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BUSINESS IMPLEMENTATION STUDY ON THE USE OF SUSTAINABLE AVIATION FUELS

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FOREWORD

In June 2022, on the 50th anniversary of the Stockholm Conference, 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 agreed to strive to achieve a collective global aspirational Vision to reduce CO_2 emissions in international aviation by 5% 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 resolved to achieve this Vision and requested 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.

In 2023, France made a voluntary financial contribution to the ICAO Environment Fund to fund three SAF feasibility or business implementation studies. In April 2024, the Civil Aviation Authority of Rwanda accepted, through an exchange of letters, to be the project beneficiary.

This business implementation study on sustainable aviation fuels (SAF) assesses the potential for producing and using sustainable drop-in SAF in Rwanda, while ensuring alignment with environmental and socio-economic sustainability criteria of ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). The study follows the guidelines set out in the ICAO "*Template for Business Implementation Reports on Sustainable Aviation Fuels*".[1]

[1] ICAO (2025), *ICAO Assistance, Capacity-building and Training for Sustainable Aviation Fuels* https://www.icao.int/act-saf

ACKNOWLEDGEMENTS

This business implementation study would not have been possible without the invaluable engagement and leadership of the Rwanda Civil Aviation Authority (RCAA) and, in particular, to Mr Alex Ruzigana, the national SAF Focal Point.

The instrumental role of the many national stakeholders who contributed to the development of this work by providing valuable information and guidance to identify SAF potential in the country should also be acknowledged.

The authors express their gratitude to all stakeholders listed in the Appendix.

EXECUTIVE SUMMARY

BACKGROUND

In 2023, in the context of the ICAO ACT-SAF Programme, and with funds from the European Union (ICAO-EU Project Phase II), ICAO provided technical assistance to Rwanda through a feasibility study for Sustainable Aviation Fuels (SAF). The aim was to identify opportunities for the establishment of a feasible SAF supply chain in the country. The study concluded that the availability of sufficient quantities of suitable feedstocks is a fundamental challenge for SAF production in Rwanda. In particular, SAF derived from municipal solid waste (MSW) has the potential to meet a significant share of the State's current aviation fuel use.

The government's strong commitment to developing the green economy was identified as a key opportunity. As SAF is more expensive than conventional aviation fuels, a sustained government support will be essential for the successful development of the sector. Such support includes promoting feedstock production and integrating the SAF industry into existing policy frameworks both for producers and users.

MARKET ANALYSIS

Rwanda's energy and aviation sectors are undergoing rapid transformation, marked by ambitious electrification goals and major infrastructure investments such as Bugesera International Airport. Despite impressive progress, the country remains totally dependent on imported aviation fuel. This fuel is transported by road tankers from ports in Kenya and Tanzania, creating vulnerabilities related to both costs and supply security. Promising developments to reduce these dependencies include the upcoming Hoima Oil Refinery in Uganda, and the East African Crude Oil Pipeline (EACOP) as well as the planned Hoima–Kampala and Eldoret–Kampala–Kigali pipelines.

The country's aviation sector is anchored by RwandAir and Kigali International Airport, while the planned expansion of Bugesera Airport presents opportunities for SAF integration. Stakeholder institutions are supportive but currently lack dedicated SAF strategies. Meanwhile, feedstock availability—including agricultural residues and MSW—provides a moderate to strong case for SAF production, especially when supported by infrastructure in Special Economic Zones (SPZs) and strategic improvements to logistics.

TECHNO-ECONOMIC ASSESSMENT AND RESULTS

The techno-economic assessment developed in this study evaluates the feasibility of SAF production in Rwanda using three main pathways: Alcohol-to-Jet (AtJ), Gasification + Fischer-Tropsch (G-FT), and Hydroprocessed Esters and Fatty Acids (HEFA).

Agricultural residues and MSW are the feedstocks selected for further assessment because they offer the most relevant domestic opportunities, although both face material supply constraints. The previous ICAO ACT-SAF feasibility study rated agricultural residues as having low-to-medium overall potential and MSW as having medium potential, noting that neither resource alone was sufficient for a conventional commercial-scale SAF facility. Used cooking oil and animal fats are available only in limited quantities and are not sufficient to support a national HEFA supply chain.

Financially, SAF production costs are high with a minimum fuel selling price of USD 1.40–1.80 per litre, exceeding conventional jet fuel prices by USD 0.50–0.90 per litre. Under the base case, returns show internal rates of return (IRRs) of 7–9% and have negative net present values (NPVs), indicating that dedicated policy support—such as subsidies, blending obligations, financial support and carbon pricing—is required to achieve commercial viability. With policy support, concessional finance, and carbon credit monetization, IRRs increase to 12–14%.

A pioneer 100 000-tonne SAF facility could meet up to 45% of Rwanda's jet fuel demand by 2035. Overall, the assessment concludes that SAF production is technically feasible and has the potential to be commercially viable under supportive policy and financing conditions. Nevertheless, the analysis also shows that feedstock availability in the country could be insufficient feedstock for this scale of production and therefore regional cooperation could contribute to make the case viable.

FINANCIAL AND OPERATIONAL ASSESSMENT OF THE PROJECT

Two pilot project models are presented:

1. **MSW-to-SAF (Gasification + Fischer-Tropsch (G-FT))**: Located in the Kigali Special Economic Zone (KSEZ), processing 20 tonnes per day of waste, yielding 1 000 litres per day of SAF. Capital expenditure (CAPEX) is estimated at USD 26.5 million, with an estimated payback period of 7–10 years and an IRR of 8–12%. The model shows significant environmental and social benefits, including annual CO_2 reductions of approximately 5 000 tonnes per year and the creation of 30–50 direct jobs.
2. **AtJ using agricultural residues**: Processes 30 tonnes per day of residues to yield 1 200 litres per day of SAF. CAPEX is USD 26.7 million, with IRR of 9–13% and a payback period of 7–9 years. Residue logistics and rural engagement strategies are detailed.

Both projects could be financially feasible under blended financing models and align well with Rwanda's climate and development strategies. Policy support, infrastructure development, feedstock supply agreements, digital traceability, and public-private partnerships will be key enablers.

RISK ASSESSMENT

The risk assessment identifies feedstock supply variability, uncertainty associated with technology scale-up, high CAPEX and OPEX, policy gaps, and market risks as critical challenges. Rwanda's fragmented logistics, absence of domestic SAF standards, and limited experience with SAF technologies further exacerbate these risks.

Key mitigation strategies include:

- Establishing biomass aggregation hubs and digital traceability systems;
- Implementing pilot projects to de-risk scale-up;
- Securing concessional finance and airline offtake agreements; and
- Introducing SAF blending mandates aligned with CORSIA.

The scenario and SWOT analyses reveal that project success hinges on policy coordination, financing, and resilient feedstock supply chains. A robust monitoring reporting and verification (MRV) system together with regional policy alignment will be essential to reduce investor risk and boost market confidence.

BUSINESS IMPLEMENTATION RECOMMENDATIONS

The study concludes with the following recommendations for the consideration by the State and other national stakeholders:

- **Develop a national SAF Roadmap** aligned with Rwanda's Vision 2050 and National Strategy for Transformation (NST2, 2024–2029), incorporating objectives consistent with ICAO's collective global aspirational Vision (5% emissions reduction by 2030), the long-term aspirational goals (LTAG) for 2050 and the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).
- **Establish a supportive policy framework**, including SAF blending mandates (e.g., 2% SAF by 2030), fuel quality standards (ASTM D7566), and MRV systems.
- **Promote Public-Private Partnerships (PPPs)** for SAF project development, using demonstration-scale models to reduce investment risks.
    - **Public sector**: Ministry of Infrastructure (MININFRA), Ministry of Environment (MoE), Rwanda Civil Aviation Authority (RCAA), and Rwanda Development Board (RDB) as the principal enabling institutions.
    - **Private sector**: Technology providers, feedstock aggregators, fuel suppliers (e.g., TotalEnergies Rwanda), and airlines (e.g., RwandAir).
- **Mobilize green financing** through blended finance mechanisms involving the Green Climate Fund (GCF), the African Development Bank (AfDB), ICAO Finvest Hub, and private investors.
- **Leverage regional integration** within the East African Community (EAC) and the Common Market for Eastern and Southern Africa (COMESA) to expand markets, harmonize SAF standards, and strengthen feedstock supply chains.
- **Invest in capacity building** through universities and technical institutions, while promoting technology transfer partnerships.
- **Prioritize the integration of SAF infrastructure** into the development of Bugesera International Airport, KSEZ, and the modernisation of the national aviation fuel supply chain.

The following implementation timeline is proposed:

- **Years 1–2**: Complete feasibility studies, establish partnerships, and secure, financing.
- **Years 3–4**: Develop and commission a demonstration-scale SAF facility.
- **Years 5–10**: Scale-up to commercial- SAF production.

Continued alignment with Rwanda's Vision 2050, the NST2, and ICAO's long-term global aspiration goal (LTAG) will be essential. The implementation of a national SAF Roadmap, harmonized regional standards, and a robust MRV framework will strengthen Rwanda's position as a regional leader in sustainable aviation fuels in Africa.

CONTENTS

FOREWORD 4

ACKNOWLEDGEMENTS 5

EXECUTIVE SUMMARY 6

Background 6

Market analysis 6

Techno-economic assessment and results 6

Financial and operational assessment of the project 7

Risk assessment 7

Business implementation recommendations 8

ABBREVIATIONS AND ACRONYMS 13

LIST OF FIGURES 15

LIST OF TABLES 16

SECTION 1. MARKET ANALYSIS 17

1.1 National assessment 17

1.1.1 Energy infrastructure 17

1.2 Aviation ecosystem and infrastructure 20

1.2.1 Organization and stakeholders of the aviation sector 20

1.2.2 Airport infrastructure 21

1.2.3 Airlines 22

1.2.4 Key challenges 23

1.3 Aviation fuel supply chain 24

1.3.1 Kigali International Airport: the centre of fuel operations 24

1.3.2 Economics of jet fuel in Rwanda 25

1.3.3 Challenges 25

1.3.4 Building the future infrastructure 25

1.4 Hoima Oil Refinery 26

1.5 Pipeline infrastructure 27

1.5.1 Hoima–Kampala Petroleum Products Pipeline 27

1.5.2 Eldoret–Kampala–Kigali pipeline 27

1.5.3 East African Crude Oil Pipeline 28

1.5.4 Potential benefits to Rwanda 28

1.6 Review of technology pathways suitable for Rwanda 29

1.6.1 Summary of evaluated feedstocks 29
1.7 Agricultural residues 32
1.7.1 Feedstock-related information 32
1.7.2 Sustainability-related issues, including greenhouse gas (GHG) emissions 33
1.7.3 Economic and market-related issues 33
1.7.4 Overall assessment 33
1.8 Waste oils 34
1.8.1 Feedstock-related information 34
1.8.2 Sustainability-related issues, including greenhouse gas (GHG) emissions 34
1.8.3 Economic and market-related issues 34
1.8.4 Overall assessment 34
1.9 Municipal solid waste (MSW) 35
1.9.1 Feedstock-related information 35
1.9.2 Sustainability-related issues, including greenhouse gas (GHG) emissions 35
1.9.3 Economic/market-related issues 36
1.9.4 Overall assessment 36
1.10 Summary of technology options 37
1.10.1 Alcohol to Jet (AtJ) Pathway 37
1.10.2 Hydroprocessed Esters and Fatty Acids (HEFA) and co-processing 37
1.10.3 Fischer-Tropsch (FT) 37
1.11 Business-case input assumptions and key parameters 38
1.11.1 General facility inputs for full-scale production 38
1.11.2 Expected capacities 39
1.11.3 Ramp-up timeline 39
1.11.4 Operational metrics 39
1.11.5 Capital expenditure (CAPEX) 40
1.11.6 Other off-site costs 40
1.12 Process and energy/utilities inputs 40
1.12.1 Availability and cost of feedstock 42
1.12.2 Operating expenditure (OPEX) 43
1.12.3 Implications for economic viability 43
1.13 Financial inputs 44
1.13.1 Cost of capital (weighted average cost of capital (WACC)) 44
1.13.2 Taxation 45

1.13.3 Internal Rate of Return (IRR) 45
1.13.4 Depreciation 45
1.13.5 Payback period 45
1.13.6 Sensitivity analysis 45
SECTION 2. TECHNO-ECONOMIC ASSESSMENT AND RESULTS 46
2.1 CAPEX and OPEX 46
2.1.1 CO_2 abatement costs 46
2.1.2 Demand and supply forecasts 47
2.1.3 Price assessment 47
2.1.4 Return on investment 48
2.2 Sensitivity analysis 48
2.2.1 Technology provider variations 49
2.2.2 Policies and incentives 49
2.3 Summary of key findings 49
SECTION 3. FINANCIAL AND OPERATIONAL ASSESSMENT OF THE PROJECT 51
3.1 Gasification and Fischer-Tropsch pathway using municipal solid waste 51
3.1.1 Collection infrastructure and process 53
3.1.2 Pilot project business case 53
3.2 Financial projections 55
3.2.1 Estimated financial returns 55
3.2.2 Funding strategy 55
3.2.3 Summary of business case 55
3.2.4 Environmental and social benefits 55
3.3 ATJ pathway using agricultural waste 55
3.3.1 Feedstock availability and sourcing 55
3.3.2 Feedstock processing and conversion 56
3.3.3 Blending and logistics 57
3.3.4 Pilot project business case 59
3.3.1 Financial and funding considerations 60
3.4 Sensitivity analysis 61
3.5 Regulatory and policy framework 61
3.6 Conclusion 62
SECTION 4. RISK ASSESSMENT 64
4.1 Feedstock supply risks 64

4.1.1 Seasonal and regional availability 64
4.1.2 Logistics and transportation challenges 64
4.1.3 Mitigation 64
4.2 Technological risks 64
4.2.1 Performance and maturity of SAF pathways 64
4.2.2 Insurance and guarantees 65
4.2.3 Mitigation 65
4.3 Financial and market risks 65
4.3.1 Capital intensity and cost uncertainty 65
4.3.2 Market competitiveness and price gap 65
4.4 Policy and regulatory risks 66
4.4.1 Risk prioritization matrix 66
4.4.2 Scenario analysis 66
4.5 Analytical review 67
4.6 Conclusion 68
SECTION 5. BUSINESS IMPLEMENTATION RECOMMENDATIONS 69
5.1 Partnership structures 69
5.1.1 Potential public sector stakeholders 69
5.1.2 Potential private sector stakeholders 69
5.1.3 Public-private partnership (PPP) and joint venture (JV) models 69
5.2 Financing strategies 70
5.2.1 Multilateral and development finance institutions 70
5.2.2 Bilateral and public sector lenders 70
5.2.3 Private sector and commercial finance 70
5.3 Action plan 70
5.4 Policy alignment 73
5.5 Conclusion 74
REFERENCES 75
APPENDIX: STAKEHOLDER ENGAGEMENT 78

ABBREVIATIONS AND ACRONYMS

ACCF	Africa Climate Change Fund
ACT-SAF	Assistance, Capacity-building and Training for Sustainable Aviation Fuels
AfDB	African Development Bank
AfCFTA	African Continental Free Trade Area
AtJ	Alcohol-to-Jet
ASTM	American Society for Testing and Materials
CAPEX	Capital Expenditure
CAEP	Committee on Aviation Environmental Protection
CIT	Corporate Income Tax
COD	Commercial Operation Date
COMESA	Common Market for Eastern and Southern Africa
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
DCC	Decentralized Collection Centre
DFI	Development Finance Institution
EAC	East African Community
EACOP	East African Crude Oil Pipeline
EAPP	Eastern Africa Power Pool
EIA	Environmental Impact Assessment
EIB	European Investment Bank
EPC	Engineering, Procurement, and Construction
EPCM	Engineering, Procurement, Construction Management
ESIA	Environmental and Social Impact Assessment
FT	Fischer–Tropsch
GCF	Green Climate Fund
GHG	Greenhouse Gas
HEFA	Hydroprocessed Esters and Fatty Acids
HKPPP	Hoima–Kampala Petroleum Products Pipeline
ICAO	International Civil Aviation Organization
IDA	International Development Association
IFC	International Finance Corporation
IPP	Independent Power Producer
IRR	Internal Rate of Return
ISAGO	IATA Safety Audit for Ground Operations
IATA	International Air Transport Association
JV	Joint Venture
KGL	Kigali International Airport
KFSF	Kampala Fuel Storage Facility
KSEZ	Kigali Special Economic Zone
KPCIP	Kabalega Petrochemical Industrial Park
LCAF	Lower Carbon Aviation Fuels
LCA	Life cycle Assessment
LPG	Liquefied Petroleum Gas
LTAG	Long-Term Aspirational Goal
MFSP	Minimal Fuel Selling Price

MININFRA	Ministry of Infrastructure (Rwanda)
MoE	Ministry of Environment
MoU	Memorandum of Understanding
MRV	Monitoring Reporting and Verification
MSW	Municipal Solid Waste
NIRDA	National Industrial Research and Development Agency
NISR	National Institute of Statistics of Rwanda
NPV	Net Present Value
NST1	National Strategy for Transformation (1st Phase)
OPEX	Operational Expenditure
PAU	Petroleum Authority of Uganda
PPP	Public-Private Partnership
PPA	Power Purchase Agreement
PtL	Power-to-Liquid
QIA	Qatar Investment Authority
RCAA	Rwanda Civil Aviation Authority
RDB	Rwanda Development Board
REG	Rwanda Energy Group
REMA	Rwanda Environment Management Authority
ROE	Return on Equity
RFCC	Residue Fluid Catalytic Cracking
RURA	Rwanda Utilities Regulatory Authority
SAF	Sustainable Aviation Fuel
SARPs	Standards and Recommended Practices
SCADA	Supervisory Control and Data Acquisition
SEFA	Sustainable Energy Fund for Africa
SEZ	Special Economic Zone
TCI	Total Capital Investment
UCO	Used Cooking Oil
UNFCCC	United Nations Framework Convention on Climate Change
UNOC	Uganda National Oil Company
USD	United States Dollar
VAT	Value Added Tax
WACC	Weighted Average Cost of Capital

LIST OF FIGURES

Figure 1. Installed electricity capacity by source in Rwanda in 2023. 18
Figure 2. Artist's impression of the future Bugesera International Airport..... 22
Figure 3. RwandAir fleet growth and passenger traffic (2010-2024). 22
Figure 4. Route network of RwandAir. 23
Figure 5. Officials unveil Rwanda's second largest fuel storage depot in the Gasabo district outside Kigali.. 24
Figure 6. Overview of the East African Crude Oil Pipeline (EACOP). 28
Figure 7. Trends in production of key agricultural crops.' 31
Figure 8. Cassava plant processing into biofuels flowchart. 32
Figure 9. Municipal solid waste (MSW) characteristics in selected Rwandan cities. 36
Figure 10. MFSP compared with Jet A-1 prices in Rwanda..... 47
Figure 11. NPV sensitivity analysis for Rwanda SAF Project. 48
Figure 12. Daily per capita generation of MSW versus GDP per capita in African countries. 51

LIST OF TABLES

Table 1. Key challenges facing the aviation industry in Rwanda. 23
Table 2. Key parameters of the Hoima Oil Refinery. 26
Table 3. Overview of evaluated feedstocks. 30
Table 4. Summary of potential crop residues from major crops in Rwanda. 33
Table 5. Estimated construction timelines and inputs for a medium-scale SAF production facility." 38
Table 6. Breakdown of estimated CAPEX required. 40
Table 7. Availability and cost of energy and utility inputs. 41
Table 8. Potential feedstock types and supply. 42
Table 9. Indicative OPEX profile for a 40 million litres per year SAF plant in Rwanda. 43
Table 10. Summary of TEA findings. 49
Table 11. Summary of the well to wing process for SAF production via the MSW pathway. 52
Table 12. Breakdown of estimated CAPEX for the MSW pathway. 54
Table 13. Breakdown of estimated OPEX for the MSW pathway. 54
Table 14. Breakdown of revenue streams for the MSW pathway. 54
Table 15. Agricultural residue types and estimated quantities. 56
Table 16. Pathway overview for AtJ conversion. 56
Table 17. Breakdown of estimated CAPEX for the ATJ pathway. 59
Table 18. Breakdown of estimated OPEX for the AtJ pathway. 59
Table 19. Breakdown of revenue streams for the AtJ pathway. 60
Table 20. Summary of business case. 60
Table 21. Summary of key economic parameters of both business cases. 63
Table 22. Summary of risks prioritized by likelihood and impact. 66
Table 23. Description of recommended actions. 71

SECTION 1. MARKET ANALYSIS

1.1 NATIONAL ASSESSMENT

This section provides an assessment of the key elements of the national scenario that will be fundamental in defining the SAF business cases assessed in this study.

1.1.1 Energy infrastructure

Rwanda's national grid had a capacity of approximately 330 MW in 2024, comprising hydropower (~50%), methane gas (~30%), solar (~10%), and peat/thermal (~10%). Industrial power access is available in designated economic zones and areas served by the high-voltage transmission network.

Expansion of electricity access

At the turn of the century, Rwanda faced widespread energy poverty. As recently as 2010, fewer than one in ten households had access to electricity.[2] Since then, the country has implemented an aggressive electrification programme that has transformed the lives of millions. By 2023, national electricity access had reached 70%, with 47% of households connected to the national grid and an additional 23% served by off-grid technologies such as solar home systems and mini-grids.

The government's target was ambitious: achieving universal access to electricity by 2024.[3] This objective has not relied solely on is expanding the national grid. In a country where many communities are located on steep terrain or far from substations, Rwanda has embraced decentralized energy models. Companies like Bboxx and Ignite Power have extended access to solar systems in remote communities through pay-as-you-go mobile payment schemes, enabling even low-income households to light their homes, charge phones, and power small appliances.

According to the Ministry of Finance and Economic Planning, these efforts have not only transformed livelihoods but have also enhanced healthcare delivery, education, and gender equity. Clinics that once relied on kerosene lamps now operate 24 hours a day with reliable electricity. Students can study after dark, while women and girls, who have traditionally borne the burden of firewood collection, can participate more actively in the country's evolving energy economy.

Diverse energy sources

Unlike many countries that depend heavily on a single source of power, Rwanda has built a relatively diverse energy portfolio—though hydropower still dominates. As of 2024, the country's total installed electricity capacity stood above 300 Megawatts, sourced from hydropower, methane gas, thermal (diesel), solar, and peat.

As shown in Figure 1, hydropower accounts for the largest share of Rwanda's electricity generation. Plants such as Nyabarongo I, Rukarara, and the under-construction Nyabarongo II have been instrumental in supporting the country's electricity grid. However, reliance on rainfall-fed rivers poses long-term risks in the face of climate variability, prompting Rwanda to diversify its energy mix.

[2] Source: Masselus, Lise et al. (2024): 10 years after: Long-term adoption of electricity in rural Rwanda, Ruhr Economic Papers, No. 1086, ISBN 978-3-96973-261-8, RWI - Leibniz-Institut für Wirtschaftsforschung, Essen, https://doi.org/10.4419/96973261

[3] Source: Republic of Rwanda, Ministry of Finance and Economic Planning. Energy Sector Strategic Plan (ESSP). Government of Rwanda https://www.minecofin.gov.rw/fileadmin/user_upload/Minecofin/Publications/STRATEGIES/Sector_Strategic_Plans/Energy.pdf

One of the most innovative developments in Rwanda's energy sector is the extraction of methane gas from Lake Kivu—a deep, biologically unique lake shared with the Democratic Republic of Congo. The KivuWatt project, operated by ContourGlobal, safely extracts methane trapped in the lake's depths and converts it into electricity. This not only provides nearly 20% of Rwanda's current power supply but also mitigates a potential natural hazard: the risk of a rare but potentially catastrophic limnic (gas) eruption.

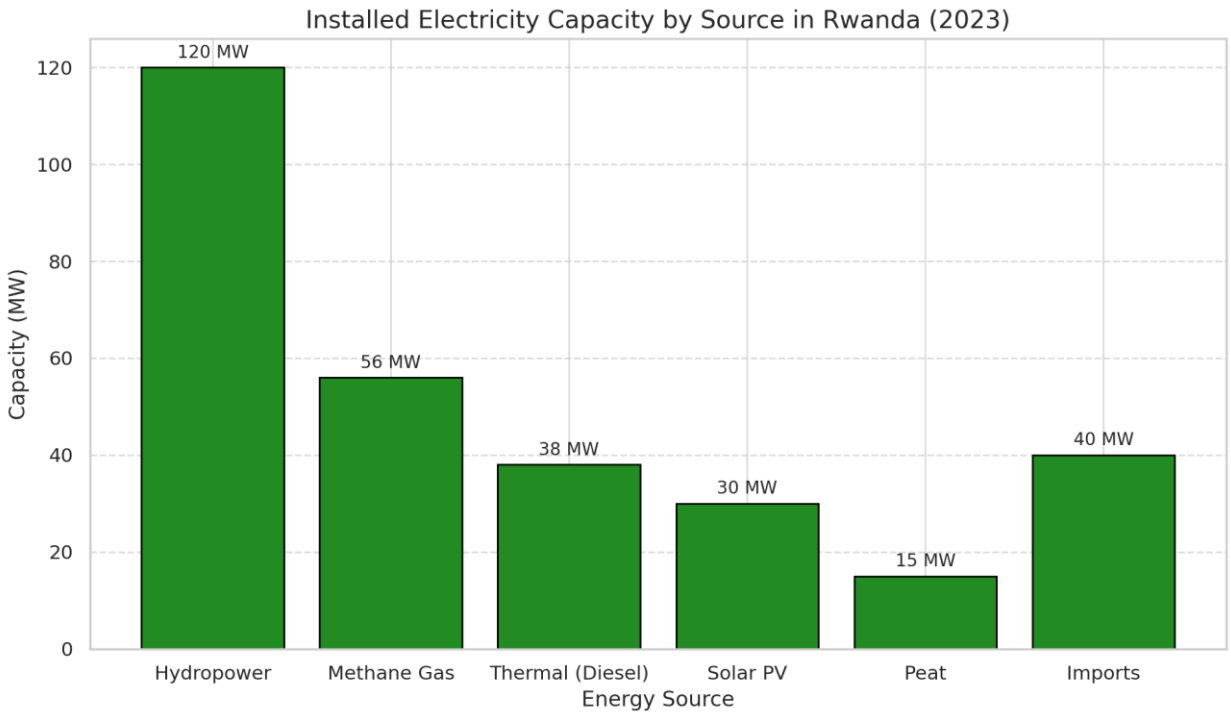


Figure 1. Installed electricity capacity by source in Rwanda in 2023.[4]

Solar power is also playing an important role in Rwanda's energy mix. The country's location near the equator provides abundant sunshine throughout the year. Utility-scale farms like Gigawatt Global's 8.5 MW solar plant at the Agahozo-Shalom Youth Village supplies electricity to the national grid, while thousands of households have adopted rooftop systems. As costs continue to decline and technologies advance, solar energy is fast becoming the backbone of Rwanda's off-grid future. Peat and diesel-fired thermal power plants complete the generation mix, although their long-term role is likely to diminish as the country transitions to cleaner energy sources.

Clean cooking

Despite significant progress in expanding electricity access, energy poverty remains a major challenge in Rwanda, particularly in the cooking sector. More than 80% of households continue to rely on traditional biomass—primarily firewood and charcoal—for cooking. This dependence contributes to deforestation, indoor air pollution, and health problems disproportionately affecting women and children.

To address these challenges, the government is promoting improved cookstoves, biogas systems, and liquefied petroleum gas (LPG). Rural households are being encouraged to adopt cleaner cooking technologies, while institutions such as schools and prisons are piloting large-scale biogas digesters.

[4] Source: Rwanda Energy Group (REG) 2023, *Installed Generation Capacity on the National Grid*, REG Facts & Figures, https://www.reg.rw/facts-figures/facts-figures-details/facts/installed-generation-capacity-on-the-national-grid/

However, adoption remains uneven, and bridging this gap will require not only wider deployment of cleaner technologies, but also sustained behavioural change, targeted subsidies, and public awareness campaigns.

Energy for industry, agriculture, and innovation

Electricity is a key enabler for economic development. Rwanda's growing industrial sector, including garment manufacturing and food processing requires a reliable and uninterrupted electricity supply. In response, industrial parks such as Bugesera Special Economic Zone (SEZ) and Kigali Innovation City are being developed with high-capacity energy infrastructure.

Agriculture, which remains the backbone of Rwanda's economy, is also benefiting from increased electrification. Solar-powered irrigation pumps are helping farmers mitigate droughts, while milk cooling centres, solar dryers, and electric mills are enhancing post-harvest processing. Together, these developments are strengthening agricultural value chains, improving food security, and supporting higher rural incomes.

In parallel, Rwanda is playing an important international role in promoting sustainable cooling technologies. As the host country of the Kigali Amendment to the Montreal Protocol, it is advancing the adoption of energy-efficient and climate-friendly refrigeration systems across the residential, commercial and healthcare sector.

Regional cooperation and energy trade

Rwanda's energy ambitions extend beyond its national borders. The country is a member of the Eastern Africa Power Pool (EAPP) and has established electricity interconnectors with neighbouring Uganda and the Democratic Republic of Congo. These cross-border transmission links enable Rwanda to import electricity during periods of domestic supply shortages and export surplus electricity when available.

These interconnections provide economic and energy security benefits by fostering regional cooperation and mutual energy security. Over the longer-term, such linkages could form the foundation of a more integrated East African electricity energy market, enabling greater specialization, more efficient use of regional energy resources and enhanced system resilience across the region.

The role of policy and investment

A key driver of Rwanda's energy transformation has been strong policy leadership and institutional reform. The sector is overseen by the Ministry of Infrastructure, regulated by the Rwanda Utilities Regulatory Authority (RURA), and implemented by the Rwanda Energy Group (REG), which is responsible for electricity infrastructure development and utility services.

A supportive policy and investment framework has also encouraged private sector participation. Rwanda has facilitated investment by independent power producers (IPPs) through streamlined permitting procedures, feed-in tariffs, and bankable power purchase agreements (PPAs). Development finance institutions, including the World Bank, African Development Bank, and the European Union, have played an important role in financing energy infrastructure and providing technical assistance.

Initiatives such as the World Bank's Rwanda Renewable Energy Fund and USAID's Power Africa programme have mobilized significant investment to support solar energy development and grid expansion. Rwanda is also exploring green bonds and other climate finance instruments to mobilize additional resources in support of its clean energy goals.

Green and resilient future

As Rwanda looks to the future, its energy strategy is one of resilience, inclusion, and innovation. The targets are:[5]

- More than 50% clean cooking solutions by 2030;
- Expanded generation capacity to over 550 MW; and
- Increased reliance on renewables and smart grid systems.

1.2 AVIATION ECOSYSTEM AND INFRASTRUCTURE

Rwanda's aviation sector, once modest and primarily regional in scope, has evolved into an important driver of the country's economic development. Over the past two decades, Rwanda has sought to position itself as a gateway between Central, East, and Southern Africa. Its compact geography and strategic location make it well placed to serve as a regional hub for travel and commerce, and the development of its aviation sector has been guided by this long-term vision.

1.2.1 Organization and stakeholders of the aviation sector

Various national entities have overall responsibility for controlling the air transport system in Rwanda and share the mission of ensuring the safety and delivery of air services to the public.

Ministry of Infrastructure (MININFRA)

The Ministry of Infrastructure (MININFRA) is responsible for infrastructure policy and development across Rwanda. Its mission is to promote sustainable infrastructure development in the areas of transport, energy, water and sanitation, housing, and human settlements, with the aim of promoting economic growth and improving the quality of life of the population. The civil aviation sector falls under the responsibility of MININFRA, which ensures that the interests and requirements of the State are reflected in the regulation of the air transport sector and the development and upgrading of the country's aviation infrastructures.

Rwanda Civil Aviation Authority (RCAA)

The Rwanda Civil Aviation Authority (RCAA) is mandated to regulate and ensure oversight of aviation safety, security, economic regulation of air services and development of civil aviation as guided by the provisions of the Chicago Convention and the 19 Annexes containing ICAO's Standards and Recommended Practices (SARPs).

RwandAir

At the forefront of air transportation in Rwanda is the national carrier, RwandAir, which operates domestic and international services to East Africa, Central Africa, West and Southern Africa as well as to Europe, the Middle East and Asia.

Rwanda Airports Company Ltd (RAC Ltd)

The Rwanda Airports Company Ltd (RAC Ltd) has within its scope the daily management, operation and provision of air navigation services for all airports in Rwanda such as: Kigali International Airport (KIA), Kamembe International Airport (KME) and Gisenyi Airport. RAC Ltd also manages the Ruhengeri Airstrip, Butare Airstrip and Nemba Airstrips.

[5] Sources: International Renewable Energy Agency (IRENA) 2025, *Renewable Energy Investment Factsheet: Rwanda*, IRENA, https://www.pseau.org/outils/ouvrages/irena_renewable_energy_investment_factsheet_rwanda_2025.pdf
United Nations (UN) 2021, *SDG7 Energy Compact of Rwanda*, United Nations Department of Economic and Social Affairs, https://www.un.org/sites/un2.un.org/files/2021/11/rwanda_energy_compact-final_copy.pdf

Akagera Aviation

Akagera Aviation is a Rwanda-based aviation company specializing in helicopter services, pilot training and a range of other aviation-related services. It also offers aerial excursions within Rwanda and neighbouring countries of the East African Community (EAC).

Societe Petroliere Aviation Ltd (SP Aviation)

Societe Petroliere Aviation Ltd (SP Aviation) is a limited company established in the Republic of Rwanda for the import and distribution of petroleum products. SP Aviation has over 13 years of experience in aviation fuel storage and aircraft services.

1.2.2 Airport infrastructure

Rwanda has six operational civil aviation aerodromes and one greenfield airport under construction. Two airports support scheduled commercial air transport operations, while the remaining four are used primarily for general aviation.

Located on the outskirts of the capital, Kigali International Airport (KGL) is Rwanda's principal international gateway. Prior to the COVID-19 pandemic, the airport handled approximately 1.2 million passengers annually and provided connections to more than 20 international destinations, including Brussels, Doha, Dubai, Nairobi, and Johannesburg. In recent years. Kigali International Airport has undergone a series of upgrades to improve its capacity and operational efficiency, including investments in digital check-in systems, security infrastructure, and additional boarding gates to accommodate growing passenger demand.

The remaining four aerodromes—Musanze airstrip, Rubavu Airport, Nemba Airstrip, and Huye Airstrip—primarily support general aviation operations, including tourist helicopter services.

To meet the long-term needs of a growing population and expanding tourism and business sectors, Rwanda has embarked on the development of Bugesera International Airport (Figure 2). Located approximately 25 km south of Kigali, the new airport represents the next phase in the country's aviation development and is expected to significantly expand national airport capacity.

The airport is being developed in phases, with the first stage expected to accommodate up to seven million passengers annually—more than six times the current capacity of Kigali International Airport. Subsequent phases are planned to double this capacity. Sustainability has been incorporated into the airport's design through the application of green building principles, including energy-efficient systems, solar integration, and carbon offsetting measures.

Backed by a strategic partnership with Qatar Airways, which recently transferred its 60% stake to Qatar Investment Authority,[6] Bugesera International Airport is envisioned to become one of Africa's leading aviation facilities. Its planned cargo terminals, aircraft maintenance hangars, VIP lounges, and shopping districts are expected to strengthen Rwanda's aviation infrastructure and enhance its role as a regional aviation hub.

[6] Source: Qatar Investment Authority (QIA) 2026, QIA partners with ATL to complete construction of New Kigali International Airport in Rwanda, https://qia.qa/en/Newsroom/Pages/QIA-partners-with-ATL-to-complete-construction-of-New-Kigali-International-Airport-in-Rwanda.aspx



Figure 2. Artist's impression of the future Bugesera International Airport.[7]

1.2.3 Airlines

Launched in 2002 and rebranded in 2009, RwandAir is the national airline. It has seen consistent passenger traffic growth since 2010, as shown in Figure 3. With a fleet of 13 modern aircraft, including Boeing 737s, Airbus A330s, and De Havilland Dash 8s, RwandAir operates flights to over 25 destinations across Africa, the Middle East, Europe, and Asia (Figure 4). Its flagship routes include Kigali to London, Brussels, Lagos, Johannesburg, and Mumbai. Committed to service excellence, RwandAir offers free onboard wi-fi on select aircraft, generous baggage allowances, and one of the best on-time performance records in the region.

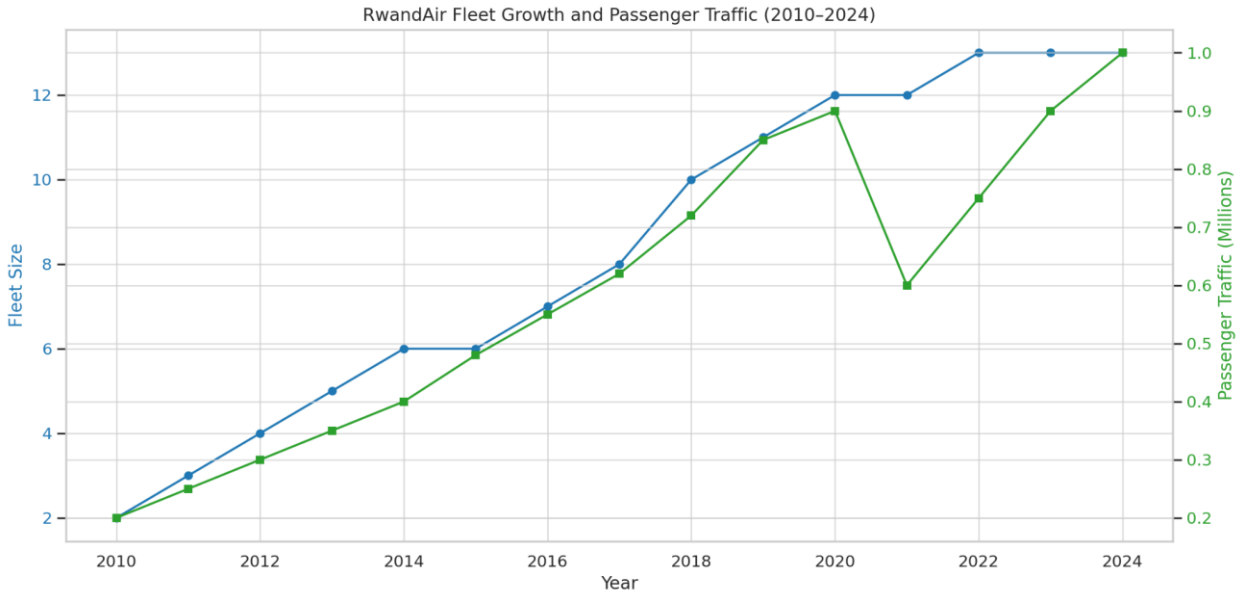


Figure 3. RwandAir fleet growth and passenger traffic (2010-2024).[8]

The airline's strategic partnerships continue to expand. Qatar Airways has been in discussions to acquire a 49% stake in RwandAir (although the transaction has not been completed at the publication of this report),

[7] Source: Global Green Growth Institute (GGGI) 2019, *Green Certification of the New Bugesera International Airport Fact Sheet*, GGGI, https://gggi.org/wp-content/uploads/2019/04/Certification-of-Bugesera-Airport-Fact-Sheet_FINAL.pdf

[8] Source: IATA, *"The Value of Air Transport to Rwanda"*, 2023.

strengthening the ties between the two carriers and paving the way for greater global integration. RwandAir's potential future membership of a global aviation alliance, which would position Kigali as a key transfer hub for international traffic to and from Africa. The airline is a member of the International Air Transportation Association (IATA), and is certified by the European Union Aviation Safety Agency (EASA), as well as IOSA and ISAGO.

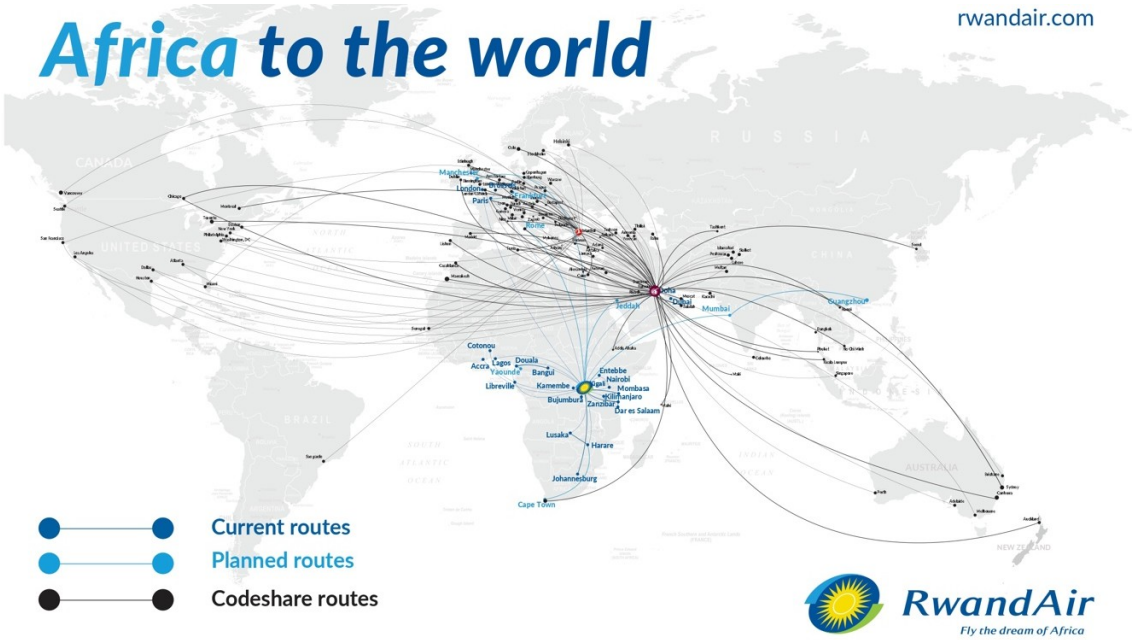


Figure 4. Route network of RwandAir.[9]

1.2.4 Key challenges

Despite its impressive trajectory, Rwanda's aviation industry continues to face a number of challenges (Table 1). Operational costs remain high due to fuel prices and limited economies of scale. There is also a shortage of skilled personnel in specialized areas such as aircraft maintenance and air traffic control. In addition, Rwanda faces strong competition from larger hubs including Addis Ababa, Nairobi, and Johannesburg.

Financing remains another challenge. Projects such as Bugesera International Airport have experienced delays due to the substantial investment required. At the same time, the sector must respond to the growing challenge of climate change by adopting new technologies and operational practices to reduce carbon emissions.

Table 1. Key challenges facing the aviation industry in Rwanda.[10]

Challenge	Description
High operational costs	Fuel prices, aircraft leases, and limited economies of scale
Regional competition	Competing hubs in Addis Ababa, Nairobi, and Entebbe

[9] Source: RwandAir 2025, *Route Map*, RwandAir, https://www.rwandair.com/rwandair-route-map/

[10] Sources: International Air Transport Association (IATA) 2023, The Value of Air Transport to Rwanda, IATA, https://www.iata.org/en/iata-repository/publications/economic-reports/the-value-of-air-transport-to-rwanda/
CAPA – Centre for Aviation 2024, RwandAir: Strategic Positioning and Competitive Dynamics in East Africa, CAPA, https://centreforaviation.com
African Development Bank (AfDB) 2023, Rwanda Infrastructure Development Update 2023, AfDB, https://www.afdb.org

Challenge	Description
Skilled labour shortage	Need for more locally trained pilots, engineers, and technicians
Infrastructure financing	Delays in opening Bugesera International Airport due to cost and investment challenges
Climate impact	Need for SAF, emissions offsetting, and green infrastructure

1.3 AVIATION FUEL SUPPLY CHAIN

As Rwanda has neither domestic oil reserves nor refining capacity, it imports all of its aviation fuel. The supply chain begins at refineries in the Middle East, Europe, or Asia, where Jet A-1 fuel is produced. The fuel is then transported by sea to two principal entry points on the East African coast: the Port of Mombasa in Kenya and the Port of Dar es Salaam in Tanzania.

From these ports, the fuel is transported overland to Rwanda by road tanker along two key transport corridors. The Northern Corridor, via Kenya and Uganda, is the primary route, known for its relatively well-developed transport infrastructure and a direct connection to Kigali. The Central Corridor, through Tanzania and the inland port of Isaka, provides an alternative route and is expected to become increasingly important as regional rail infrastructure continues to develop.

The journey concludes at fuel storage depots serving Kigali International Airport, including facilities in Gasabo District (Figure 5), where the fuel is stored before distribution to the airport.



Figure 5. Officials unveil Rwanda's second largest fuel storage depot in the Gasabo district outside Kigali.[11]

1.3.1 Kigali International Airport: the centre of fuel operations

Kigali International Airport (KGL) is not only the centre of Rwanda's air transport network but also the hub of its aviation fuel supply chain. Jet A-1 fuel is stored in dedicated tanks under strict regulatory oversight. The

[11] Source: The New Times Rwanda 2016, Government officials tour SP fuel storage facility, photograph https://www.newtimes.co.rw

fuel storage facilities are equipped with filtration systems, safety valves, fire suppression systems, and monitoring equipment to ensure fuel quality and operational safety.

Following quality control checks, the fuel is delivered to the aircraft for refuelling. Large commercial aircraft, including those operated by RwandAir or Qatar Airways, are fuelled using the airport's hydrant system, while smaller aircraft, regional operators and aircraft parked at remote stands are served by specialized refuelling vehicles.

1.3.2 Economics of jet fuel in Rwanda

Behind every litre of jet fuel delivered is a complex cost structure. As a landlocked country with no domestic refining capacity, Rwanda relies entirely on imported aviation fuel transported over long distances, resulting in some of the highest aviation fuel prices in the East African region. Between 2015 and 2025, the price of Jet A-1 at Kigali International Airport fluctuated between USD 0.75 and USD 1.30 per litre, according to the S&P index, remaining slightly higher than prices at airports such as Nairobi and Entebbe. These price levels reflect a combination of:

- International oil market fluctuations;
- Inland transport and handling costs;
- Border taxes and fuel levies; and
- Storage and depot charges.

The Rwanda Utilities Regulatory Authority (RURA) plays a central role in the aviation fuel supply chain by licensing fuel importers, overseeing compliance with safety standards, and monitoring the market to promote price transparency and ensure a reliable fuel supply.

1.3.3 Challenges

Although Rwanda's aviation fuel system operates efficiently by regional standards, it remains exposed to a number of structural vulnerabilities. The most significant is its reliance on overland transport from foreign ports. Fuel supplies can be disrupted by traffic congestion, border delays, political instability in neighbouring countries, global shipping constraints, or natural phenomenon such as extreme weather events.

Rwanda also lacks a pipeline infrastructure. Unlike Kenya or Uganda, which are developing refined petroleum product pipelines to reduce dependence on road transport, Rwanda's aviation fuel supply continues to rely on road tankers traversing mountainous terrain and multiple border crossings. In addition, the country's aviation fuel storage capacity remains limited. This poses a risk to both the continuity of airline operations and the resilience of the national fuel supply system.

1.3.4 Building the future infrastructure

Despite the challenges, Rwanda is exploring a number of strategic infrastructure investments to strengthen its aviation fuel supply chain.

Eldoret–Kampala–Kigali product pipeline (planned)

- A proposed extension of Kenya's existing pipeline system toward Uganda and Rwanda for the transport of refined petroleum products.
- Would connect Uganda's planned refinery in Hoima to Rwanda via Kampala.
- Could significantly reduce the cost of overland fuel transport while enhancing security of supply.

Bugesera International Airport – fuel infrastructure

- Construction of a dedicated bulk fuel storage terminal.
- A fuel hydrant system is planned to serve the airport's main aprons.
- The project could provide an opportunity to establish a green fuel depot and support future (SAF pilot projects.

Digital fuel monitoring

- Deployment of automated fuel inventory tracking systems and remote flow meters at storage depots and on refuelling vehicles.
- Expected to improve operational transparency and reduce fuel losses.

1.4 HOIMA OIL REFINERY

Energy infrastructure developments near Lake Albert in Uganda could have implications for Rwanda's future fuel supply. Hoima, located in Uganda's Bunyoro sub-region, is a focus of these developments and an important component of Uganda's energy strategy.

The planned Hoima Oil Refinery is located at Kabaale, Buseruka sub-county, within the Kabalega Petrochemical Industrial Park (KPCIP). Together with associated infrastructure and industrial development projects, it could support regional economic integration, economic diversification and energy security. Benefits for Rwanda would depend on the development of effective cross-border supply arrangements.

Located close to the Kingfisher and Tilenga oil fields, the refinery is being designed to process an initial 60 000 barrels of crude oil per day.[12] Its modular design will allow for a potential expansion to 120 000 barrels per day, in line with projected growth in regional energy demand. The key parameters of the project are summarized in able 2. The refinery will incorporate advanced processing units, including atmospheric distillation, vacuum distillation, and residue fluid catalytic cracking (RFCC), enabling the production of refined petroleum products such as diesel, gasoline, jet fuel, and liquefied petroleum gas (LPG).

Table 2. Key parameters of the Hoima Oil Refinery.[12]

Component	Details
Daily refining capacity	60 000 barrels per day
Expansion potential	Up to 120 000 barrels per day
Main feedstock	Kingfisher and Tilenga crude oil
Power source	100 MW Nzizi gas-fired plant
Multi-product pipeline	211 km (Hoima to Namwabula)
Storage capacity	8+ tanks with combined 300 000 m^3 capacity
Main outputs	Diesel, Jet A-1, LPG, gasoline, naphtha

[12] Petroleum Authority of Uganda (PAU) 2025, *Uganda Refinery Project – Project Profile*, PAU, https://www.pau.go.ug/projects/midstream/uganda-refinery-project/

Component	Details
Development status	As of August 2026, the project was reported to be moving toward a Final Investment Decision (FID), targeted for Q1 2027.
Anticipated commissioning	Operations initially targeted to commence in late 2029 or early 2030, although the schedule remains subject to the project's final investment decision and subsequent construction progress.

The refinery project includes a planned 211 km multi-product pipeline (Hoima–Kampala Petroleum Products Pipeline or HKPPP) to the Kampala Fuel Storage Facility (KFSF) in Namwabula. Together with associated pipeline systems and road improvements, such as the Hoima–Kaiso–Tonya Road, this infrastructure is expected to improve efficiency and reliability of refined petroleum product distribution across the region. In addition, the Hoima–Kinyara–Kafu high-voltage transmission line, currently under development, is expected to strengthen regional electricity transmission and enhance energy system reliability.

The new international airport in Kabaale is intended to support cargo movements, including heavy equipment for petroleum-sector development, and could strengthen regional connectivity and trade. Separately, the Hoima refinery could provide an additional regional source of refined petroleum products for Rwanda. This could diversify supply routes and reduce exposure to some transport-related disruptions but would not by itself establish protection from international petroleum-price volatility.

Potential wider economic benefits of the refinery include job creation, industrial development and secondary investment in fertilizer production, LPG bottling, plastics manufacturing and lubricant blending. These activities represent possible downstream opportunities rather than confirmed outcomes of refinery development. The proposed tax concessions and logistics support associated with the Kabalega Industrial Park SEZ could create opportunities for Rwandan companies, subject to the applicable incentive framework and commercial conditions.

For Rwanda, the Hoima Oil Refinery represents a potential opportunity to strengthen regional cooperation, diversify conventional fuel supply and support economic development. Its contribution would depend on project completion and the availability of commercially competitive products and reliable delivery arrangements to Rwanda. The refinery is therefore a key potential future component of the regional fuel supply system, rather than an established supply source for the SAF business cases assessed in this study.

1.5 PIPELINE INFRASTRUCTURE

Several crude oil and refined product pipelines are under development or discussion in the region.

1.5.1 Hoima–Kampala Petroleum Products Pipeline

As described above, the HKPPP is a 211 km pipeline envisioned as part of the Uganda Refinery Project.[12] As of October 2026 its status was unconfirmed, linked to the pre-FID status of the refinery itself. Its completion would allow efficient transport of refined petroleum products from the Hoima refinery to Kampala.

1.5.2 Eldoret–Kampala–Kigali pipeline

The Kenya Pipeline Company operates a 1 342 km pipeline from the port of Mombasa to Eldoret in northwestern Kenya, through Nairobi (including a branch to Kisumu). Talks have been ongoing since 1995 about a potential extension into Kampala and potentially beyond. In 2024, the presidents of Kenya and

Uganda reconfirmed their plans to extend the pipeline to Kampala (350 km). A potential extension from Kampala to Kigali (484 km) has also been tabled. As of October 2026, no timeline has been established for either section of the extended pipeline.

1.5.3 East African Crude Oil Pipeline

The East African Crude Oil Pipeline (EACOP) (see Figure 6 below) is a 1 443 km crude oil pipeline from Hoima to the port in Tanzania which is planned to start operations end of 2026. It will connect Kabaale Industrial Park in Hoima (and the nearby oilfields) to the port of Tanga in Tanzania. From here the crude oil can be transported abroad or processed at the proposed Tanga Oil Refinery.

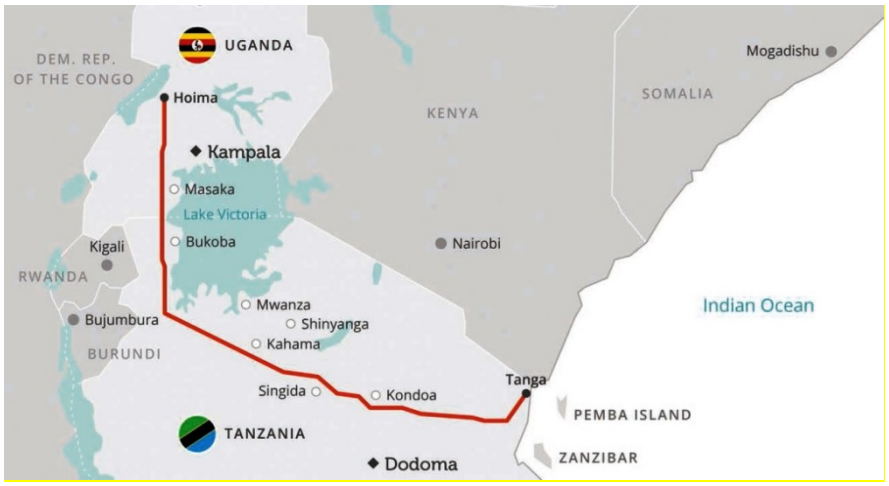


Figure 6. Overview of the East African Crude Oil Pipeline (EACOP).

1.5.4 Potential benefits to Rwanda

Rwanda currently imports all of its petroleum products by road tankers from the ports of Mombasa and Dar es Salaam. These long-distance supply routes—extending over approximately 1 500 km through Kenya or Tanzania—are not only costly but also exposed to a range of risks, including border delays, road congestion, fuel theft, and geopolitical instability, all of which can affect the reliability and security of fuel supply.

The combination of the proposed Hoima-Kampala pipeline and a possible extension of the Eldoret pipeline from Kampala to Kigali presents a key opportunity for more secure and efficient sourcing of jet fuel to Rwanda's aviation sector. Both cost and GHG emissions per unit of jet fuel would be reduced compared to long-distance road transport. Such developments would align well with Bugesera International Airport's vision to become a regional aviation hub.

In addition to economic benefits, pipeline developments enhance energy security. With pipeline-fed storage facilities in Kigali, Rwanda could build strategic reserves capable of insulating the country from regional fuel shortages. This aligns with Rwanda's broader goals of green growth and logistics modernization, contributing to long-term development strategies under Vision 2050.

These developments, including the almost operational EACOP, are part of a broader regional energy development programme. Together, these projects are expected to strengthen regional energy infrastructure by supporting both upstream and downstream activities while contributing to greater regional integration and energy security. The pipelines could also support the objectives of the African Continental

Free Trade Area (AfCFTA) by strengthening regional trade infrastructure, reducing transport constraints, and promoting greater regional value addition in petroleum products.

In Rwanda, the proposed pipelines complement several flagship infrastructure and development initiatives:

- Bugesera International Airport, which would benefit from a more secure and reliable supply of jet fuel;
- KSEZ, where industrial users require stable supply of petroleum products; and
- SAF development, with the potential for future integration into the country's fuel supply and distribution network.

The development of several refineries and pipelines in the region promises to significantly change the supply landscape of fossil jet fuel. This is a crucial context for the long-term development of SAF initiatives in Rwanda and the broader region which should fit into infrastructural changes. However, with the two product pipelines still unconfirmed, for current analysis long-term road transport should be assumed for the foreseeable future.

1.6 REVIEW OF TECHNOLOGY PATHWAYS SUITABLE FOR RWANDA

The 2023 ICAO feasibility study evaluated potential availability of domestic feedstocks for production of SAF in Rwanda. Given the limitations noted in the feasibility study with respect to use of starch and sugar crops, oilseeds, and CO_2, the primary focus of this implementation study will be on crop residues, municipal solid waste (MSW), waste fats and oils as potential feedstocks for SAF.

This section provides a summary of the technology pathways available to process such potentially available feedstocks and complements the assessment of feedstock options identified in the previous ICAO study.

1.6.1 Summary of evaluated feedstocks

The 2023 ICAO feasibility study identified the principal domestic feedstocks with potential for SAF production in Rwanda. A summary of the study's findings is provided below for reference (Table 3). The subsequent sections discuss in greater detail the feedstocks most relevant to the use cases examined in this report, with particular focus on those offering the greatest near-term potential for SAF production.

Given the limitations noted in the feasibility study with respect to the use of starch and sugar crops, oilseeds, and CO_2, the primary focus of this implementation study will be on crop residues, MSW, waste fats and oils as potential feedstocks for SAF. Figure 7 illustrates production (in 2020 and projected to 2024) of various agricultural crops in Rwanda. Among these, residues from cassava, maize, and potato processing are the most likely feedstocks for SAF production.

Table 3. Overview of evaluated feedstocks.

Feedstock considered	Conversion pathway	Feedstock evaluation (supply)	Sustainability evaluation	Economic/market evaluation	Overall
Starch and sugar crops[24]	AtJ/ETJ	**Very low** Lack of suitable area for cultivation, competition with food production.	**Very low** High risk of competition with food production, with implications for food security.	**Low** Unlikely to provide sufficient feedstock to support commercial-scale SAF production.	**Very low**
Oilseed crops[29]	HEFA	**Very low (uncertain)** Lack of suitable area for cultivation, competition with food production Uncertain potential for cultivating oil seed crops on marginal land.	**Very low** High risk of competition with food production, with implications for food security	**Very low (uncertain)** Low productivity demonstrated on marginal land to date. Uncertain potential of new oil seed varieties.	**Very low**
Agricultural residues (crop and food processing)[24]	AtJ/ETJ; G-FT	**Low** Competing uses for animal feed, energy, and material applications. Fragmented land holdings and limited mechanization make residue collection and aggregation difficult.	**Medium** Risk of competition with existing uses for energy, materials, and animal feed.	**Low** Feedstock collection costs are likely to be high. Available resource is insufficient on its own to support a commercial SAF facility.	**Low-medium**
Waste oils (UCO, animal fats)[22]	HEFA	**Low** Limited availability, although the resource could contribute to SAF production.	**Medium** Risk of competition with existing uses for UCO.	**Low** Available resource is too limited to meet the requirements of a commercial HEFA facility.	**Low**

Feedstock considered	Conversion pathway	Feedstock evaluation (supply)	Sustainability evaluation	Economic/market evaluation	Overall
Municipal Solid Waste (MSW)[27]	G-FT	**Medium** Use for SAF is consistent with national waste management objectives. Available quantities are insufficient to support commercial scale production. Collection and feedstock aggregation infrastructure is limited.	**High** Reduces GHG emissions by diverting waste from landfill and open dumping. Helps address land and water pollution associated with current waste management practices.	**Low** Available resource is insufficient on its own to support a commercial SAF facility.	**Medium**
CO_2 + renewable electricity	FT	**Low** CO_2 is not currently captured in Rwanda. Electricity demand would significantly exceed current national generation capacity.	**High** Potential to reduce industrial CO_2 emissions through carbon capture and utilization.	**Low** Electricity costs remain relatively high compared with other markets.	**Low**

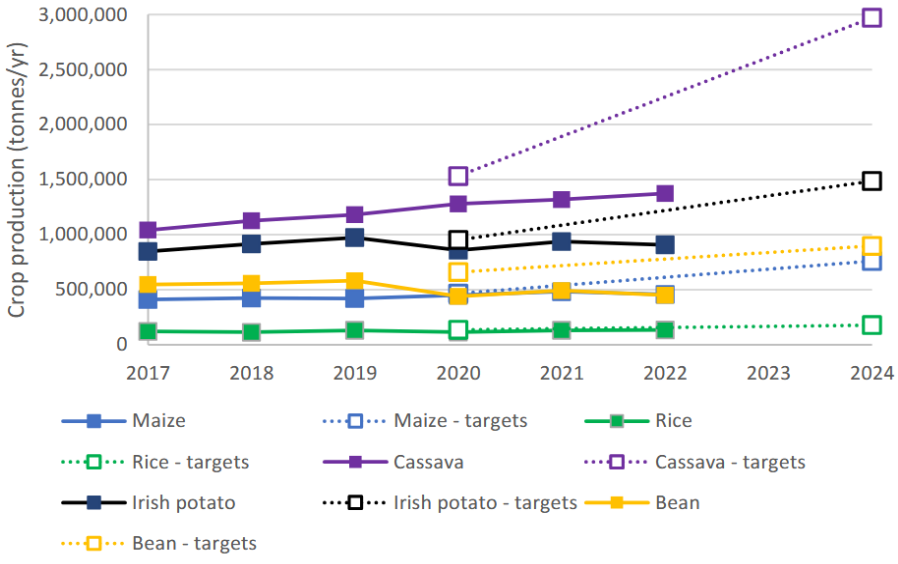


Figure 7. Trends in production of key agricultural crops.[13,14]

[13] National Institute of Statistics of Rwanda (NISR) 2023, *Seasonal Agricultural Survey (SAS) 2017–2022*, NISR.
[14] Ministry of Agriculture and Animal Resources (MINAGRI) 2018, *Strategic Plan for the Transformation of Agriculture in Rwanda, PSTA4 (2018–2024)*, Government of Rwanda.

1.7 AGRICULTURAL RESIDUES

1.7.1 Feedstock-related information

The production of conventional agricultural residues in Rwanda is estimated at 1.0 to 1.1 million tonnes per year. Cassava pseudo-stems and banana peels and leaves could contribute a further 6 million tonnes of residues. The principal sources of agricultural residues are rice and wheat straw, maize stover, and cassava stems and peels (Figure 10). However, there is limited information on the current use of these residues for applications such as animal feed and bioenergy (e.g., briquettes). Maize stover is commonly used as animal feed, while maize cobs are used as a solid fuel alternative to wood-based fuels. Nonetheless, the proportion of stover that is recovered and used remains uncertain. Significant quantities of residues are also generated from banana and plantain production (Eliasson and Carlsson, 2020), although a proportion is retained on the land to maintain soil fertility and productivity.

Cassava is a major staple crop in Rwanda, producing starch-rich tuberous roots. In additional to the edible roots, the stems, leaves, peels and processing residues (bagasse) provide potential feedstock for the production of renewable fuels, including ethanol, biogas, and SAF. Cassava stems are also rich in starch, which can be readily extracted. Rwanda produced approximately 1.4 million tonnes of cassava in 2023, generating an estimated 550 thousand tonnes of residues from stems and peels, together with a further 4.2 million tonnes of residues from pseudo-stems.

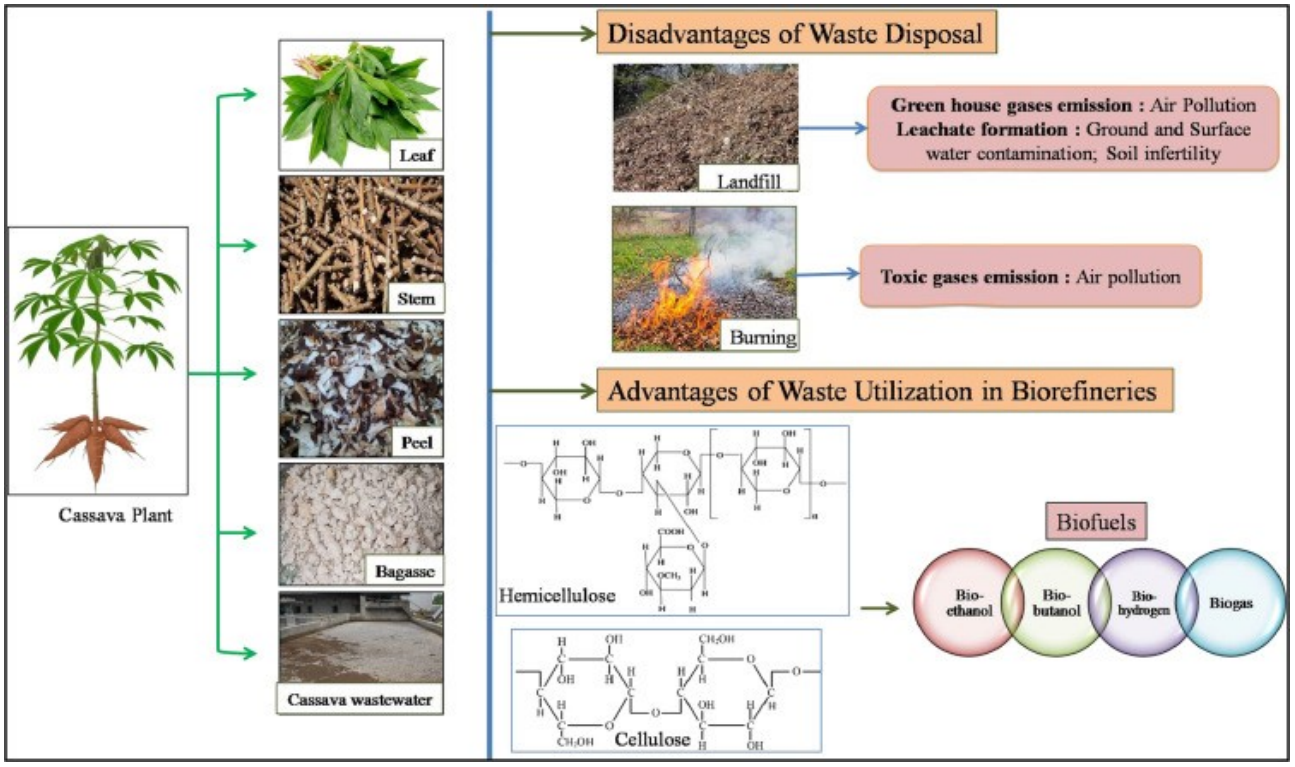


Figure 8. Cassava plant processing into biofuels flowchart.

Residues from the processing of food crops may be suitable feedstocks for SAF production. Sugarcane bagasse and starch-rich residues from the processing of maize, cassava, and potatoes could serve as suitable feedstocks when produced in sufficient quantities. A key advantage of food processing residues compared with agricultural crop residues, is that they are already collected and concentrated at a processing facility,

simplifying their recovery and utilization. However, as shown in Table 4, current data indicate that less than 10% of Rwanda's agricultural crops is processed,[24] and the resulting residues are typically used to generate energy at processing facilities or sold for external use as fuel elsewhere.

Table 4. Summary of potential crop residues from major crops in Rwanda.[24]

Primary Crop	Annual Production, '000 tonnes	Residue type	residue to product ratio	residue quantity, '000 tonnes
Maize	420	cobs	0.27	113
Maize	420	stover	2	840
Cassava	1400	stems and peels	0.4	560
Cassava	1400	Pseudo-stems	3	4200
Banana	2500	leaves	0.48	1200
Banana	2500	peels	0.44	1100
Sugarcane	114	bagasse	0.25	29
Sugarcane	114	tops	0.32	36

1.7.2 Sustainability-related issues, including greenhouse gas (GHG) emissions

Crop residues can be a sustainable, lower carbon-intensity feedstock for fuel and energy production, provided that proper attention is given to management of soil carbon, ensuring sufficient residues are left in the field to avoid soil degradation. The default CORSIA life cycle GHG emissions for SAF production from agricultural residues is 7.7 gCO2eq/MJ, provided that collection and removal of the residues do not require nutrient replacement.

1.7.3 Economic and market-related issues

Based on the ICAO Rules of Thumb, the 1.0 million tonnes of conventional crop residues could produce 140 000 tonnes of distillates, including around 40 000 tonnes of SAF, when processed using the gasification-Fischer Tropsch (G-FT) pathway. Alternatively, if these residues are first converted to lignocellulosic ethanol, and subsequently to SAF via the AtJ pathway, annual SAF production is estimated at 140–170 million litres (assuming an Ethanol yield of approx. 230-280 L/t and an Ethanol to ATJ conversion of 0,6). Cassava pseudo-stems could produce approximately 200 million litres of SAF via the G-FT pathway, or around 600 million litres of SAF via the lignocellulosic ethanol - SAF AtJ pathway.

Despite the significant theoretical production potential of these residues, the cost of collecting and supplying them to a biofuel facility remains uncertain. The ICAO Rules of Thumb estimate a collection cost of approximately of USD 110 per tonne for agricultural residues; however, actual costs can vary considerably between countries depending on labour and transport costs and residue density in the field. In Rwanda, highly fragmented landholdings and low levels of mechanization are expected to constrain the quantity of residues that can be economically recovered for energy production and increase collection costs.

1.7.4 Overall assessment

There are significant quantities of agricultural residues with potential for bioenergy production, provided that appropriate collection infrastructure and supply chains are developed. The commercialization of these residues could provide an additional source of income for farmers; however, this benefit would need to be balanced against the cost of SAF production.

1.8 WASTE OILS

1.8.1 Feedstock-related information

Waste oils, including used cooking oil (UCO) and tallow, are potential feedstocks for SAF production via the HEFA pathway.[22] The main source of UCO is the food service and food processing sectors. Per capita edible oil consumption in Rwanda is estimated at 2.5 litres per person. Based on the country's current population of 14.2 million, this equates to an annual edible oil consumption of around 35 million litres, of which only a small proportion is likely to be recoverable as UCO. Tallow by-products are currently used for food (edible tallow) and soap production (inedible tallow) and are therefore unlikely to be available as feedstock for SAF production.

According to the ICAO feasibility study, an unpublished 2017 survey of UCO generation in Rwanda estimated that approximately 26 000 litres per month of UCO are generated by food processing facilities, hotels, bars and restaurants. Of this total, around 15 000 litres per month are generated in the City of Kigali. The survey also estimated that approximately one quarter of UCO generated is disposed of as waste and could therefore be recovered for SAF production without competing with existing uses.

1.8.2 Sustainability-related issues, including greenhouse gas (GHG) emissions

As UCO and tallow are by-products of the food sector, the GHG emissions associated with these feedstocks are primarily attributable to their collection and preprocessing, as upstream emissions are allocated to their primary use in food production. Additional environmental benefits may also be realised where UCO and tallow are diverted from disposal or other lower-value waste management pathways.

Life cycle GHG emissions associated with SAF produced from UCO and tallow are therefore expected to be relatively low. According to the default CORSIA life cycle emissions values, SAF produced from UCO and tallow has life cycle GHG emissions of 13.9 gCO2eq./MJ and 22.5 gCO2eq./MJ, respectively. assuming production in a stand-alone facility (ICAO, 2022a).

1.8.3 Economic and market-related issues

The volumes of UCO generated from households, food processing facilities, restaurants, and hotels, are relatively small. Given the challenges associated with waste oil collection, together with the presence of contaminants and impurities, it may be difficult to recover and process sufficient quantities of UCO for SAF production, particularly as a commercially viable HEFA facility typically requires more than 200 million litres of waste oils annually.

Although UCO is a by-product of food preparation, it has established commercial uses and therefore an existing market value. The 2017 survey reported a median price of 500–600 Rwanda Francs (RWF) per litre, equivalent to USD 465–560 per tonne. Higher prices, ranging from 750–1 000 RWF per litre (USD 700–930 per tonne), were reported by food processors reflecting the use of higher value sunflower oil.

1.8.4 Overall assessment

Ultimately, UCO and tallow are only likely to be viable feedstock if domestic supplies are supplemented by imports from neighbouring countries. It would therefore be worthwhile to explore opportunities to transport UCO and tallow between Rwanda and neighbouring jurisdictions, such as Uganda, for processing at a larger SAF production facility. The resulting SAF could then be supplied to Rwanda, Uganda or other regional markets.

1.9 MUNICIPAL SOLID WASTE (MSW)

According to the literature, per capita MSW generation in sub-Saharan Africa averages approximately 0.46 kg per day.[26,27] A high proportion of the waste is organic, reflecting the widespread preparation of fresh food and the relatively limited use of packaging for goods sold in the local markets (He et al., 2024). This high organic content makes the waste stream well suited to bioenergy and biofuel production.

1.9.1 Feedstock-related information

Preliminary conservative estimates in Kigali, based on waste collection truck counts, indicate that approximately 400 tonnes of MSW are collected and landfilled each day (MININFRA, 2022) which would be 146 000 tonnes/year. A separate study estimates that around 230 000 tonnes of MSW are collected annually in the city.[15] Several sampling studies have reported that organic material accounts for approximately 60-80% of urban waste and more than 90% of rural waste (MININFRA, 2022). However, no data are available on the quantities or compositions of commercial and industrial solid waste.

Comparable data are limited outside of Kigali. A study conducted by the Global Green Growth Institute (GGGI) in the cities of Huye and Muhanga found that less than 10% of the waste generated is collected and properly managed; with the majority being openly dumped or burned.

According to the Huye District Sanitation Master Plan, per capita waste generation is approximately 0.7 kg per day, equivalent to at least 50 tonnes of solid waste per day or more than 18 000 tonnes of MSW annually. Approximately 75% of the waste is organic, with a proportion being converted into compost. In Muhanga, per capita waste generation is estimated at 0.6 kg per day, corresponding to approximately 30 tonnes of solid waste per day, of which around 65% is organic. The district currently has no dedicated waste management facility.

To use MSW as a feedstock for biofuel production, the inorganic fraction must first be removed through pretreatment. Inorganic materials cannot be converted into biofuel and may, adversely affect downstream processing by introducing trace metals and other contaminants.

The low waste collection rates observed in these urban areas suggest significant potential to increase feedstock availability through an improved collection system. Expanding waste collection infrastructure would not only strengthen waste management practices but also increase the quantity of MSW available for biofuel and bioenergy production.

1.9.2 Sustainability-related issues, including greenhouse gas (GHG) emissions

The large quantity of uncollected solid waste represents a significant environmental challenge. The high organic content of both collected and uncollected waste also results in considerable biomethane generation potential, creating a substantial GHG burden as the organic material decomposes over time. Improving waste collection and diverting the organic fraction to biofuel and bioenergy production would provide important environmental benefits by reducing landfill gas emissions and GHG emissions from unmanaged wastes.

Under CORSIA, the default life cycle GHG emissions value for SAF produced from MSW via the gasification-FT pathway is 5.2 g/MJ, assuming that the MSW feedstock is 100% biogenic. Processing MSW containing non-biogenic materials, such as plastics and textiles, increases the life cycle GHG emissions in accordance with

[15] E3S Web of Conferences 80, 03004 (2019) https://doi.org/10.1051/e3sconf/20198003004

the methodology specified under CORSIA.[16] Based on the estimated organic content of Kigali MSW (60%-80%), the CORSIA default life cycle GHG emissions for SAF are projected to range from 39 to 73 gCO2eq./MJ compared with 84.5 gCO2eq./MJ for conventional jet kerosene (ICAO, 2022a).

1.9.3 Economic/market-related issues

Standard assessments of SAF production from MSW via G-FT pathway indicate a minimum facility capacity of 100 million litres of distillates per year (ICAO Rules of Thumb), of which around 40 million litres would be SAF. A facility of this scale would require about 300 000 tonnes of MSW annually, significantly more than Kigali generates per year. High-level cost estimates, based on a North American reference plant, indicate a capital cost of approximately USD 8 per litre of annual distillate. A larger plant with a processing capacity of 1.0 to 1.5 million tonnes of MSW per year is projected to have a substantially lower capital cost, of approximately USD 2.9 per litre of annual distillate production capacity.

An alternative approach is to separate the organic fraction of MSW and process it independently to produce alcohols, particularly methanol, which subsequently can be converted to SAF. However, this technology has yet to be demonstrated at commercial scale, and a default life cycle GHG emission value for this pathway has not yet been established under CORSIA.

1.9.4 Overall assessment

MSW is an attractive feedstock for SAF production, although its heterogeneous composition presents certain challenges. The greatest near-term opportunity lies in Kigali, where approximately 230 000 tonnes of MSW are generated annually (Figure 9). Of this total, about 150 000 tonnes comprise organic material suitable for biofuel production. If processed via the G-FT pathway, this resource could produce approximately 45 000 tonnes of distillates, including around 18 000 tonnes (20 million litres) of SAF annually.

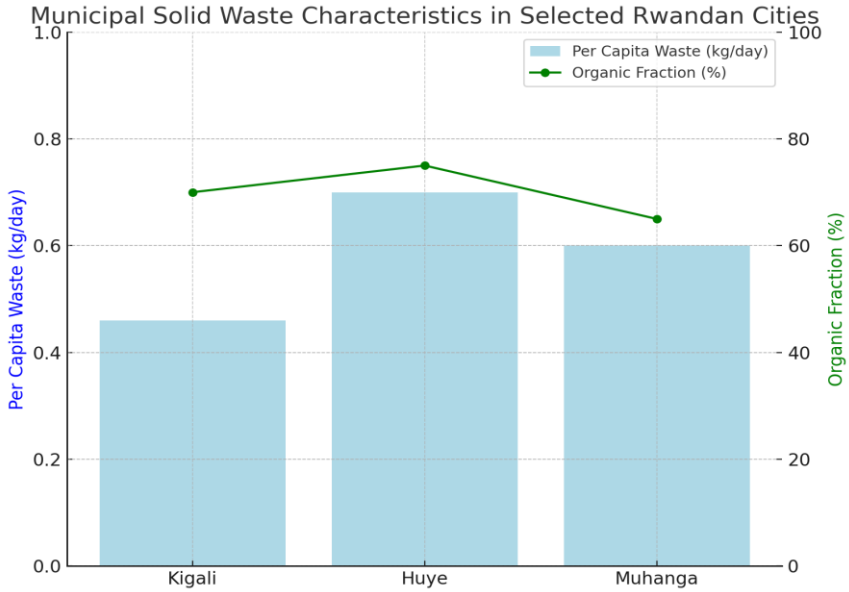


Figure 9. Municipal solid waste (MSW) characteristics in selected Rwandan cities.[26]

[16] ICAO document on CORSIA Default Life cycle Emissions: https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO%20document%2006%20-%20Default%20Life%20Cycle%20Emissions%20-%20October%202024.pdf

Rwanda could strengthen MSW collection and utilize the organic fraction for biofuel and bioenergy production, thereby addressing several challenges simultaneously: managing the growing volume of MSW, reducing emissions associated with waste decomposition, and lowering aviation emissions through the displacement of fossil-derived jet fuel. The principal challenge lies in the heterogeneous nature of MSW, which requires extensive and potentially costly sorting to isolate the processible organic fraction. Although MSW gasification is a well-established technology, its integration with SAF production has, to date, proven technically and financially challenging, largely because of impurities that remain in the feedstock even after sorting. Separating the organic fraction for conversion into biogas or (m)ethanol may therefore represent a more cost-effective and technically viable near-term pathway for utilizing MSW.

1.10 SUMMARY OF TECHNOLOGY OPTIONS

1.10.1 Alcohol to Jet (AtJ) Pathway

The AtJ pathway combines two established commercial processes: (i) the conversion of starch or sugars into ethanol, and (ii) the dehydration and oligomerization of ethanol to produce jet-range alkanes. These processes may be carried out separately—for example, ethanol produced from sugarcane at one location and transported to a second facility for conversion into SAF. Alternatively, the two processes can be co-located, allowing the sharing of utilities and process integration, thereby reducing both capital costs and the carbon intensity of the resulting fuel. Sugarcane bagasse could potentially provide the heat and electricity required for both processes.

In Rwanda, maize, cassava, potatoes and their associated residues are all potential feedstocks for the AtJ pathway. Among these, agricultural and processing residues offer the greatest potential, as their use avoids direct competition with food and animal feed applications.

1.10.2 Hydroprocessed Esters and Fatty Acids (HEFA) and co-processing

The HEFA pathway is a well-established technology for producing SAF. It involves hydrodeoxygenation of renewable and waste-derived fats and oils to produce a mixture of renewable diesel and SAF. The renewable diesel can subsequently undergo an additional isomerization step to increase the yield of SAF, albeit at the expense of renewable diesel production.

The HEFA process may be implemented in a standalone facility, or renewable and waste oils may be co-processed with crude oil into a conventional oil refinery. Co-processing at renewable oil blend levels of approximately 5% is already well established; while the potential for higher blend ratios is currently being evaluated. Ultimately, co-processing represents one of the lowest capital options for SAF production.

In the context of Rwanda, crude maize oil recovered during maize processing could be used as a feedstock for biofuel production. Alternatively, UCO could be collected and used via the HEFA pathway following feedstock pre-treatment to remove water and other impurities.

1.10.3 Fischer-Tropsch (FT)

The gasification Fischer-Tropsch (G-FT) process involves conversion of biomass such as crop residues or MSW into syngas, followed by catalytic conversion of the cleaned syngas into hydrocarbons, usually comprising a mixture of naphtha, renewable diesel and SAF.

While gasification and FT synthesis are independently used at the commercial scale and have a long history of converting natural gas and coal into liquid fuels, the track record of combining MSW or biomass gasification

with FT synthesis has been mixed. One of the main challenges is the variability in feedstock composition—particular for MSW, and to a lesser extent, for biomass such as agricultural residues. Effective management of feedstock quality and the resulting syngas impurities is critical to the successful operation of the G-FT process.

1.11 BUSINESS-CASE INPUT ASSUMPTIONS AND KEY PARAMETERS

This section provides a structured baseline profile and key parameters for a medium-scale facility, which is the business-case assumption taken as most technically and economically feasible for this study. Based on the information available from previous studies and the review of technology pathways suitable for Rwanda, medium-scale SAF production facilities (30–50 million litres per year) based on either the ATJ or FT pathway, using agricultural residues or MSW as feedstock, have been selected for further assessment.

The study presents the financial and operational assessment of two representative business cases:

1. A gasification and Fischer-Tropsch pathway using MSW as the feedstock; and
2. An alcohol-to-jet (AtJ) pathway using agricultural residues as the feedstock.

1.11.1 General facility inputs for full-scale production

To complement the aforementioned industrial developments, the viability of a SAF production facility also needs to be assessed. For a medium-scale facility (30–50 million litres per year SAF output) based on either the AtJ or FT pathway and using agricultural residues or MSW feedstocks, this section presents a structured baseline profile for Rwanda. The corresponding assumptions are summarized in Table 5.

Table 5. Estimated construction timelines and inputs for a medium-scale SAF production facility.[17,18,19]

Stage	Activities	Duration (typical)	Notes for Rwandan context
Pre-FEED / feasibility	Technical studies, EIA, permits, feedstock aggregation agreements	9–12 months	Time may be extended by Rwandan environmental licensing processes and land acquisition approvals
FEED (Front-end engineering design)	Detailed engineering, procurement planning	6–9 months	International EPC contractors likely to be engaged, with some local subcontractors
EPC (Engineering, procurement and construction)	Site preparation, civil works, equipment fabrication and installation	18–24 months	Shipping lead times via Dar es Salaam/Mombasa + Kigali inland transport add ~3–4 months buffer
Commissioning and start-up	Test runs, calibration, operator training	3–6 months	Initial batches often below spec until processes stabilize

[17] World Bank 2016, Project Management and Engineering Guidelines for Energy Infrastructure, Energy & Extractives Global Practice, World Bank, https://www.worldbank.org/en/topic/energy

[18] African Development Bank (AfDB) 2019, *Midstream and Downstream Oil & Gas Infrastructure Development Guidelines*, African Natural Resources Centre, AfDB.

[19] International Energy Agency (IEA) 2021, *Energy Infrastructure Project Timelines: Engineering, Construction and Commissioning Benchmarks*, IEA.

Total time from project start to initial production: ~3.5–4 years from early feasibility to first commercial SAF delivery.

1.11.2 Expected capacities[20]

Baseline design capacity

At full design capacity, the facility is expected to produce approximately the following main outputs:

- SAF: Approximately 40 million litres per year (~250 000 barrels per year) at full design capacity.
- Renewable diesel: 5–8 million litres per year, suitable for use in the road transport sector or for export.
- Naphtha: 1–3 million litres per year, suitable as a petrochemical feedstock or blending component.
- CO_2 (if captured): 20–40 000 tonnes per year, with potential applications in the beverage industry or for e-fuel production.

Economic implications

Co-products can increase project revenues by approximately 5–15% depending on offtake agreements. The quantity and composition of co-products will vary according to the technology pathway and feedstocks used.

1.11.3 Ramp-up timeline[21]

Typical ramp-up profiles for new SAF production facilities, particularly first-of-a-kind plants in the region, are about 40–60% of design capacity in year 1, 80–90% of design capacity in year 2 and 95–100% of design capacity Year 3 onwards.

The pace of ramp-up may be constrained by several factors, including the maturity and reliability of feedstock supply chains, operator training and process optimisation, and the reliability of supporting utilities such as power, water and process heat.

1.11.4 Operational metrics[22]

Once steady-state operations have been achieved, a commercial biofuel facility would typically be expected to achieve an availability of approximately 85–90%. Planned shutdowns for scheduled maintenance would generally account for around four to six weeks per year, typically distributed across two or three maintenance outages. Unplanned downtime could represent approximately 3–5% of annual operating hours, primarily as a result of feedstock variability or equipment failures, with potentially higher levels during the initial years of operation.

The facility would typically have a design life of approximately 20–25 years, with major refurbishments generally required every 8–10 years. Its economic life, however, may be influenced by the prevailing policy and incentive framework, as well as the duration and terms of long-term offtake agreements, such as airline purchase agreements extending over 10–15 years.

[20] International Air Transport Association (IATA) 2023, *Net Zero Roadmap: Sustainable Aviation Fuel Technical Guidelines*, IATA.
[21] International Energy Agency (IEA) 2021, *Advanced Biofuels: Potential for Cost Reductions and Scale-up*, IEA.
[22] U.S. Department of Energy (DOE) 2020, *Bioenergy Technologies Office: Multi-Year Program Plan*, U.S. DOE.

1.11.5 Capital expenditure (CAPEX)

Based on comparable facilities in emerging markets (adjusted for Rwanda's import costs & scale), the estimated CAPEX is outlined in Table 6.

Table 6. Breakdown of estimated CAPEX required.[17]

Item	Cost estimate (USD million)
Land and site prep	2–3
Feedstock pre-treatment units	10–15
Conversion units (AtJ or FT)	35–50
Utilities and infrastructure	8–12
Storage, blending, handling	5–7
EPCM, contingencies (15–20%)	10–15
Total CAPEX	**70–100**

The main cost drivers in Rwanda are:

- Higher freight & inland transportation costs for heavy process equipment.
- Potential cost savings through the adoption of modular plant design fabricated overseas.

1.11.6 Other off-site costs

Off-site infrastructure costs are also expected to be significant. Establishing feedstock aggregation hubs and covered storage facilities could require an upfront investment of USD 3–5 million, in addition to ongoing operating costs. Dedicated transport fleets, GPS tracking systems, and fuel handling equipment may require a further USD 2–4 million in capital expenditure, with annual operating costs estimated at USD 1–2 million. Upgrades to supporting utilities, such as a dedicated electrical substation or water treatment plant, could add another USD 3–5 million. Initial training programmes for plant operators, developed in partnership with Rwandan technical and vocational institutions, are estimated to cost USD 0.5–1 million, while compliance with ASTM D7566 fuel specifications and environmental monitoring requirements could require a further USD 0.3–0.5 million during project start-up.

These are broadly consistent with comparable biofuel projects in Africa and with international SAF facilities of a scale aligned with Rwanda's feedstock availability and market size. Experience from projects such as LanzaJet's Freedom Pines Fuels in the United States, Neste's Singapore expansion, and Red Rock Biofuels indicates that the projected construction timelines, capacity ramp-up profiles, and plant availability assumptions are realistic. Although co-product yields and overall economic performance will vary depending on the technology pathway selected, the operational and financial benchmarks presented here provide a practical basis for assessing the viability of SAF production in Rwanda.

1.12 PROCESS AND ENERGY/UTILITIES INPUTS

Developing a SAF facility in Rwanda requires a clear understanding of the availability and cost of energy inputs, feedstocks, and operating expenditures, as these factors are central to both technical feasibility and long-term economic viability. Rwanda's industrial energy and utility landscape is well-developed by regional

standards, yet it still presents some unique constraints and opportunities for SAF producers. Those are detailed respectively in Table 7, Table 8 and Table 9 below.

Table 7. Availability and cost of energy and utility inputs.

Input	National/regional availability	Current cost (indicative)	Notes / transition pathways
Electricity	Rwanda's national grid capacity is ~330 MW (2024), dominated by hydro (~50%), methane gas (~30%), solar (~10%), and peat/thermal (~10%). Industrial access possible in SEZs and near high-voltage lines.	Industrial tariff ~USD 0.11–0.13/kWh (REG industrial tariff schedule).	Government target is 60% renewable electricity share by 2030; potential for direct PPAs with hydropower or solar IPPs to increase green content for SAF LCA scores.
Process heat (steam)	No national steam network; generated on-site via biomass boilers (bagasse, wood residues) or LPG-fired units.	Biomass fuel ~USD 35–50/ton; LPG ~USD 1.35–1.50/kg (imported).	Biomass steam generation aligns with lower-carbon operations but requires storage space and supply contracts.
Water	Abundant in most regions; Kigali area supplied by WASAC. Industrial bulk water tariff ~USD 0.75–1.20/m^3. Borehole abstraction possible with permit.	Supply security high near Kigali; more complex in rural industrial sites.	Treatment (RO, demineralisation) needed for process use; cost ~USD 0.15–0.20/m^3.
Hydrogen	No current domestic production; imported bottled H_2 for industrial use is costly (>USD 8–10/kg).	Grey hydrogen possible from imported LNG or pipeline gas (currently absent in Rwanda); green hydrogen would require dedicated electrolyser + RE supply.	For AtJ or FT upgrading, imported H_2 would be cost-prohibitive unless paired with a small on-site electrolyser powered by RE.
Natural gas	No national gas pipeline network; only bottled LPG via import.	~USD 25–28/MMBtu equivalent.	Likely unsuitable as primary energy input due to cost and logistics.

Sustainability consideration

Rwanda is well positioned to transition from grey to clean power more rapidly than many of its African peers, owing to its already high share of hydropower and planned expansion of solar generation. For international SAF certification schemes, including CORSIA, and the EU Renewable Energy Directive (RED II), the carbon intensity of grid electricity will be a critical factor in demonstrating compliance with life cycle assessment (LCA) requirements.

1.12.1 Availability and cost of feedstock

Table 8. Potential feedstock types and supply.

Pathway	Feedstock	Estimated national/regional supply	Price range (USD/tonne, 2024)[23]	Notes
AtJ[24,25]	Agricultural residues (maize stalks, sorghum stems, rice husks, coffee husks, sugarcane bagasse)	1.2–1.5 million tonnes per year (seasonal variability ±20%)	20–35 (farmgate); 40–55 delivered to hub	Supply concentrated in Eastern, Northern, and Southern provinces; collection hubs required.
FT[26,27]	MSW (organic fraction)	Kigali ~550–600 tonnes per day; national urban ~1 200–1 400 tonnes per day	(-20) to 0 (negative pricing possible with tipping fee)	Requires pre-sorting; moisture content high (35–50%), drying needed.
HEFA[28,29]	UCO	Kigali & major towns: ~5–6 million litres per ear recoverable	400–700 USD/tonnes	Fragmented collection; high contamination risk.
HEFA[30,31]	Animal fats/tallow	Small-scale slaughterhouse output ~1 500–2 000 tonnes per year	350–500 USD/tonnes	Limited scale, primarily for niche blending.

Supply chain observations

- Agricultural residues are abundant but scattered; logistics cost is a major factor.
- UCO has high unit value but limited national volume; could be imported from East African ports to supplement.
- MSW offers the lowest or even negative feedstock cost but has the highest preprocessing requirement.

Price variability and long-term contracts

- Agricultural residues: Seasonal volatility ±15–20% depending on harvest yields; long-term supply contracts (5–7 years) with farmer co-operatives possible, securing base prices with inflation adjustments.
- UCO and tallow: Prices linked to global commodity markets and can swing ±30–40% annually; import contracts possible but subject to port supply chain delays.

[23] S&P Global Platts 2024, *Biofuels Price Assessments: Feedstocks (Residues, UCO, Tallow)*, S&P Global Commodity Insights.
[24] Food and Agriculture Organization (FAO) 2022, *Crop Residue Availability and Bioenergy Potential in East Africa*, FAO.
[25] International Renewable Energy Agency (IRENA) 2021, *Renewable Energy Prospects: East Africa*, IRENA.
[26] Rwanda Environment Management Authority (REMA) 2021, *Rwanda State of Environment and Outlook Report*, REMA.
[27] Kigali City Council 2022, *Kigali Waste Management Master Plan*, City of Kigali.
[28] United Nations Industrial Development Organization (UNIDO) 2020, *Market Assessment of Waste Oils and Fats in East African Cities*, UNIDO.
[29] Rwanda Utilities Regulatory Authority (RURA) 2023, *Hospitality and Food Services Waste Oil Compliance Report*, RURA.
[30] FAO 2020, *Livestock Value Chain and By-Product Utilization in Rwanda*, FAO.
[31] Rwanda Agriculture and Animal Resources Development Board (RAB) 2022, *National Livestock Production Statistics*, RAB.

- MSW: Potentially stable or negative pricing under municipal waste management agreements; requires policy alignment with city authorities.

1.12.2 Operating expenditure (OPEX)

Table 9. Indicative OPEX profile for a 40 million litres per year SAF plant in Rwanda.

Cost component	Cost [USD million/year]	% of OPEX	Notes
Feedstock procurement and transport[32]	10–14	35–45%	Varies with pathway; MSW lower cost but higher processing.
Utilities (electricity, water, process heat, hydrogen)[33]	5–7	20–25%	Hydrogen cost can dominate if imported.
Labour and operations[34]	2.5–3.5	10–12%	Local staffing with ~5–10% expat technical oversight in early years.
Maintenance and consumables[35]	2–3	8–10%	Includes catalyst replacement, filters, etc.
Certification, compliance, insurance[36]	0.5–1	2–4%	Includes ASTM D7566, environmental monitoring.
Overhead and administration[37]	1–1.5	5–7%	Management, finance, HQ functions.

The total annual OPEX is expected to be around USD 21–28 million per year (excluding debt service).

1.12.3 Implications for economic viability

- Electricity sourcing: A power purchase agreement (PPA) with a hydropower or solar generation facility could improve LCA performance and facilitate access to markets governed by CORSIA and EU/ICAO, although it may involve higher upfront electricity tariffs than the national grid mix.
- Feedstock contracting: Securing long-term feedstock supply agreements with indexed pricing can reduce exposure to commodity price volatility, particularly for agricultural residues and UCO.
- Hydrogen strategy: Hydrogen is a key cost driver for both AtJ and FT pathways. Developing local green hydrogen production could reduce reliance on import while improving sustainability performance.
- Waste feedstock policy support: For MSW-based pathways, supportive policies and appropriate tipping fee structures could reduce feedstock costs significantly and, in some cases, result in net-negative feedstock cost.

[32] International Air Transport Association (IATA) 2023, *Sustainable Aviation Fuel: Technical and Economic Guidelines*, IATA.
[33] International Energy Agency (IEA) 2021, *Advanced Biofuels: Potential for Cost Reductions and Scale-Up*, IEA.
[34] U.S. Department of Energy (DOE) 2020, *Bioenergy Technologies Office: Multi-Year Program Plan*, DOE.
[35] S&P Global Commodity Insights 2022, *Renewable Diesel and SAF Refinery Operating Costs Report*, S&P Global.
[36] ASTM International 2022, *ASTM D7566 – Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons*, ASTM.
[37] International Renewable Energy Agency (IRENA) 2022, *Renewable Fuels for Aviation: Technology and Cost Overview*, IRENA.

The interaction between electricity sourcing, feedstock strategy, and cost control will ultimately determine the commercial viability of a SAF facility in Rwanda. Access to low-carbon electricity through renewable PPAs could improve market access and strengthen compliance with international sustainability requirements, while long-term securing feedstock contracts would reduce exposure to price volatility and supply risks. Similarly, developing a local green hydrogen strategy, ideally based on renewable-powered electrolysis, could reduce dependence on imported hydrogen while improving life cycle GHG performance. For MSW-based pathways, integrated waste management policies and appropriate financial incentives, could provide a reliable feedstock supply at low or potentially negative costs.

Taken together, these parameters form the foundation for a detailed financial model, enabling investors and policymakers to assess the net present value (NPV), internal rate of return (IRR), and payback period for a Rwandan SAF facility under a range of input price and market scenarios. By aligning technical planning with local resource availability, the project can be positioned to achieve both economic and environmental sustainability.

1.13 FINANCIAL INPUTS

This section presents the baseline financial parameters and modelling framework for a SAF production facility in Rwanda, drawing on regional capital market conditions, African infrastructure financing benchmarks, and experience from the biofuel sector. These parameters are indicative and will require further refinement in consultation with lenders, investors, and local tax authorities once the project structure has been defined.

1.13.1 Cost of capital (weighted average cost of capital (WACC))

For a medium-scale SAF production facility in Rwanda, financing is expected to comprise a combination of development finance institutions (DFIs), commercial lenders, and equity investors.[38] A representative capital structure is outlined below.

- Debt: 55–65% of total capital
    - Project finance interest rates in East Africa typically range from 8–12% (USD-denominated) depending on the level of risk mitigation provided through guarantees, export credit agencies, or other credit enhancement mechanisms.
    - Access to concessional climate finance could reduce borrowing costs to approximately 5–7%.
- Equity: 35–45% of total capital
    - The required return on equity (ROE) for biofuel projects in emerging markets typically ranges from 14–20.

Indicative WACC (real, post-tax):

- Base case: 9–11%
- With concessional finance: 7–9%

[38] International Finance Corporation (IFC) 2020, *IFC Project Finance and PPP Structuring Guidelines*, IFC.

1.13.2 Taxation

- Corporate income tax (CIT): 30% (standard rate in Rwanda).[39]
- Investment incentives:
    - Tax exemptions of up to seven years may be available for strategic manufacturing and renewable energy projects under Rwanda's Investment Code. Accelerated depreciation may also be available for renewable energy assets.
- VAT: 18% on goods and services, with potential exemptions for imported capital equipment.

1.13.3 Internal Rate of Return (IRR)

- Target equity IRR: 14–18% (base case).
- Target project IRR (unlevered): 10–14%.[40]
- The project IRR could be enhanced through:
    - Reduced feedstock costs under MSW supply agreements
    - Carbon credit revenues (estimated at USD 3–8 million per year, depending on SAF production volumes and carbon prices)
    - Premium pricing for SAF in export markets.

1.13.4 Depreciation

- Straight-line depreciation over 15–20 years for plant and machinery.
- Accelerated depreciation (e.g., 50% in Year 1) may be available for eligible renewable energy assets under Rwanda's investment promotion framework, improving early-year tax shields and project cash flow. [41]

1.13.5 Payback period

- Base case: 8–10 years from commercial operation date (COD).[38]
- With concessional finance and carbon credits: 6–8 years.
- A shorter payback may be possible if SAF is sold into higher-value export markets; such as the European Union or the United Kingdom.

1.13.6 Sensitivity analysis

The financial model should test the following key variables over a range of approximately ±10–30%:[32]

1. Feedstock price – A major driver of OPEX; MSW-based pathways are generally more resilient than pathways relying on UCO or agricultural residues.
2. SAF selling price – Influenced on policy incentives, carbon credit revenues, and access to export markets.
3. Plant availability – A reduction in availability from 90% to 80% could reduce the IRR by approximately 2–3 percentage points.
4. Hydrogen cost – A significant cost driver for both the FT and AtJ pathways; local green hydrogen production could improve both project economics and sustainability performance.
5. CAPEX overruns – A 10% increase could extend the payback by approximately one year.
6. Policy incentives – The removal of tax incentives or carbon credit mechanisms could reduce the IRR by approximately 3–5 percentage points.

[39] Rwanda Revenue Authority (RRA) 2024, *Corporate Income Tax, VAT & Investment Incentive Guidelines*, RRA.
[40] Climate Policy Initiative (CPI) 2022, *Cost of Capital for Low-Carbon Infrastructure in Emerging Markets*, CPI.
[41] Rwanda Development Board (RDB) 2023, *Investment Code and Incentive Framework*, RDB.

SECTION 2. TECHNO-ECONOMIC ASSESSMENT AND RESULTS

The techno-economic assessment provides the analytical foundation for determining the financial and technical viability of a SAF production project in Rwanda. Using the input parameters established during the preceding scenario and assumption-setting phase, this section brings together the key feedstocks, cost structures, economic performance indicators, and investment metrics. The results not only assess the feasibility of the proposed SAF facility but also benchmark its performance against international reference values, including those published by ICAO.

2.1 CAPEX AND OPEX

The preliminary cost estimates for SAF production in Rwanda are shaped by the dual challenges of infrastructure readiness and supply chain integration.

CAPEX

The total capital investment (TCI) includes land acquisition within or adjacent to Rwanda's Special Economic Zones (SEZs), procurement of processing technology (e.g., gasification-Fischer–Tropsch (G-FT), or alcohol-to-jet (AtJ) pathways), feedstock pre-treatment facilities, blending and storage infrastructure, and site utilities. Preliminary estimates indicate that CAPEX could range between USD 200–400 million for a facility with a processing capacity of 100 000–150 000 tonnes per year, depending on the selected technology pathway and technology provider.

OPEX

Rwanda's OPEX profile is expected to be driven primarily by feedstock collection and logistics—particularly for agricultural residue and MSW-based SAF pathways—as well as by energy and utility costs, labour, and maintenance. Feedstock aggregation costs are projected to be 30–40% higher than in more industrial markets due to fragmented agricultural production systems and logistical constraints. However, these higher costs are expected to be partially offset by lower labour costs and the availability of underutilized biomass resources.

2.1.1 CO_2 abatement costs

The environmental performance of the project can be assessed through the CO_2 abatement cost, which represents the cost of avoiding one tonne of CO_2 emissions through the substitution of conventional jet fuel with SAF.

- Base-case abatement cost: Estimated at USD 180–250 per tonne of CO_2 emissions avoided, depending on the feedstock and technology pathway.[42]
- Although this remains higher than current global carbon market prices, it compares favourably with the implicit ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), estimated

[42] World Bank 2023, *State and Trends of Carbon Pricing 2023*, World Bank.

at approximately at USD 150–200 per tonne of CO_2.[43] The project's emissions reduction potential therefore positions Rwanda's SAF industry not only as a means of supporting aviation decarbonisation and regulatory compliance, but also as an opportunity to access climate finance.

2.1.2 Demand and supply forecasts

Rwanda's demand for aviation fuel is expected to increase steadily with the expansion of RwandAir and the planned commissioning of Bugesera International Airport. [44,45]

- Demand forecast: Total jet fuel consumption is projected to increase from an estimated 120–150 million litres per year in 2025 to approximately 250–300 million litres per year by 2035.
- Supply potential: A modest SAF production facility with a capacity of 100 000 tonnes per year, (approximately 125 million litres annually) could meet around 35–45% of Rwanda's projected aviation fuel demand by 2035, particularly if supported by regional offtake agreements with neighbouring countries such as Uganda, Kenya, and Tanzania.

2.1.3 Price assessment

The minimal fuel selling price (MFSP) represents the minimum selling price required for a SAF project to break-even over its economic lifetime.

- Base case MFSP: Estimates for Rwanda's proposed SAF pathways indicate an MFSP of USD 1.40–1.80 per litre, depending on the feedstock, technology pathway and technology provider.
- Comparison with conventional jet fuel: This remains significantly higher than the current Jet A-1 at Kigali International Airport, which averages USD 0.75–0.95 per litre, depending on global oil price fluctuations. The resulting price differential of USD 0.50–0.90 per litre highlights the important role that policy support measures—such as subsidies, tax incentives, or blending mandates—could play improving the commercial viability of SAF.

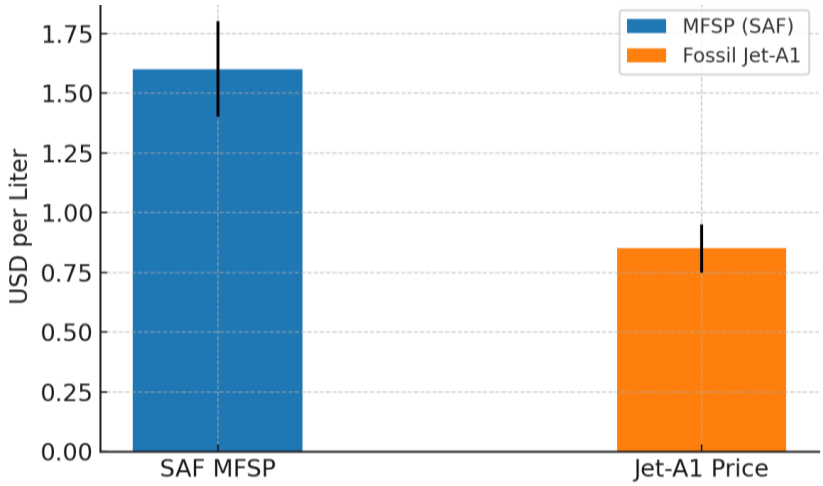


Figure 10. MFSP compared with Jet A-1 prices in Rwanda.[46]

[43] International Civil Aviation Organization (ICAO) 2022, *CORSIA: Eligible Fuels, Emissions Reductions and Cost Considerations (CORSIA Doc 101)*, ICAO.
[44] International Civil Aviation Organization (ICAO) 2022, *Rwanda State Action Plan for CO_2 Emissions Reduction in International Aviation*, ICAO.
[45] East African Community (EAC) 2021, *Regional Aviation Sector Market Outlook*, EAC Civil Aviation Safety and Security Oversight Agency.
[46] International Energy Agency (IEA) 2021, *Sustainable Aviation Fuels: Outlook and Cost Analysis*, IEA.

2.1.4 Return on investment

Financial modelling under a 20-year project horizon indicates the following:

- Net present value (NPV): Under a base-case scenario, and in the absence of policy support measures, the NPV is estimated to remain marginally negative ranging from USD −15 million to USD −30 million. This is primarily attributable to the high upfront CAPEX and the gap between the MFSP and the prevailing price of conventional Jet A-1 fuel.
- Internal rates of return (IRR): Under the base-case scenario, the project IRR is estimated at 7–9%, below the 10-12%typically required for infrastructure and energy projects in East Africa. However, under a policy-supportive scenario—for example, through excise duty exemptions for SAF, preferential financing, or long-term international offtake agreements—the IRR could increase to 12–14%, bringing the project within a commercially viable range.

2.2 SENSITIVITY ANALYSIS

A sensitivity analysis indicates that the economic viability of the project is most strongly influenced by three factors (Figure 11):

- Feedstock costs: A 20% increase in feedstock cost results in an approximately 15% reduction in NPV, highlighting the importance of efficient feedstock collection systems and stable feedstock prices. Conversely, a 20% reduction in feedstock costs is projected to increase NPV by a similar magnitude.
- Energy and utility costs: Given Rwanda's relatively high electricity tariffs compared with neighbouring countries, energy and utility costs—particularly for electricity-intensive pathways such as PtL—have a significant influence on the MFSP.
- Carbon pricing and policy support: The introduction of a carbon credit valued at USD 50–70 per tonne of CO_2 emissions avoided has the greatest positive effect, resulting in a strongly positive NPV and increasing the IRR to above 15%.

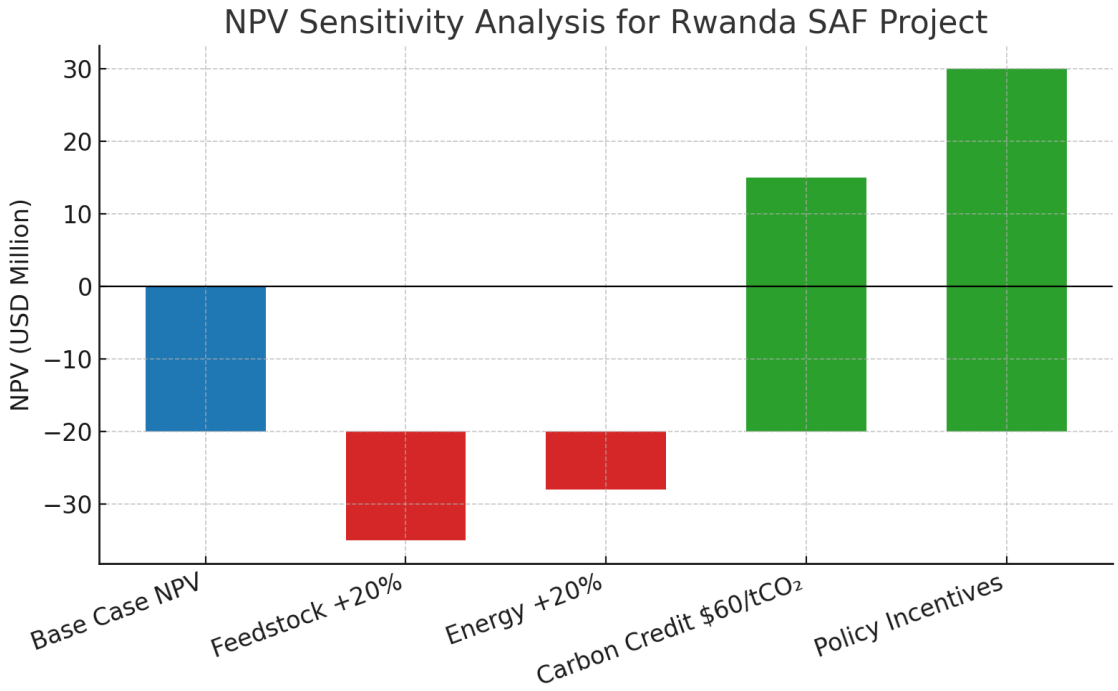


Figure 11. NPV sensitivity analysis for Rwanda SAF Project.

2.2.1 Technology provider variations

Different technology providers for the same production pathway (e.g., G-FT) can result in CAPEX and OPEX variations of up to 15–20%. For example, established European technology providers may have higher upfront capital costs but lower operational risk, whereas emerging Asian providers may offer more competitive CAPEX but require greater operational oversight. These trade-offs should be considered alongside Rwanda's policy objectives of promoting technology transfer and strengthening local capacity.

2.2.2 Policies and incentives

Policy support mechanisms will play a decisive role in the financial viability of Rwanda's SAF project.

- Value added tax (VAT) exemption: Exempting SAF production and blending activities could reduce the MFSP by approximately USD 0.10–0.15 per litre.
- Blending mandates: The gradual introduction of a 2–5% SAF blending mandate for all flights departing from Kigali could create a guaranteed domestic market.
- Climate finance and grants: Access to financing from sources such as ICAO's Finvest Hub, the Green Climate Fund (GCF), or the Africa Climate Change Fund (ACCF) could help finance a portion of CAPEX thereby, reducing investor risk exposure and improving overall project viability.

2.3 SUMMARY OF KEY FINDINGS

The techno-economic analysis indicates that SAF production in Rwanda is technically feasible but economically constrained under the base-case scenario. Although CAPEX and MFSP remain high relative to conventional jet fuel, policy support measures, carbon pricing mechanisms, and regional offtake agreements could significantly improve the project's economic viability and transform it into a strategically valuable investment. Importantly, the sensitivity analyses underscore that feedstock availability, energy prices, and policy incentives are the key factors in influencing project outcomes.

Table 10. Summary of TEA findings.

Category	Key findings
CAPEX	Estimated at USD 200–400 million for a facility with a capacity of 100 000–150 000 tonnes per year, including land within a SEZ, core processing technology, feedstock pre-treatment, storage, and utilities.
OPEX	Primarily driven by feedstock logistics, energy and utility costs, labour and maintenance. Feedstock aggregation costs in Rwanda are estimated to be 30–40% higher than in more industrialized markets.
CO_2 abatement cost	Estimated at USD 180–250 per tonne of CO_2 emissions avoided; comparing favourably with values associated with CORSIA (approximately USD 150–200 per tonne).
Jet fuel demand forecast	National jet fuel demand is projected to increase 120–150 million litres in 2025 to 250–300 million litres by 2035.
SAF supply potential	A facility with a capacity of 100 000 tonnes per year (approximately 125 million litres) could meet 35–45% of Rwanda's projected jet fuel demand by 2035, with additional opportunities through regional offtake agreements.

Category	Key findings
MFSP	Estimated at USD 1.40–1.80 per litre compared with USD 0.75–0.95 per litre for conventional Jet A-1 fuel resulting in a price differential of USD 0.50–0.90 per litre that would require policy support to bridge.
Financial viability	Under the base-case scenario, the project IRR is estimated at 7–9%. With policy support measures, IRR could increase to 12–14%; making the project commercially viable.
Key sensitivities	Feedstock costs: ±20% variation results in an approximately ±15% change in NPV. Energy costs: high electricity tariffs increase the MFSP, particularly for PtL pathways. Carbon pricing: carbon credits of USD 50–70 per tonne of CO_2 emissions avoided could increase the IRR to above 15%.
Tech provider variability	Different technology providers may result in 15–20% variations in CAPEX and OPEX, requiring a balance between capital cost and operational risk.
Policy support measures	A VAT exemption could reduce the MFSP by USD 0.10–0.15 per litre. A 2–5% blending mandate could establish a guaranteed domestic market, while climate finance could improve project bankability and reduce investment risk.

SECTION 3. FINANCIAL AND OPERATIONAL ASSESSMENT OF THE PROJECT

3.1 GASIFICATION AND FISCHER-TROPSCH PATHWAY USING MUNICIPAL SOLID WASTE

As shown in Figure 14, the daily per capita municipal solid waste (MSW) generation across African countries ranged from 0.1 kg to 1.49 kg in 2016. Of the 54 African countries assessed, 21 recorded per capita MSW generation rates above the continental average of 0.49 kg per day. These included Seychelles (1.49 kg per day), Rwanda (1 kg per day), South Africa (0.98 kg per day), Libya (0.95 kg per day). In contrast, Ethiopia, Lesotho, Sudan and Guinea recorded rates less than 0.2 kg per day.

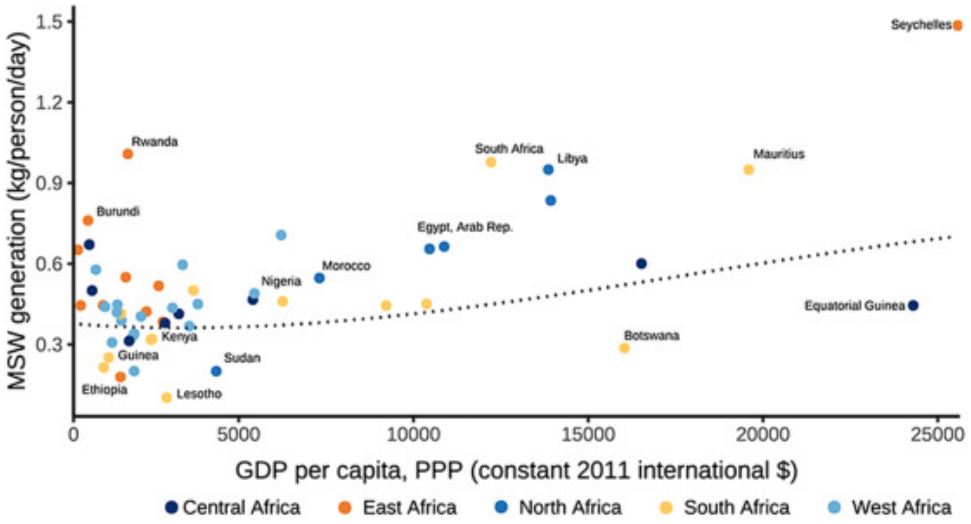


Figure 12. Daily per capita generation of MSW versus GDP per capita in African countries.[47]

Kigali currently operates the main Nduba landfill, which serves as the city's primary waste disposal site. However, its remaining capacity is becoming increasingly constrained, improvements in waste management are needed. This presents an opportunity to integrate SAF production into Rwanda's broader waste strategy.

Kigali generates approximately 600–1 000 tonnes of MSW per day of which around 70% is organic material, 15–20% consist of plastics and paper, and the remainder comprises inorganic materials. Most of this waste is currently disposed of in landfills, with only limited recycling and composting. Integrating a waste-to-SAF facility could divert an estimated 30–50% of landfill-bound waste, thereby reducing pressure on landfill capacity, lowering methane emissions, and delivering broader environmental benefits

[47] Shi, Y., Wang, Y., Yue, Y., Zhao, J., Maraseni, T. & Qian, G. 2023, 'Unbalanced status and multidimensional influences of municipal solid waste management in Africa', *Environmental Science and Pollution Research*, vol. 30, no. 2.

The Kigali Special Economic Zone (KSEZ) offers strategic advantages as a potential site for Rwanda's first MSW-to-SAF plant:

- Close proximity to Kigali's municipal waste collection points;
- Existing industrial infrastructure (power, water, logistics access);
- Potential integration with nearby aviation fuel facilities at Kigali International Airport and Bugesera International Airport; and
- Alignment with KSEZ's circular economy and green industry ambitions.

Table 11. Summary of the well to wing process for SAF production via the MSW pathway.[48]

Step	Description
Waste collection	Segregation and aggregation of suitable MSW
Pre-treatment	Sorting, shredding, and moisture reduction
Gasification	Conversion of MSW to syngas
Gas cleaning	Removal of impurities (e.g., sulphur, tar)
Fischer–Tropsch synthesis	Catalytic conversion of syngas to hydrocarbons
Refining and blending	SAF blending with conventional aviation fuel
Transportation and delivery	Transport of blended SAF to airports for storage and subsequent uplift into aircraft

Considering the well-to-wing process outlined in Table 11, this section focuses on waste composition, collection and current waste management practices. Supplementary information on pre-treatment, gasification and Fischer-Tropsch-(G-FT) synthesis is provided in SECTION 2. Drawing on this information, a business case has been developed and analyzed.

Rwanda, particularly the City of Kigali, has established a relatively robust MSW management system aimed at promoting sustainability, environmental protection, and urban cleanliness.

According to the City of Kigali, in 2024, the MSW composition in Rwanda was:

- Organic waste (~60-70%)
- Plastics (~10-12%)
- Paper and cardboard (~5-8%)
- Metals and glass (~5-6%)
- Textiles and others (~5-10%)

[48] European Commission (EC) Joint Research Centre 2018, Review of Syngas Cleaning Technologies for Advanced Biofuels, JRC Science for Policy Report.

3.1.1 Collection infrastructure and process

The waste collection infrastructure in Rwanda, especially in the City of Kigali, is managed through partnerships between municipal authorities and private waste collection companies, such as COPED and AGRUNI. These operators systematically collect waste from residential areas, commercial establishments, and industrial facilities, according to collection schedules ranging from daily to weekly, depending on the population density and characteristics of the area served. The City of Kigali alone generates approximately 600 to 1 000 tonnes of MSW per day, highlighting the scale and importance of an efficient waste management system.[27]

Rwanda's waste collection infrastructure is concentrated primarily in urban municipalities, particularly the City of Kigali, with emerging collection systems in secondary cities such as Huye, Rubavu, Musanze, and Muhanga. Responsibility for municipal solid waste management rests with municipal authorities, led by the City of Kigali, which implements a decentralized system through partnerships with private sector operators.

The City of Kigali has divided its waste collection system into operational zones, with licensed private waste collection companies responsible for service delivery within each zone. These service areas are allocated performance-based contracts that are reviewed annually to ensure effective service delivery and compliance with environmental regulations.

Municipal waste collection in Rwanda combines door-to-door collection from residential, commercial, and institutional premises, with communal collection points strategically located throughout neighbourhoods. Door-to-door collection typically takes place once or twice a week, while communal collection points are serviced daily or as required based on waste accumulation.

Waste is generally collected using compactor trucks and open-back vehicles depending on road accessibility, population density, and the type of waste collected. The road network in the City of Kigali supports the use of modern compactor trucks, whereas secondary cities often rely on smaller vehicles or conventional trucks, that require manual loading and handling.

Formal waste sorting facilities remain limited but are gradually expanding. The City of Kigali has established waste sorting facilities, including the sorting station at the Nduba landfill, where plastics, metals, paper, glass, and organic waste are manually separated. Nevertheless, significant volumes of waste still require manual or mechanical pre-treatment to achieve feedstock quality standards required for waste-to-fuel conversion.

Currently, most collected waste is transported to and disposed of at the Nduba Landfill, the City of Kigali's primary waste disposal site. However, waste segregation at the source remains limited, presenting a significant opportunity to improve the quality and recoverability of MSW. Enhanced source segregation could substantially increase the suitability of MSW as a feedstock for SAF production.

3.1.2 Pilot project business case

This business case assesses the viability of a demonstration-scale facility capable of processing 20 tonnes per day of MSW using G-FT technologies, producing approximately 1 000 litres per day of SAF in the KSEZ.

<u>Detailed breakdown of estimated financial inputs</u>

Using existing techno-economic data, industry cost inputs and market analyses on the MSW-to-fuels pathway, the estimated CAPEX, OPEX and financial output are presented in Table 12, Table 13 and Table 14 below.

Table 12. Breakdown of estimated CAPEX for the MSW pathway.[17]

Item	Cost (USD million)
Land acquisition and site preparation	1.0
MSW sorting and pre-treatment equipment	4.5
Gasification unit	7.0
Fischer–Tropsch conversion unit	7.5
Syngas cleaning and conditioning	2.5
Storage, blending, and handling	1.5
Miscellaneous and contingency (10%)	2.5
Total CAPEX	**26.5**

Table 13. Breakdown of estimated OPEX for the MSW pathway.[32]

Item	Annual cost (USD thousand)
Labour and operations	300
Maintenance and spare parts	150
Energy and utilities	250
Waste feedstock costs	50
Administrative and miscellaneous	100
Total annual OPEX	**850**

Table 14. Breakdown of revenue streams for the MSW pathway.

Source	Annual revenue (USD thousand)
SAF Sales (1 000 litres per day at USD 1.50 per litre)	547.5
Waste disposal fees (municipalities)[27]	150.0
Carbon credit revenues (estimated based on carbon accounting and credit markets in North America)	175.0
Government incentives/subsidies for SAF production and uplifting (estimated)	100.0–200.0
Total annual revenue	**972.5–1 072.5**

3.2 FINANCIAL PROJECTIONS

3.2.1 Estimated financial returns

The project is expected to achieve a payback period of approximately seven to ten years. This estimate takes into account projected increases in fuel prices and the continued growth of carbon markets. Over the course of the project's lifetime, the NPV is expected to remain positive, although this will depend on market conditions, carbon pricing, and the availability of financial incentives. The IRR is estimated at between 8% and 12%, making the project potentially attractive to impact investors.

3.2.2 Funding strategy

The project will adopt a blending finance approach, combining grants, concessional loans, and private equity. Potential funding sources include FONERWA, the AfDB, impact investment funds, and local commercial banks.

3.2.3 Summary of business case

The CAPEX for the pilot-scale facility is estimated at USD 26.5 million and the OPEX are projected to be between USD 0.8 and 1.2 million per year. The revenue model is based on the sale of SAF at premium market prices, as well as income from carbon credit revenues and municipal waste disposal fees. The anticipated payback period is approximately seven to ten years. The IRR is expected to range from 8% to 12%, making the project potentially attractive to impact investors. Funding sources will follow a blended finance approach, leveraging government subsidies and investments from FONERWA, the GCF, the AfDB, and private investors.

3.2.4 Environmental and social benefits

The project would reduce the amount of waste sent to landfill by approximately 7 300 tonnes annually, based on the assumed plant capacity. It is also expected to avoid approximately 5 000 tonnes of CO_2 emissions each year. The initiative would support job creation, providing an estimated 30 to 50 direct jobs and more than 100 indirect jobs. In addition, it would contribute to improved local air and water quality.

3.3 ATJ PATHWAY USING AGRICULTURAL WASTE

The AtJ pathway presents a viable and strategic option for SAF production in Rwanda, leveraging the country's substantial agricultural residue resources, including maize stalks, sorghum straw, rice husks, sugarcane bagasse, cassava peels, and banana stems (Table 15). As a predominantly agrarian economy, Rwanda generates significant quantities of lignocellulosic biomass, much of which remains underutilized or is openly burned, contributing to environmental degradation and GHG emissions. This presents a valuable opportunity to convert these residues into, high-value SAF for aviation the aviation sector.

3.3.1 Feedstock availability and sourcing

The total recoverable volume of agricultural residues is estimated at 600 000–800 000 tonnes per year. To ensure a reliable and sustainable feedstock supply, the collection strategy should incorporate the following elements:

- Decentralized Collection Centres (DCCs): Established near farming cooperatives, rice mills, cassava processing facilities.
- Private sector participation: Public-private partnerships could be used to engage waste aggregators and agricultural cooperatives to manage feedstock collection and initial pre-processing.

- Seasonal logistics planning: Collection activities should be aligned with crop harvest cycles to ensure consistent year-round supply of feedstock.

Table 15. Agricultural residue types and estimated quantities.[31]

Crop type	Common residue	Estimated annual residue (t/year)	Notes
Maize	Stalks, cobs	300 000–400 000	High residue-to-grain ratio
Rice	Husks, straw	100 000–150 000	Concentrated in Eastern Province
Sorghum	Straw	80 000–100 000	Seasonal but abundant
Sugarcane	Bagasse	50 000–70 000	Mainly from Kabuye Sugar Works
Cassava	Peels	60 000–90 000	Waste from rural and peri-urban processing
Bananas	Pseudostems, peels	500 000+	One of the most available and underused biomass types

3.3.2 Feedstock processing and conversion

The proposed Alcohol-to-Jet (AtJ) pathway would convert agricultural residues into SAF through a sequence of feedstock preparation, biochemical conversion, ethanol purification and catalytic upgrading steps as described in Table 16.

Table 16. Pathway overview for AtJ conversion.[49]

Step	Description
Feedstock collection	Agricultural residues collected at village or sector level
Pre-treatment	Drying, size reduction (chipping/shredding), mild hydrolysis
Fermentation	Conversion of sugars to ethanol using yeast or bacteria
Ethanol purification	Distillation and dehydration of ethanol to fuel-grade
AtJ conversion	Catalytic conversion of ethanol to SAF-range hydrocarbons (e.g., via ethanol oligomerization, dehydration, oligomer cracking)
Hydroprocessing & blending	Hydrogenation and isomerization to meet jet fuel specifications
Distribution	Transport of SAF to airports or fuel storage terminals

Agricultural residues would initially be collected at the village or sector level and transported to the processing facility. The feedstock would then undergo pre-treatment, including drying, size reduction

[49] National Renewable Energy Laboratory (NREL) 2019, *Process Design and Economics for the Conversion of Lignocellulosic Biomass to Ethanol*, NREL.

through chipping or shredding, and mild hydrolysis, to make the structural carbohydrates more accessible for subsequent conversion.

Following pre-treatment, the resulting sugars would be converted into ethanol through fermentation using suitable microorganisms, such as yeast or bacteria. The ethanol would subsequently be purified through distillation and dehydration to achieve fuel-grade specifications. The purified ethanol would then be converted into SAF-range hydrocarbons through the AtJ process, which typically involves a combination of ethanol dehydration, oligomerisation and oligomer cracking. The resulting hydrocarbon stream would undergo hydroprocessing, including hydrogenation and isomerisation, to achieve the required properties and specifications for use as jet fuel. The final SAF product would then be transported to airports or fuel storage terminals for distribution and blending as required.

The location of the facility will be an important consideration, particularly given the need to balance access to feedstock with the availability of industrial infrastructure, utilities and access to SAF offtake markets.
Two potential locations have been identified:

1. the Kigali Special Economic Zone (KSEZ)
2. the Nyagatare Industrial Park.

KSEZ offers several advantages for an SAF facility. Its proximity to Kigali International Airport and RwandAir could facilitate integration with the aviation fuel supply chain and provide access to potential SAF offtakers. The site also benefits from relatively reliable electricity and water supply, established road infrastructure and existing industrial support services. Furthermore, locating the facility within KSEZ would be consistent with Rwanda's broader Green Industrialization policy objectives and could facilitate access to an established industrial ecosystem.

Nyagatare Industrial Park presents a different set of advantages, primarily related to feedstock availability. The area is located close to major maize, cassava and rice production regions, which could provide access to significant quantities of agricultural residues and reduce the distance associated with feedstock transportation. The availability of relatively large land parcels could also support the development of an integrated biorefinery incorporating feedstock handling, conversion and associated utilities. In addition, the favourable agro-industrial zoning framework in the area could support the development of a large-scale biofuel production facility.

The final site selection should therefore consider the relative importance of feedstock availability and logistics, airport and fuel-market access, infrastructure and utilities, land availability, and the potential for future expansion.

In particular, the choice between KSEZ and Nyagatare Industrial Park will depend on the balance between locating the facility closer to the principal feedstock sources and locating it closer to the aviation fuel offtake and existing industrial infrastructure.

3.3.3 Blending and logistics

Feedstock logistics and transport

An efficient and well-coordinated feedstock logistics network is the foundation of any sustainable fuel production system. For Rwanda's AtJ SAF pathway, the process begins with the aggregation of agricultural residues from rural farms and agro-processing facilities located across the country. These residues—including

maize stalks, cassava peels, rice husks, and banana stems—are collected and transported to strategically located regional biomass hubs, which serve as initial consolidation points before further processing.

To accommodate Rwanda's varied terrain and rural road networks, first-mile transport solutions are tailored to local conditions. In areas with good road access, small trucks are used, while tractors provide transport in more remote or rugged locations. This flexible transport model ensures the continuous movement of biomass from farms to aggregation centres, supporting a reliable year-round supply of feedstock for SAF production.

Once collected, the residues are transferred to intermediate storage facilities located near the regional biomass hubs. These facilities are equipped with protective coverings and drying infrastructure to maintain low moisture content, which is critical for preserving the quality and energy value of the biomass. Appropriate storage also reduces the risk of degradation and microbial growth, while facilitating efficient pre-treatment prior to processing.

Following conditioning, the biomass is transported in bulk by heavy-duty trucks to the SAF production facility, ideally located within industrial zones such as the KSEZ or the Nyagatare Industrial Park. These vehicles are designed to transport heavy loads over long distances, providing an efficient link between rural sources and industrial processing facilities.

To enhance traceability and transparency throughout the value chain, digital monitoring systems could play an important role. Potential initiatives include the GPS-enabled vehicle tracking and blockchain-based residue certification platforms. These technologies provide real-time visibility of feedstock movements, support the verification of sustainability claims and facilitate carbon accounting—an increasingly important requirement for international SAF markets and carbon credit schemes.

Blending and fuel distribution

Following conversion of ethanol into SAF through the ATJ pathway, the refined fuel undergoes a blending stage to meet industry-standard performance and safety specifications. On-site blending tanks at the SAF facility enable the controlled blending of SAF with conventional Jet A-1 fuel. Blending ratios of up to 50%, are possible, depending on certification requirements and market demands.

Following the blending, the fuel is integrated into Rwanda's existing aviation fuel distribution infrastructure. Both Kigali International Airport and Bugesera International Airport provide opportunities for fuel storage and uplift, given their expanding aviation activity and strategic locations. These airports could accommodate upgraded fuel storage facilities and dedicated infrastructure for SAF blends, supporting their gradual adoption by airlines operating in Rwanda.

To ensure fuel quality and compatibility, the entire blending and distribution process must comply with ASTM D7566, the internationally recognized standard for alternative aviation turbine fuels. Compliance with this standard ensures that SAF produced via the AtJ pathway can be used safely in existing aircraft and jet engines without modification.

The blended fuel is distributed using dedicated fuel bowsers for direct delivery to aircraft or airport storage facilities. Over the long term, Rwanda could integrate SAF into its existing aviation fuel distribution network as supporting infrastructure is developed, offering greater logistical efficiency and potential cost savings.

A key enabler in this supply chain could be collaboration with TotalEnergies Rwanda, the country's principal supplier of aviation fuel. Partnering with an established fuel supplier would provide access to existing fuel

handling expertise, established safety procedures, and airport fuelling infrastructure, thereby facilitating the transition from pilot-scale projects to commercial-scale SAF deployment.

3.3.4 Pilot project business case

This demonstration-scale facility will utilize agricultural residues to produce SAF via the AtJ conversion pathway. The facility, situated within Rwanda's KSEZ, is designed to process approximately 30 tonnes per day of agricultural residues, yielding approximately 1 200 litres per day of SAF. For the AtJ pathway, the estimated CAPEX, OPEX and financial output is illustrated in Table 17, Table 18 and Table 19.

Table 17. Breakdown of estimated CAPEX for the ATJ pathway.[17]

Item	Cost (USD million)
Land acquisition and site preparation	1.2
Feedstock collection and pretreatment unit	3.8
Fermentation and alcohol production unit	6.5
AtJ conversion unit	8.0
Product purification and conditioning	3.0
Storage, blending, and handling	1.8
Miscellaneous and contingency (10%)	2.4
Total CAPEX	**26.7**

Table 18. Breakdown of estimated OPEX for the AtJ pathway.[32]

Item	Annual cost (USD thousand)
Labour and operations	350
Maintenance and spare parts	200
Energy and utilities	300
Agricultural residue costs	100
Administrative and miscellaneous	120
Total annual OPEX	**1 070**

Table 19. Breakdown of revenue streams for the AtJ pathway.

Source	Annual revenue (USD thousand)
SAF sales (1 200 litres per day at USD 1.60 per litre)	701
Carbon credit revenues (estimation based on carbon markets in North America)	210
Agricultural waste management fees[31]	80
Government incentives/subsidies for SAF production and uplifting (estimation)	100–200
Total annual revenue	**1 091–1 191**

3.3.1 Financial and funding considerations

Based on the assumptions outlined above and as summarised in Table 20 below, the proposed facility would require an estimated capital investment of approximately USD 26.7 million for the pilot-scale plant, with annual operating costs estimated at approximately USD 1.0–1.2 million. The principal revenue streams would include the sale of SAF at premium market prices, revenues from carbon credits, potential agricultural waste management fees and applicable government incentives. Under the assumed market and policy conditions, the project could achieve an estimated payback period of approximately 7–9 years. The Internal Rate of Return (IRR) is estimated at approximately 9–13%, while the Net Present Value (NPV) is expected to remain positive over the project lifetime, subject to prevailing fuel prices, carbon market conditions and the availability of policy incentives.

Table 20. Summary of business case.

Parameter	Description
Capital cost (CAPEX)	USD 26.7 million for pilot-scale facility
Operating cost (OPEX)	USD 1.0–1.2 million per year
Revenue streams	Sale of SAF at premium market prices, carbon credit revenues, agricultural waste management fees, government incentives
Payback period	Approximately 7–9 years
Internal Rate of Return (IRR)	Estimated IRR of 9–13%
Funding approach	Blended finance approach leveraging governmental subsidies, concessional finance, impact investment

Given the capital requirements and the emerging nature of the SAF market, a blended finance structure would be appropriate for supporting project development and reducing investment risk. Such an approach could combine grants, concessional loans, private equity and other sustainable finance instruments. Potential sources of financing could include Rwanda's FONERWA, the Green Climate Fund (GCF), the African Development Bank (AfDB), international impact investment funds, agricultural development banks and local commercial banks. The combination of concessional and commercial financing could help address the

relatively high upfront capital requirements while improving the project's ability to attract private investment.

Overall, the business case would be supported by the combination of SAF sales, carbon-related revenues and potential policy or waste-management incentives. The project's financial performance would nevertheless remain sensitive to SAF market prices, feedstock costs, carbon prices, financing conditions and the availability and duration of government support mechanisms. Consequently, securing long-term offtake arrangements and appropriate policy and financial support would be important factors in achieving the projected financial returns.

Beyond its financial performance, the project could generate significant environmental and socio-economic benefits. At the assumed plant capacity, the facility could utilise approximately 10 950 tonnes of agricultural residues annually, contributing to improved agricultural waste management and reducing the amount of residues that would otherwise require disposal or remain unused. The project is estimated to deliver approximately 7 500 tonnes of CO_2 emissions reductions per year, subject to the final technology configuration, feedstock characteristics and applicable emissions accounting methodology.

The facility could also contribute to local economic development through the creation of an estimated 40–60 direct jobs and approximately 120 indirect jobs across feedstock collection, logistics, plant operations, maintenance and supporting services. By creating a market for agricultural residues, the project could provide additional economic opportunities for rural communities while encouraging more sustainable agricultural practices. These environmental and social benefits, combined with the potential contribution to Rwanda's emerging low-carbon aviation fuel sector, would strengthen the project's broader development impact alongside its commercial objectives.

3.4 SENSITIVITY ANALYSIS

The financial robustness of the SAF business case is sensitive to several key input parameters, including:

- Feedstock costs and availability: The availability of agricultural residues, MSW, and imported oils may vary depending on seasonal production, global commodity prices, and the efficiency of collection systems.
- Energy costs: Rwanda's reliance on imported fossil fuels could increase OPEX if the expansion of renewable electricity generation does not keep pace with demand.
- SAF market prices and policy incentives: A supportive policy framework—including minimum guaranteed SAF purchase prices, blending mandates, carbon pricing mechanisms, or carbon credits—could significantly reduce investment risk and improve project economics.

Scenario analysis indicates that, under base-case assumptions the project achieves moderate NPV and IRR. However, less favourable feedstock or energy price scenarios could result in an NPV. Under such circumstances, government support measures, including fiscal incentives, concessional financing, or long-term offtake agreements with airlines, may be required to restore viability.

3.5 REGULATORY AND POLICY FRAMEWORK

The regulatory framework for SAF development in Rwanda will need to align with international requirements, including ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). Compliance will require robust sustainability assessments, including life cycle assessment (LCA) of greenhouse gas (GHG) emissions, feedstock traceability, and certification under internationally recognized sustainability schemes. Environmental Impact Assessments (EIAs), together with permits relating to land use, and access to water

and energy resources, will also be required, with approval processes expected to take approximately 18–24 months.

Policy measures—including reduced tax rates for renewable fuels, exemptions from import duty on SAF equipment, and alignment with Rwanda's Green Growth and Climate Resilience Strategy—could help create a more favourable investment environment. Lessons can also be drawn from Rwanda's renewable energy sector, where streamlined approval processes and strong public-private partnerships have supported project implementation.

Engagement with domestic and regional stakeholders will be critical to reducing project risk and strengthening the financial case. RwandAir, as the national carrier, could serve as the anchor customer through long-term SAF offtake agreements. Partnerships with regional airlines, such as Kenya Airways and Ethiopian Airlines, could further improve economies of scale, given Kigali's growing role as a regional aviation hub. Fuel suppliers, investors, and international development partners—including the ICAO Finvest Hub, Africa Climate Change Fund (ACCF), and Green Climate Fund (GCF)—could also play an important role in project financing.

Preliminary stakeholder consultations indicate strong alignment with Rwanda's ambition to become a regional leader in green aviation and climate-resilient growth. However, they also highlight several gaps, including the absence of blending and certification facilities and limited awareness of SAF business models among local stakeholders. Addressing these gaps through targeted capacity-building, infrastructure investment and supportive policy measures will be essential to facilitate successful project implementation.

3.6 CONCLUSION

The financial and operational assessment highlights both the opportunities and challenges associated with SAF deployment in Rwanda. While the proposed projects are exposed to cost, feedstock, and regulatory risks, Rwanda's growing aviation sector, combined with the global drive to decarbonize air transport, presents a compelling case for early investment. Positive NPVs under supportive policy scenarios, together with strong airline offtake potential and Rwanda's emergence as a regional aviation hub, suggests a viable long-term investment opportunity.

Strategic government support, effective stakeholder engagement, and compliance with international sustainability standards will be critical to overcoming the financial and operational challenges identified in this assessment. Ultimately, Rwanda's SAF initiative has the potential not only to decarbonize the aviation sector but also to stimulate industrial development, create green jobs, and position the country as a regional leader in climate-aligned innovation. A summary of the key findings is provided in Table 21.

In summary:

- Rwanda has significant feedstock potential from underutilized agricultural residues;
- The AtJ pathway aligns well with Rwanda's green growth, rural development, and aviation decarbonization objectives;
- Early-stage investment should focus on a demonstration facility integrated within the KSEZ or Nyagatare Industrial Park;
- Policy incentives, green finance, and private-public partnerships will be essential to support commercial deployment; and
- A successful demonstration project could serve as a model for SAF production across sub-Saharan Africa.

Table 21. Summary of key economic parameters of both business cases.

Dimension	MSW-to-SAF	AtJ (using agricultural waste)
Primary feedstock	MSW (organic, paper and plastic fractions)	Agricultural residues (maize, rice, cassava, sorghum, banana, etc.)
Feedstock availability	Kigali: 600–1 000 tonnes of MSW: per day, with 60–70% organic content	National agricultural residues: an estimated 600 000–800 000 tonnes per year (recoverable)
Waste challenge addressed	Diverts 30–50% of landfill-bound waste; reducing pressure on the Nduba landfill	Reduces open burning of agricultural residues while supporting sustainable agriculture and rural incomes
Pilot plant scale	20 tonnes of MSW → ~1 000 litres of SAF per	30 tonnes of agricultural residues per day → ~1 200 litres of SAF per day
CAPEX	USD 26.5 million	USD 26.7 million
Annual OPEX	~USD 0.85 million per year	~USD 1.07 million per year
Annual revenues	USD 0.97–1.07 million per year (SAF, waste disposal fees, carbon credits incentives)	USD 1.09–1.19 million per year (SAF, carbon credits, agricultural waste fees, incentives)
Estimated payback period	7–10 years	7–9 years
Estimated IRR	8–12%	9–13%
Environmental benefits	~7 300 tonnes less waste sent to landfill annually; ~5 000 tonnes of CO_2 emissions avoided per yar	~10 950 tonnes of agricultural residues utilized annually; ~7 500 tonnes of CO_2 emissions avoided per year
Employment	30–50 direct jobs; more than 100 indirect jobs	40–60 direct jobs, approximately 120 indirect jobs
Key strengths	Addresses Kigali's MSW management challenge; significant methane emissions reduction; strong circular-economy benefits	Utilizes Rwanda's largest biomass resources; scalable beyond Kigali; strong rural development benefits
Key risks	Feedstock heterogeneity, limited source segregation, and extensive pre-treatment requirements	Seasonal feedstocks availability; complex logistics; and moisture management
Strategic fit for Rwanda	Supports improved MSW management in Kigali and aligns with KSEZ circular economy	Leverages Rwanda's extensive agricultural residue resource and supports the country's agro-industrial development strategy

SECTION 4. RISK ASSESSMENT

The development of a SAF industry in Rwanda requires not only a robust technical and financial foundation but also a clear understanding of the risks that could affect project implementation. Risk assessment is therefore a key component of project planning, ensuring that potential risks are identified, evaluated, and prioritized. In the Rwandan context, these risks include feedstock supply reliability, technology maturity, financial viability, market competitiveness, and regulatory compliance. Addressing these risks through appropriate mitigation measures and ongoing monitoring will be essential to supporting the long-term viability and resilience of SAF development.

4.1 FEEDSTOCK SUPPLY RISKS

4.1.1 Seasonal and regional availability

Agricultural residues, municipal solid waste (MSW), and other biomass resources identified as potential SAF feedstocks are inherently subject to seasonal variations and regional availability constraints. Rwanda's agriculture-based economy, while rich in biomass resources, is highly dependent on rainfall patterns and is increasingly vulnerable to climate variability. Droughts or excessive rainfall may affect the availability and consistency of biomass streams, including maize stalks, sorghum husks, and cassava residues, thereby introducing uncertainty into feedstock supply chains. Seasonal variability of up to ±20% have been identified (see SECTION 1).

4.1.2 Logistics and transportation challenges

Given Rwanda's hilly terrain and dispersed rural settlements, transporting feedstock from farms and collection centres to centralized processing facilities presents logistical challenges. Limited rural road infrastructure can increase first-mile transport costs, while traffic congestion around Kigali may create additional challenges for the delivery of feedstock to SAF production or blending facilities. These logistical constraints could increase operating costs, reduce project competitiveness, and discourage private investment unless appropriate mitigation measures are implemented.

4.1.3 Mitigation

- Establish regional biomass aggregation hubs near major agricultural areas.
- Invest in rural feeder roads, intermediate storage facilities, and decentralized pre-treatment facilities to reduce transport distances and improve logistics efficiency.
- Implement digital monitoring systems such as GPS tracking and blockchain-based certification to improve feedstock traceability, operational efficiency and sustainability reporting.

4.2 TECHNOLOGICAL RISKS

4.2.1 Performance and maturity of SAF pathways

While pathways such as gasification Fischer-Tropsch (G-FT) and alcohol-to-jet (AtJ) have achieved ASTM D7556 certification, their deployment in Rwanda remains untested. In the case G-FT, although gasification and FT synthesis are both well-established commercial technologies, the combination of these technologies for the conversion of MSW and waste biomass into SAF has, however, proven challenging. Several commercial projects have experienced technical and financial difficulties, largely due to the variability of feedstock composition. On-going technology developments could position the G-FT pathway as a promising long-term solution.

For both pathways the principal technical risks relate to scale-up and the reliability of imported equipment. Although demonstration-scale facilities may perform well under controlled operating conditions, scaling-up to commercial production can expose unforeseen integration and operational challenges, particularly given Rwanda's relatively limited industrial base, and experience with advanced biofuel technologies.

4.2.2 Insurance and guarantees

Technology providers often offer performance guarantees mitigate risks associated with conversion efficiency, product yields, and compliance with international fuel quality standards (ASTM D7566). In the absence of such guarantees, investors may perceive SAF projects as high risk, limiting access to debt financing.

4.2.3 Mitigation

- Implement robust feedstock quality management to ensure consistent and reliable supply of suitable feedstock.
- Begin with a pilot or demonstration plant to validate technology under Rwandan conditions before commercial-scale deployment.
- Engage international technology licensors and insurers to provide performance guarantees and reduce technology related-risks.
- Foster partnerships with Rwandan academic and research institutions to build local technical capacity, particularly in feedstock collection, characterization and quality management.

4.3 FINANCIAL AND MARKET RISKS

4.3.1 Capital intensity and cost uncertainty

The development of SAF production facilities requires significant upfront capital investment, with capital expenditure (CAPEX) estimates subject to considerable uncertainty during the early stages of project development (±30–50%).[50] Operating expenditure (OPEX) is also exposed to fluctuations in feedstock prices utility tariffs, and foreign exchange rates, given Rwanda's reliance on imported equipment, technology and certain process inputs.

4.3.2 Market competitiveness and price gap

The global aviation industry continues to face the challenge of the price premium associated with SAF relative to conventional jet fuel. Without clear policy support or blending mandates, RwandAir and other regional carriers may be reluctant to adopt SAF due to the potential for higher operating costs, and consequently, increased ticket prices. This could affect their competitiveness relative to airlines operating in neighbouring markets where SAF blending obligations do not apply. In addition, SAF production facilities may face competition for feedstock and investment from renewable diesel projects, particularly where policy incentives favour the decarbonization of road transport over aviation. ICAO has undertaken detailed analyses of the potential impact of SAF production costs on airline operating costs and ticket prices, taking into the account the price differential between SAF and conventional jet fuel, as well as aircraft type and size.[51]

[50] Climate Policy Initiative (CPI) 2022, *Cost of Capital and Finance Risk for Clean Energy in Africa*, CPI.
[51] International Civil Aviation Organization (2022) *Placing Costs Associated with LTAG Integrated Scenarios in Context of International Aviation*.

Mitigation

- Secure concessional financing from climate finance mechanisms, such as the Green Climate Fund (GCF), ICAO ACT-SAF, and the Africa Climate Change Fund).
- Implement phased blending mandates supported by tax incentives and/or carbon credit mechanisms, to reduce the cost differential with conventional fuel.
- Establish public-private partnerships (PPPs) to support early-stage project development and reduce private sector investment risk.

4.4 POLICY AND REGULATORY RISKS

The absence of clear national SAF policies or blending targets creates regulatory uncertainty for project developers and investors. In addition, inconsistent or poorly coordinated policies across the East African Community (EAC) could create market distortions by encouraging airlines to refuel in jurisdictions where SAF blending requirements do not apply.

Mitigation

- Introduce clear, phased SAF blending mandates aligned with ICAO's CORSIA targets.
- Promote the harmonization of SAF policies across EAC Member States to minimize competitive distortions and support regional market development.
- Ensure alignment between aviation decarbonization strategies and Rwanda's broader climate commitments under the Paris Agreement.

4.4.1 Risk prioritization matrix

Taking into account risks identified in the previous sections, together with the specific challenges discussed in Sections 4.1 - 4.3, the following summary in Table 22 has been compiled.

Table 22. Summary of risks prioritized by likelihood and impact.

Risk category	Likelihood	Impact	Priority
Feedstock supply variability	High	High	Critical
Financial and market competitiveness	High	High	Critical
Logistics and transport	Medium	High	High
Technology reliability	Medium	High	High
Policy and regulatory gaps	Medium	High	High
Competition with renewable diesel production	Medium	Medium	Moderate

4.4.2 Scenario analysis

Scenario analysis enables stakeholders to assess the robustness of SAF projects under a range of plausible conditions:

- Base case scenario: Moderate feedstock availability, stable policy environment, and access to concessional financing enable SAF to achieve cost competitiveness at a 15–20% blend by 2030.
- Optimistic scenario: Strong regional policy alignment, rapid development of feedstock aggregation infrastructure, and declining technology costs enable SAF to approach cost parity with conventional jet fuel, supporting 30% blend adoption.
- Pessimistic scenario: Climate-induced feedstock shortages, delays in policy implementation, and high financing costs limit SAF deployment to pilot-scale projects, making it difficult to achieve ICAO's long-term decarbonization objectives.

Risk monitoring and review

A structured risk monitoring framework should be embedded within project governance. This should include:

- Quarterly reviews of feedstock supply and logistics performance conducted by accredited auditors and benchmarked against previous audit results.
- Annual technology audits to assess plant efficiency and compliance with ASTM D7556 fuel quality standards, ensuring product quality and operational safety. Where non-compliance is identified, corrective actions—including recommissioning, recertification, or permit reviews, where required—should be undertaken.
- Annual reviews of policy alignment with regional EAC aviation and energy strategies to ensure continued coordination between SAF mandates, grants and subsidy schemes. Greater policy harmonization across the region could encourage SAF production, facilitate its uptake, and reduce market distortions.
- Periodic financial reviews supported by sensitivity analyses, to update CAPEX, OPEX, and revenue projections in response to changing market conditions. These reviews can support measures to improve operational efficiency and strengthen the projects long-term financial performance.
- Regular stakeholder engagement forums to review emerging risks and adapt mitigation measures in response to evolving market, policy, and environmental conditions.

4.5 ANALYTICAL REVIEW

STRENGTHS	WEAKNESSES
• Abundant waste biomass resources • Strong government commitment to green growth • Potential to serve as a regional aviation hub • Strategic location for regional supply networks	• Limited industrial base • High upfront capital investment requirements • High perceived investment risk • High cost of SAF production • Fragmented feedstock collection and logistics • Seasonal variability in agricultural biomass availability
OPPORTUNITIES	**THREATS**
• SAF development can help addressing waste challenges • Access to climate finance • Economic growth through job creation and technical capacity development • Opportunity to become a regional leader in SAF production • Export potential within the EAC	• Limited policy support for SAF • Delays in policy development and implementation • Competition from renewable road transport fuels • Technology maturity and deployment risks • Climate variability affecting feedstock availability

4.6 CONCLUSION

The implementation of SAF in Rwanda presents a promising opportunity to decarbonize the aviation sector, stimulate rural economic development, and enhance energy security. However, its successful deployment will depend on the effective management of a range of technical, financial and policy-related risks. Feedstock availability, technology reliability, financial viability and policy alignment emerge as the most critical risk areas. Mitigation measures—including infrastructure investment, international partnerships, policy reforms, and scenario-based planning—will be essential to reduce investment risks and support the long-term competitiveness of the sector. Through a robust risk management and monitoring framework, Rwanda has the potential to position itself not only as an early adopter of SAF in Africa but also as a regional hub for sustainable aviation and low carbon innovation.

SECTION 5. BUSINESS IMPLEMENTATION RECOMMENDATIONS

The implementation of a SAF project in Rwanda requires not only technical feasibility and financial viability, but also a clear, pragmatic, and well-structured implementation strategy. This section outlines the proposed implementation pathways and provides recommendations on project partnerships, financial arrangements, institutional coordination, and phased implementation. These recommendations are intended to support the development of a commercially viable SAF industry that is aligned with Rwanda's national development priorities and international climate commitments.

5.1 PARTNERSHIP STRUCTURES

5.1.1 Potential public sector stakeholders

The Government of Rwanda, through the Ministry of Infrastructure (MININFRA), the Ministry of Environment (Mo)E, and the Rwanda Civil Aviation Authority (RCAA), is well positioned to serve as the principal enabler of SAF deployment. These institutions have key roles in developing aviation policy, supporting the energy transition strategies, and advancing national climate resilience objectives. The Rwanda Development Board (RDB) could play an important role in facilitating investment promotion and coordinating investor engagement, while the Rwanda Energy Group (REG) could support the integration of reliable and low-carbon energy supplies for SAF production facilities.

5.1.2 Potential private sector stakeholders

The private sector will play a central role in providing the technical expertise, operational capability, and commercial investment required for the successful deployment of SAF. Key stakeholders may include:

- International technology providers specializing in SAF conversion pathways (e.g., HEFA, AtJ, G-FT), providing technology licensing, process expertise, and performance guarantees.
- Local agribusinesses and waste management companies, supporting feedstock aggregation, logistics, and supply chain continuity.
- Fuel suppliers and distributors, such as TotalEnergies Rwanda, responsible for fuel blending, quality assurance, and airport fuel distribution.
- Airlines, including RwandAir, whose long-term offtake agreements could strengthen SAF project bankability and provide demand certainty.

5.1.3 Public-private partnership (PPP) and joint venture (JV) models

A Public private partnership (PPP) or joint venture (JV) structure is recommended to balance public sector oversight with private sector expertise. Key structuring considerations include:

- **Allocation of responsibilities and investment**: The government may assume responsibility for land acquisition, enabling infrastructure, and policy support, while private partners would be responsible for plant design, technology integration, financing, and operational management.
- **Access to technology**: Long-term technology licensing agreements or technology transfer agreements should be established to facilitate knowledge transfer and support the development of local technical capacity.

- **Procurement approach**: Engineering, procurement, and construction (EPC) services, should be procured through transparent and competitive procurement processes, supported by international tendering, where appropriate, to ensure cost effectiveness, quality and technical reliability.
- **Risk allocation**: Performance guarantees, feedstock supply agreements, and power purchase agreements (PPAs) should be used to allocate technical, commercial and operational risks appropriately among project partners rather than concentrating them on a single entity.

5.2 FINANCING STRATEGIES

- **Equity-debt financing**: A typical SAF project may adopt an equity-to-debt ratio of 30:70, with government incentives helping to reduce the perceived risks for lenders.
- **Offtake-backed financing**: Long-term SAF offtake agreements with airlines can provide predictable revenue streams, strengthen project bankability and improve access to debt financing.
- **Carbon credits**: The monetization of avoided emissions through voluntary and compliance carbon markets could provide an additional revenue stream and improve project economics.
- **Phased investment approach:** Development should begin with a demonstration-scale facility to validate the technology and de-risk feedstock supply chains, before progressively scaling up to commercial production capacity.

5.2.1 Multilateral and development finance institutions

Multilateral climate and infrastructure finance providers are natural financing partners, given Rwanda's strong track record in mobilizing international climate finance. Potential partners include:

- World Bank Group (IFC, IDA, MIGA), providing blended finance, credit guarantees, and equity financing.
- African Development Bank (AfDB), including the Sustainable Energy Fund for Africa (SEFA), supporting sustainable energy and climate-related investments.
- Green Climate Fund, building on Rwanda's accreditation as a National Implementing Entity.
- ICAO's Finvest Hub, supporting SAF projects that contribute to the decarbonization of international aviation.

5.2.2 Bilateral and public sector lenders

Bilateral development agencies and public sector financial institutions may provide concessional loans, technical assistance, and grant funding to support the development of SAF projects. Potential partners include the FCDO/UK PACT, Africa Climate Change Fund, and the European Investment Bank (EIB).

5.2.3 Private sector and commercial finance

Private equity firms, green infrastructure funds, and international commercial banks could participate once long-term offtake agreements and appropriate government support mechanisms are established. Early engagement with regional commercial banks, such as the Bank of Kigali and Equity Bank Rwanda, is recommended, as they can provide local financial intermediation and strengthen investor confidence.

5.3 ACTION PLAN

An effective action plan, as presented in Table 23, requires alignment with Rwanda's national development frameworks, including Vision 2050, the Green Growth and Climate Resilience Strategy, and the National Strategy for Transformation (NT1), while ensuring coherence with relevant international aviation and climate frameworks.

Table 23. Description of recommended actions.

SHORT-TERM (2025-2028) - Preparatory phase		
Aim 1: Strengthen policy and regulatory frameworks		
Recommended action	**Timeline**	**Potential lead entity**
Establish a National SAF Taskforce and adopt a Rwanda SAF Roadmap**,** aligned with the National Strategy for Transformation (NST2), Green Growth Strategy, and ICAO's LTAG and CORSIA frameworks.	2026	MININFRA, MINECOFIN, REMA, RCAA, RDB
Develop and adopt SAF sustainability criteria and a certification framework aligned with CORSIA and ASTM D7566.	2027	RCAA, REMA
Develop a fiscal incentive package, including VAT and excise exemptions, accelerated depreciation, and customs relief for SAF equipment).	2027	MINECOFIN, MINICOM, RRA, MININFRA
Update national aviation fuel specifications and permitting procedures to explicitly allow the use of SAF blends at Kigali International Airport and Bugesera International Airport.	2028	RCAA, RSB, Total Energies Rwanda, RwandAir
Issue regulatory guidance on waste-to-fuel projects, environmental impact assessment (EIA) requirements, and land-use planning for SAF facilities withing special economic zones (SEZs).	2028	REMA, RDB, City of Kigali, KSEZ Authority
Aim 2: Secure feedstock supply availability and sustainability compliance readiness		
Recommended action	**Timeline**	**Potential lead entity**
Complete national assessment of MSW, agricultural residues, UCO feedstock availability.	2026	MININFRA, MINAGRI, City of Kigali, NISR
Sign framework MoUs with key feedstock suppliers, including COPED, AGRUNI, district waste operators, farmer cooperatives, agro-processors.	2027	City of Kigali, MINAGRI
Design and pilot improved MSW segregation and collection systems in Kigali (Nduba catchment) to provide feedstock suitable for waste-to-SAF production.	2027	City of Kigali, COPED, AGRUNI, REMA
Establish feedstock traceability and monitoring, reporting verification (MRV) system compatible with CORSIA and other internationally recognised sustainability voluntary schemes.	2028	REMA, RCAA, MINAGRI

Develop sustainability guidelines and training programmes for farmer cooperatives and waste operators covering residue harvesting, collection and sorting.	2028	MINAGRI, REMA, RAB
Aim 3: Establish financial and operational readiness		
Recommended action	**Timeline**	**Potential lead entity**
Complete bankable feasibility studies and detailed techno-economic assessments for MSW-to-SAF and AtJ demonstration plants	2026	MININFRA, RDB, consultants, ICAO/Finvest support
Identify and secure suitable sites within the KSEZ or other industrial parks, including zoning approvals and preliminary EIAs.	2027	RDB, KSEZ Authority, City of Kigali, REMA
Develop the PPP framework and transaction structure, including risk allocation, tariff arrangements and offtake agreements.	2027	MINECOFIN, MININFRA, RDB
Secure indicative financing commitments through blended finance mechanisms involving FONERWA, GCF, AfDB, impact investors, and local financial institutions.	2028	FONERWA, MINECOFIN, RDB
Launch an EPC tender for at least one demonstration-scale SAF facility.	2028	MININFRA
Aim 4: Strengthen regional collaboration		
Recommended action	**Timeline**	**Potential lead entity**
Sign MoUs with regional airlines and CAAs (e.g., Kenya Airways, Ethiopian Airlines, Uganda Airlines) covering future SAF offtake and technical cooperation.	2026	RwandAir, RCAA, MININFRA
Join or establish an East African SAF platform to promote harmonized standards, certification, and joint access to climate finance.	2026	MININFRA, RCAA, EAC
Explore regional feedstock aggregation opportunities and logistics corridors with neighbouring countries.	2027	MININFRA, MINAGRI
Develop a concept for Kigali International Airport and Bugesera International Airport as a regional SAF hub serving multiple EAC airlines.	2028	MININFRA, RwandAir, RCAA, RDB

MID-TERM (2028-2030) - Demonstration and scale-up phase		
Aim 5: Initiate demonstration-scale SAF production		
Recommended actions	**Timeline**	**Potential responsible entity**
Reach final investment decision (FID) and financial close for at least one demonstration-scale SAF facility (MSW-to-SAF or AtJ.	2028	MINECOFIN
Construct, commission and commence operation of the demonstration plan, including integration with airport fuel infrastructure.	2029	EPC contractor, TotalEnergies Rwanda, RCAA
Certify the first SAF batches under ASTM D7566 and CORSIA sustainability requirement, and initiate pilot offtake with RwandAir.	2029	RCAA, RwandAir, SAF producer, certification bodies
Evaluate technical, financial, environmental, and social performance, and prepare scale-up strategy incorporating lessons-learned report.	2030	MININFRA, RDB, REMA
LONG-TERM (2030-2035) - Commercialization phase		
Aim 6: Scale-up commercial SAF production beyond 2030		
Recommended action	**Timeline**	**Potential lead entity**
Reach FID for the first commercial-scale SAF facility (approximately 100 000 tonnes per year) and expand feedstock aggregation networks nationwide.	2030-2031	MININFRA, MINAGRI
Integrate SAF into routine fuel supply operations at Kigali International Airport and Bugesera International Airport through dedicated blending, storage, and distribution infrastructure.	2031-2032	RCAA, airport authorities, fuel suppliers, RwandAir
Introduce and progressively increase a SAF blending mandate for international departures.	2032-2034	MININFRA, RCAA, MINECOFIN, airlines
Attract additional investment in commercial SAF production, including a second production facility and export-oriented capacity, positioning Rwanda as a regional hub for sustainable aviation.	2033-2035	RDB, MININFRA, FONERWA, AfDB

5.4 POLICY ALIGNMENT

A coherent and stable policy framework is essential to support the long-term development of a SAF industry in Rwanda. Key recommendations include:

- Integration with Rwanda's State Action Plan: SAF deployment should be explicitly incorporated into Rwanda's national aviation emissions reduction strategy and aligned with the monitoring and implementation of ICAO's long-term aspirational goal (LTAG).

- Fiscal incentives: Introduce targeted fiscal measures, such as tax exemptions for SAF equipment, customs duty relief, and, where appropriate SAF blending mandates or other market-based incentive to encourage investment.
- Regulatory alignment: Harmonize national regulations with ICAO's CORSIA requirements, ensuring that SAF produced in Rwanda is eligible under internationally recognized sustainability and carbon accounting frameworks.
- Regional integration: Strengthen coordination with EAC Member States to promote harmonized SAF sustainability standards, certification requirements, tariff regimes, and supporting logistics infrastructure.

5.5 CONCLUSION

The successful implementation of SAF in Rwanda is both ambitious and achievable, provided it is supported by strong partnerships, diversified financing mechanisms, and a coherent policy framework. A well-structured public private partnership (PPP) model can facilitate appropriate risk-sharing, mobilize private investment, accelerate technology transfer while concessional climate finance can help de-risk early-stage investments.

Implementation should follow a phased and adaptive approach, beginning with a demonstration-scale facility and progressing towards commercial-scale production, while remaining aligned with Rwanda's green growth objectives and ICAO's LTAG framework.

By fostering collaboration between public and private stakeholders, international financing partners, and relevant policy institutions, Rwanda has the opportunity to position itself not only as a regional pioneer in sustainable aviation fuel production, but also as a model for climate-smart industrial development in Africa.

REFERENCES

1. African Development Bank (AfDB) 2019, *Guidelines for Midstream Oil and Gas Infrastructure Development in Africa*, African Natural Resources Centre, AfDB.
2. African Development Bank (AfDB) 2019, *Midstream and Downstream Oil & Gas Infrastructure Development Guidelines*, African Natural Resources Centre, AfDB.
3. African Development Bank (AfDB) 2023, *Rwanda Infrastructure Development Update 2023*, AfDB.
4. ASTM International 2022, *ASTM D7566 – Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons*, ASTM.
5. CAPA – Centre for Aviation 2024, *RwandAir: Strategic Positioning and Competitive Dynamics in East Africa*, CAPA, https://centreforaviation.com.
6. Climate Policy Initiative (CPI) 2022, *Cost of Capital and Finance Risk for Clean Energy in Africa*, CPI.
7. Climate Policy Initiative (CPI) 2022, *Cost of Capital for Low-Carbon Infrastructure in Emerging Markets*, CPI.
8. East African Community (EAC) 2021, *Regional Aviation Sector Market Outlook*, EAC Civil Aviation Safety and Security Oversight Agency.
9. European Commission (EC) Joint Research Centre 2018, *Review of Syngas Cleaning Technologies for Advanced Biofuels*, JRC Science for Policy Report.
10. Food and Agriculture Organization (FAO) 2020, *Livestock Value Chain and By-Product Utilization in Rwanda*, FAO.
11. Food and Agriculture Organization (FAO) 2022, *Crop Residue Availability and Bioenergy Potential in East Africa*, FAO.
12. Global Green Growth Institute (GGGI) 2019, *Green Certification of the New Bugesera International Airport Fact Sheet*, GGGI, https://gggi.org/wp-content/uploads/2019/04/Certification-of-Bugesera-Airport-Fact-Sheet_FINAL.pdf.
13. Green Climate Fund (GCF) 2022, *GCF Financing Framework for Low-Carbon Industrial Projects*, GCF.
14. ICAO 2022, *CORSIA: Eligible Fuels, Emissions Reductions and Cost Considerations (CORSIA Doc 101)*, International Civil Aviation Organization.
15. ICAO 2022, *Rwanda State Action Plan for CO_2 Emissions Reduction in International Aviation*, International Civil Aviation Organization.
16. ICAO 2022 (3 April), *Rwanda State Action Plan: Mitigation of Greenhouse Gas Emissions in the Aviation Sector*, International Civil Aviation Organization, https://www.icao.int/sites/default/files/sp-files/environmental-protection/Documents/ActionPlan/RWANDA-State-Action-Plan.pdf.
17. International Air Transport Association (IATA) 2023, *Net Zero Roadmap: Sustainable Aviation Fuel Technical Guidelines*, IATA.
18. International Air Transport Association (IATA) 2023, *Sustainable Aviation Fuel: Technical and Economic Guidelines*, IATA.
19. International Air Transport Association (IATA) 2023, *The Value of Air Transport to Rwanda*, IATA, https://www.iata.org/en/iata-repository/publications/economic-reports/the-value-of-air-transport-to-rwanda/.

20. International Energy Agency (IEA) 2021, *Advanced Biofuels: Potential for Cost Reductions and Scale-up*, IEA.
21. International Energy Agency (IEA) 2021, *Energy Infrastructure Project Timelines: Engineering, Construction and Commissioning Benchmarks*, IEA.
22. International Energy Agency (IEA) 2021, *Sustainable Aviation Fuels: Outlook and Cost Analysis*, IEA.
23. International Energy Agency (IEA) 2022, *Global Hydrogen Review 2022*, IEA.
24. International Finance Corporation (IFC) 2020, *IFC Project Finance and PPP Structuring Guidelines*, IFC.
25. International Renewable Energy Agency (IRENA) 2021, *Renewable Energy Prospects: East Africa*, IRENA.
26. International Renewable Energy Agency (IRENA) 2022, *Renewable Fuels for Aviation: Technology and Cost Overview*, IRENA.
27. International Renewable Energy Agency (IRENA) 2025, *Renewable Energy Investment Factsheet: Rwanda*, IRENA, https://www.pseau.org/outils/ouvrages/irena_renewable_energy_investment_factsheet_rwanda_2025.pdf.
28. Kigali City Council 2022, *Kigali Waste Management Master Plan*, City of Kigali.
29. Masselus, L. et al. 2024, *10 years after: Long-term adoption of electricity in rural Rwanda*, Ruhr Economic Papers No.1086, RWI – Leibniz-Institut für Wirtschaftsforschung, Essen, https://doi.org/10.4419/96973261.
30. Ministry of Agriculture and Animal Resources (MINAGRI) 2018, *Strategic Plan for the Transformation of Agriculture in Rwanda, PSTA4 (2018–2024)*, Government of Rwanda.
31. Ministry of Infrastructure (MININFRA) 2020, *Rwanda Energy Policy*, Government of Rwanda.
32. National Institute of Statistics of Rwanda (NISR) 2023, *Seasonal Agricultural Survey (SAS) 2017–2022*, NISR.
33. National Renewable Energy Laboratory (NREL) 2019, *Process Design and Economics for the Conversion of Lignocellulosic Biomass to Ethanol*, NREL.
34. Oyeyinka, S.A. & Oyeyinka, A.T. 2018, '*Cassava waste biomass: A review of its potential for sustainable biofuels production'*, *BioResources*, vol. 13, no.1, pp. 2160–2189.
35. Petroleum Authority of Uganda (PAU) 2020, *Map of Hoima Oil Refinery, Kabalega Industrial Park, and Hoima–Kampala Products Pipeline*, PAU.
36. Petroleum Authority of Uganda (PAU) 2025, *Uganda Refinery Project – Project Profile*, PAU.
37. Republic of Rwanda, Ministry of Finance and Economic Planning 2023, *National Strategy for Transformation (NST1): Priority Infrastructure Projects*, Government of Rwanda.
38. Republic of Rwanda, Ministry of Finance and Economic Planning, *Energy Sector Strategic Plan (ESSP)*, Government of Rwanda, https://www.minecofin.gov.rw/fileadmin/user_upload/Minecofin/Publications/STRATEGIES/Sector_Strategic_Plans/Energy.pdf.
39. Rwanda Agriculture and Animal Resources Development Board (RAB) 2022, *National Livestock Production Statistics*, RAB.
40. Rwanda Development Board (RDB) 2023, *Investment Code and Incentive Framework*, RDB.

41. Rwanda Energy Group (REG) 2023, *Installed Generation Capacity on the National Grid*, REG Facts & Figures, https://www.reg.rw/facts-figures/facts-figures-details/facts/installed-generation-capacity-on-the-national-grid/.
42. Rwanda Energy Group (REG) 2024, *Electricity Statistics & Tariff Schedule*, REG.
43. Rwanda Environment Management Authority (REMA) 2021, *Rwanda State of Environment and Outlook Report*, REMA.
44. Rwanda Ministry of Trade and Industry (MINICOM) 2023, *Energy Price Bulletin: Biomass & LPG Tariffs*, Government of Rwanda.
45. Rwanda Revenue Authority (RRA) 2024, *Corporate Income Tax, VAT & Investment Incentive Guidelines*, RRA.
46. Rwanda Utilities Regulatory Authority (RURA) 2023, *Hospitality and Food Services Waste Oil Compliance Report*, RURA.
47. RwandAir 2025, *Route Map*, RwandAir, https://www.rwandair.com/rwandair-route-map/.
48. S&P Global Commodity Insights 2022, *Renewable Diesel and SAF Refinery Operating Costs Report*, S&P Global.
49. S&P Global Platts 2024, *Biofuels Price Assessments: Feedstocks (Residues, UCO, Tallow)*, S&P Global Commodity Insights.
50. Shi, Y., Wang, Y., Yue, Y., Zhao, J., Maraseni, T. & Qian, G. 2023*, 'Unbalanced status and multidimensional influences of municipal solid waste management in Africa'*, Environmental Science and Pollution Research, vol. 30, no. 2.
51. The New Times Rwanda 2016, *'Government officials tour SP fuel storage facility'*, photograph, https://www.newtimes.co.rw.
52. U.S. Department of Energy (DOE) 2020, *Bioenergy Technologies Office: Multi-Year Program Plan*, DOE.
53. United Nations (UN) 2021, *SDG7 Energy Compact of Rwanda*, UN Department of Economic and Social Affairs, https://www.un.org/sites/un2.un.org/files/2021/11/rwanda_energy_compact-final_copy.pdf.
54. United Nations Industrial Development Organization (UNIDO) 2020, *Market Assessment of Waste Oils and Fats in East African Cities*, UNIDO.
55. Water and Sanitation Corporation (WASAC) 2024, *Bulk Water Tariff Structure and Supply Zones*, WASAC.
56. World Bank 2016, *Project Management and Engineering Guidelines for Energy Infrastructure*, World Bank.
57. World Bank 2017, *International Oil & Gas Pipeline Construction Standards and Cost Structures*, World Bank Energy & Extractives Global Practice.
58. World Bank 2023, *Africa Energy Price Database*, World Bank.
59. World Bank 2023, *State and Trends of Carbon Pricing 2023*, World Bank.
60. World Economic Forum (WEF) 2023, *Clean Skies for Tomorrow: Sustainable Aviation Fuel Policy Toolkit*, WEF.
61. World Economic Forum (WEF) 2023, *Global Clean Energy Financing Trends*, WEF.

APPENDIX: STAKEHOLDER ENGAGEMENT

The following stakeholders were engaged in this business implementation study:

1. Ministry of Environment (MOEN)
2. Ministry of Infrastructure (MININFRA)
3. Rwandair
4. Societe Petroliere Aviation Ltd (SP Aviation)
5. Rwanda Utilities Regulatory Authority (RURA)
6. Ministry of Economics and Finance (MINECOFIN)
7. Rwanda Water Resources Board (RWB)