Low Emission and Climate Resilient Development Strategy (2020-2050)

In 2021, the Ethiopian Ministry of Planning and Development developed a strategy to create a low-emission and climate-resilient economy – Long Term Low Emission and Climate Resilient Development Strategy (LT-LEDS) (FDRE, 2021a). This new strategy builds upon the Ethiopian Climate Resilient Green Economy (CRGE) Strategy developed in 2011. The current strategy sets sector-specific targets for emission reductions and aims to align with the goals of the COP21 Paris Agreement, ultimately striving for a net-zero ambition by 2050.

The strategy supports Ethiopia's NDC target of a 68.8% emissions reduction by 2030, as set out in the NDC implementation plan, and helps align it with the long-term goals of the Paris Agreement (FDRE, 2021b).

In its sectoral emission targets scenarios, the strategy places greater emphasis on renewable energy (hydropower, solar and wind) development and the electrification of end-use sectors, such as transport, residential, commercial and industry, to reduce emissions. The significant role of hydropower in the energy mix (currently contributing approximately 90%) is highlighted. The strategy outlines that the total installed capacity is expected to approach 120 GW by 2050 (see Figure 3).

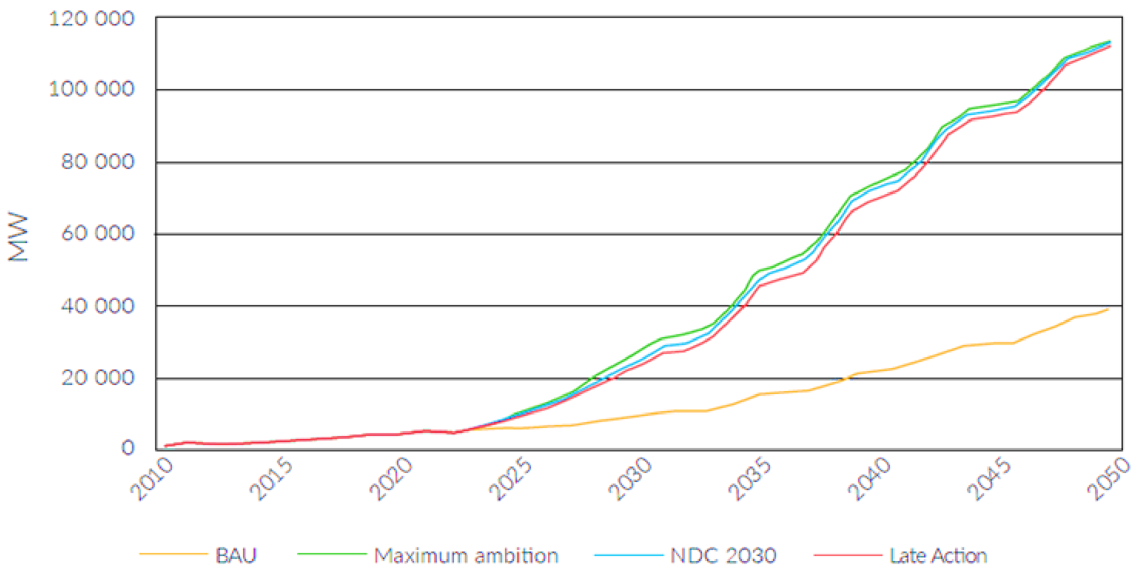


Figure 3. Projected power generation under the Long-Term Low Emission and Climate Resilient Development Strategy. From FDRE (2021a).

For the road transport sector, the strategy indicates a shift from fossil-based fuels to hybrid and electric mobility to ensure significant emission reductions. According to the strategy, under the business-as-usual scenario (BAU), total emissions from the transport sector were 4.81 million tons of CO_2e in 2020 and are expected to increase to approximately 15.63 million tons of CO_2e by 2050 if no mitigation action is taken.

1.4.2 Ethiopia's Climate Resilient Green Economy National Adaptation Plan

Ethiopia's Environment, Forest, and Climate Change Commission co-ordinated the development of the state's National Adaptation Plan (NAP), which was published in 2019 (FDRE, 2019a). The NAP seeks to lessen vulnerability to climate change impacts by strengthening adaptive capacity and resilience, primarily by incorporating climate adaptation into long-term economic development planning. The NAP is thereby interlinked with the Climate Resilient Green Economy strategy (FDRE, 2015), which identifies four pillars of the green economy:

- Improving crop and livestock production practices for higher food security and farmer income while reducing emissions.
- Protecting and restoring forests for their economic and ecosystem services, including their role as carbon sinks.
- Expanding electricity generation from renewable sources for domestic and regional markets.
- Leapfrogging to modern and energy-efficient technologies in the transport, industrial, and building sectors.

The NAP documents historic climate trends and future projections in Ethiopia. A decreasing trend in rainfall is documented over several timescales, particularly from 1951 to 2008. In contrast, rainfall projections anticipate annual precipitation increase of 4% to 12% by 2100 compared to the 1975-2005 baseline, with greater percentage increase in the northern, southern, and east-southern regions. Temperature trends indicate a general increase over the 50-year period starting in 1954, with projected average temperature changes ranging from -0.5°C to 6°C by 2100 relative to the 1975-2005 baseline.

A changing climate poses various risks to Ethiopia's diverse agro-ecological zones. The lowlands are particularly sensitive to rising temperatures and prolonged drought, whereas the highlands are more vulnerable to intense or irregular rainfall. Climate risks, such as more frequent droughts and floods, seasonal shifts in rainfall and temperature patterns, and extreme events such as heatwaves and storms, could significantly impact Ethiopian agriculture. These impacts include shorter growing seasons, greater prevalence of crop diseases, lower productivity of soils, increased risk of crop failure, and the contraction of pastoral zones, which can have profound implications for agricultural productivity, water resources, ecosystems, and human well-being, which are multifaceted and interlinked (Sinore and Wang, 2024).

The NAP outlines key adaptation strategies to be implemented to help mitigate risks of climate change. Key areas of relevance to the civil aviation sector and potential SAF value chains are:

- Enhancing food security through improved agricultural productivity focusing on selecting resistant and tolerant crop varieties, increasing use of organic fertilizers and appropriate mechanization, and monitoring of crops for diseases and pests.
- Strengthening sustainable natural resource management by protecting landscapes and watersheds, with a focus on energy (preserving hydroelectric capacity), on water (improving ground water recharge), and on agriculture (rehabilitating degraded lands).
- Improving soil water harvesting and water retention, increasing irrigation agriculture, developing water infrastructures, improving water allocation and governance, and diversifying water harvesting technologies.
- Improving ecosystem resilience by conserving biodiversity, including the preservation and management of agro-diversity within specific agro-climatic zone.
- Enhancing alternative and renewable power generation and management, promoting a diverse energy mix, improving efficiency, and accelerating access to off-grid solutions.
- Building a sustainable transport system, by maintaining and improving infrastructure and ensuring reliable transportation networks for the movement of goods.
- Developing climate-adaptive industrial systems, by promoting smart production processes, efficient use of raw materials, and improved waste management practices.
- Strengthening value chains and marketing systems to improve their resilience and efficiency.
- Developing adaptation technologies, including for flood control, agricultural productivity, and resource conservation.

1.5 AGRICULTURE

The agricultural sector contributes 32% to Ethiopian GDP (ADBG, 2025). Overall, GDP has risen rapidly in the past 20 years, reaching USD 1,270 per capita and an annual growth rate of 7.1% in 2022/23 (ADBG, 2025; FAOSTAT, 2025a). Agriculture in Ethiopia is dominated by smallholdings, ranging in size from 0.5 ha to 2 ha, which represent 95% of total agricultural output and 85% of agricultural employment. In contrast, medium- and large-scale commercial farms contribute only 5% of output (FAO, 2016). Principal crops include cereals (wheat, sorghum, barley, millet), maize, coffee, and beans (Figure 4). Production output of principal crops increased consistently during the decade following 2008, although the rates of increase have been less significant in recent years (Figure 5 and FAOSTAT, 2025a).

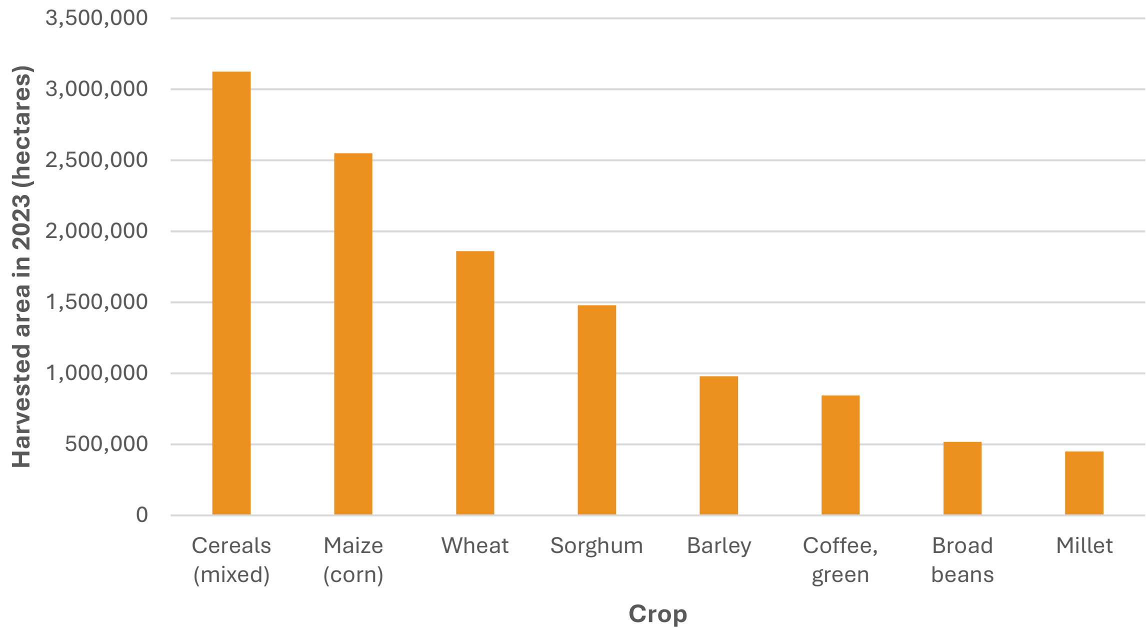


Figure 4. Harvested area for key agricultural crops in 2023 (FAOSTAT, 2025b).

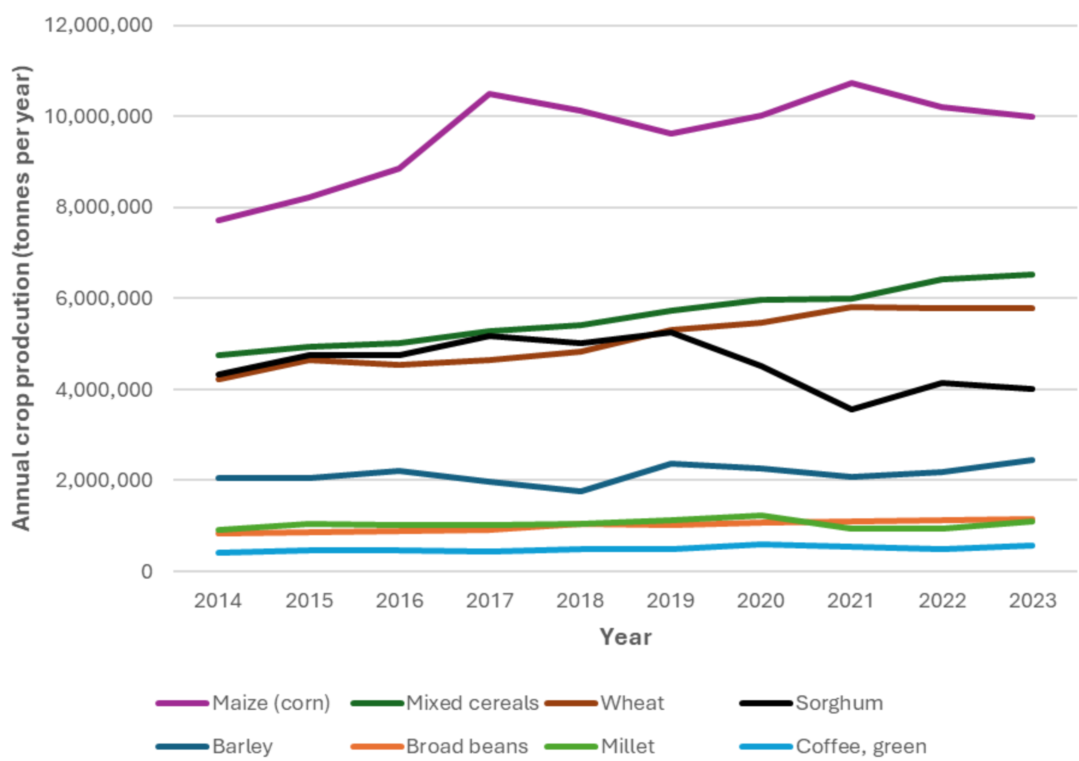


Figure 5. Production trends of key agricultural crops, 2014-2023 (FAOSTAT, 2025b).

Ethiopia's agricultural sector faces significant challenges, particularly due to underdeveloped supply chain infrastructure. The main obstacles include inadequate road infrastructure, poor coordination, inefficient transportation and logistics systems, and a lack of capacity. Furthermore, the country's smallholder farmers are widely dispersed, which limits economy of scale for production (hampering access to inputs, mechanization, and irrigation) and complicates aggregation of production.

A number of national policies and strategies have aimed to increase productive output of Ethiopia's agricultural sector, including the Agricultural Sector Policy and Investment Framework (PIF) (FDRE, 2010a), Growth and Transformation Plan (GTP) I (Ethiopian ATA, 2014; FDRE, 2010b) and GTP II (FDRE, 2016). The recent Homegrown Economic Reform Agenda (FDRE, 2020) recognizes the substantial progress achieved under GTP I and GTP II, while also noting the limited success in structural transformation in the sector. Key areas identified for advancing the economic development of the agricultural sector are detailed in Ethiopia's A Homegrown Economic Reform Agenda: Pathway to Prosperity (FDRE, 2020):

- Address logistics bottlenecks, as Ethiopia ranked 126th out of 160 countries on the logistics performance index in 2016, with missing or inadequate logistics for agricultural supply chains.
- Improve power reliability and access.
- Create legal frameworks to enhance land use, enabling farmers to overcome land fragmentation that hinders the transition from smallholders to medium- and large-scale farming.
- Enhance productivity through access to modern inputs and services, including training, equipment provision, and modernization and expansion of extension services.
- Establish links between agriculture producers, commodity marks and commercial value chain.
- Accelerate growth of strategic crops for import substitution – including grains, edible oils, raw sugar – while increasing exports of coffee, oilseed and pulses.
- Develop a legal framework for agriculture-focused financial services to address the under-provision of credit to agriculture, strengthen cooperatives, and enable saving, borrowing and transferring of money which will allow farmers to acquire inputs more easily.

1.6 ENERGY

1.6.1 Overview of Ethiopia's energy sector

Ethiopia consumed 1.99 PJ of primary energy sources in 2022 (IEA, 2025), following an average annual growth rate of 2.9% over the decade since 2012. Energy consumption is dominated by biomass sources, representing 83% of total energy use. While the share of biomass in the total energy supply has declined from over 91% in 2012, the absolute consumption of biomass energy has increased over this period by more than 25%. Biomass fuels are primarily used by households for cooking, with urban populations purchasing wood-based fuels, and rural populations relying on the collection of biomasses from wood, agriculture residue (e.g., straw) and other sources.

Electricity generation in Ethiopia is predominately hydroelectric, representing over 90% of generation capacity in the country (GIZ, 2023). At end 2021, total hydroelectric capacity was 3.7 GW (derated from installed capacity 4.1 GW), with an additional 7 GW under construction and 11.2 GW indicated as candidate future plants (GIZ, 2023). Commissioning of the Grand Ethiopian Renaissance Dam is significantly expanding generation capacity, currently producing up to 2.4 GW of power (MoWE, 2025). The ultimate hydropower potential in Ethiopia is estimated at 45 GW (GIZ, 2023).

Other renewable energy sources are available and being developed to varying degrees. Wind power currently contributes around 320 MW to generation capacity and is expected to rise to approximately 700 MW with additional capacity already committed for construction. Overall wind power potential in Ethiopia has been estimated at 100 GW (GIZ, 2023). Solar photovoltaic generation (PV) has similar potential, although its contribution to grid-connected generation remains minimal today. Previously committed solar PV plants

(Gad-1 and Dicheto) were expected to provide 250 MW of capacity to the grid but were cancelled in 2022 due to lack of funding to progress the developments (Fana, 2022).

Biomass and waste fuels are being increasingly utilized for power generation. Bagasse, a byproduct of sugarcane crushing, can be combusted to meet the energy requirements of sugar factories and surplus electricity can be exported. Bagasse-fired generation is in place at Finchaa Sugar Factory (31 MW power generation capacity, of which 21 MW is available for export) and Metehara Sugar Factory (9 MW power generation). Committed plans for power generation at Beles, Wolkayit, Omo Kuraz, and Kessem facilities will total an additional installed capacity of 342 MW (EAPP, 2014). In Addis Ababa, the Reppie waste-to-energy (WtE) facility incinerates municipal solid waste for electricity generation. The facility, in operation since 2019, has a processing capacity of 1,400 tonnes per day and an installed power capacity of 50 MW. However, actual utilization of the WtE facility is below its capacity, due to challenges identified with operational and safety management (JICA, 2024) and the low calorific value of MSW inputs resulting in high operating costs.

The electricity sector is expected to expand rapidly in the near future, increasing both generation capacity and electricity access. The National Electrification Plan (NEP 2.0) aims to increase both on-grid and off-grid electricity access, aiming for 65% grid access by 2025 and increasing rapidly beyond this date. However, meeting these ambitious targets may prove challenging, as it requires doubling on-grid access, and tripling off-grid access from their 2022 levels of 33% and 11%, respectively (FDRE, 2019b). Meanwhile, the Ethiopia Electrical Power (EEP) Expansion Program 2020-2030 aims to increase generation capacity from 4.5 GW in 2020 to 13 GW by 2025 and 17 GW by 2030 (GIZ, 2023). This growth will include diversification from hydropower — which would still provide 73% of capacity— by developing wind, solar, geothermal and biomass projects (municipal solid waste and bagasse). Improved energy access and generation capacity will supply increasing demands from domestic, commercial, and transport sectors (~ doubling consumption), industry (50% increase), and agriculture, where irrigation energy use will increase by more than 3%. In total, electricity consumption is expected to nearly quadruple from 15 TWh/year to 55 T by 2030 (GIZ, 2023). USAID projects slightly lower electricity demand in Ethiopia, 52 TWh/year by 2030, increasing to 135 TWh by 2045 (GIZ, 2023). Projected least-cost expansion of electricity generation capacity will be dominated by large-scale hydropower. In the near-term this will be achieved through staged commissioning of the Grand Ethiopian Renaissance Dam up to 2030, with 6 of 13 planned turbines commissioned by 2025. Investment in additional large scale hydroelectric plants (Beko Abo, Genji, Geba 2, and Upper Mandaya) will drive capacity growth in the medium term (3.2 GW by 2034), with additional longer-term capacity growth realized by solar power (MoWE, 2025).

Key challenges are faced by the Ethiopian energy sector at present (MoWE, 2025): hard currency shortages have made difficult obtaining spare parts to maintain electricity generation infrastructure; limited private sector investment slows uptake of renewable energy opportunities; reliability of supply with interruptions on average for 3% of time; high inflation and low electricity tariff has weakened the financial stability of the power sector; internal security concerns affect infrastructure projects; and electricity access remains low at approximately 55% of the population (World Bank, 2025e).

Transport fuels in Ethiopia are predominately petroleum-based. The country does not produce crude oil domestically nor refine petroleum products and instead is reliant on imports of finished fuels. In 2023, Ethiopia imported USD 2.5 billion worth of refined petroleum fuels, representing the country's largest import (OEC, 2025). Over 90% of petroleum fuel imports originate from Kuwait and Saudi Arabia, arriving to Ethiopia by truck from Djibouti. In the past, ethanol-gasoline blending standards were established with aim to achieve up to 10% ethanol by volume blends (Ministry of Transport, 2009). However, due largely to competition for limited molasses feedstock, the ethanol biofuel use in the transport sector was not successful and was ultimately terminated after 2017. Future projections for fossil fuel demand, including aviation fuel, indicate a long-term increase as shown in Table 2. An average annual growth rate of 9% has been assumed for the jet fuel market, whereas for diesel and gasoline, the respective annual growth rates are 5%, aligning with the expected overall GDP growth rate for the country (MoWE, 2025).

Table 2. Projected fossil fuel demand through 2035.

Fuel Type	2030 (in million litres)	2035 (in million litres)
Jet fuel (local demand)	1,041	1,676
Diesel	4,216	5,381
Gasoline	1,326	1,692

1.6.2 Energy Policy – Draft (2023)

The new draft of the revised energy policy envisions an increase in per capita energy consumption in Ethiopia, aligning with the economic reform agenda (FRDE, 2020). The main objective of the policy is to expand electricity access throughout the country and diversify the energy sources beyond the current heavy reliance on hydropower.

Ethiopia does not produce fossil fuels, relying entirely on imports to meet its fuel demand. As a result, a significant portion of the country’s export earnings is spent on petroleum products, placing considerable pressure on foreign currency reserves. To address this issue, the draft policy proposes strategies to reduce dependence on imported fuels. Suggested solutions for transitioning to clean and renewable energy sources include e-mobility options, such as electric cars and trains, biofuels for road transportation, and sustainable aviation fuels as alternatives. Furthermore, the policy emphasizes the importance of research and development to advance the deployment of sustainable aviation fuels in Ethiopia.

1.6.3 National Sustainable Energy Development Strategy (N-SED) Ethiopia (2024-2030)

The National Sustainable Energy Development (N-SED) Strategy aligns with the draft energy policy and emphasizes the importance of inclusive and sustainable energy development in Ethiopia. It recognizes that the country's energy demand is increasing and that this demand must be met in a sustainable, affordable, and reliable manner.

The objective of the strategy is to guide actions aimed at accelerating the transition to a sustainable energy future while integrating social, economic, environmental, and technological dimensions. Ethiopia has abundant renewable energy resources, and the strategy emphasizes initiatives to further develop and enhance capacity through investment and innovation. The primary renewable energy sources identified include hydroelectric power (HEP), solar and wind energy, geothermal energy, and bioenergy.

The strategy emphasizes the potential of Sustainable Aviation Fuel (SAF) as a promising liquid biofuel that can be developed in Ethiopia. It points out that feedstocks like Brassica carinata have significant potential for SAF production. Furthermore, the strategy highlights Ethiopia's geographical position as an aviation hub, creating a market opportunity for supplying SAF. Consequently, promoting domestic production of SAF is identified as one of the key goals of the strategy.

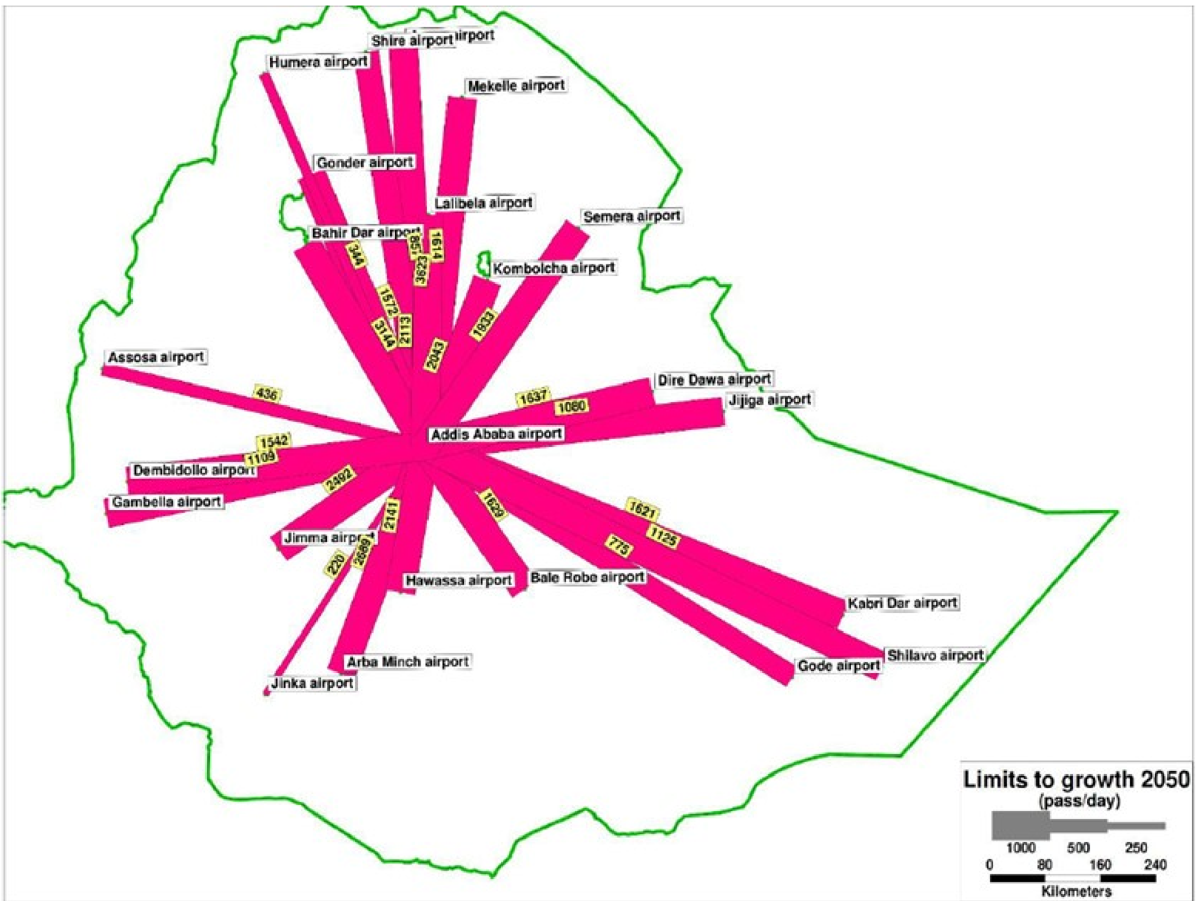
1.6.4 Ethiopian Transport Master Plan: Aviation 2022-2052

Ethiopia has established a comprehensive thirty-year integrated master plan for its transport sector, with a specific focus on the aviation industry developed by the Ministry of Transport and Logistics. This master plan serves as a guide for the future development of Ethiopia's aviation sector, addressing investment needs, infrastructure development (including airports) market dynamics, and fleet enhancement while also exploring innovative approaches to transform the country’s aviation landscape (MoTL, 2022).

The plan envisions expanding airports across Ethiopia, with an emphasis on supporting various economic activities and upgrading domestic airports to meet international standards. It also anticipates expanding the airline fleet.

In terms of environmental considerations, the master plan acknowledges the implementation of the ICAO CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation) and calls for Ethiopian Airlines to align with international commitments. This includes exploring opportunities for financing carbon emission reduction projects through various global financing mechanisms.

Additionally, the master plan includes projected passenger traffic scenarios for domestic flights, indicating a significant increase in demand through 2050 (Figure 6). To achieve the planned expansions of fleets, airports, and infrastructure development, the required investment is estimated to range between USD 11.6 to 25.6 billion.



Source: simulated by the TransCAD model

Figure 6. Projected passenger domestic traffic in the year 2050 for the Limits to Growth Scenario. From MoTL (2022).

1.6.5 Ethiopia's Climate Resilient Transport Sector Strategy

The climate-resilient transport strategy was developed in 2017 to establish an integrated and modern transport system that aligns with Ethiopia's national development plan and climate resilience objectives. The strategy places strong emphasis on reducing Greenhouse Gas emissions (GHG) from the transport sector and outlines a comprehensive and coordinated set of aspirational targets and actions to address challenges identified in the accompanying sector assessment (MoT, 2009).

Specific targets are set to be achieved by 2030, covering all major modes of transport, including road, air, and rail. Regarding aviation targets, the strategy highlights the need for expansion within the sector, including fleet growth, expanding destinations, and airport development. It notes that improving access to domestic destinations can stimulate economic development by facilitating the movement of goods and services throughout the country, thereby integrating rural districts into broader economic networks.

The strategy also defines specific goals for the aviation sector in terms of GHG emission reduction. These goals include improving fuel efficiency, introducing biofuel blends of up to 10%, and reducing operational emissions by 20% every seven years.

1.6.6 Revised Biofuel Strategy (to be published in 2025)

The revision of the Biofuel Development and Utilization Strategy aimed to update the existing framework to align with the current global dynamics of the biofuel sector. It addressed the shortcomings of the 2007 strategy and explored potential feedstocks for alternative fuel production, particularly for transportation fuel and clean cooking energy sources.

The original 2007 biofuel development strategy focused on the production of bioethanol and biodiesel, emphasizing three feedstock options: castor, Jatropha, and palm oil. This strategy was developed during the fuel crisis of 2007/2008, which attracted many foreign investors due to the favourable policy environment and incentives provided by the government.

The revised biofuel strategy adopts a broader approach to reflect current global trends in the biofuel sector. It evaluates various feedstock options and applications, including the production of SAF and clean cooking fuels. Additionally, it integrates lessons learned from other countries to refine the strategy.

The revised strategy also establishes a long-term vision with specific blending targets: 5% SAF blending by 2030 and 10% by 2035; 2% biodiesel blending by 2030 and 5% by 2035; 10% bioethanol blending by 2030 and 15% by 2035; and a 2% bioethanol blending for household cooking.

1.7 AVIATION FUEL SUPPLY CHAIN

The Ethiopian Petroleum Supplies Enterprise (EPSE) is a public organization responsible for purchasing and distributing petroleum products to meet the country’s fossil fuel demand. It also manages the administration of national petroleum reserves. EPSE operates 13 reserve depots across various regions to ensure fuel availability during emergency disruptions caused by natural disasters or human-made crises. Additionally, EPSE imports coal for cement factories, ceramics, and metal industries as directed by the government.

As a landlocked country, Ethiopia relies on the port of Djibouti for its fuel imports. EPSE has a branch office at the port, to facilitate the supply chain, and is the sole entity authorized to supply petroleum products in Ethiopia. Currently, nearly all of the country's fuel demand is met through the Djibouti port.

EPSE primarily sources aviation fuel from the Middle East, specifically Kuwait and Saudi Arabia. The fuel is delivered to the Horizon terminal in Djibouti, where it undergoes quality testing by EPSE’s certification body. Once certified, the fuel is delivered to distributors by truck, who then supply Ethiopian Airlines with Jet A1 fuel. The main distributors include the National Oil Company (NoC), Total Energies, TAF Oil, Delta energies, JR, and Oil Libya (OLA). Refined aviation fuel is transported from the Djibouti port to Addis Ababa Bole International Airport and selected regional airports by truck (Figure 7). In addition to at the Djibouti terminal, in-country laboratory tests are conducted to further ensure fuel quality.

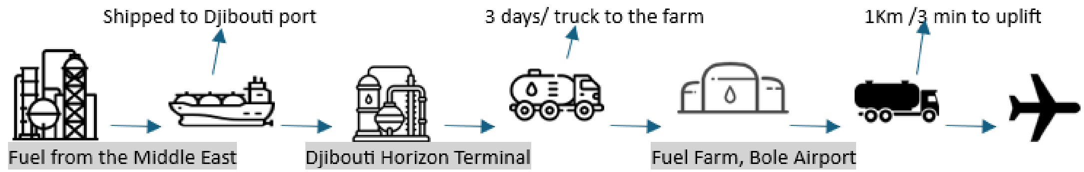


Figure 7. Overview of the aviation fuel supply chain in Ethiopia.

Integrating SAF within the Ethiopian jet fuel supply chain would leverage existing facilities and infrastructure. Imported SAF would expect to be delivered as a blended fuel to Djibouti, with no additional domestic requirement for blending or certification beyond current capabilities. It is expected that domestically produced SAF would be blended within the current domestic supply chain, most likely at current storage facilities such as the Awash Fuel Depot. Domestic production of SAF would necessitate new blending facilities and fuel certification capabilities.

For both imported and domestically produced SAF, fuels would be blended prior to arrival at Bole Airport. This would be in line with JIG1530 standard, as SAF must meet ASTM D1655 specifications for aviation use to ensure quality control and manage risk, as airports are not equipped for necessary blending or full certification process.

1.7.1 Current and projected aviation fuel demand

Ethiopia has 21 regional airports and one international airport, Bole International Airport at Addis Ababa, which serves scheduled commercial airline traffic (Figure 8). The aviation sector is set to grow rapidly, with estimated growth rate of 6% per year to 2040, tripling its size from 2023 (IATA, 2023). Ethiopian Airlines is the largest African airline by passenger and freight volumes. In 2022, it carried a total of 11.3 million passengers, of which 4.6 million were intercontinental, 4.5 million were regional, and 2.2 million were domestic, amounting to 34.97 million Revenue Passenger Kilometres (RPK) (AFRAA, 2023). That same year, the airline also transported 742,189 tonnes of freight (AFRAA, 2023).

In Ethiopia, jet fuel prices are not determined by open market dynamics but are set by government, with periodic adjustments to reflect global price movements and policy choices. As of May 2025, the price of aviation fuel is ETB 109.56 per litre, which is equivalent to approximately USD 0.78 per litre. This represents a modest decrease from the January 2025 price of ETB 113.20 per litre, or about USD 0.80 per litre (Addisbiz, 2025). In comparison, at-refinery jet fuel spot price data indicates an Africa region price equivalent to USD 0.57 per litre (IATA, 2025), but it is important to note that this index excludes additional costs for import, logistics, and currency costs to supply Ethiopia market.

Information on aviation fuel consumption is presented in Figure 9, which shows both historic and projected estimates in-country fuel uplift, and projected total global jet fuel consumption for national carrier Ethiopian Airlines from 2020 to 2030. Fuel consumption in Ethiopia declined in 2020 and 2021 due to the COVID-19 pandemic, followed by a period of recovery. By 2022 and 2023, fuel demand had surpassed 2019 levels, indicating growth in the sector. Projected global fuel uplift by Ethiopian Airlines is also presented in Figure 9, showing expected long-term growth in aviation fuel demand from the airline's operations across the globe (RSB, 2021).

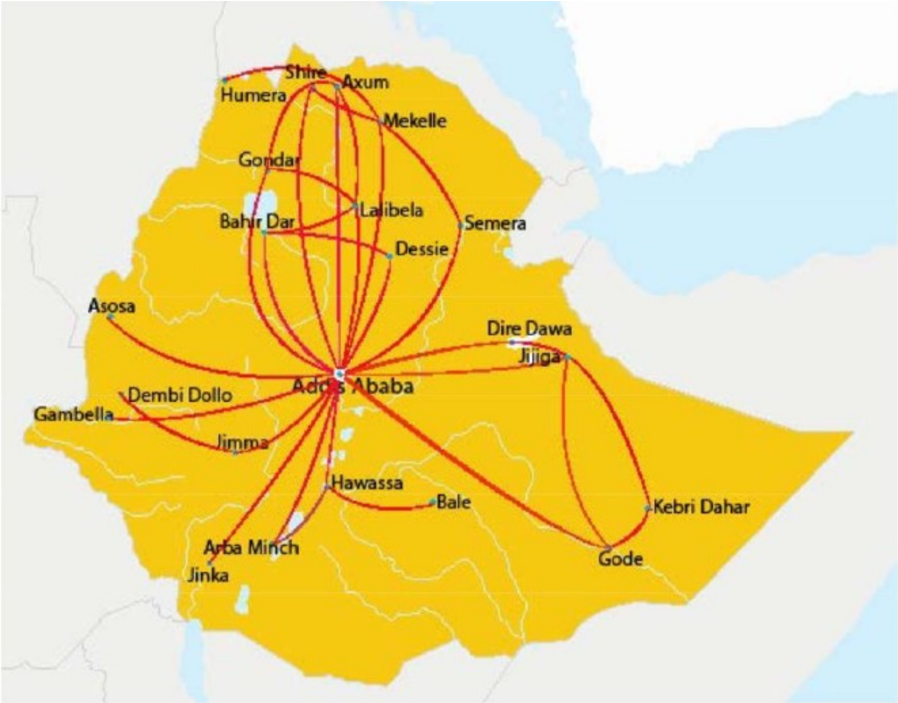


Figure 8. Location of civil aviation airports in Ethiopia with scheduled service by commercial carriers. From MoTL (2022).

The updated Biofuels Strategy establishes ambitious SAF blending targets of 5% by 2030 and 20% by 2035 (MoWE, 2025). These correspond to 52 million litres of SAF uplift in Ethiopia in 2030, expanding to 335 million litres by 2035.

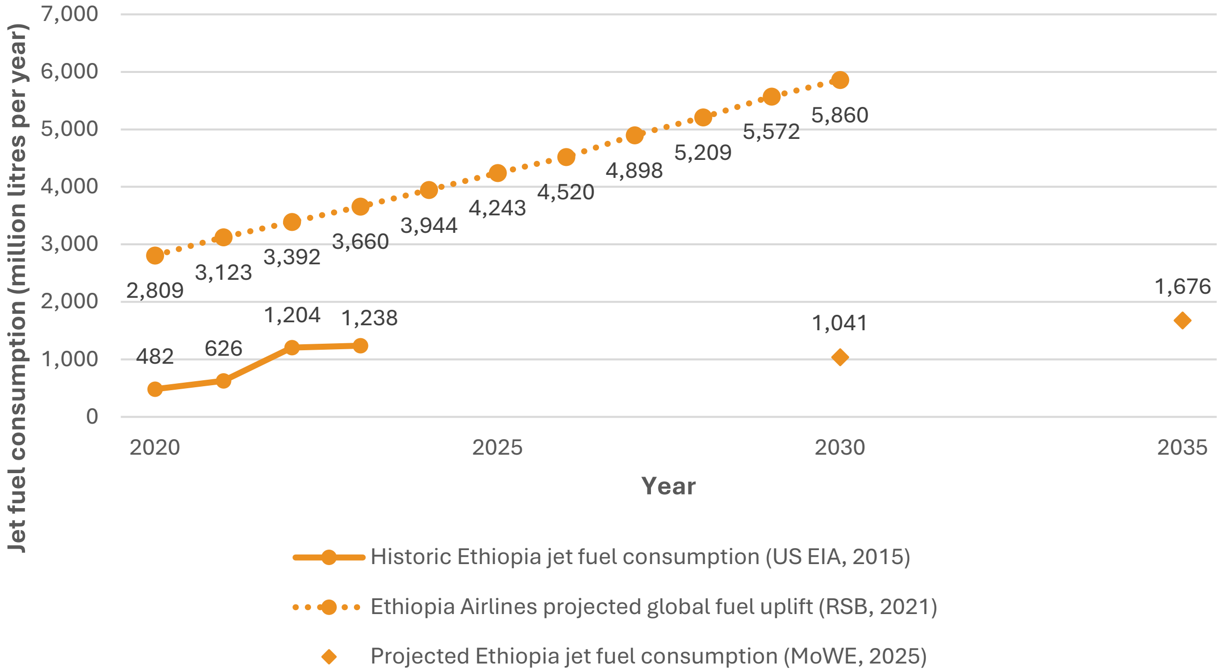


Figure 9. Summary of available historic and projected jet fuel consumption data for the Ethiopia market.[2]

[2] Data for historic jet fuel consumption in Ethiopia is available to 2023 (US EIA, 2025); projected Ethiopian Airlines global fuel uplift is available covering 2020-2030 time period (RSB, 2021); and projected Ethiopia future jet fuel consumption for years 2030 and 2035 are available from MoWE (2025).

SECTION 2. EVALUATION OF FEEDSTOCKS AND PATHWAYS FOR SAF PRODUCTION

2.1 INTRODUCTION

There are a number of routes to produce SAF, and for some feedstocks, there is more than one possible production route. A summary of key production routes, suitable feedstocks, and expected capacity of future commercial operations is presented in Table 3.

The hydrotreatment of oils (vegetable oils, animal fat, and used oils) to produce hydroprocessed esters and fatty acids (HEFA) is a high yielding process (83% by mass, ICAO (2023)) where hydrogen is input to a catalytic process to convert input triglycerides to straight chain alkane hydrocarbons, followed by a second step of isomerization and cracking of alkanes to obtain the desired products.

The Fischer-Tropsch (FT) conversion process is a multi-step process, where feedstocks are gasified with clean-up of resulting syngas, prior to FT conversion to SAF and other hydrocarbon products. FT fuels can be produced from biogenic feedstocks, including agricultural residues, organic wastes, and forestry biomass, as well as from carbon dioxide and/or carbon monoxide and hydrogen.

Alcohol-to-jet (ATJ) processes first produce alcohols (ethanol, isobutanol) which then undergo dehydration, oligomerization, and hydrogenation reactions to form synthetic paraffin (SAF) and coproducts.

The pyrolysis-based production route first converts feedstock into a “biocrude” intermediate product, which is then upgraded to aviation fuel via catalytic cracking and deoxygenation processes. The HEFA, FT and ATJ processes and resulting blends of up to 50% by volume are certified; however, pyrolysis-based production is not yet a certified route to aviation fuel.

Table 3. Summary of ASTM approved SAF conversion processes, associated feedstocks, and estimated technology readiness level (TRL).

Process	Abbreviation	Suitable feedstocks	Current blending ratio by volume (%)	Technology Readiness Level (TRL)	ASTM reference
Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene	FT	Biomass	50%	7-8	ASTM D7566 Annex A1
Synthesized paraffinic kerosene from hydroprocessed esters and fatty acids	HEFA	Vegetable oils, animal fats, used cooking oils	50%	8-9	ASTM D7566 Annex A2

Synthesized iso-paraffins from hydroprocessed fermented sugars	SIP	Biomass used for sugar production	10%	6-7	ASTM D7566 Annex A3
Synthesized kerosene with aromatics derived by alkylation of light aromatics	FT-SKA	Biomass	50%	6-7	ASTM D7566 Annex A4
Alcohol to Jet synthetic paraffinic kerosene	ATJ-SPK	Ethanol, isobutanol and isobutene from biomass	50%	7-8	ASTM D7566 Annex A5
Catalytic hydrothermolysis jet fuel	CHJ	Vegetable oils, animal fats, used cooking oils	50%	7-8	ASTM D7566 Annex A6
Synthesized paraffinic kerosene from hydrocarbon – hydroprocessed esters and fatty acids	HC-HEFA-SPK	Algae	10%	5-6	ASTM D7566 Annex A7
Synthetic paraffinic kerosene with aromatics	ATJ-SKA	C2-C5 alcohols from biomass	50%	7-8	ASTM D7566 Annex A8
Co-hydroprocessing of esters and fatty acids in a conventional petroleum refinery		Vegetable oils, animal fats, used cooking oils from biomass processed with petroleum	5%	8-9	ASTM D1655 Annex A1
Co-hydroprocessing of Fischer-Tropsch hydrocarbons in a conventional petroleum refinery		Fischer-Tropsch hydrocarbon co-processed with petroleum	5%	7-8	ASTM D1655 Annex A1
Co-processing of HEFA		Hydroprocessed esters/fatty acids from biomass	10%	8-9	ASTM D1655 Annex A1

The expected capacities of mature and commercially competitive SAF production facilities (Table 4) range from 96,000 tonnes SAF/year (FT from agricultural residues) to 440,000 tonnes SAF/year (HEFA) and 560,000 tonnes SAF/year (ATJ) (ICAO, 2023). It is worth noting that recent jet fuel consumption in Ethiopia is estimated at 1,238 million litres per year, or 990,000 tonnes per year. At this demand level, SAF production from a single facility could supply approximately 10% to more than 50% of current domestic jet fuel consumption. Projections of future passenger and cargo demand figures would significantly increase jet fuel demand from current consumption (see 1.7). Indicative capital investment costs and fuel minimum selling price estimates are shown in Table 5, representing general global estimates of production technology and feedstock cost.

Table 4. Estimates of SAF facility capacity and feedstock costs for key SAF production routes (ICAO, 2023).

Technology, feedstock type and price, yield, total annual distillate scale, annual SAF production for both nth and pioneer facilities							
Processing Technology	**Feedstock**	**Yield (ton distillate/ ton feedstock)**	**Feedstock Price (USD)**	**Total Capacity (million L/year)**		**SAF production (million L/year)**	
				nth	**pioneer**	**nth**	**pioneer**
FT[3]	MSW	0.31	30/tonne	500	100	200	40
FT[3]	forest residues	0.18	125/tonne	400	100	160	40
FT[3]	agricultural residues	0.14	110/tonne	300	100	120	40
ATJ	ethanol	0.6	0.41/L	1000	100	700	70
ATJ	isobutanol-low	0.75	0.89/L	1000	100	700	70
ATJ	isobutanol-high	0.75	1.20/L	1000	100	700	70
HEFA	FOGs	0.83	580/tonne	1000	-	550	-
HEFA	soybean oil[4]	0.83	809/tonne	1000	-	550	-
FT	CO_2 from Direct Air Capture (DAC) , H_2	0.24	300/tonne, 6/kg	1000	-	200	-
FT	waste CO_2, H_2	0.24	300/tonne, 6/kg	1000	-	200	-
Pyrolysis[5]	forest residues	0.23	125/tonne	400	100	180	40
Pyrolysis[5]	agricultural residues	0.21	110/tonne	400	100	180	40

[3] Feedstock price is for pre-processed feedstock.
[4] 2013-2019 average price of soybean and canola oils.
[5] Pyrolysis ASTM approval is pending.

Table 5. Estimate of SAF production facility total capital investment (TCI), capital cost, and minimum selling price (MSP) for key SAF production routes (ICAO, 2023).

Total capital investment (TCI), capital cost, and minimum selling price (MSP) for n^th and pioneer facilities for each pathway							
Processing Technology	Feedstock	TCI (million USD)		Capital Cost (USD/L total distillate)		MSP (USD/L)	
		nth	pioneer	nth	pioneer	nth	pioneer
FT[3]	MSW	1428	813	2.9	8.1	0.9	2.1
FT[3]	forest residues	1618	1088	4	10.9	1.7	3.3
FT[3]	agricultural residues	1509	1267	5	12.7	2	3.8
ATJ	ethanol[6]	328	117	0.3	1.2	0.9	1.1
ATJ	ethanol, agricultural residues	581	170	0.6	1.7	2.2	2.5
ATJ	isobutanol-low[6]	332	94	0.3	0.9	1.3	1.5
ATJ	isobutanol-high[6]	410	110	0.4	1.1	1.7	1.9
HEFA	FOGs	448	-	0.4	-	0.8	-
HEFA	vegetable oil	456	-	0.5	-	1	-
FT	DAC CO_2, H_2	3366	-	3.4	-	4.4	-
FT	waste CO_2, H_2	3209	-	3.2	-	3.5	-
Pyrolysis[5]	forest residues	1038	594	2.6	5.9	1.3	2.1
Pyrolysis[5]	agricultural residues	1084	619	2.7	6.2	1.3	2.2

2.2 PREVIOUS WORK ON FEEDSTOCK EVALUATION FOR SAF IN ETHIOPIA

The feedstock analysis undertaken in the present feasibility study, as indicated in the Methodology section at the beginning of this document, is intended to complement, and not replicate, significant work that has already been undertaken regarding the feasibility of SAF feedstocks and SAF production in Ethiopia.

A preliminary review undertaken in the context of this study identified key works completed to date on SAF in Ethiopia, including WWF South Africa and IIASA (2019), RSB (2021) and RSB (2022) (see Table 6). Together, these studies have covered key areas of interest, including agricultural land availability; preliminary

[6] Alcohol feedstock is corn-based.

evaluations of the potential of key feedstocks and technologies to realize SAF production in Ethiopia; the availability of industrial and logistic infrastructure; and they provide a broad understanding of the policy and regulatory contexts of relevance to renewable and low carbon fuels for the aviation sector.

Table 6. Summary of identified potential feedstocks and assessment findings (RSB, 2021).

Feedstock	Listed in CORSIA documents	Advantage	Disadvantage	Conversion technology
Sugarcane molasses	Yes	Large scale plantations available	Needs irrigation and it is an intensive crop (requires mechanization for harvesting)	HEFA-SPK
Crop residue	Yes	Abundant across the country	Lack of necessary collection and logistic system	FT+ AtJ
Municipal Solid Waste	Yes	Contributes to circular economy	Variable supply	FT –SPK
Jatropha	Yes	Proven high yield oil production	Plantations cannot easily be mechanized	HEFA-SPK
Castor seed	No	Could be cultivated on marginal lands with relatively low water requirements. High oil content.	Growing global markets for use in industrial and pharmaceutical applications(competition) Potential to comply CORSIA needs to be demonstrated with LCA study (since it is not currently listed in CORSIA documents)	HEFA-SPK
Brassica carinata (Ethiopian mustard)	Yes	Oil is efficiently converted into aviation fuel. Tolerant to both heat and drought	Has similar ecology as bread wheat and barley	HEFA-SPK
Prosopis juliflora	No	Harness economic benefits of invasive species management. RSB assessment indicates that they could be CORSIA compliant.	Current use for firewood, charcoal and construction purposes. As not currently listed under CORSIA, more LCA work is needed to be certified under CORSIA.	FT –SPK
Solaris (tobacco)	No	Can participate in an integrated crop-livestock system & climate-smart agricultural production system.	Requires soils of high fertility that are prioritized for food production	HEFA-SPK

The preliminary assessment carried on at the initiation of this study identified the opportunity to undertake a "deep-dive" with further collection and analysis of data to provide a higher resolution understanding of the availability and quality of key feedstocks for SAF production, their potential environmental impacts, and their economic and market potential. The following facts were considered:

- Additional investigation of cropping methods is needed to demonstrate potential of Brassica carinata as a secondary crop that avoids other crop displacement – necessary to achieve low ILUC value approved under CORSIA – and potential co-benefits for example in soil improvement and weed suppression as cover crop/crop rotation.
- Further assessment is needed on the Alcohol to Jet pathway, particularly with expansions in the sugar industry having taken place after the previous studies, and a lack of quantitative data on sugarcane molasses ethanol production and economics in Ethiopia.
- The potentials of Municipal solid waste (via Fischer-Tropsch conversion) were not sufficiently assessed.
- Electricity-based fuels (via Fischer-Tropsch conversion using CO_2/H_2) were not evaluated.
- While Ethiopia's 2007 biofuel development strategy identified castor seeds as a potential feedstock, very little information was available to assess its potential.

The findings of the pre-feasibility study were discussed with Ethiopia SAF stakeholders during the project kick-off workshop, including the national SAF Technical Committee. During this workshop, participants reviewed previous studies, including the current national SAF roadmap. The objective was to decide whether to conduct a further assessment of feedstock or to proceed directly to a business implementation study. The stakeholders recommended conducting a more detailed assessment of selected feedstocks before initiating the business implementation study and reached a consensus on which feedstocks the study should focus on. As a result, the scope of the current feasibility study is to will focus on the following feedstock and conversion technology options:

- Brassica carinata / HEFA
- Sugarcane molasses / ATJ
- Municipal solid waste / FT
- Castor seed / HEFA
- Electricity-based fuels – CO_2/H_2 - FT

2.3 BRASSICA CARINATA

2.3.1 Feedstock-related information

Brassica carinata, commonly known as Ethiopian mustard, is a crop native to Ethiopia. It is primarily cultivated for oil, which is traditionally used to grease the clay pans for baking injera (Ethiopian flatbread) and for cooking, often mixed with oil seeds such as niger and linseed (Delesa, 2009).

The ideal growing conditions for Brassica carinata are high altitudes, typically between 2,000 and 2,600 meters, although it can also thrive at elevations of up to 3,200 meters (Abdeta, 2022). This crop is predominantly grown in the Oromia and Amhara regions, specifically in areas such as Arsi, Bale, West Shewa, East Wellega in Oromia, and West Gojam and South Gonder in Amhara. The total suitable land for Brassica carinata production in Ethiopia is estimated to be 29,902,340 hectares based on the results from the crop suitability map analysis (RSB, 2022) (see Figure 10).

Cultivation practices commonly employed include monocropping, crop rotation, and intercropping with cereals during the rainy season. Additionally, the leaves of Brassica carinata are consumed as food (RSB, 2022).

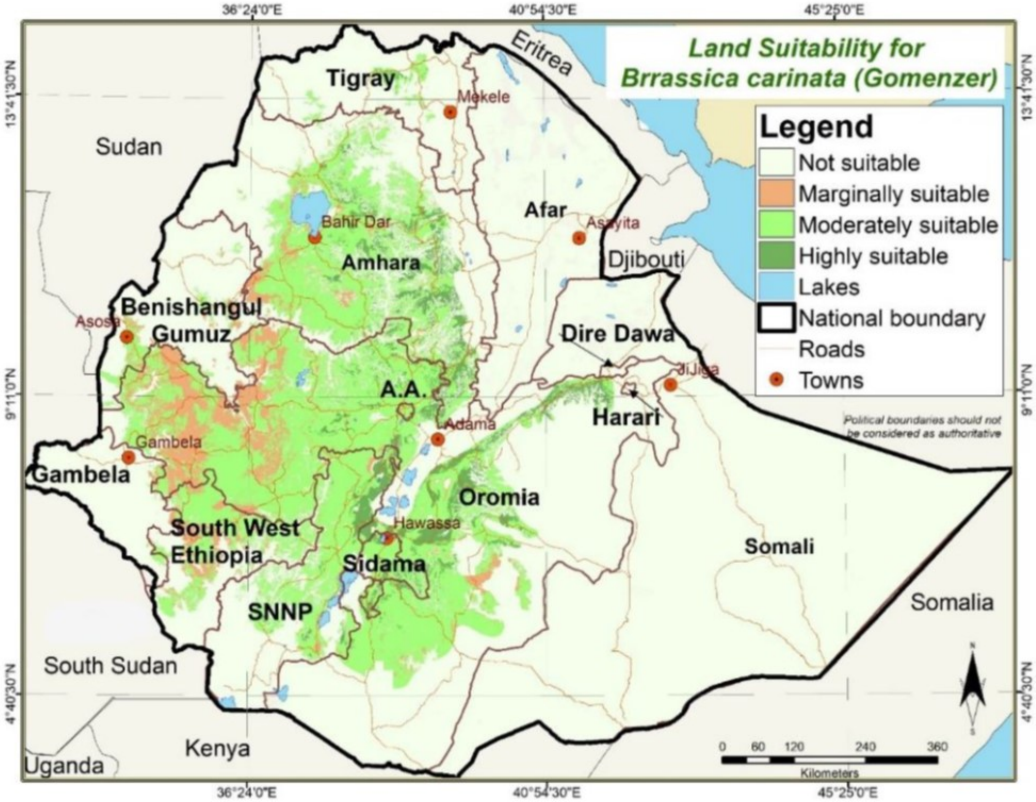


Figure 10. Suitability map of Brassica carinata (RSB, 2022).

The production of Brassica carinata has been on a downward trend over the past decade for several reasons. The primary factor contributing to this decline is the competition for agricultural land, which is increasingly being used for the cultivation of cereals such as wheat and barley, among others. As illustrated in Figure 11, production has dropped from 70,000 tons in 2011 to just over 10,000 tons in 2020, representing a reduction of 60% over the past ten years. In terms of agricultural land, coverage has decreased from 45,000 hectares in 2011 to less than 10,000 hectares today (RSB, 2022).

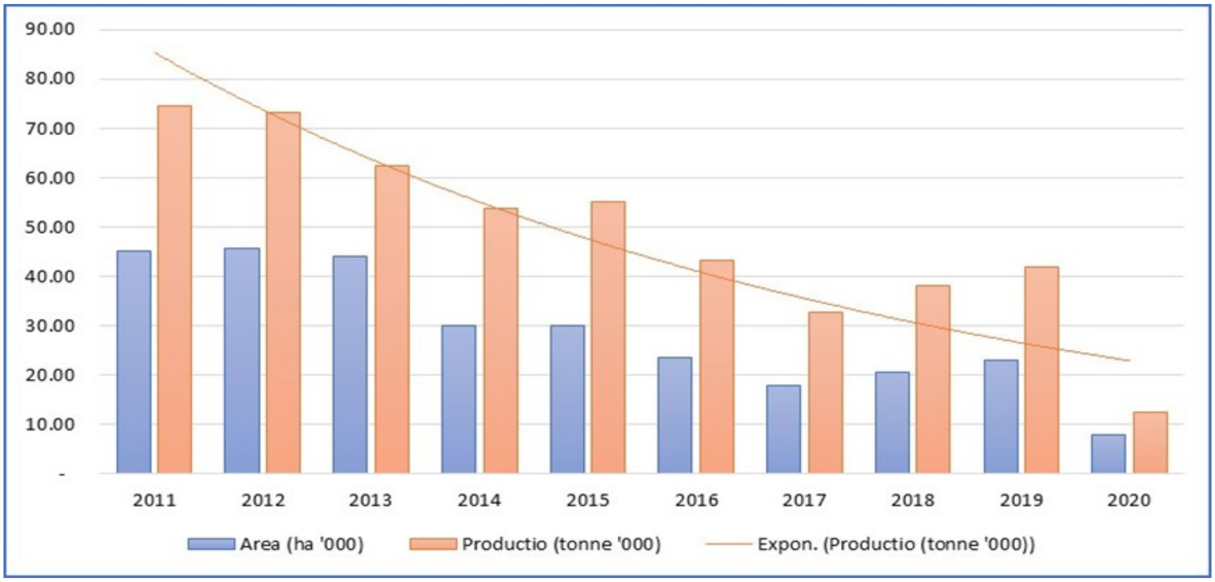


Figure 11. Area coverage and production trend of Brassica carinata in Ethiopia (RSB, 2022).

In terms of variety, the federal government has distributed more than 10 types of crops to enhance yields through research centres. Among these, the Derash, Tesfa, and Yellow Dodola varieties are the most commonly used. Yellow dodola variety demonstrated higher yield from research trials (RSB, 2022). Recent field trials of these main varieties at specific locations have shown significant results in terms of both yield and oil content as shown in Table 7.

Table 7. Yield performance of selected Brassica carinata varieties. Source: Field trial results from Zoscales Partners (2025).

Variety	Average yield (t/ha)	Pods/plant	Seeds/pod	Oil content (%)
Derash	2.42	225	13.1	49.1
Tesfa	2.31	205	12.9	48.1
Yellow dodola	2.13	159	12.8	42.6

The pilot field trial conducted by the referenced private company demonstrated that the Derash variety yielded higher results compared to other varieties in this specific trial. As shown in the table above, the oil content ranged from 42% to 49% across the three varieties. Additionally, Table 8 compares the growth characteristics of the three varieties, including days to maturity and plant height, among other factors in the specific agroecology.

Table 8. Growth characteristics of three Brassica carinata varieties (Zoscales Partners, 2025).

Parameter	Derash	Tesfa	Yellow Dodola
Days of emergence	10.2	12.1	14.3
Days to 50% flowering	60.3	56.8	72.3
Days to maturity	164.8	171.7	181.4
Plant height(cm)	171.4	176.0	173.4
Branches/Plant	13.07	12.94	12.8

2.3.2 Sustainability aspects

Brassica carinata can be an approved feedstock for Sustainable Aviation Fuel (SAF) under the ICAO CORSIA sustainability standard, when grown as a secondary crop — that is, cultivated in rotation or between food crop cycles avoiding other crops displacement —avoiding competition with food production. It is recognized for its potential to reduce greenhouse gas (GHG) emissions as one of the oilseed feedstocks. However, the production of carinata must take place as a secondary crop to prevent competition for agricultural land, thereby avoiding land-use change issues and indirect emissions.

According to the ICAO's Default CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels, the default HEFA life cycle emissions for Brassica carinata grown as a secondary crop are about 21.7 gCO2e/MJ (the sum of a default core LCA of 34.4 gCO2e/MJ and an ILUC global value of -12.7 gCO2e/MJ) with a GHG saving of around 75.6 % relative to fossil jet fuel (89 g Co2 e/MJ) (ICAO, 2024). This makes carinata one of the potential feedstocks for SAF production. The life cycle emission of carinata production in Ethiopia have shown significant reduction in GHG emissions (see Figure 12) (RSB, 2022). The baseline results shown from agricultural cultivation from carinata seed is 270 gCO_2e/kg which is equivalent to 6.28 gCO_2e/MJ of carinata seed using the RSB GHG tool. This is a significant reduction compared to the baseline of 89 g Co2 e/MJ for conventional fuel.

This shows that by using actual values calculated using the ICAO CORSIA methodology instead of the default ones, a possibility considered in the CORSIA standard, the certified final GHG reductions could potentially be much better than the ones shown above by using the default values.

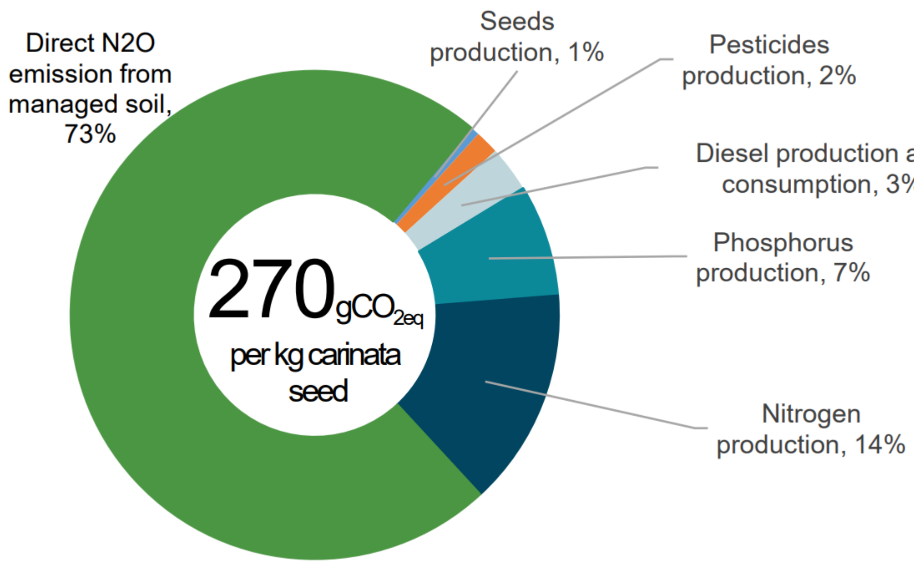


Figure 12. Summary of life cycle greenhouse gas emissions for carinata seed production in Ethiopia. From RSB (2022).

Brassica carinata cultivation as a rotational or cover crop may provide co-benefits to soils and agricultural productivity. International experiences from the Americas have also indicated that production of carinata as a rotational or cover crop has additional environmental benefits to soil improvement (nitrogen fixation) and prevent soil loss (Prendez-Rodriguez, 2022; Nuseed, 2024). It also serves as a natural pesticide, helping to control weeds and diseases, particularly in cereal-producing regions such as Oromia and parts of the Amhara region. Additionally, according to researchers in the field, there is potential to utilize drought-resistant varieties that can thrive in the lowlands, where land competition is less intense in Ethiopia (FAO, 2010).

As a secondary crop, Brassica carinata can meet the sustainability criteria required for CORSIA eligible fuels (ICAO, 2022). Should demand for SAF feedstock production become significant, there is a risk that such drivers could encourage agricultural producers to increase production by displacing other land uses. In such a scenario, it would become important to manage and monitor the production of Brassica carinata, and other SAF feedstocks, to ensure that sustainability criteria continue to be met.

2.3.3 Economic and market aspects

Current production of Brassica carinata is limited and production occurs at local scales. To establish a functioning industrial sector, a comprehensive supply chain is needed, which includes seed crushing, oil extraction, storage, and the final refining process for SAF production. Currently, Ethiopia lacks the infrastructure to support the entire value chain for SAF production; however, there is potential to develop some industrial capabilities in response to the increasing international demand.

According to the pre-feasibility study on the Brassica carinata for SAF production (RSB, 2022), the average cost of producing carinata ranges from USD 410 to 580 per hectare. Estimated revenues are between USD 677 and 847 per hectare, accounting for all generated revenues, including byproducts such as the leaves, the cake, etc.). The study highlighted that the cost of production and revenue for Brassica carinata are competitive compared to the global averages for major producers of this crop.

A recent pilot study focusing on three main varieties of Brassica carinata seeds found that production costs at the farm level could range from ETB 60,000 to 100,000 per hectare, which is approximately equivalent to USD 468 to 781, based on an exchange rate of 128 ETB/USD. The study notes that if production is scaled up and includes sourcing from smallholder farmers/outgrowers, costs could increase to between USD 781 and 1,015 per hectare. While this higher production cost may seem significant, it could potentially be reduced to align with the global average through the use of improved seeds, mechanized and commercial farming techniques, and advanced agricultural inputs to increase yields.

According to oil industry experts, the production of carinata could be economically viable if its byproducts, particularly the seed cake, had greater market value, such as for use in animal feed. Currently, the existing variety of carinata has a high toxicity level, making it unsuitable for animal feed or other applications. As a result, the business case for carinata production is currently weak and unappealing to potential investors. To strengthen its viability, it is essential to develop low-toxicity varieties or economically implement effective detoxification processes (e.g., Uddin, 2024). The cake could also be used as a briquette for clean household cooking.

Scaling up Brassica carinata in Ethiopia must address challenges related to the prevalence of smallholder farmers in the country's agricultural sector – such challenges are generally applicable to Ethiopia's agricultural sector and are discussed in a wider sector context in 1.5. Small landholdings and fragmented production systems make it difficult to achieve economies of scale required for appropriate mechanization, irrigation, and supply of inputs. Further, market access and value chain development for oilseed crops remain underdeveloped, which restricts incentives for farmers to invest in carinata as a new crop.

Increased agricultural activity for SAF feedstock production, including of Brassica carinata, is expected to support socio-economic benefits for agricultural sector stakeholders (see 1.2). A practical example is the cultivation of Brassica carinata. In this case, smallholder farmers can earn additional income by selling the leaves apart from the seeds, while the crop residue can be utilized for fencing and roofing materials (RSB, 2022).

2.3.4 Summary

Key opportunities:

- There is over 29 million hectares of land suitable for farming and agricultural practices, such as crop rotation with Brassica carinata. This, along with growing interest from investors, is crucial. The potential of carinata as a rotational crop alongside barley and wheat offers an opportunity for large-scale production. However, further research is needed to assess its economic viability and integration with food production.
- The potential demand for sustainable oily feedstock markets from international sustainable aviation fuel (SAF) developers is promising, as demand and production for SAF will predominantly rely on HEFA-derived fuels until 2035.
- Brassica carinata is cultivated as a secondary crop and can meet the sustainability criteria under CORSIA, offering an opportunity to attract investment.

Key challenges:

- The competition for land suitable for agriculture, particularly for cereal production, is increasing.
- Scalability of production must address challenges associated with small and fragmented landholdings and associated lack of access to appropriate mechanization, irrigation, and supply chain/markets.
- Current production of Brassica carinata is limited and production occurs at local scales. Establishing a supply chain and scaling up production would be necessary.

- The Brassica carinata market is unstable due to limited market linkages and underdeveloped biofuel production. Additionally, production volumes fluctuate significantly as it is primarily cultivated by smallholder farmers, which creates uncertainty and market volatility.

2.4 SUGARCANE MOLASSES

2.4.1 Feedstock-related information

Sugarcane and molasses are common feedstocks for the production of ethanol. Brazil is the largest ethanol producer globally by this pathway, producing nearly 33 billion litres in 2023 (USDA, 2023).

Sugarcane is cultivated domestically in Ethiopia, with annual sugar production ranging between 0.29 and 0.40 million tonnes per year (FAOSTAT, 2025b). Sugarcane is processed in seven factories, with a total crushing capacity of 59,250 tonnes of sugarcane per day. Actual capacity utilization is approximately 10% of the design capacity. Ethiopia aims to expand sugar production in the near future, towards self-sufficiency by 2028 (ENA, 2023). This plan entails growing domestic production to 3 million tonnes from current production of 360,000 tonnes and would result in greater utilization of current capacity.

In Ethiopia, ethanol is currently produced from the molasses co-product of sugar refining. Ethanol production capacity exists at the Metehara and Finchaa Sugar Factories, with respective capacities 12.5 million litres and 20 million litres ethanol per year (Ethiopian Sugar Industry Group, 2023a; Ethiopian Sugar Industry Group, 2023b). Actual production of ethanol is lower than the design capacity, declining from peak capacity factor in 2014/2015 (2007 E.C.) of 57% to 25% in 2018/19 (2011 E.C.) and below 10% in 2022/23 (2015 E.C.) (Figure 13). Competition for molasses has increasingly diverted this feedstock from ethanol production to the beverage sector, with corresponding reduction in ethanol output. Additional competitive uses exist, including as animal feed, which could further constrain current limited molasses availability for ethanol production. If domestic sugar production is increased to meet self-sufficiency targets, substantially more molasses would be available for ethanol production (and competing uses) in the future.

Current ethanol production is marketed as a beverage, and for use as a transport fuel and cooking fuel. As a transport fuel, ethanol can be blended with gasoline in blends up to 10% ethanol by volume. Over the decade 2009 to 2018, approximately 64 million litres was utilized in this manner, reducing the cost of fuel imports by approximately 50 million USD (Yimam, 2022). However, a lack of competitiveness with other markets for molasses and ethanol resulted in termination of its use in blended fuels after 2017. Other factors that contributed to the limited success of ethanol use in transport include the limited ethanol production capacity (at Metehara and Finchaa sugar factories only), reliance in some cases on older technologies with low efficiency, and to some extent social unrest in the regions. Further, there are ambitions to utilize ethanol as a cooking fuel, although progress in encouraging the shift from kerosene fuels has been slow (RSB, 2021; ECCA, 2020). SAF production via ATJ is a potential competitor with beverage and other energy applications of ethanol.

Byproducts of sugar and ethanol production could be considered for their potential as SAF feedstocks. Bagasse, the fibrous residue that remains after crushing sugarcane for juice production, could be utilized as a "second generation" feedstock for ethanol production. This could be done either via gasification and Fischer-Tropsch synthesis, or by first converting cellulose and hemicellulose fractions to sugars and subsequently fermenting to ethanol. It is technically more challenging to produce ethanol from bagasse, requiring enzymatic, chemical, and/or thermomechanical pre-treatment to liberate sugars from the feedstock's lignin structure. Bagasse, however, is commonly used for power generation to provide the energy needs of sugar factories and to export surplus generation to neighbouring customers. Electricity generation from bagasse is already undertaken at Finchaa Sugar Factory (31 MW power generation capacity, of which 21 MW is available for export) and Metehara Sugar Factory (9 MW power generation). Committed plants for power generation at Beles, Wolkayit, Omo Kuraz, and Kessem facilities will total an additional installed capacity of 342 MW (EAPP, 2014).

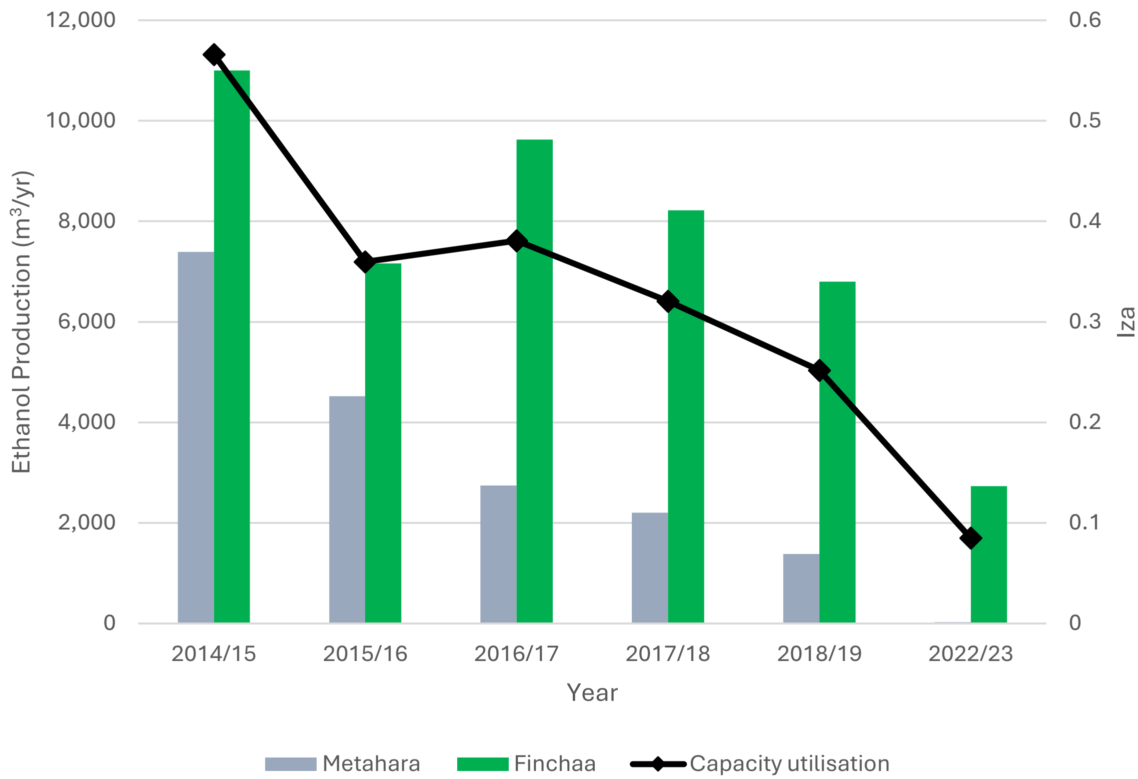


Figure 13. Recent ethanol production statistics at Metahara and Finchaa Sugar Factories. Data from Yimam (2022) and Ethiopia Sugar Industry Group (personal communication).

A second byproduct with potential as a SAF feedstock is carbon dioxide (CO_2) arising from ethanol fermentation process. Recovery of CO_2 from fermentation requires dehumidification but can avoid more costly and energy-intensive processes needed to recover CO_2 from flue gases where it is mixed with air and other combustion products. A key challenge to utilization of fermentation CO_2 is the scale of availability. At design capacity of 20 million litres ethanol per year, the Finchaa Sugar Factory would produce 15,100 tonnes CO_2. This quantity of CO_2 would be insufficient to supply a commercially viable e-fuels facility on its own, with a production potential of approximately 3,600 tonnes distillate fuel per year (of which SAF would be approximately 720 tonnes) far below the expected capacity of future facilities of ~ 800,000 tonnes per year (1 billion litres per year) (ICAO, 2023).

2.4.2 Sustainability aspects

As a coproduct of sugar production, molasses can meet the ICAO CORSIA sustainability standard. Sugarcane is a crop-based biofuel feedstock, and so environmental risks exist in its production related to occupation of land, input of agri-chemicals such as synthetic fertilizers, herbicides and pesticides, and consumption of water for irrigation.

The expansion of ethanol production would necessitate a shift of land use to sugarcane cultivation from its current status, and care must be taken to ensure this shift did not create unintended negative impacts, such as indirect land use change (ILUC), socio-economic impact on communities where land use is taking place, water consumption, and biodiversity consequences. Crop-based feedstocks can be entitled to a zero ILUC value, provided that approaches are met to demonstrate a low risk of negatively impacting land use. This can be done by demonstrating a yield increase, through improving agricultural practices, intercropping or sequential cropping methods, or improving post-harvest losses. Alternatively, utilization of previously unused lands, such as marginal lands, underused or unused lands, degraded pasture, and land in need of remediation can demonstrate a low risk of ILUC. Land occupation for biofuel production can also impact biodiversity on site, and prior studies have identified a risk to certain species from the historic and projected expansion of sugarcane cultivation in Ethiopia (Degefa, 2019; Semie, 2019).

Water consumption is potentially significant for sugarcane cultivation, as rainfall is not sufficient to meet plant needs. Fito et al (2017) estimated the water footprint of sugarcane cultivation and ethanol production for the Metehara facility, finding a statistically higher water use than global average, exceeding water use intensity of sugarcane and ethanol production in major producing regions such as Brazil. Kedir (2022) evaluated irrigation practices in the Awash basin (supplying Metehara and Wonji Sugar Factories), finding a diversity of irrigation practices and potential to improve water productivity through application of best practices across the area. A study of the Kuraz irrigation scheme area found a majority of land highly suitable for sugarcane production but note a need to manage risk of water use, soil degradation, and displacement of current land uses (Haile, 2025).

Sugarcane-derived SAF has the potential to be low-GHG, with CORSIA default life cycle emissions of 24.0 gCO_2 per MJ SAF and 24.1 gCO_2 per MJ SAF when produced via isobutanol and ethanol, respectively (ICAO, 2024). Including global ILUC values would increase emissions by 9.1 gCO_2e/MJ SAF and 8.5 gCO_2e/MJ SAF, respectively, although ILUC estimate specific for Ethiopia is not available. A small number of life cycle assessment studies have been conducted for ethanol production from sugarcane in Ethiopia. These found emissions to range between 35 gCO_2e/MJ ethanol and 57 gCO_2e/MJ ethanol (Gabisa, 2019; Desta, 2022). Neither study considered ILUC impacts, nor the further processing of ethanol to SAF. However, these results do indicate that the production of ethanol in Ethiopia may entail greater GHG emissions savings than anticipated in the CORSIA default values, although a more rigorous review and evaluation in line with CORSIA LCA methodology would be required to reach firm conclusions.

2.4.3 Economic and market aspects

Ethanol production cost is dependent on the cost of sugarcane supply, scale of production, and integration with sugar production. Limited data on ethanol production costs in Ethiopia are publicly available, with key data provided by Ethiopia Sugar Industry Group (Table 9). Ethanol production at the Metahara Sugar Factory was less than 1% of design capacity, with a cost of ETB 185 per litre (Metahara Sugar Factory). At higher outputs, it could be expected that ethanol production costs would decrease, due to more efficient use of capital equipment and fixed operating costs.

The reported 2023 production cost data is equivalent to USD 842 per tonne ethanol (Finchaa) and USD 4,296 per tonne ethanol (Metahara) at the June 2023 average exchange rate (54.58 ETB/USD). Both values are high relative to wholesale ethanol world market prices, which ranged from USD 290 to 550 per tonne between 2020 and 2023 (OECD, 2024). However, recent currency devaluation has seen the value of ETB decline significantly relative to the USD. Converting the 2023 production cost data using recent exchange rate of 133.3 ETB/USD (1st June 2025) results in substantially lower prices that could be in line with wholesale world market prices. It is not clear how production costs will have changed since 2023, for example, if costs of inputs have risen due to currency devaluation. Ethanol feedstock costs represent approximately 75% to 85% of total operating costs for SAF production, and so ensuring ethanol production cost is competitive is important for the viability of the ATJ pathway.

Table 9. Summary of key cost data on sugarcane cultivation and ethanol production.[7]

	Unit	Omo Kuraz 1-3	Omo Kuraz 2	Finchaa	Metehara	Wonji
Sugarcane cultivation, per area cultivated	ETB/ha USD/ha (2023) USD/tonne (2025)	68,706 1,259 515				
Sugarcane cultivation, per output of sugarcane	ETB/tonne USD/tonne (2023) USD/tonne (2025)	1,501 27.50 11.26	2,363 43.29 17.73	1,400 25.65 10.50	1,149 21.05 8.62	1,914 35.07 14.36
Ethanol production	ETB/L USD/L (2023) USD/L (2025)			36 0.66 0.27	185 3.39 1.39	
Ethanol production	ETB/tonne USD/tonne (2023) USD/tonne (2025)			45,970 842 345	234,457 4,296 1,759	

It is unlikely that ethanol production from molasses would be sufficient to supply domestic SAF production on its own but could still represent a significant production of ATJ feedstock and enable Ethiopia to participate in the SAF value chain (Table 10). The ICAO SAF Rules of Thumb (ICAO, 2024) for a SAF facility anticipate commercial production at 1,000 million litres distillate fuels per year (700 million litres SAF), requiring an input of 1.3 million tonnes of ethanol per year. Ethanol production capacity at the Metehara and Finchaa facilities, which total 25,600 tonnes per year, is at 2% of this expected scale. If Ethiopia achieves self-sufficiency in sugar production, an additional 430,000 tonnes molasses per year could be generated[8]. Ethanol production from this additional molasses supply could total approximately 86,000 tonnes per year of feedstock, requiring expansion from current ethanol production capacity. This could potentially achieve ethanol output at 7% of the expected scale required for a large SAF facility.

Economies of scale are essential for scaling up of sugarcane production, requiring larger, consolidated land areas, irrigation infrastructure, and significant upfront investment. As a result, sugarcane production in Ethiopia has historically been dominated by state-owned and commercial plantations, supplemented with outgrower schemes to increase supply by smallholder production.

A recent techno-economic analysis investigated the economic viability of SAF production from sugarcane molasses in Ethiopia considered smaller scale facilities, from 2,000 barrels distillate fuel per day (approximately 115 million litres fuel output per year) to 6,500 barrels per day (approximately 380 million litres fuel output per year) (World Bank, 2025b). Minimum fuel selling prices were found to range from 2.30 to USD 2.60 per litre, exceeding market prices for conventional fuel in Ethiopia (USD 1.30 per litre) and the 2024 average world market price for SAF (USD 1.83 per litre). The smallest scale facility exceeds what could be supplied if considering only additional molasses arising from planned expansion of domestic sugar production, and so production cost would likely be higher than this range under such a feedstock supply scenario.

[7] Data provided by Ethiopian Sugar Industry Group, for production in year ending June 2023. Cost data are converted to USD equivalent based on June 2023 average exchange rate (54.58 ETB/USD) and more recent June 2025 exchange rate (133.3 ETB/USD).

[8] Calculated with data from Ethiopia Sugar Industry Group, based on molasses yield of 4% and average sugar yield of 8% on sugarcane input.

Table 10. Summary of existing ethanol production capacity and recent utilization (2023). Data from Ethiopian Sugar Industry Group.[9]

Year	Finchaa (20 million L/year capacity)	Metahara (12.5 million L/year capacity)	Total (32.5 million L/year capacity)	Feedstock supply potential for AtJ SAF facility[5] (%)
Annual ethanol production (million L/year) (% capacity utilization)				
2014/15	11.0 (55%)	7.4 (59%)	18.4 (57%)	1.1%
2015/16	7.2 (36%)	4.5 (36%)	11.7 (36%)	0.7%
2016/17	9.6 (48%)	2.7 (22%)	12.4 (38%)	0.8%
2017/18	8.2 (41%)	2.2 (18%)	10.4 (32%)	0.6%
2018/19	6.8 (34%)	1.4 (11%)	8.2 (25%)	0.5%
2022/23	2.7 (14%)	0.03 (<1%)	2.8 (8%)	0.2%

2.4.4 Summary

Key opportunities:

- Ethanol production is an established industry, with significant production capacity in country.
- Ambitions to achieve sugar production self-sufficiency would greatly increase availability of molasses feedstock.

Key challenges:

- Competing uses for beverage industry, and in future potentially for animal feed.
- Current ethanol production costs are high relative to global wholesale averages, although this is uncertain due to recent currency exchange fluctuations.
- Reliance on molasses as the sole feedstock is unlikely to achieve scale required for economically viable SAF production.

2.5 MUNICIPAL SOLID WASTE

2.5.1 Feedstock-related information

Municipal solid waste (MSW) is a diverse feedstock, with variable inputs and, in general, limited data availability for estimating SAF production potential. Estimates regarding the quantity of MSW generated, its composition, and its distribution across Ethiopia are available from prior surveys and studies (e.g., JICA, 2024; Gebrekidan, 2024; EPA, 2025).

The availability of MSW is correlated to population, with the largest quantities found in Addis Ababa. Waste in the city is aggregated at sub-city level prior to transport to final disposal sites from transfer depots (see Figure 14).

[9] Assuming a 1,000 million litres distillate fuel facility, requiring 1.3 million tonnes ethanol per year as feedstock input, based on SAF Rules of Thumb (ICAO, 2024).

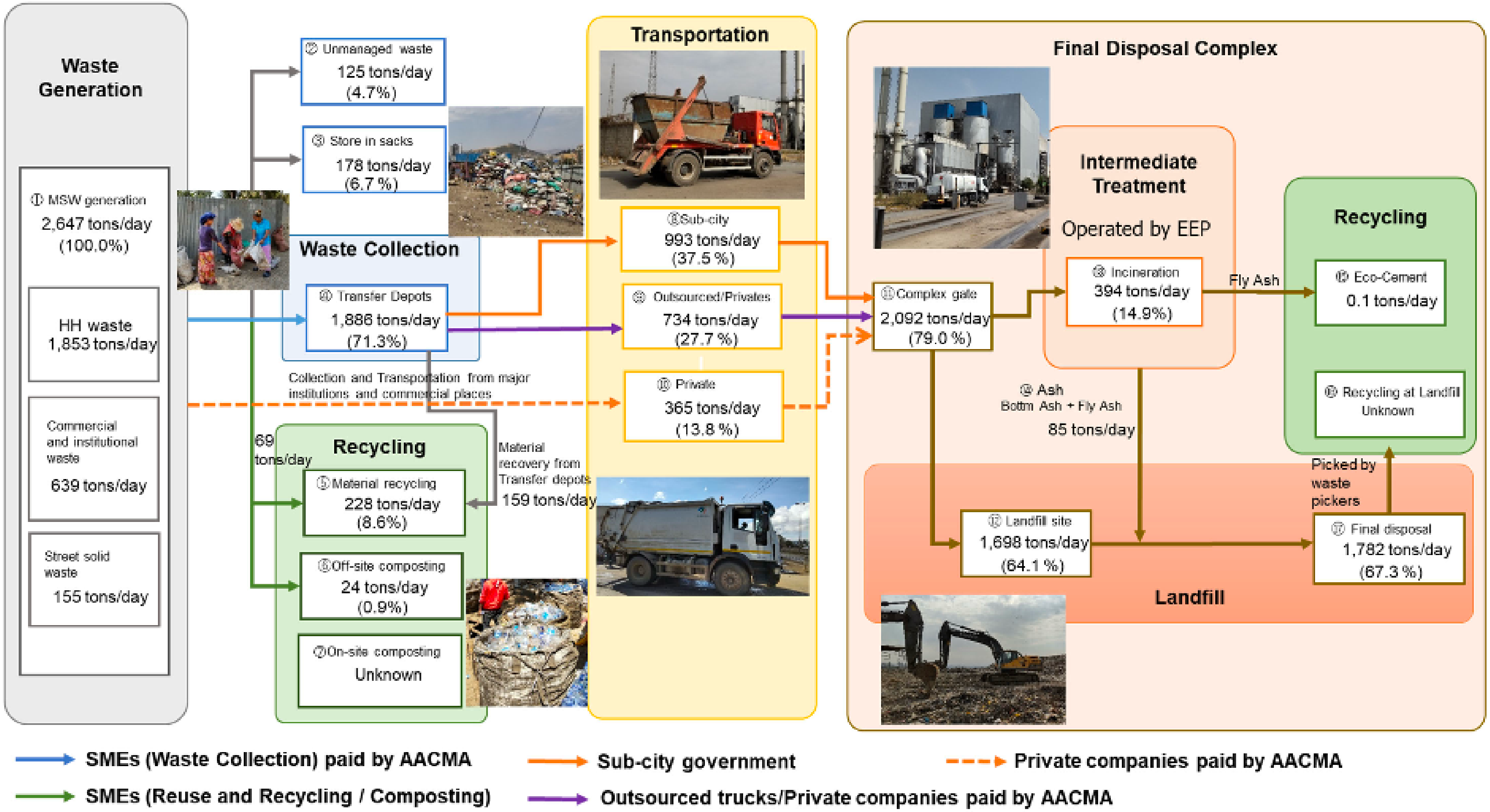


Figure 14. Mass flow of waste in Addis Ababa 2022/23 to final treatment. From JICA (2024).

A portion of the waste is sent for intermediate treatment via incineration at the Reppe Waste to Energy (WtE) facility, located at the Koshe landfill site. The Reppe facility, in operation since 2019, has a capacity of 1,400 tonnes per day and can generate up to 50 MW of electricity. However, actual utilization of the WtE facility is far below its capacity, due to operational and safety management issues (JICA, 2024) as well as the low calorific value of MSW inputs, which results in high running costs. In 2022, only 22% of collected waste was incinerated. The vast majority of waste is ultimately disposed of via landfilling at the Koshe site, the only operating landfill serving Addis Ababa. The reported rates of material recycling and composting are low, at 9% and 1% respectively (calculated from JICA (2024)).

Nationally, there is significant availability of MSW in cities and major regional towns, although data on the quantities and composition of this waste stream is inherently uncertain. Gebrekidan et al (2024) conducted a systematic review of MSW in Ethiopia based on published information, finding an average MSW generation rate of 0.38 kg per person per day (ranging from 0.18 kg to 0.55 kg). A higher per capita waste generation rate of 0.67 kg per person per day is reported in Addis Ababa by Ethiopia EPA (EPA, 2025). Table 11 shows the annual solid waste generation in the country (EPA, 2025). The biogenic fraction of waste is found to be 73% on average, ranging from 51% to 92.8% (Gebrekidan et al., 2024). Collection practices vary across the country, with low rates of formally collected waste in some cities and limited capacity for waste sorting and formal management. Overall, 31.8% of waste in Ethiopia is reported as being collected (Gebrekidan et al., 2024).

Table 11. Annual solid waste generation in regional cities in Ethiopia. Data from EPA (2025).

City / town	Annual solid waste generation (tonnes per year)
Addis Ababa	985,537
Asella	150,000
Hawassa	98,428
Shashamane	86,870
Bahir Dar	82,954[10]
Adama	82,839
Bule Hora	67,058
Dire Dawa	65,459
Wolaita Sodo	29,398
Dilla	25,740
Hosaena	25,598
Gambela	14,515
Ambo	13,284
Butajira	9,702
Arba Minch	7,001
Asosa	1,423

Landfilling of organic materials results in the generation of methane-rich landfill gas. Methane is a potent GHG with a global warming potential approximately 30 times that of carbon dioxide over a 100-year time frame. Reducing the landfilling rate is a current policy objective in Addis Ababa's waste management strategy. As outlined in the Ten-Year Development Plan 2020/21 - 2030/3, enhancing the recycling and reuse of waste, along with the use of incineration to avoid waste disposal are key strategic priorities. A central goal is to divert all waste to WtE facilities, maximizing the generation of useful energy from MSW in the city.

SAF production from MSW could align with future WtE ambitions, as a higher value route to utilizing waste as a feedstock. Given that Ethiopia benefits from significant renewable electricity resources with potential for future expansion (see 1.6), production of higher value SAF from MSW could be a preferred use of this limited feedstock over electricity generation. Other alternative uses of MSW should be considered, for example using mixed waste to produce refuse-derived fuel (RDF), for use in cement production. Such opportunities may compete with SAF production even over the longer term.

MSW is a challenging feedstock due to its heterogeneous nature, which often needs pre-treatment/sorting and drying to meet input specifications for conversion processes. Advanced gasification technologies for SAF production from MSW are not yet in commercial operation, with a technology readiness level (TRL) estimated between 6 and 8 (Knowledge Transfer Network, 2021), where TRL9 indicates full commercial deployment.

[10] Calculated by authors based on provided per capita waste generation rate.

De-risking SAF production from MSW requires demonstrating feedstock processing and gasification technologies that can consistently produce clean syngas suitable for downstream synthesis. This would also support the development of a supply chain for MSW collection, aggregation, and pre-gasification processing — providing valuable insights into the requirements, opportunities, and challenges of sourcing significant quantities of MSW for fuel/energy production.

2.5.2 Sustainability aspects

Diverting MSW from landfilling and uncontrolled dumping would mitigate significant pollution and health risks associated with current waste management. In Addis Ababa, approximately 75% of waste is currently disposed of in open landfills. Waste diversion is aligned with the city's broader waste management ambitions and supports environmental objectives to improve urban living conditions and reduce GHG emissions.

Positioning MSW as a feedstock for SAF production, could also incentivize more formalized collection. According to available data, an average of 68% of waste generated in Ethiopian cities and towns is ultimately disposed of through illegal dumping (Gebrekidan et al., 2024).

SAF production from MSW sources can be characterized by low GHG emissions, provided that the waste's carbon content is predominantly biogenic. Based on reported MSW composition in Addis Ababa (JICA, 2024) and standard assumptions regarding the carbon content of various waste fractions, the non-biogenic carbon content is estimated at 53%. Applying the CORSIA default life cycle assessment methodology would result in GHG emissions of approximately 96 gCO_2e/MJ for SAF derived from unsorted MSW, higher than the 84.5 gCO_2e/MJ associated with conventional jet kerosene (ICAO, 2024). Therefore, meeting CORSIA's emissions reduction requirements would require sorting MSW to create a feedstock richer in biogenic material. Waste pickers may already be conducting informal sorting at the landfill, recovering an unknown volume of recyclable materials. This would potentially reduce the fossil carbon content of waste available for SAF production, and lower its life cycle GHG emissions, depending on how extensively plastics are recovered by the waste pickers.

2.5.3 Economic and market aspects

Household MSW waste collection in Addis Ababa is financed by the Addis Ababa Cleansing Management Agency (AACMA). Recent data indicate MSW collection cost at sub-city level of ETB 880 per tonne (USD 6.40), and transport cost to landfill of ETB 426 per tonne (USD 3.40). It remains unclear if a SAF production facility using MSW as feedstock would be responsible for these collection costs.

Diversion of MSW to SAF production could avoid current landfill disposal costs. Landfilling costs in Addis Ababa are reported at ETB 218 per tonne (USD 1.70), which currently offers little financial incentive to divert waste from landfill.

The AACMA manages the collection of approximately 2,650 tonnes MSW per day in Addis Ababa, while total MSW generation in the city is estimated at 3,300 tonnes per day. This represents a high waste collection rate of approximately 85% (JICA, 2024), limiting potential increases in available MSW through improved collection schemes in the city. A recent techno-economic analysis has assessed the SAF production potential and associated costs with MSW in Addis Ababa (World Bank, 2025b). Diverting all currently landfilled waste to SAF production could produce 1,781 barrels of SAF per day, or approximately 80,000 tonnes per year. However, the estimated minimum selling price of SAF via FT is estimated at USD 3.50 per litre—nearly double the global average SAF price in 2024 (USD 1.83 per litre).

As Ethiopia's largest city, Addis Ababa is the primary source of MSW and therefore offers the greatest potential scale for SAF production. MSW availability in other cities and towns is significantly lower, so commercial-scale SAF production may require aggregation of supply from multiple sources. Given the high moisture content of MSW, it could be advantageous in this case to pre-process the feedstock prior to transport to a SAF production facility. The additional cost of waste transport, and the need for decentralized pre-processing facilities, would negatively impact the financial viability of SAF production.

2.5.4 Summary

Key opportunities:

- Waste to SAF aligns with waste management and climate change strategies.
- Improving collection rates, reducing illegal dumping, and diverting waste from landfill offer significant environmental and GHG reduction benefits.

Key challenges:

- Limited and inconsistent data on waste composition creates uncertainty in assessing feedstock potential.
- Current focus on WtE for electricity generation, may limit MSW for SAF in the short- and medium-term.
- High technological risk due to the complexity of gasifying heterogeneous MSW.

2.6 CASTOR SEED

2.6.1 Feedstock-related information

Castor seed is an oilseed crop recognized as a potential feedstock for SAF, provided it meets ICAO CORSIA sustainability criteria. The Ethiopian SAF roadmap also identifies castor as a promising SAF feedstock in the country (RSB, 2021). Castor is a non-food oilseed used for industrial purposes, similar to coconut and linseed. It has an oil content of approximately 50%, with a seed yield of 3 tonnes per hectare, and it has the potential for even higher yields (EIAR, 2008).

It is considered a valuable source of biodiesel, as it does not compete with food production and contributes to emissions reduction. Additionally, castor has traditional uses in medicine and lighting. In Ethiopia, it grows annually in the lowlands and as a small perennial tree in the highlands (Alemaw et al, 2016). It is often used as a boundary or fencing plant and can be found in hedgerows, along stream banks, and beside roads as a wild oilseed. It is also intercropped with maize and sorghum in cultivated fields.

Castor seeds achieve optimal yields in areas with 600-700 mm of annual rainfall. The plant is drought-tolerant and can grow with limited water once established, as long as there is adequate moisture during the flowering period. It is well adapted to warm, tropical to subtropical climates, thriving in temperatures between 20-26 °C and under clear, sunny conditions. However, castor is highly susceptible to waterlogging and requires well-drained, medium-fertility soils. While the plant shows vigorous growth in fertile soils, it also responds well to fertilization in less fertile environments. The crop is primarily cultivated in the Rift Valley Oromia region, which holds the largest share of suitable land for castor cultivation (42.5%), followed by the Benishangul-Gumuz region (15.93%), the SNNP region (14.72%), and the Amhara region (11.96%) (RSB, 2021).

The production of castor seeds in Ethiopia has been inconsistent and largely seasonal. Significant investment in biofuels occurred during the 2007/08 fuel price crisis, leading to a global increase in demand for biofuels. Ethiopia's 2007 biofuel development strategy identified castor seeds as a potential feedstock, attracting interest from numerous international investors. Three main companies attempted to produce biodiesel at a pilot level, but their efforts have not scaled up. The primary feedstock used by these companies for biodiesel production is Jatropha and castor. The main companies involved in these attempts are the Africa Power Initiative (API), Bati Biofuel Development, and Atrif Alternative Energies (RSB, 2022). However, once fuel prices stabilized, the biofuel sector struggled to establish a viable business case, leading to a slowdown in

activity that has persisted since. Only a few trials were conducted, but these did not progress or scale up beyond pilot scale (RSB, 2022).
Research on castor in Ethiopia dates back to the 1950s, with several improved varieties developed by national research institutes over the years. Studies indicate that castor seed tolerates moisture and can thrive in the lowlands of Ethiopia, even in high temperatures. Additionally, perennial castor can be cultivated as hedges and shelters for animals. One early study by the Ethiopian Institute of Agricultural Research (EIAR) reported the highest seed yield of 3.3 tonnes per hectare and an oil content of 59% at Arbamich (EIAR, 2008).

The average yield of castor per hectare has improved with the introduction of more advanced varieties from research institutes, typically ranging from 0.5 to 1.5 tonnes per hectare, with an oil content of 49%. The castor variety known as 'Hiruy,' cultivated in the Rift Valley, has shown yields of 1.5 tonnes per hectare with similar oil content (Alemaw et al., 2013). A more recent trial conducted by the private sector company Agropeace Bio Ethiopia Plc reported a significantly higher yield of 6 tonnes per hectare in the Somali region. However, the details of this trial are not publicly available, and so the growing conditions under which such high yield was achieved and the potential to replicate high yields cannot be verified.

2.6.2 Sustainability aspects

Castor oil has the potential to qualify as a feedstock for SAF under the CORSIA program, through production on marginal arid lands and thereby avoiding competition with food production. It has demonstrated compliance with ASTM D7566 specifications, making it suitable for use as a drop-in fuel (Seber et al., 2022).

Life Cycle Assessment (LCA) results for the HEFA production pathway indicate a significant reduction in GHG emissions, with a carbon intensity of 39.5 g CO_2e/MJ (see Figure 15), well below the CORSIA baseline of 89 g CO_2e/MJ. This represents a reduction of more than 55%, exceeding the minimum 10% emission reduction threshold established by CORSIA (Seber et al., 2022).

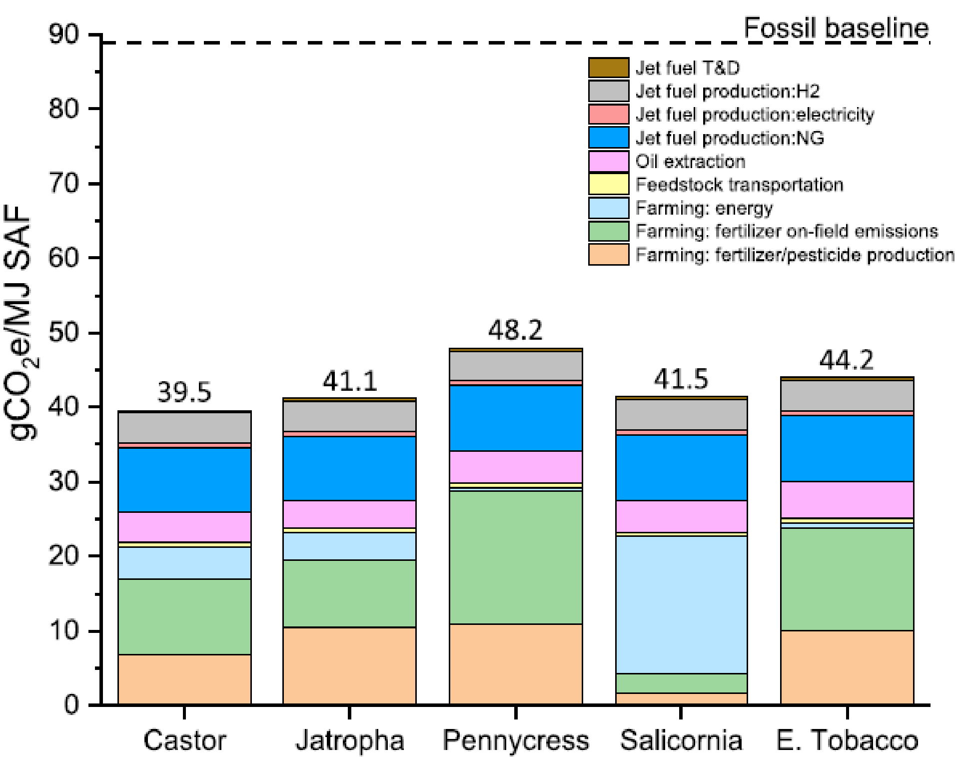


Figure 15. GHG emissions of oilseed-HEFA pathway (Seber et al., 2022).

As illustrated in Figure 15, castor is identified as a promising feedstock with lower GHG emissions, alongside other crops like Jatropha, Pennycress, and Salicornia. In terms of land use, castor can be produced without competing with food crops, as it can grow in dry climates and less fertile soils, including as hedges. In the highlands of Ethiopia, where cereal production is high, castors can serve as an alternative rotational crop in areas where sorghum, teff, and haricot beans are the primary crops (Alemaw, 2013).

2.6.3 Economic and market aspects

Castor production and processing remain undeveloped in Ethiopia. While some small-scale pilot trials of castor oil production have been conducted, these efforts did not progress or scale up.

Current price for castor seed ranges between USD 1.48 and 2.89 per kg while castor oil wholesale prices range between USD 5.46 and 8.46 per kg according to market research (Selina Wamucci, 2025). The relatively high cost of castor feedstock translates to a significant increase in the production cost for SAF derived from castor oil: at a yield of 83% (ICAO, 2023), these prices represent feedstock cost of USD 6,600 to 10,200 per tonne SAF, which is uncompetitive with HEFA SAF production cost estimates of approximately USD 1,600 per tonne (Department for Transport, 2024). Experts involved in castor seed exports in Ethiopia report prices around 1 USD per tonne; no price estimate is available for castor oil production in the country. The HEFA pathway for SAF production requires large quantities of feedstock oil, further elevating the overall economic costs. As a result, the high price of castor feedstock makes SAF production using castor less competitive compared to using other types of oil. Moreover, competition for feedstock from industries such as cosmetics and pharmaceuticals has contributed to rising prices of castor beans in Ethiopia. Despite challenges in seed collection and the lack of structured supply chains, several actors are actively sourcing seeds from smallholder farmers for export.

Given the lack of an established castor production industry, analysing the country's economic and market aspects is challenging. General challenges facing development in Ethiopia’s agricultural sector related to fragmented landholdings, limited access to inputs and appropriate mechanization, and underdeveloped supply chain infrastructure (see 1.5) would also apply to castor production. However, the feedstock holds significant promise, and further research is needed to fully understand its potential. Adopting a regional approach to SAF production could unlock substantial export opportunities, particularly to neighbouring countries with existing biorefinery infrastructure.

2.6.4 Summary

Key opportunities:

- Castor thrives in marginal lands of the Asosa and Somali regions, which require moderate to low rainfall. This area is suitable for cultivation since there is less competition for food production.
- The global market for castor oil is expanding, creating opportunities for castor seed exporters such as farmers in Ethiopia.
- Castor has a relatively low carbon footprint, supporting global decarbonization requirements.

Key challenges:

- The supply chain is unstructured, and production is fragmented across various locations in the country.
- Limited facilities exist for castor oil extraction and refining.
- Low awareness of castor oil’s market potential across applications hinders production growth and investment.

2.7 ELECTRICITY-BASED FUELS

2.7.1 Feedstock-related information

The production of electricity-based fuels (e-fuels, or e-SAF in the context of aviation fuels), also referred to as Power-to-X (PtX) requires a carbon source, in the form of carbon dioxide (CO_2) and/or carbon monoxide (CO), and hydrogen. CO_2 can be captured from point sources, where industrial processes such as electricity generation and cement manufacture generate large quantities of CO_2 at a high concentration. Alternatively, CO_2 can be captured from the air using direct air capture (DAC), an emerging technology that extracts CO_2 directly from ambient air. Point-source capture is more energy-efficient due to the higher CO_2 concentration.

Cement production facilities represent potential point sources of CO_2 in Ethiopia. As of 2017, the sector had a production capacity of 13.3 million tonnes per year, with about two thirds of this capacity located around Addis Ababa (World Bank, 2017) (Figure 16). The Lemi National Cement Plant, located in North Shewa Zone of the Amhara Region, was inaugurated in 2024. With a capacity of 15,000 tonnes of cement per day, the facility approximately doubles previous domestic cement production (Addis Insight, 2024).

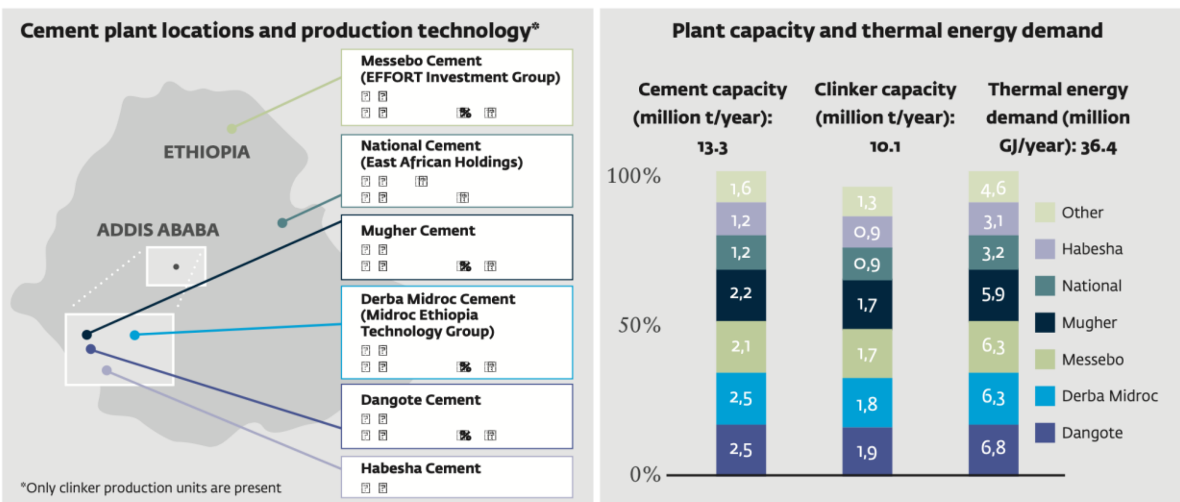


Figure 16. Locations of cement plants and production capacities, as of March 2017 (World Bank, 2017).

Other point sources of CO_2 include ceramics factories, the Reppie WtE facility in Addis Ababa, and ethanol plants. Capture of CO_2 from ethanol facilities can be achieved at high efficiency and low cost, due to the high purity of the stream from sugar fermentation. However, the scale of CO_2 production at ethanol plants is typically too small for economically viable e-fuel production. The largest existing ethanol plant, at the Finchaa Sugar Factory, has a capacity of 20 million litres of ethanol per year, and so could supply only 15,000 tonnes CO_2 per year if operating at full capacity.

While the production of e-SAF is energy-intensive, it can be viable where there is sufficient low-cost, low carbon electricity – needed both for hydrogen production and the fuel synthesis process. Renewable energy sources already provide more than 95% of Ethiopia's electricity supply, dominated by hydropower generation (90%) with a smaller contribution from wind (7%) and an increasing solar, especially in off-grid applications (GIZ, 2023).

Ethiopia benefits from substantial renewable energy potential, and this resource could support e-SAF production. Hydropower capacity is estimated at 45 GW, with 20 GW currently operational (3.7 GW in 2021), 7 GW under construction, and 11 GW projected). Reservoir-based hydropower also supports grid stability, complementing intermittent renewable energy sources such as wind and solar, both of which have estimated technical potentials around 100 GW (EEP 2021). As highlighted in 1.6, the electricity sector is expected to expand rapidly in the near future, to increase grid access and supply growing demands particularly in domestic, commercial and transport sectors, where demand is expected to double by 2030. Growth in electricity generation capacity is expected to be achieved in the near- and medium-term through full commissioning of the Grand Ethiopian Renaissance Dam and the development of additional large-scale hydroelectric projects, with longer-term expansion of generation capacity through solar power (MoWE, 2025). Additional electricity demands related to potential e-SAF production would be additional to these projections.

Beyond e-SAF, Ethiopia is exploring other PtX applications including green hydrogen and green ammonia as a fertilizer. In October 2024, a Green Hydrogen Training Workshop facilitated stakeholder mapping of water and renewable energy inputs for e-SAF and ammonia, SWOT analysis, and milestone planning for technology development. While opportunities include abundant renewable resources and local demand for fertilizers and fuels, key challenges persist: technology costs, water availability, and limited local technological expertise. The Ethiopia National Green Hydrogen Strategy (MoWE, 2024) positions green hydrogen as a driver for green economic growth that can contribute to socio-economic transformation while supporting global climate action efforts. Potential applications include transport (road, shipping, aviation), feedstock for the chemical sector and in particular for nitrogen fertilizers (via ammonia), and energy storage to provide dispatchable electricity. However, significant barriers remain, notably low awareness, lack of technical capacity, and high costs relative to conventional alternatives.

2.7.2 Sustainability aspects

Electricity-based fuels are not included in default life cycle GHG emissions published by ICAO [ICAO, 2024]. Existing studies of e-SAF, however, indicate the potential for very low GHG emissions where renewable electricity is used in hydrogen production and as the energy source for CO_2 capture and fuel synthesis. Recent work published by CONCAWE and Aramco report GHG emissions below 6 g CO_2e per MJ, representing over a 90% reduction compared to fossil kerosene (CONCAWE, 2022).

Under the CORSIA LCA methodology, point sources of CO_2 are treated as waste streams, so zero emissions are attributed to the CO_2 captured for e-SAF production. Emissions from the combustion of e-SAF are also considered zero, based on the assumption that the CO_2 would have been released by the point source anyway if it had not been captured. As a result, those emissions are allocated to the original emitting plant, not to the e-SAF.

Under the European Union’s Renewable Energy Directive III, recently adopted rules for Renewable Fuels of Non-Biological Origin (RFNBO) place limits on the use of fossil-based CO_2. After 2036, fuels derived from CO_2 emitted by fossil-fuel-based electricity generation will no longer be eligible, with this restriction expanding to all fossil CO_2 sources after 2041 (European Commission, 2023). Biogenic CO_2 sources, such as emissions from ethanol refineries, and CO_2 from direct air capture remain eligible under the Directive and could therefore represent a viable long-term option if this pathway is pursued in Ethiopia.

Water demand is a key factor for e-SAF production, as freshwater is required for hydrogen production via electrolysis using renewable electricity sources. Net water consumption is estimated at 0.035 litres per MJ (CONCAWE, 2022). For context, using the CO_2 emissions from the Lemi Cement facility (3 million tonnes CO_2 per year) for e-fuel production would require approximately 870 million litres of freshwater. The implications of this water demand must be carefully evaluated when selecting production sites to avoid depleting freshwater resources or competing with other critical uses such as irrigation.

2.7.3 Economic and market aspects

To illustrate the economic and market aspects of e-SAF production, we consider a hypothetical case where the CO_2 output of the Lemi Cement facility – estimated at 3 million tonnes CO_2 per year – is fully utilized for e-fuel production. This could produce approximately 900 million litres of e-fuels annually, of which approximately 180 million litres would be SAF (144,000 tonnes)[11] (ICAO, 2023). Such a facility would operate at roughly 90% of the capacity of a typical n^{th} plant as defined by ICAO (ICAO rules of thumb) and could meet around 15% of Ethiopia's domestic jet fuel demand in 2023 (US EIA, 2025).

The production of e-SAF requires large quantities of electricity for low-carbon hydrogen generation, CO_2 capture, and fuel synthesis. In the example above, producing 900 million litres of e-fuel annually (180 million litres of SAF) would demand approximately 24 TWh of electricity.[12] This demand exceeds total current grid electricity generation in Ethiopia (15 TWh), which already provides access to only 55% of the population (World Bank, 2025e). Current electricity sector planning (e.g., MoWE, 2025) does not consider potential future e-SAF production. Any such production would need to be developed in a way that does not compromize energy access for households or other essential users.

Compared to other aviation fuels, e-SAF is currently very expensive (see Figure 17). At present, production costs are estimated to be 7 to 10 times higher than fossil kerosene, and 2 to 3 times higher than SAF produced via the HEFA process (ICCT, 2022). Electricity is the primary cost driver, accounting for 50 to 60% or more of total production costs (ICCT, 2022; CONCAWE, 2022). Estimated costs of renewable electricity generation in Ethiopia range from USD 0.024 to 0.142 per kWh for hydropower, and around USD 0.03 and 0.075 per kWh for solar PV and wind power, respectively (GIZ, 2023). These costs are highly competitive against global estimates, in particular for solar and the lower end of hydropower cost range, which are within the lowest quartile of global estimated prices (IEA, 2020).

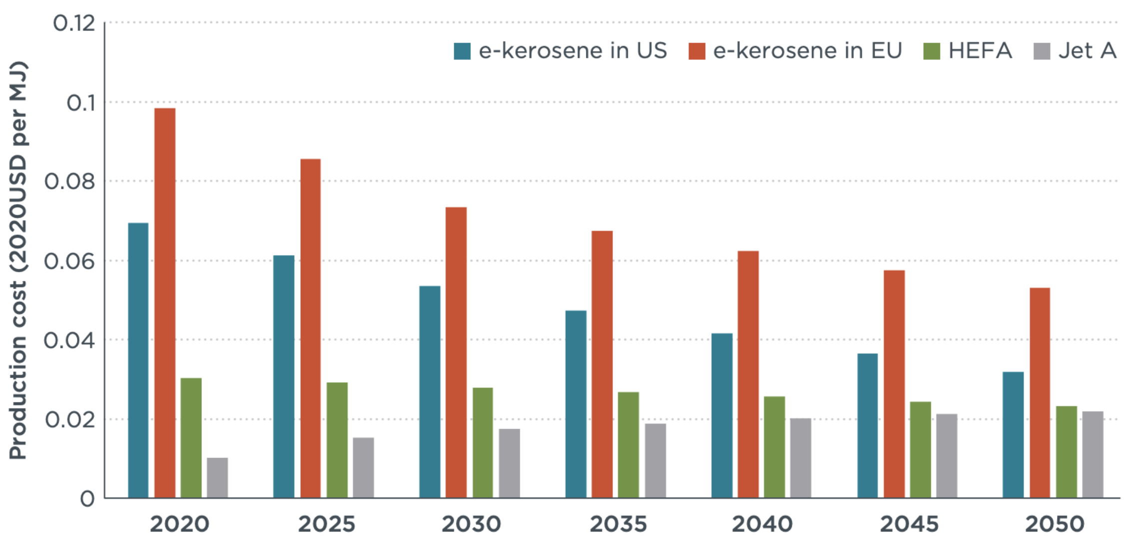


Figure 17. Estimated cost of e-SAF (e-kerosene) in US and EU markets, and comparison with HEFA and conventional Jet A kerosene fuels. From ICCT (2022).

Although e-fuel technologies are expected to become more cost-efficient over time, e-SAF is unlikely to become cost-competitive with HEFA or fossil kerosene by 2050 (ICCT, 2022). As such, the commercial viability

[11] Calculated based on ICAO SAF Rules of Thumb

[12] Calculated based on electricity consumption data for e-fuel process (methanol to kerosene) [CONCAWE, 2022]

of e-SAF production, therefore, will depend heavily on the national regulatory context, and potential limitations on production of SAF from other feedstocks and production pathways.

2.7.4 Summary

Key opportunities:

- Availability of large-scale point source CO_2 as feedstock.
- Abundant and potentially low-cost renewable electricity resources.

Key challenges:

- Less mature SAF production pathway, entailing significant technological risk.
- High production costs compared to both fossil kerosene and other SAF production pathways.
- Extremely high electricity demand, exceeding Ethiopia's current total grid electricity generation.

2.8 AGRICULTURAL RESIDUES

Agricultural residues are a potentially significant feedstock for future SAF production in Ethiopia and globally. Estimates of feedstock availability in Sub-Saharan Africa indicate that 40 million tonnes/year of feedstock could potentially be available for SAF production by 2030 (IATA, 2025c). Ethiopia's primary economic activity is agriculture, which employs over 60% of the population, primarily smallholder farmers in rural areas. As a result, there is a substantial amount of agricultural residue available for various uses. Ethiopia has the potential to generate bioenergy (including SAF) from its agricultural residues, such as maize, coffee husks, sorghum, and wheat straw. Significant quantities of agricultural residues arise from the production of cereals, pulses, coffee, and other food crops, with over 57 million tonnes/year potentially available after accounting for technical recoverability (Tolessa, 2023). Residues from cereals production represent the greatest quantity, 46 million tonnes/year, with availability centred in Oromia and Amhara regions. Hypothetical fuel production based on the residue availability estimate of Tolessa (2023) (reported in Table 12) could yield total distillate output of 7,853 tonnes/year. SAF output of 3,927 million litres/year would significantly exceed projected Ethiopia jet fuel demand in 2035, at 1,676 million litres/year (see 1.7.1).

Table 12. Estimated agricultural residue production in Ethiopia and associated distillate and SAF production potential.

Region	Residue production[13] (1,000 tonnes/year)	Recoverable residue[13] (1,000 tonnes/year)	Distillate production potential[14] (1,000 tonnes/year)	SAF production potential[14] (1,000 tonnes/year)	SAF production potential (million litres/year)
Oromia	40,390	26,023	3,539	1,416	1,770
Amhara	25,233	15,319	2,083	833	1,042
SNNP	12,607	9,392	1,277	511	639
Tigray	5,582	3,659	498	199	249
B/Gumuz	1,943	1,517	206	83	103
Sidama	1,438	1,143	155	62	78
Somale	620	507	69	28	34
Harari	104	85	12	5	6
Dire Dawa	55	44	6	2	3

[13] Data on agricultural residue generation and recoverable fraction from Tolessa (2023).

[14] Distillate and SAF yield from agricultural residues by FT process.

Gambela	47	38	5	2	3
Afar	23	17	2	1	1
Total	**88,042**	**57,744**	**7,853**	**3,141**	**3,927**

While there is a significant amount of agricultural residue available for bioenergy purposes, several challenges and limitations hinder the use of this feedstock for SAF production. Similar to the other potential feedstocks, issues such as weak supply chains due to the scattered nature of smallholder farmers and inadequate infrastructure development to support supply aggregation limit the viability of agricultural residues as a SAF feedstock. Competition with other uses—such as animal fodder, rural energy for household cooking, and soil fertility management—is significant and would restrict the viability of these resources as a reliable feedstock for SAF production (RSB, 2021). For agricultural residues to be regarded as a viable feedstock for sustainable aviation fuel (SAF) or any other bioenergy sources, there must be alternative sources of animal feed available beyond these residues. Furthermore, new cooking technologies should be developed to ensure that rural livelihoods are not adversely impacted by competition for these resources.

Utilization of agricultural residues for SAF production faces important technical challenges. SAF production via the FT pathway is less technologically mature than HEFA route from oil feedstocks. Smaller scale pilot and demonstration projects have demonstrated technical feasibility of FT. However, sustained fuel production has not been commercially achieved, with failed projects in Europe and US.

Unlike SAF production from more established bio-based commodities, such as ethanol and oilseeds which can be traded internationally, SAF pathways from agricultural residues lack a saleable intermediate product. This limits the opportunity for early commercialization through exports and, in turn, could constrain investment in the upstream collection, processing and logistics systems needed to grow a domestic SAF value chain.

2.9 SUMMARY OF EVALUATED FEEDSTOCKS

Table 13 summarizes the key findings of the preceding feedstock analysis sections. The “traffic lights” are a qualitative indicator representing the authors’ view on the balance of strengths/opportunities and challenges/risks that are detailed in the feedstock analysis.

Table 13. Summary of evaluated feedstocks

Feedstock / conversion pathway	Feedstock evaluation	Sustainability evaluation	Economic and markets evaluation	Overall
Brassica carinata / HEFA	• Large areas of agricultural land suitable for rotational cropping indicates potential for scale-up.	• Can meet CORSIA sustainability criteria if grown as secondary crop. • Risk of competition for land with food crops.	• Variable production outputs due to limited market linkages. • Reliance on smallholder production makes supply chain establishment challenging.	
Sugarcane molasses / ATJ	• Established ethanol production capacity. • Ambitions for greater domestic sugar production will increase molasses supply, potentially for ethanol production. • Competing uses in beverage industry, and in future for animal feed.	• Ethanol production demonstrated to achieve low carbon footprint. • Expansion of sugarcane cultivation will entail changes in land use with potential impact on water use, biodiversity.	• Current ethanol production costs are high vs global average wholesale price. • Insufficient projected molasses supply scale to support SAF production on its own.	
Municipal solid waste / FT	• Limited and inconsistent data on waste composition. • Current focus on WtE for electricity generation limits feedstock availability for SAF in near- and medium-term	• Waste use for SAF may improve collection rates, reduce illegal dumping, and divert waste from landfill, with environmental benefit.	• Low-cost feedstock. • High technology risk for mixed waste gasification, fuel synthesis.	
Castor / HEFA			• Expanding global market for castor oil.	

	•Can be produced in marginal lands in Asosa and Somali regions, avoiding competition with food production.	•Comparatively low carbon footprint relative to alternative oilseed crops.	•Low local awareness of market potential hinders production growth and investment. •Limited infrastructure for extraction and refining. •Supply chain is unstructured, and production fragmented across the country.	
e-SAF / FT	•Availability of large CO_2 point source. •Abundant renewable electricity potential.	•Must ensure deployment compatible with water and energy access.	•Renewable electricity globally cost-competitive. •Relatively higher cost vs other SAF options.	
Agricultural residues / FT, A	•Large technical potential, but dispersed and seasonal availability. •Strong competition with existing uses.	•Can be low-GHG. •Risk to rural energy supply, animal feed, soil fertility management.	•Costs for collection, transport and sorting are high. •FT pathway is high technology risk.	

SECTION 3. IMPLEMENTATION SUPPORT AND FINANCING

3.1 IMPLEMENTATION SUPPORT

3.1.1 Feedstock supply chains

The creation of efficient SAF feedstock supply chains, capable of aggregating large quantities of feedstock at low cost, is essential for Ethiopia to participate in the SAF value chain. Existing infrastructure, such as oilseed milling and ethanol production facilities, provides an important foundation for expansion. However, current oilseed milling capacity utilization is low – only 3% to 7% – due to limited oilseed availability and competition from importers (AGRA, 2022). Improving access to agricultural inputs, scaling up smallholder production to achieve greater efficiencies of scale, and developing scalable and sustainable cultivation models are critical to addressing current capacity gaps. Ongoing initiatives aimed at improving agricultural productivity and efficiency (FDRE, 2020) will support future SAF feedstock production by tackling logistics bottlenecks; improving energy access and power reliability; providing inputs, equipment and training; and facilitating the transition of smallholders to medium and large-scale farming.

3.1.2 Fuel production technology transfer, de-risking, and skills development

Ethiopia can leverage its existing experience in biofuel production to advance toward commercial scale SAF manufacturing. In-country capacity exists for ethanol production from molasses, which is relevant to the AtJ pathway. For HEFA, Ethiopia's past experience with biodiesel production—albeit only at pilot scale—provides a foundation to build upon. However, additional refining technologies required to convert feedstock to SAF have not yet been implemented at an industrial scale in Ethiopia. Both HEFA and AtJ production routes require hydrogen inputs. While Ethiopia holds strong potential to become a green hydrogen producer (GIZ, 2023), it currently does not produce hydrogen domestically and imports only minimal quantities annually (World Bank, 2025d).

3.1.3 Fuel blending and certification

All aviation fuels used in Ethiopia are currently imported as finished fuels. There are existing capacity and know-how in the country to store and distribute aviation fuels. However, domestic fuel production would require expanding existing fuel testing capabilities to fully certify the fuels, as current testing is used only to verify testing completed in Djibouti.

3.1.4 Skills development

Implementing a new SAF value chain requires comprehensive skills development across all activities. Starting in agriculture, awareness and training on SAF feedstock opportunities and markets, and associated cropping systems, are essential to promote feedstock production alongside food crops. Building on existing skills in feedstock processing —such as oilseed crushing and ethanol production — is necessary to grow the labour force and scale-up production. Additionally, future SAF production will require skilled workers in refining technologies and fuel testing/certification. Leveraging Ethiopia's public education resources– from agricultural extension services that inform farmers about SAF feedstock cultivation, to universities and research institutions developing improved crop varieties, processing technologies, and innovative business models– is key to realizing the vision of a robust SAF value chain.

3.2 FINANCING

Inward investment in Ethiopia has faced challenges in recent years due to social unrest and currency instability. Investor concerns around security and organizational disruptions inhibit investment. At the same time, severe foreign currency shortages and rapid depreciation of the Ethiopian birr have created barriers to importing equipment, repatriating profits, and maintaining financial stability for foreign investors. Recent data from the Ethiopian Investment Commission indicates that Ethiopia has attracted USD 3.8 billion in Foreign Direct Investment during the 2023/24 Ethiopian fiscal year, which concluded on July 7, 2024. This is a positive sign that Ethiopia is becoming a desirable investment destination. In this section, we will explore both local and international potential financing sources for SAF in Ethiopia.

3.2.1 Domestic financing potential

Ethiopian Investment Holding (EIH)

The Ethiopian Investment Holding (EIH) is a newly established state-owned entity created by the Ethiopian government to drive investments in the country (EIH, 2025). Its mission is to promote national transformation by managing strategic sectors such as finance, infrastructure, energy, logistics, manufacturing, and agriculture. The EIH oversees more than 40 state-owned enterprises and has significant influence in critical sectors, including telecommunications and transportation, with Ethiopian Airlines being one of its key assets. As one of the government's strategic investment arms, the EIH could play a major role in the development of SAF, particularly given its portfolio that includes Ethiopian Airlines.

Development Bank of Ethiopia

The Development Bank of Ethiopia (DBE) plays a crucial role in supporting medium- to large-scale investment projects aimed at fostering economic growth in the country (DBE, 2025). The Bank has financed mega projects in the past to support the transformation and industrialization of the Ethiopian economy. It primarily focuses on projects in the agriculture, manufacturing, and mining sectors. In addition to providing concessional financing, it offers technical assistance to these priority sectors. The Development Bank of Ethiopia could also serve as a key financial resource for the development of SAF feedstock in Ethiopia.

Other potential financing opportunities include the newly established Ethiopian Capital Market, which will provide access to funds once the Ethiopian Securities Exchange (ESX) becomes operational soon. This market will serve as a source of capital raising, among other benefits, which can be directed toward SAF investments. In terms of non-financial support, the Ethiopian Investment Commission (EIC) offers non-financial support to investors by providing services such as business licenses, work permits, and investment permits. The EIC is an autonomous government entity dedicated to encouraging investment in Ethiopia. Recently, the board has adopted a new Directive Proclamation No.1001/2024, passed in March 2024, which liberalizes and allows foreign investors to export, import, wholesale and trade sectors (EIB, 2024). This also provides non-financial incentives for foreign investors interested in SAF projects. Furthermore, Directive, No. 1082/2025, offers detailed guidance on due diligence for foreign investors planning to invest in Ethiopia.

3.2.2 Regional and global initiatives

Regional initiatives provide additional funding and financial support to advance SAF production and use in Ethiopia. The African Development Bank (AfDB), as outlined in its Climate Change and Green Growth Strategic Framework (AfDB, 2023), has developed an action plan to support climate adaptation, mitigation and investment in the green economy across Africa. The AfDB aims to mobilize USD 25 billion in climate finance between 2020 and 2025, maintaining 40% of its financing as climate-related over this period. Key investment priorities for climate mitigation include agriculture/land use, energy, and transport sectors. Relevant initiatives to SAF include: the Sustainable Energy Fund for Africa, which seeks to improve access to renewable energy and efficient energy services; the African Circular Economy Facility to promote circular economy business models; the Africa NDC Hub, to build capacity, finance, and technology development/transfer and support efficient climate mitigation and adaptation actions; and the Africa Climate Change Fund which supports projects targeting greenhouse gas emission reductions and climate resilience across member states.

At the global level, the Green Climate Fund (GCF) supports developing countries' efforts toward climate change mitigation and adaptation. To date, GCF supports 12 projects in Ethiopia, with 399 million USD in total financing (GCF, 2025). These projects focus on addressing investment gaps (in energy, productivity, mobility/logistics), supporting sub-national mitigation solutions, and improving access to energy services.

The World Bank Group's strategy in Ethiopia aligns with fostering inclusive and sustainable growth, with key interventions in education, employment, and access to markets. The World Bank currently manages 37 national projects and 10 regional projects in Ethiopia, with a total commitment of 15.34 billion USD. These projects cover sectors such as agriculture, sustainable land management, energy transport, and trade logistics (World Bank, 2025c).

The European Investment Bank (EIB) launched the Greening Financial Systems Programme, in May 2025, collaborating with the National Bank of Ethiopia and commercial banks (EIB, 2025). The program aims to improve the technical understanding of climate risks, increase climate finance, and develop a green taxonomy for Ethiopia. This initiative may offer further opportunities for financing Sustainable Aviation Fuel (SAF) investments.

SECTION 4. ACTION PLAN

4.1 POLICY AND REGULATORY FRAMEWORK

Ethiopia has pursued a climate-resilient development pathway since 2011, guided by a policy framework aimed at building a climate-resilient green economy. More recently, the national macroeconomic policy has highlighted the importance of integrating a net-zero emissions goal by 2050. A key step in this direction is the launch of the Long-Term Low Emission Development Strategy (LT-LEDS).

With respect to SAF, Ethiopia's SAF roadmap (2021), the updated biofuel strategy (2025), and the Climate Resilient Transport Strategy (2015) provide the foundational policy framework for advancing the SAF agenda. The updated biofuel strategy outlines specific blending targets for bioethanol used for road transport, SAF and clean cooking. It establishes ambitious SAF blending targets of 5% by 2030, which translates to a demand of 52 million litres of local jet fuel, and 20% by 2035 (MoWE, 2025).

As summarized in SECTION 1, there are a wide range of existing policies and strategies present in Ethiopia today that have relevance to SAF, including initiatives to increase productivity while protecting ecology in the agricultural sector, to improved provision of transport and logistics infrastructure, to expand electricity generation and its reliable availability to end-users, and to mitigate greenhouse gas emissions through production and use of domestic, low carbon and renewable fuels. To accelerate progress, it is essential to ensure policy coherence and cross-sectoral alignment enabling the formulation of a targeted SAF policy.

A targeted SAF policy must address key regulatory gaps in certification, blending standards, quality assurance, and establishment of off-take agreements. Such a policy should establish clear targets, mandates, and incentives to facilitate the growth of SAF in Ethiopia. Environmental sustainability and certification, infrastructure development, sustainable feedstock supply, and market development are key components in developing a policy and regulatory framework to accelerate the deployment and production of SAF in Ethiopia.

4.2 CRITICAL SUCCESS FACTORS

4.2.1 Implementation plan for the SAF roadmap and revised biofuel strategy to facilitate SAF production in the country

The SAF roadmap (2021) and revised Biofuel Strategy (2025) have established clear targets for Sustainable Aviation Fuel (SAF) production, along with specific timeframes. It also identifies potential feedstocks and outlines the necessary policy and regulatory frameworks to support SAF production in the country. An implementation plan is needed to translate these strategies into action, encouraging collaboration among policymakers, investors, and innovators to advance SAF production in Ethiopia.

Academic institutions as drivers of research and innovation in SAF technologies: Institutions such as Addis Ababa University, Jimma University, and Ethiopian Aviation University offer aviation-related courses and can play a pivotal role in closing the skills gap and advancing SAF research and development. Furthermore, these institutions will serve as valuable resources for on-the-job training for policymakers and other key stakeholders involved in the supply chain.

4.2.2 Creating scalable and sustainable feedstock supply chains

The ability to produce significant quantities of SAF feedstocks — while maintaining food production and complying with CORSIA sustainability criteria — is fundamental to building Ethiopia's SAF value chain. For agricultural feedstocks, solutions to address land management and infrastructure challenges related to fragmented smallholder farming and supply chain logistics are needed. Expanded cropping trials for key feedstocks such as Brassica carinata, castor, and sugarcane including on less productive and marginal lands, will improve the data quality and inform cultivation strategies. Agricultural sector modelling is also needed to assess the scalability of SAF feedstock production within rotational cropping, cover cropping, and other sustainable farming systems.

4.2.3 Innovating crop varieties, management practices, and processing to maximize value

Current cost estimates for oilseed crops suggest they are not yet economically viable SAF feedstocks. However, improved crop management—targeted use of inputs, mechanisation, and scaling up smallholder production—can reduce costs. For Brassica carinata, increasing the market value of seed cake would correspondingly reduce the cost of oil production. Identifying lower-toxicity varieties, detoxification processes, could unlock higher-value markets such as animal feed.

4.2.4 Creating market conditions to encourage SAF production and uptake

Given the higher cost of SAF compared to conventional jet fuels, robust policy measures are required to create demand and incentivize investment. A review of policy and regulatory options, and an assessment of their potential effectiveness and broader economic impacts, is necessary. While there is significant potential for renewable fuel production in the country, this must deliver strategic and socio-economic benefits if produced at higher cost. Attracting investment in SAF feedstock supply chains and production facilities will require long-term policy and regulatory certainty.

4.2.5 Green Hydrogen Strategy can underpin longer-term opportunities for e-SAF

While e-SAF is currently a less-proven SAF production route, it presents a long-term opportunity to harness Ethiopia's abundant renewable resources for fuels production. Advancing the sector through near-term applications such as green ammonia production to displace current fertilizer imports, would develop expertise and infrastructure in country to support other future applications in transport and renewable fuels.

4.2.6 Ethiopian Airlines as a SAF off-taker

Ethiopian Airlines, one of Africa's leading carriers, is expanding its destinations and fleet and has expressed interest in using SAF. The airline aims to grow its fleet to 271 aircraft by 2035, with rising jet fuel demand making it a natural off-taker for domestic SAF production.

4.3 SUMMARY OF OPPORTUNITIES AND CHALLENGES FACING SAF PRODUCTION IN ETHIOPIA

Table 14. Summary of opportunities and challenges facing SAF production in Ethiopia.

Strengths	• Strong government commitment to low-carbon development, including specific support for SAF in the revised Biofuel Strategy • Significant potential for agricultural feedstocks, including rotational and intercropping of non-edible oilseed crops • Established ethanol production capacity, with potential growth in production aligned to planned expansion of domestic sugar sector • Abundant renewable energy resources with potential for low-cost renewable electricity generation

	• Ethiopia's strategic position as a major African aviation hub with growing fuel demand
Weaknesses	• Lack of refining, blending and certification capacity within the country • Limited technical/agronomic data on key feedstocks and scalability • High production costs for some feedstocks relative to global benchmarks • Fragmented and underdeveloped supply chains and processing infrastructure • Skills and institutional capacity gaps across agriculture, refining, and certification
Opportunities	• Alignment with existing initiatives to expand domestic sugar sector and thereby increase molasses availability for ethanol production • Waste-to-SAF aligns with urban waste management and climate goals • Green hydrogen and ammonia initiatives can build expertise and infrastructure for future e-SAF production • Potential to position as an early-mover SAF hub in Africa • International finance could be tapped for SAF value chain development
Threats	• Competition for feedstocks with food, feed, energy and export markets • Global SAF cost competitiveness – Ethiopian SAF may struggle against cheaper imports • Risk of unsustainable land use change if crop feedstocks expand without safeguards • Technological uncertainty for less mature pathways (MSW gasification, e-SAF)

4.4 ACTION PLAN

The Ethiopia SAF roadmap has laid the foundation for SAF development in Ethiopia, by identifying potential feedstocks and conversion pathways, and setting a three-phase, ten-year roadmap to achieve domestic SAF production by 2030. The first phase (2021-2023) focused on creating an enabling environment, through policy and regulatory reforms, the design of feasibility studies, and initial development of infrastructure. Phase 2 (2024-2028) aims to demonstrate SAF production by completing feasibility studies, developing required infrastructure, attracting investment, and establishing offtake agreements for domestically produced and ASTM certified SAF that meets CORSIA sustainability standards. Phase 3 (2029-2030) targets achieving 10% SAF blend for the national carrier and exploring longer-term SAF opportunities.

Throughout the process of conducting this study, we engaged with various stakeholders whose insights have been instrumental in shaping our recommendations to further enhance the SAF roadmap (see Table 15).

We propose the following key revisions based on our analysis:

1. **Further demonstration of feedstock potential, scalability, and identification of viable business cases:** A more in-depth analysis is required on crop-based SAF feedstocks, particularly on cropping strategies, financial viability, and scalability to achieve production quantities required for SAF production. The Ethiopia SAF Roadmap intended to deliver feasibility studies on feedstocks during Phase 1 and 2; however, field trial data is limited for key potential crops such as Brassica carinata and castor. Sources of seed research & development funding should be identified to support larger and

more ambitious studies, to identify viable and scalable feedstock opportunities, and to provide evidence for investment through identification of viable business cases.

2. **Mapping supply chains for identified routes**: Comprehensive mapping of the SAF supply chain—from feedstock to fuel—will enhance the roadmap's utility. Linking this with improved understanding of feedstock strategies (see Point 1) and infrastructure needs for supply aggregation, processing, and transport can help highlight opportunities and gaps, guiding potential investors in identifying areas for intervention in SAF development in Ethiopia.
3. **Build feedstock supply chains from the bottom-up:** A bottom-up approach should prioritize the development of small-scale production and supply chains for promising feedstocks. This early phase can mitigate investment risk and provide a foundation for scaling up. Alignment with domestic biofuel opportunities (e.g.: biodiesel and bioethanol for road transport markets) or export markets (as a SAF feedstock or for alternative markets) can encourage investment during this early stage of development. Ongoing efforts to boost oilseed and sugar self-sufficiency offer a strategic entry point. They can support the expansion of feedstock infrastructure and capacity building – including farmer engagement, logistics and milling/processing facilities, as well as generating byproducts (e.g., molasses for ethanol) of relevance to future SAF production.
4. **Further study on emerging and non-biobased feedstocks**: The current SAF roadmap focuses largely on energy crops and bio-based residues. Current efforts to increase renewable electricity production and access can lay the foundation for the on-going expansion of renewable electricity capacity, eventually supporting e-SAF production. Therefore, the study suggests it would be beneficial to further explore such pathways, including FT and emerging e-methanol to SAF.
5. **Revision of targets and timeframes**: The study recommends revising the timeframes and targets outlined in the roadmap to ensure they provide a realistic horizon for the development of SAF value chains. Targets should be underpinned by robust data on feedstock production and business models, and aligned with national strategies such as the biofuel strategy and Ethiopia's long-term national policy frameworks. This includes the transport policy, energy policy, and the Long-Term Low Emission and Climate Resilient Development Strategy (LT-LEDS).
6. **Revise policy frameworks and incentive mechanisms**: The current roadmap outlines various policy frameworks and incentive mechanisms to facilitate SAF development and deployment in Ethiopia. A more detailed and targeted incentive mechanism is essential to help policymakers create schemes that attract investment and foster an environment that encourages both domestic and foreign direct investment (FDI) in the SAF sector.
7. **Revision of capacity and skills development:** A detailed assessment of capacity development and training needs at various levels is essential. Structured training programs should be developed for aviation professionals and other key actors. Academic and training institutions should be repurposed or strengthened to deliver tailored programs supporting SAF feedstock development, processing, certification, and fuel production.

Table 15. Summary of recommended actions.

Recommended Actions	Timeline	Potential Responsible Entity	Key Performance Indicators (KPIs)
RA 1: Further demonstration of feedstock potential and scalability			
1.1. Conduct multi-season agricultural feedstock trials (carinata, castor, sugarcane), including trials of developed seed varieties	2025-2030	MoWE, MoA, MoPD, EIAR, EIH, ECCA, EPA and others	Number of feedstock varieties tested across agro-ecological zones; Yield achieved in multi-season trials

1.2. Supply chain mapping and smallholder integration pilots	2028-2032	MoWE, MoA, MoPD, EIAR, EIH, ECCA, EPA and others	Number of smallholder farmers engaged in pilots
1.3. Identification of viable business cases and pilot scale opportunities for SAF feedstock production and pre-processing	2025-2032	MoWE, MoA, MoPD, EIAR, EIH, ECCA, EPA and others	Completed business cases for at least 3 feedstock-technology pathways
1.4. Explore the potential of non-biogenic feedstocks for SAF production, including e-SAF and geological methane sources (Afar)	2027-2032	MoWE, MoTL, research institutes and others	Completed business cases for non-biogenic feedstock pathways
RA 2: Mapping supply chains for identified routes			
2.1. Detailed mapping of SAF supply chain stakeholders for key feedstock value chains	2028-2030	MoA, MoWE, MoPD, MoTL, EIAR and others	Number of feedstocks with full supply chain maps completed; Number of value chain stakeholders consulted
2.2. Quantify resource flows and employ geospatial analysis to identify infrastructure gaps and required investment	2029-2031	MoA, MoWE, MoPD, MoTL, EIAR and others	Delivery of supply chain maps; Estimate completed of infrastructure investment required
RA 3: Build feedstock supply chains from the bottom up			
3.1. Pilot farmer-based production models for priority SAF feedstocks	2026-2030	MoA, MoWE, EIAR, MoPD	Number of production models completed
3.2. Identify aggregation hubs and pre-processing capacity needs for export markets	2028-2030	MoA, MoWE, EIAR, MoPD, EIH	Estimate of storage and processing infrastructure needs
3.3. Scale up export-oriented feedstock supply chains, in line with national strategies for oilseed and sugar	2030 onwards	MoPD, MoWE, MoA, EIH, and others	Quantity and value of SAF feedstock export revenues
3.4. Leverage synergies with domestic biofuel opportunities (biodiesel, bioethanol for road transport)	2030-2035	MoWE, MoPD, MoA	Quantity of biodiesel, bioethanol sold to domestic market
RA 4: Create market conditions to encourage domestic SAF production and uptake			
4.1. Revise the roadmap's targets and timeframes based on data regarding feedstock production and business models, ensuring alignment with national strategies.	2026-2028	ECAA, MoTL, MoWE, MoA and others	Updated SAF targets and timelines published by 2028
4.2. Develop policy incentives (SAF blending mandate; tax relief) aligned with current government policies to encourage foreign direct investment	2028-2032	MoPD, MoTL, EIH, EIC, MoF, ECAA and others	SAF blending policy adopted; SAF incentives launched

4.3. Mobilize international climate finance for first-of-a-kind SAF projects	2030-2035	MoWE, MoPD, MoA, EIH	Value of mobilized finance by 2035
4.4. Create offtake agreements with Ethiopian Airlines	2030-2035	MoWE, MoPD, MoA, EIH, EAG	Completed offtake agreements
RA 5: Establish pilot-scale SAF production facilities towards commercialisation			
5.1 Establish pilot-scale SAF production facilities	2031-2035	EIH, Private sector, and other partners	Pilot SAF facility commissioned; Annual SAF production achieved; Life cycle GHG reduction quantified relative to fossil baseline
5.2. Train workforce in refinery operations and certification standards	2031-2035	Universities (eg.AAU), ECAA, Ethiopian Airlines University, and other international partners	Number of people trained in SAF refining and certification
5.2. Scale up to commercial SAF production	Post-2035	EIH, Private sector, and other partners	First commercial SAF facility commissioned; Domestic installed SAF production capacity; Domestic SAF production quantity;

The sequencing of actions shown in the Gantt chart (Figure 18) highlight stepwise progression required to establish a SAF value chain in Ethiopia. Early emphasis is placed on developing the evidence base for investment and policy design through feedstock trials, business case development, and supply chain mapping. These foundational activities underpin the scaling-up of farmer-led production, piloting and expanding infrastructure for aggregating and processing feedstocks, developing interim export markets for SAF feedstocks, and mobilizing finance for required investment. In the later stages, efforts shift towards offtake agreements, developing pilot-scale SAF production, and training the workforce. Activities culminate in post-2035 opportunities for commercial-scale deployment of SAF production through innovation, research and development, and fostering partnerships. This phased approach ensures that technical, financial, and institutional capacities develop in parallel, reducing risk and ensuring long-term sustainability of the future SAF sector in Ethiopia.

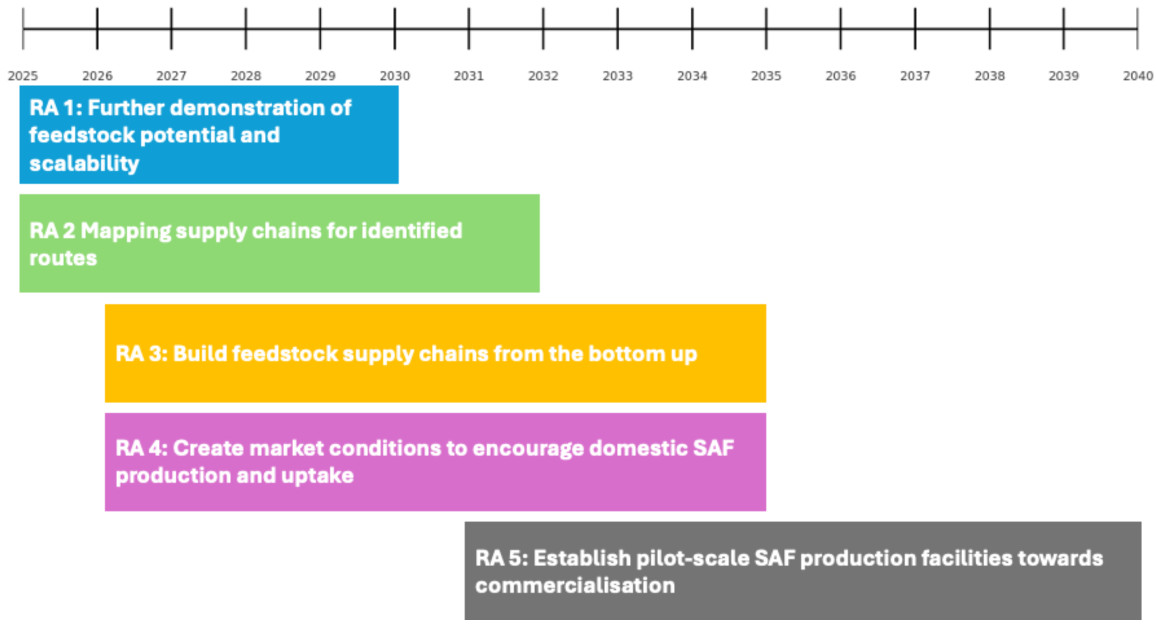


Figure 18. Sequencing and timeline of action plan recommendations.

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APPENDIX: LIST OF ORGANISATIONS AND INSTITUTIONS ENGAGED

1. Ethiopian Civil Aviation Authority (ECAA)
2. Environment Protection Authority (EPA)
3. Ministry of Agriculture (MoA)
4. Ministry of Foreign Affairs
5. Ethiopian Petroleum Supply Enterprise
6. Ethiopian Airlines
7. Ethiopian Institute of Agricultural Research
8. Ethiopian Sugar Industry Group
9. Ethiopian Mineral and Biofuel Corporation
10. Zoscales Partners (Private sector)
11. 54 Capital (Private sector)
12. SAF Technical Committee