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RWANDA

FEASIBILITY STUDY ON THE USE OF SUSTAINABLE AVIATION FUELS

ICAO-EUROPEAN UNION ASSISTANCE PROJECT: CAPACITY BUILDING FOR CO_2 MITIGATION FROM INTERNATIONAL AVIATION

PHASE II

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FOREWORD

In 2022, the 41st ICAO Assembly adopted a long-term global aspirational goal (LTAG) for international aviation of net-zero carbon emissions by 2050 in support of the UNFCCC Paris Agreement's temperature goal. Each ICAO Member State will contribute to achieving the goal in a socially, economically and environmentally sustainable manner and in accordance with its national circumstances. The ICAO Assembly also affirmed that specific measures to assist developing States as well as to facilitate access to financial support, technology transfer and capacity building should be initiated as soon as possible.

In support to these Assembly Resolution provisions, ICAO has launched the ICAO Assistance, Capacity-building and Training for Sustainable Aviation Fuels (ICAO ACT-SAF), which aims to provide tailored support for States in various stages of SAF development and deployment, facilitate partnerships and cooperation on SAF initiatives under ICAO coordination and serve as a platform to facilitate knowledge sharing and recognition of all SAF initiatives around the globe.

In line with the ICAO ACT-SAF objectives, ICAO has been actively partnering with the European Union (EU) to develop assistance projects that support Member States' initiatives to reduce the climate impacts of international civil aviation. The first phase of the ICAO Assistance Project with the European Union (EU) Funding was launched in 2013 and provided support to 14 participating States in Africa and the Caribbean.

Among other results, this project led to development of four feasibility studies on the use of Sustainable Aviation Fuels (SAF) in Burkina Faso, Kenya, Dominican Republic, and Trinidad and Tobago. After completion of the first phase, in 2020 ICAO and the EU decided to add a second phase to the Assistance Project, in order to provide support to 10 African States. This Phase 2 of the project funded three feasibility studies on sustainable aviation fuels in Cote d'Ivoire, Rwanda, and Zimbabwe.

The following feasibility study assesses the potential for production and use of socially acceptable, environmentally friendly, and economically viable drop-in SAF in Rwanda. The study follows the general structure and information provided in the "Template for Feasibility Studies on Sustainable Aviation Fuels", developed in the context of the ICAO ACT-SAF programme. Such analysis includes:

- information on the specific circumstances of the State, explaining the unique characteristics and factors that could affect the development and deployment of SAF in the State;
- the identification of priority pathways for SAF production
- information on implementation support and financing needed for the implementation of the priority pathways identified; and
- recommendation of an action plan aligned with the State's governmental policies related to the SAF development, with a focus on the priority pathways identified.

EXECUTIVE SUMMARY

A. Background

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

The Rwandan economy has undergone rapid growth over the past decade, and looking forward, ambitions to achieve greater prosperity, reduce poverty, increase opportunities for all are embedded within a long-term Green Growth and Climate Resilient Strategy (Republic of Rwanda, 2015). Widespread support for the development of the green economy is available in Rwanda, including planned actions in the agricultural, waste, and energy sectors to increase productivity, improve resilience to climate change, and to mitigate current greenhouse gas (GHG) and other environmental impacts. Green technologies are actively supported, including investment support in newer technologies from the research and development stage through to commercial deployment. SAF is not specifically considered in existing policy and regulation, or published sectoral strategies.

However, there is strong alignment between the potential benefits of SAF production and use in Rwanda and existing government objectives. For example, the production of SAF from solid wastes is compatible with waste-to-energy ambitions, and has the potential to make significant contributions to Rwanda's GHG emissions reduction commitments by greatly reducing methane emissions from organic waste disposal at dumpsites and landfills. In the agricultural sector, SAF production could provide desired economic diversification, should suitable feedstocks be available without conflicting with food security and other energy applications.

The present study examines the feasibility of feedstock supply in Rwanda for SAF production, including biomass crops, agricultural and food processing residues, waste oils, and solid wastes. Key factors are considered, including current and projected future availability, competition with other uses, technology readiness, environmental and social sustainability effects, and potential for financial viability. Critical success factors for future SAF production are considered, through which capacity building needs to overcome barriers are identified. Policy and regulatory recommendations are considered. A forward-looking Action Plan builds on the findings of the study to suggest near- and medium-term actions to support future SAF implementation in Rwanda.

B. Key findings

The availability of sufficient quantities of suitable feedstocks is a fundamental challenge for SAF production in Rwanda. Diversion of cropland or crop outputs for SAF is unlikely to avoid negatively impacting food security and so cannot be recommended. It is uncertain if marginal lands unsuitable for staple crop production could be utilised for SAF feedstock cultivation. Agricultural and food processing residues have a high utilisation rate at present in animal feed and energy applications and so are unavailable for SAF production. Should significant crop production gains be realised in the future, it is possible that residual materials could become available, but at present this is highly uncertain. Waste oils are a suitable feedstock for SAF production, but are only available in very limited quantities in Rwanda, and so at best can provide a small portion of feedstock supply to a SAF facility.

Solid wastes provide a potential opportunity for SAF production, with potential to provide approximately 15% of aviation fuel use in Rwanda (in 2019). With a present priority to address solid waste management in Rwanda, there is potential for quick implementation of new ways of managing this waste stream, while also addressing methane emissions from dumping or landfilling of solid wastes due to their high organic content. Key challenges for utilising solid wastes for SAF relate to the very limited data available at present about solid waste arisings, its composition, and its current management; technology risk due to the gasification of a highly heterogeneous feedstock; and insufficient supply of solid wastes on their own for the expected scale of a commercially viable facility.

Achieving viable SAF production in Rwanda will require addressing of critical success factors. **Establishing feedstock supply chains**, capable of aggregating sufficient supply of suitable feedstocks, requires first the collection of data related to relevant feedstocks, their current uses, and anticipated future production trends. Further investigation is needed to assess the technical, economic, and environmental factors of relevance to potential feedstock supply chains as a prerequisite for establishing a SAF production industry. **De-risking process technologies and developing skills** must address Rwanda's limited industrial experience with process technologies necessary for SAF production. Smaller scale technology demonstration and commercialisation projects would develop domestic expertise in key technology areas. Longer-term, a strategy for technology transfer and skills development within the workforce to design, operate and maintain facilities for fuel production, blending and testing/certification is needed. **Demonstrating financial viability and GHG emissions reduction potential**, through prospective assessments based on high quality data related to feedstock supply chains in Rwanda, will help to make the strategic case for developing a SAF production industry. **Creating SAF certification capacity** is necessary to certify blended fuels produced within Rwanda, a capacity that is currently lacking. **Establishing an appropriate regulatory framework to encourage investment** is needed to create a market for SAF given its higher production cost compared with conventional fuels. Long-term certainty of policy and regulatory support for SAF production and use is a necessary precondition to attract private investment in the SAF value chain. **Developing a regional strategy for SAF production and use** is needed to address the mismatch of the capacity expected for a commercially viable SAF production facility with the limited availability of domestic feedstocks for SAF production, and current aviation fuel demand in Rwanda. Regional co-ordination of SAF policies and regulations will also help to ensure that competitiveness is not negatively affected by measures to encourage or mandate the use of SAF.

Table ES.1 - Critical Success Factors for achieving SAF production in Rwanda

Factor	Requirements
Establish feedstock supply chains capable of aggregating sufficient supply of suitable feedstocks	Collection of data related to relevant feedstocks, their current uses, and anticipated future production trends Further investigation of technical, economic, and environmental factors relevant to supply chains
De-risk process technologies and develop requisite skills	Smaller scale technology demonstration and commercialisation to develop expertise in key technology areas Strategy for technology transfer and skills development within the workforce to design, operate and maintain facilities for fuel production, blending and testing/certification
Demonstrate financial viability and greenhouse gas reduction potential	Prospective assessments based on high quality data for Rwanda supply chains and production scenarios
Create SAF certification capacity	Develop infrastructure and requisite skills to certify manufactured and blended fuels in-country
Establish appropriate regulatory framework to encourage investment	Long term certainty of policy and regulatory support for SAF
Develop a regional strategy for SAF production and use	Identify areas for co-operation to achieve required scale for viable SAF production and ensuring adequate demand for finished fuels Co-ordination of regional SAF policies and regulations to ensure competitiveness is not negatively impacted by

C. Policy implications

SAF by nature is a cross-sector product and requires consideration of policies related to feedstock supply (agriculture, waste management); competing uses (energy, transport); and wider economic and environmental drivers. The existing solid waste management strategy is expected to make significant progress in increasing waste collections, establishing infrastructure to aggregate supply, and, in the longer term, encouraging value addition to waste streams. While the immediate focus is on safe disposal of solid wastes via sanitary landfilling, deeper GHG emissions reductions will be achieved in future by diverting organic wastes from landfill, including to SAF production. Policies to encourage or mandate landfill diversion will be required.

Action to address data limitations regarding the availability of solid waste, waste oils, and agricultural residues is a necessary first step to improving understanding of the potential viability of SAF production from these feedstocks. Once greater certainty has been made regarding current and future availability of feedstocks, it will be necessary to prioritise uses for these limited materials to deliver the greatest socio-economic benefit, or provide a strategic opportunity, and provide appropriate fiscal and non-fiscal supports to achieve these benefits.

A policy or regulatory driver will be required to incentivise or mandate the use of SAF, given its higher production cost when compared with conventional fuels. Fiscal support for SAF must ensure that the cost to the State is balanced by the wider socio-economic benefit to Rwanda of the SAF production value chain, which is only likely to be achieved where significant value-add takes place within the country (through production/processing of feedstocks, the manufacture of fuel, fuel blending and certification, and/or export of fuel).

Regulatory support, for example through mandating a share of SAF within the Rwanda aviation fuels market or applying a "carbon tax" mechanism to penalise GHG emissions of fuels, would require regional alignment to avoid potential market effects. Mandates without subsidy will increase the cost of fuel, with potential negative implications for regional competitiveness if undertaken unilaterally.

D. Opportunities and challenges

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

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

Opportunities	• Strong government commitment in developing the Green Economy • Diversion of solid wastes from dumpsites to fuels production, including SAF, is aligned with climate change mitigation actions and waste management strategy • Potential for social benefits through adding value and diversification of agriculture and waste management sectors
Challenges	• Limited availability of suitable feedstocks • Agricultural land is required for food production and cannot be diverted to biomass crops • Waste collection infrastructure and practices are limited or non-existent in many areas • Lack of technical expertise in relevant technology areas • Fuel refining, blending and testing/certification infrastructure is lacking • Competition for waste and byproduct streams with animal feed, electricity, and solid fuel applications

Achieving SAF production in Rwanda would require addressing capacity building needs to be met:

Infrastructure needs:

- Road improvements and a transfer site network capable of efficiently aggregating supply of feedstocks to scale required for commercially-viable SAF production
- Reliable access to process inputs, including electricity
- Fuel blending, testing and certification facilities

Technology needs:

- Process technologies related to feedstock conversion, SAF production processes, and downstream separations
- Production, storage, transportation and handling of hydrogen

Skills needs:

- Design, construction, operation and maintenance of systems within the SAF value chain, from feedstock collection, storage and transport, to fuel production and downstream activities related to fuel blending, testing and certification
- Training capacity to develop skilled workers in the above areas

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ABBREVIATIONS AND ACRONYMS

AfDB	African Development Bank
ATJ	Alcohol-to-jet
BRD	Development Bank of Rwanda
FAO	Food and Agriculture Organization of the United Nations
FT	Fischer-Tropsch
GCF	Green Climate Fund
GDP	Gross domestic product
GHG	Greenhouse gas
HEFA	Hydroprocessed esters and fatty acids
ICAO	International Civil Aviation Organization
kt	kilotonnes
MINIAGRI	Rwanda Ministry of Agriculture and Animal Resources
MININFRA	Rwanda Ministry of Infrastructure
MINIRENA	Rwanda Ministry of Natural Resources
MSW	Municipal solid waste
NDC	Nationally Determined Contributions
NIRDA	National Industrial Research and Development Agency
NIST	National Institute of Statistics Rwanda
RAC	Rwanda Airports Company
RCAA	Rwanda Civil Aviation Authority
RGF	Rwanda Green Fund
RSB	Roundtable on Sustainable Biomaterials
RURA	Rwanda Utilities Regulatory Authority
SAF	Sustainable Aviation Fuel
SP	Societe Petroliere
UCO	Used cooking oil

SECTION 1. STATE-SPECIFIC INFORMATION

1.1 GEOGRAPHY, DEMOGRAPHY, LAND USE AND CLIMATE CHANGE

1.1.1 Geography of Rwanda

Rwanda has a tropical climate that is characterised by four climatic seasons, with a long dry season from June to August, a short dry season from December to February, a long rainy season from March to May and a short rainy season from September to November. The country consists of four main climatic regions: the eastern plains, the central plateau, the highlands, and the regions around Lake Kivu. The Rwandan landscape is dominated by its hills, and agro-ecological zones are defined largely by elevation between highland tropics in the west of the country, and lowland tropics in the east. The total land area of Rwanda is 26,338 square kilometres. The vast majority of land cover in Rwanda is classified as cropland by Food and Agriculture Organization of the United Nations (FAO), with shrub and grassland in the east of the country, and some forest cover in the southwest (Figure 1).

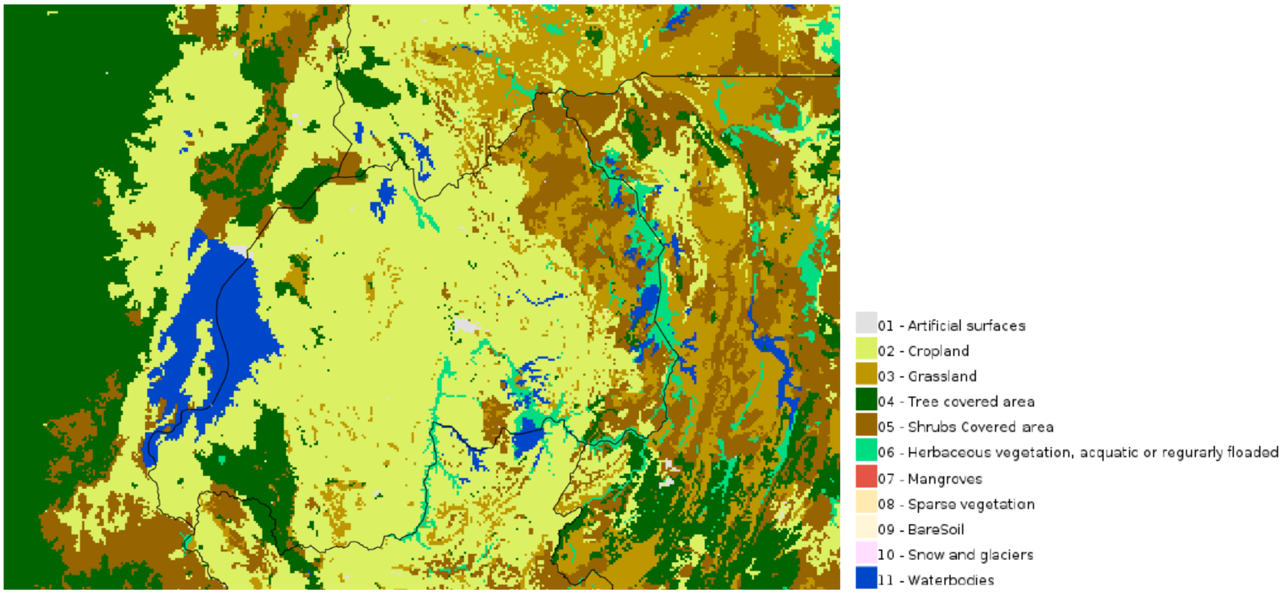

Figure 1. Dominant land use types in Rwanda. FAO Global Land Cover Share Database (2013)

1.1.2 Demography of Rwanda

Rwanda has a population of 13.46 million in 2021, growing at an annual rate of approximately 2.4% (World Bank, 2022a). Correspondingly, the population density of Rwanda is 533 people per square kilometre, the highest in Africa and third highest globally among countries with population greater than 10 million people. The median age in Rwanda, 19.0 years, is similar to the African median age of 18.6 years, but young compared with the global median of 30.0 years. Eighty-two percent of Rwandans live in rural areas.

1.1.3 Land use, agriculture and climate change risk

The Rwandan economy is undergoing rapid growth, with gross domestic product (GDP) expanding at an average rate of 6.4% per year from 2012 to 2021 (World Bank, 2022b). Agriculture is an important economic sector, contributing approximately 26% to GDP in 2020 (Republic of Rwanda, 2021), with its industrial sector and services sector (including tourism) contributing approximately 19% and 46% to GDP, respectively (ITA, 2022). Agriculture is the main economic activity in Rwanda, with approximately 67% of total employment in the agricultural sector (Republic of Rwanda, 2021). Principle crops include beans, maize, sweet potatoes, bananas, sorghum, and potatoes (Figure 2). Key agricultural exports, coffee, tea, and some value-added products including pyrethrum and canned tomatoes and regional exports of foodstuffs to Eastern Africa, generated USD 465.4 million in 2019 (ITA, 2022).

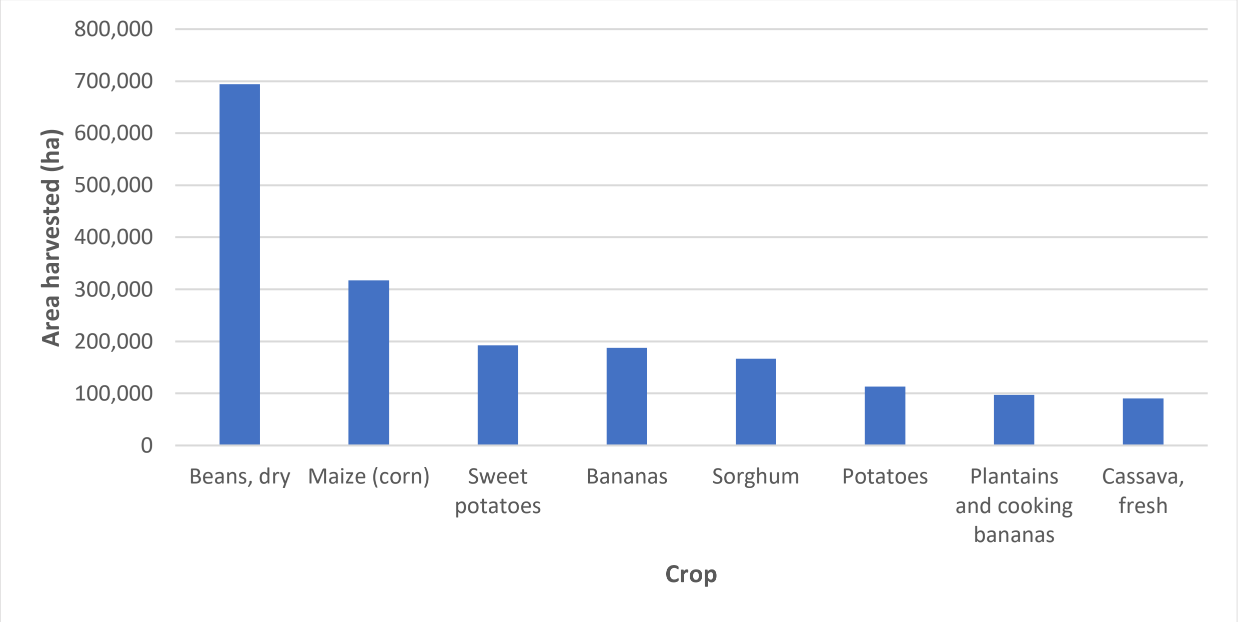

Figure 2. Main agricultural crop production in Rwanda, by area harvested in 2021. Data from FAOSTAT.

The agricultural sector in Rwanda faces a number of key challenges related to its geography, climate change, demographics, and production practices (see Table 1). These challenges, and the strategies to address them, have significant influence on the current and future availability of feedstocks for domestic SAF production.

Table 1. Challenges facing Rwanda's agricultural sector

Geography and climate	○ With its hilly landscape, 90% of croplands are on slopes ranging from 5% to 55% (FAO, 2023). Consequently, soil loss due to erosion can contribute to decreasing fertility. ○ Dependence on rainfed agriculture, results in a strong dependence on seasonal rainfall and associated risks in seasonal variability
Vulnerability to climate change	○ Increased variability in seasonal rainfall (impact on rain-fed agriculture) ○ Higher prevalence of high rainfall events (landslide risk, soil erosion) ○ Pests ○ Changing suitable climatic zone for key crops
Demographics	○ High population density has resulted in fragmented land holdings ○ Growing population creates pressure on land availability and contributes to further fragmentation ○ Food security: approximately 20% of Rwandans are food insecure with low consumption of healthy foods (Republic of Rwanda 2021); prevalence of undernourishment reported as 35.8% (FAO et al, 2022)
Production practices and supply chains	○ Low input use of fertilisers, irrigation and 15echanization, resulting in low levels of productivity – yields estimated as being 40-50% below potential (Republic of Rwanda, 2021) ○ Underdeveloped supply chains and limited private sector investment, resulting in high food wastage and lower food quality (Republic of Rwanda, 2021).

Climate change is expected to deliver rising temperatures, increases in the intensity and frequency of heavy rain events, and increased duration of dry spells. The annual mean temperature is expected to increase, by 1.1 to 3.9 °C by the end of the century. This is accompanied by a strong likelihood of increased heat wave duration by as much as 85 days, with increased temperatures expected across all seasons (NCEA, 2015). Projections of rainfall indicate the likely increase in total annual rainfall, but this will not be seen equally across the country, with frequent rainfall deficits expected in parts of the eastern and southern provinces, and increased rainfall in parts of the western, northern, and southern provinces (World Bank, 2021).

Projected trends in climate towards 2050 are expected to result in significant impacts on Rwanda's agricultural sector. With almost total reliance on rain-fed agriculture, projections of longer dry spells pose a significant risk to agricultural productivity. The risk of soil loss due to erosion and associated land degradation is exacerbated by the expected increase in intensity and frequency of heavy rain events. Rising temperatures risk impacting the quality and productivity of key export crops (tea and coffee), and will be detrimental to bean production, due to the requirement of cooler temperatures, which is significant given the current role of beans in Rwandan food supply. However, increasing temperature would be advantageous for yields of other key crops such as banana, cassava, sorghum, and yam. For these crops, a greater share of cropland would become suitable for production (FAO, 2022).

1.2 TRADE, GOVERNANCE AND AVIATION FUEL SUPPLY CHAIN

To inform the current study, Rwandan stakeholders have been consulted a range of sectors with responsibility and/or interest in aviation fuels and specifically the future potential for SAF production in country[1].

- Ministry of Infrastructure (MININFRA): responsible for infrastructure policy and development in areas of transportation, energy, water, sanitation, housing, and human settlement. The civil aviation sector is under the control of MININFRA, ensuring that the interests and requirements of the state are respected by all stakeholders, and upgrading the country's aviation infrastructures.
- Rwanda Civil Aviation Authority (RCAA): responsible for regulation and oversight of aviation safety, security, economic regulation of air services, and development of civil aviation.
- RwandAir: National carrier, operating domestic and international services to East Africa, Central Africa, West and Southern Africa, Europe, the Middle East, and Asia.
- Rwanda Airports Company Ltd (RAC): responsible for daily management, operation and provision of air navigation services for all airports in Rwanda.
- Aviation Travel and Logistics (ATL): a holding group wholly owned by the Government of Rwanda, with mission to manage aviation related activities.
- Societe Petroliere Aviation Ltd (SP Aviation): limited company responsible for the import and distribution of petroleum products, including aviation fuel storage.
- Rwanda Environmental Management Authority (REMA): responsible for integrating environmental issues and climate change into Rwanda's development.
- Rwanda Agriculture and Animal Resources Development Board (RAB): responsible for implementing national policy, laws and strategies on agriculture.
- Rwanda Utilities Regulatory Authority (RURA): responsible for regulation of utilities, including renewable and non-renewable energy, sanitation, transport, and other sectors.
- The National Industrial Research and Development Agency (NIRDA): a government institution mandated to support industrial innovation through technology monitoring, acquisition, development and transfer, and applied research.
- Rwanda Green Fund (FGF): an investment fund established by the Government of Rwanda, with a mandate to invest in public and private projects towards sustainable development and a green economy.
- Rwanda Development Board (RDB): a government institution with mandate to support business and investment in Rwanda in support of economic development and private sector growth.

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[1] Note that the views expressed in this report are those of ICAO consultant, and do not necessarily reflect the views of these stakeholders.

1.3 ENERGY

1.3.1 Overview of Rwanda's energy sector

The total energy supply in Rwanda is reported as 195,789 TJ in 2020, with a compound annual growth rate of 2.67% from 2010. Energy supply is dominated by biomass, representing 90% of energy supply in 2020, having declined from a 93.9% share in 2010 (Figure 3). However, absolute biomass use has increased consistently over the 10-year period from 2010, reaching 176,140 TJ in 2020 (IEA, 2022). Biomass energy use is predominately by households (91%), while industry is responsible for 4% of demand, largely for tea industries and small-scale brick making (MININFRA, 2018).

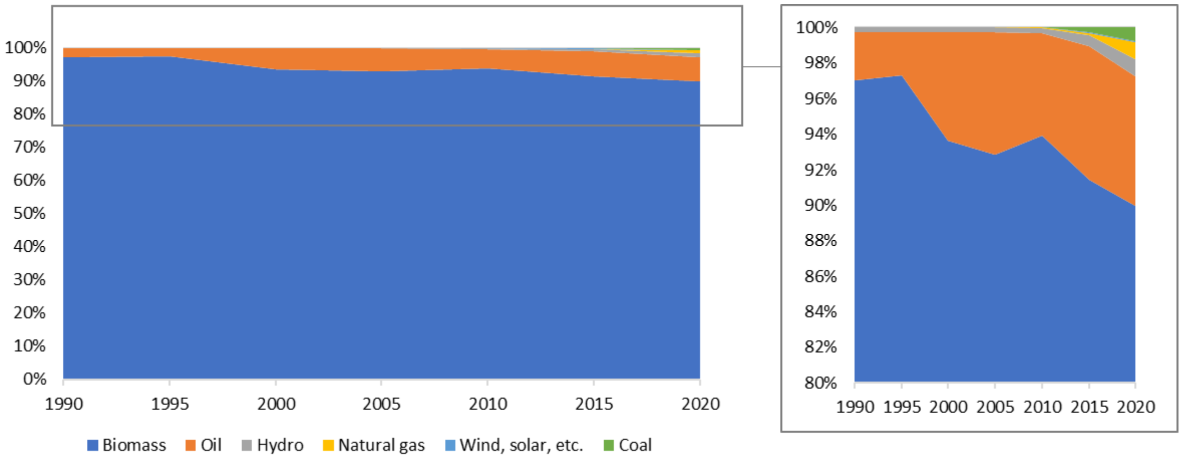

Figure 3. Total energy supply (TES) by source, Rwanda 1990-2020 (IEA, 2022).

Oil is the second largest energy source in Rwanda, representing over 8% of energy supply in 2019 (IEA, 2022). Rwanda is reliant on imports of petroleum fuels, arriving in the country via the Northern Corridor (Kenya, 7.1% of supply) and the Central Corridor (Tanzania, 92.9% of supply) (MININFRA, 2018). In the near term, petroleum use is anticipated to grow at approximately 8% annually, due to growing demands for transportation in aviation and heavy industry. Similarly, Rwanda has no domestic production of natural gas, and relies on imported gas products (predominately liquefied petroleum gas (LPG)) (MININFRA, 2018). Import is by road tanker, entering from Kenya and Tanzania. There is potential for domestic production of petroleum and natural gas, and existing policy is aimed at providing an appropriate regulatory set-up for the exploration and development of resources. Petroleum and natural gas reserves in Rwanda are unknown, but by inferring from identified deposits in neighbouring countries in the Great Lakes region, it is expected that significant reserves will be identified (MININFRA, 2018).

Biodiesel production has not been deployed at a commercial scale in Rwanda to date. Following a successful pilot production facility producing biodiesel from imported palm oil, the Rwanda Biodiesel Company was established in 2012, aimed at establishing a network of domestic small-scale oilseed producers (such as jatropha) (Biofuels Digest, 2012). However, the project was abandoned in 2017, as lower than expected jatropha production resulted in uncompetitive production costs using imported palm oil feedstock (The East African, 2017a). An ongoing partnership between NIRDA and Italian energy company Eni aims to develop improved seed varieties for oil crops to address this barrier, with potential applications for biodiesel as well as SAF (RDB, 2022)

Meeting Rwanda's growing demand for biomass fuels (fuelwood, charcoal), is seen as a significant challenge. The National Forest Policy (2017) notes limited scope for increasing biomass output, due to the scarce availability of land for plantation forestry, and notes only incremental production gains that could be achieved through improved forest management, rehabilitation, and productivity improvement (MINIRENA, 2017).

As such, the focus for managing bioenergy demand is on improving the efficiency of fuel use to reduce demand pressures on wood-based fuels. Ambitions to reduce reliance on firewood, through the provision of improved cookstoves and transition to modern fuels, have multiple objectives including improving health by reducing exposure to smoke, providing training and economic development opportunities by reducing time spent collecting wood (predominately by women and children), and preserving forested areas (MININFRA, 2018). Alternative fuels such as LPG and electricity, are expensive and currently used by only 0.5% of households (MININFRA, 2018). Government programmes to support the use of improved cooking technologies have been in place since the 1980s, aiming to move households from traditional 3-stone fires, typified by low efficiency and high particulate matter emissions, towards modern efficient cookstoves with higher efficiency, lower emissions, and in some cases providing electrical energy as well as heat for cooking.

Renewable electricity generation potential in Rwanda is significant, and there is potential to greatly increase the supply of electricity from hydroelectric and solar energy sources. Already almost 60% of installed electricity generation capacity in Rwanda is from low-carbon sources, most of which is from hydroelectricity (IRENA, 2022), of a total electricity generation capacity of 332.6 MW in 2023 (REG, 2023). Due to its topography, there are significant opportunities for run-of-river projects to increase hydroelectric generation capacity (Niyotenze et al., 2020), while there are also opportunities to take advantage of Rwanda's ample solar resources, ranging from 4.3 to 5.2 kWh/m^2/day irradiation (RURA, 2023). Improving access to electricity, currently at 47% of the population, is a priority, through the extension of the national grid and establishing off-grid electricity solutions.

1.3.2 Current and projected aviation fuel demand

Rwanda currently has six civil aviation airports, of which two operate commercial air operations and four operate general air operations (Figure 4). Kigali International Airport is the largest airport by passenger volumes (1.1 million passengers in 2019). Kamembe Airport operates one commercial flight per week, serving approximately 13,000 passengers in 2019. Four airstrips – Musanze, Rubavu, Nemba and Huye primarily receive helicopters which principally serve tourists travelling through the country (RCAA, 2022).

Prior to the COVID-19 pandemic, international and domestic passenger and cargo air travel in Rwanda was increasing briskly. International passengers increased by 14.4% from 2018 to 2019, reaching 1.12 million, while domestic passengers grew by 17.9% to 0.85 million over the same period. International cargo increased by 12.7% over the same period (RCAA, 2022). Rwandan jet fuel consumption – by all airlines - was reported as 1.17 thousand barrels per day in 2019 (US EIA, 2023), equivalent to 59 kilotonnes (kt) per year (Figure 4). Since 2010, jet fuel demand had been increasing at a compound annual growth rate of 8.1%. Jet fuel demand was lower in 2020 and 2021 at 32 kt/year in both years (US EIA, 2023), due to the impacts of Covid-19 on demand for international air travel.

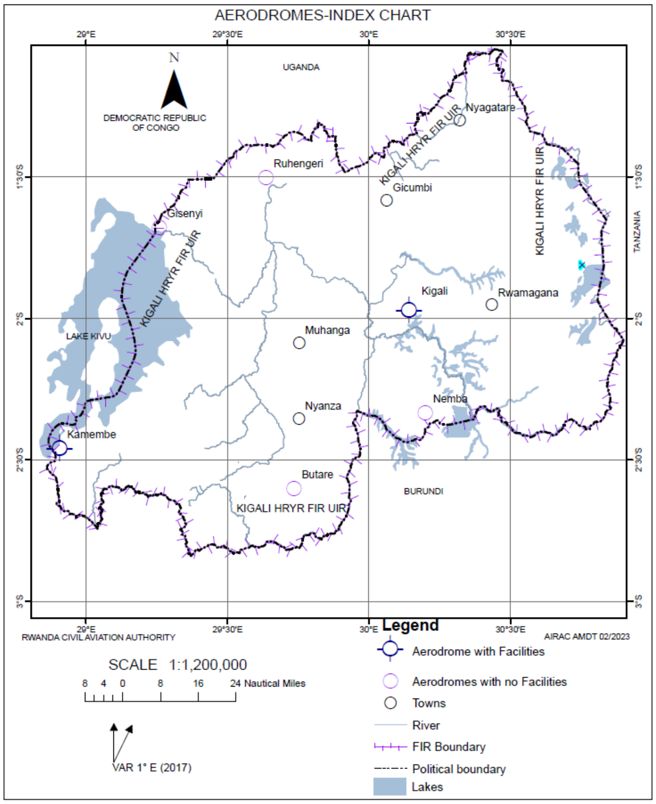

Figure 4. Location of airports within Rwanda. Kigali Aerodrome is the single international facility.

The Rwanda State Action Plan reports roundtrip international aviation fuel demand for the national carrier, RwandAir, including both inbound and outbound flights for cargo and passengers. International aviation fuel demand for the year 2019 is estimated at 115 kt (Figure 5), resulting in greenhouse gas (GHG) emissions of 365 kt CO_2 equivalent (RCAA, 2022). Fuel use from 2020 onwards is estimated by RCAA assuming a 4% annual growth rate. In the absence of any mitigating measures, fuel use would reach approximately 390,000 tonnes by 2050 (RCAA, 2022). The Rwanda State Action Plan details efficiency improvements that are anticipated to considerably reduce fuel use over this period, through the use of newly purchased more efficient aircraft, optimising aircraft-route selection to minimise fuel use, improved aircraft monitoring and flight procedures, and efficiencies for ground side equipment to mitigate emissions at airport. These actions, taken in the period 2020 to 2025, are estimated to reduce aviation fuel use by 81,796 tonnes of fuel per year, a 56% reduction in projected fuel use in 2025 (RCAA, 2022). As interventions beyond 2025, such as continuing replacement of aircraft with more fuel-efficient models, are excluded from the analysis, this level of fuel savings is projected to remain constant up to 2050, resulting in an annual fuel use of approximately 308,000 tonnes in 2050.

Air traffic capacity is expected to increase significantly with the completion of the new Kigali International Airport in Bugesera District, which is scheduled for completion in 2026. This new facility will have capacity for 8.2 million passengers/year in the first ten years, and the potential to expand to 14 million in Phase 2. For cargo, 150,000 tonne/year capacity is initially planned, which can be doubled following the first 10-year period. If fulfilled, this planned capacity would increase by more than ten times current cargo flights and increase by five-fold passenger numbers. It is estimated that aviation fuel consumption will be 1,770 m^3/day during the first 10-year phase, or 519,000 tonne/yr, increasing to 4,184 m^3/day or 1,228,000 tonne/yr with expanded passenger and cargo numbers during Phase 2 (ATL, 2023).

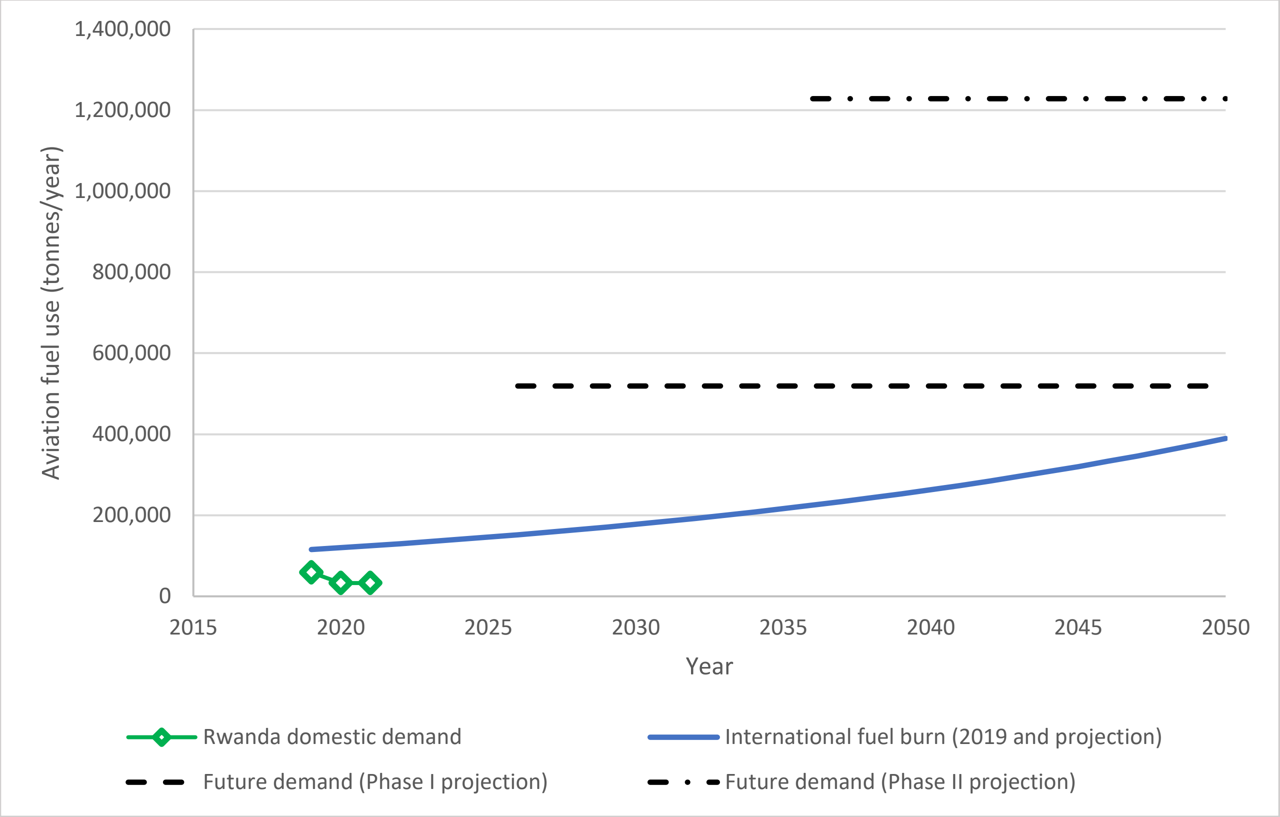

Figure 5. Rwanda aviation fuel demand data and projections. Rwanda demand (2019) – aviation fuel consumption in Rwanda (US EIA, 2023); International fuel burn – inbound and outbound flight fuel use in 2019 and future projections (RCAA, 2022); Future demand projections for new International Airport (ATL, 2023).

1.4 SUSTAINABLE AVIATION FUELS WITHIN THE RWANDAN POLICY CONTEXT

Successful deployment of SAF production in Rwanda requires awareness of the potential synergies and conflicts with existing policy and strategy. SAF by nature is a cross-sector product and requires consideration of policies related to feedstock supply (agriculture, waste management); competing uses (energy, transport); and wider economic and environmental drivers. Ambitions for improved transport and irrigation infrastructure and intensification of agriculture may improve availability and access to agricultural residues, while solid waste management objectives will improve the collection of wastes and encourage value-add through waste-to-energy, which in the longer term could include higher value outputs such as SAF. Potential conflicts do exist, and it is essential that SAF plans are complementary to ambitions to improve food security. Competition will exist where constraints in feedstock availability require decisions to allocate between possible end uses (SAF, road transport fuels, electricity, industrial energy). The following provides a summary of key policies and strategies, and their relevance to SAF production in Rwanda.

National policies for energy and climate are developed in the context of national level commitments, such as Vision 2050 aspirations (Republic of Rwanda, 2015), as well as regional and international commitments. The Vision 2050 report outlines the Government of Rwanda's ambitions for a modern, market-oriented and climate-resilient agricultural sector (Republic of Rwanda, 2015). Comprehensive strategies for achieving medium-term targets in the agricultural sector are further elaborated in pathways for transformation in the food sector to meet the 2030 Sustainable Development Goals (Republic of Rwanda, 2021). Of specific relevance to SAF are drivers to 1) improve sustainable production through land use consolidation, capacity building, land protection, agro-industrialisation and value chain infrastructure investments; 2) contribute to sustainability by improving climate resilience and applying circular economy principles; 3) support rural economic development outside of farming, through creating an enabling environment with access to infrastructure and energy; and 4) support investment across the value chain.

Rwanda Energy Policy (MININFRA, 2015) highlights a range of measures to be undertaken to ensure access to modern, efficient, sustainable and affordable energy services. These include regulations, new codes and standards, and the introduction of economic incentives such as subsidies to encourage energy efficiency. Regarding biomass energy, the policy's main focus is on switching from traditional biomass fuels (fuelwood, charcoal) towards modern energy technologies and cleaner fuels. A call is made for developing a new biofuels policy, aimed at taking advantage of stronger regional integration to create markets for these fuels. Public transport, agricultural transport, and agro-processing machinery are viewed as particularly suitable markets for these fuels. The release date of the updated biofuels policy has not been announced.

Regarding climate change, the National Green Growth and Climate Resilience Strategy for Climate Change (Republic of Rwanda, 2011) outlines a range of strategies to improve the resilience of the agriculture, energy and transport sectors, and to encourage low carbon development across the economy. Programmes of Action related to the intensification of agriculture and diversification in local and export agriculture markets are potentially beneficial to SAF production with a focus on improving the productivity of crops and associated residues, and the potential to add value to agricultural and food processing residues for SAF production. Drivers for increasing renewable generation in the national grid will improve access to low-carbon and low-cost electricity inputs for SAF production, while ambitions for increasing private investment in green industry could see SAF as an exemplar industry capable of adding value to waste and biomass feedstocks. The Programme of Action related to efficient and resilient transportation systems could be an incentive to SAF as a route to low-carbon aviation, but also introduces competition for limited feedstocks with the production of road fuels such as biodiesel.

The Rwanda National Environment and Climate Change Policy (MoE, 2019) presents a range of Policy Objectives aimed at economic transformation, enhancement of natural ecosystems, meteorological systems, climate adaptation, governance, and investment. Within this policy, there are potential roles for SAF in delivering a low-carbon fuel through circular management of wastes and residual materials; contributing to economic development; and by preventing pollution through improved management of wastes. Ambitions to promote green investment may benefit SAF production, which could be a route for capital inflows to construct production facilities and related supply chain infrastructure. Importantly, objectives related to conserving, preserving and restoring ecosystems make clear the need for ensuring SAF production does not increase pressures on land use and natural ecosystems. Further, if SAF is produced via bioprocessing, any potential use of engineered microorganisms must satisfy biosafety regulations.

Rwanda's Nationally Determined Contributions (Republic of Rwanda, 2020) identify key sectors for achieving emissions reductions such as energy (increased renewable generation; vehicle standards and electrification; improved cook stoves), waste management (landfill gas utilisation and deploying waste-to-energy processes), and agriculture (soil conservation and land management, compost production, and livestock management). Drivers for improved waste management in particular have a longer-term potential to support high-value production, such as SAF, from wastes. This ambition is reiterated in the National Integrated Solid Waste Management Strategy (MININFRA, 2022), with a more refined focus on waste management. Within this strategy, waste is viewed as a resource, and SAF production from waste would align with providing economic opportunities and job creation by valorising this resource. Further, key ambitions in improving access to waste collection and developing transfer stations, will greatly increase the share of waste that is collected and can be considered as a potential feedstock.

1.5 AVIATION FUEL SUPPLY CHAIN

All aviation fuel consumed in Rwanda is imported, as there is no refining capacity in the country. Imports arrive via truck transport from Kenya via the Northern Corridor (7.1% of supply) and from Tanzania via the Southern Corridor (92.9% of supply) (MININFRA, 2018). Regionally, there is a lack of refining capacity, with the Mombasa oil refinery ceasing operations in 2013 and Dar-es Salaam in 2001. As a consequence, all petroleum-based fuels are imported from outside of the East Africa region, principally from the Middle East (United Arab Emirates, Saudi Arabia, Oman), India and Malaysia.

Implementing SAF production in Rwanda would require the provision of infrastructure to blend fuels within the country. In addition, the capacity to certify fuels would need to be created. Current import of finished fuels means that certification has taken place prior to arrival in Rwanda, and is ensured by chain of custody. Where testing and recertification are necessary, this is currently completed out of the country (SP Aviation, 2023).

SECTION 2. EVALUATION OF FEEDSTOCKS FOR SUSTAINABLE AVIATION FUEL PRODUCTION

There are a number of routes to produce SAF, and for some feedstocks there is more than one possible production route. A summary of key production routes, suitable feedstocks, and expected capacity of future commercial operations is presented in Table 2. The Fischer-Tropsch (FT) conversion process is a multi-step process, where feedstocks are gasified with clean-up of resulting syngas, prior to FT conversion to SAF and other hydrocarbon products. FT fuels can be produced from biogenic feedstocks, including agricultural residues, organic wastes, and forestry biomass, as well as from carbon dioxide and/or carbon monoxide and hydrogen.

The hydrotreatment of oils (vegetable oils, animal fat, and used oils) to produce hydroprocessed esters and fatty acids (HEFA) is a high yielding process (83% by mass, ICAO rules of thumb) where hydrogen is input to a catalytic process to convert input triglycerides to straight chain alkane hydrocarbons, and a second isomerisation and cracking of alkanes to desired products. Alcohol to jet (ATJ) processes first produce alcohols (ethanol, isobutanol) which then undergo dehydration, oligomerisation, and hydration reactions to synthetic paraffin (SAF) and coproducts.

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

The expected capacities of mature and commercially competitive SAF production facilities range from 96,000 t SAF/yr (FT from agricultural residues) to 440,000 t SAF/yr (HEFA) and 560,000 t SAF/yr (ATJ) (ICAO, 2023). It is worth noting that these capacities are significantly higher than current aviation fuel consumption in Rwanda (<60,000 t/yr).

At this demand level, SAF production from a single facility could far exceed demand and so export routes would be required to bring SAF to market in neighbouring countries. However, anticipated future passenger and cargo numbers at the new international airport (under construction) would greatly increase aviation fuel demand, by nearly nine times the current fuel demand (Phase 1, ~519,000 tonnes/year) and up to twenty times current demand (Phase 2, ~1,228,000 tonnes/year).

Table 2. Summary of key sustainable aviation fuel production routes, feedstocks, and expected capacity.

Process	Suitable feedstocks	Expected nth plant SAF capacity [1]	Current blending ratio by volume (%) [2]
Fischer-Tropsch (FT), via gasification	Agricultural residues (lignocellulose) Municipal solid waste Forestry biomass CO_2	120-200 million L/year (96,000 to 160,000 t/yr)	50%
Hydroprocessed esters and fatty acids (HEFA)	Vegetable oils Waste oils Animal fat (tallow)	550 million L/year (440,000 t/yr)	50%
Alcohol to Jet (ATJ)	Sugar and starch crops Agricultural residues (lignocellulose)	700 million L/year (560,000 t/yr)	50%
Pyrolysis	Agricultural residues (lignocellulose) Forestry biomass	180 million L/year (144,000 t/yr)	N/A

Notes: 1. ICAO, 2023; 2. IATA, 2023

2.1 AGRICULTURAL FOOD CROPS

2.1.1 Feedstock-related information

Improving food security is a key objective, and it is essential that any deployment of SAF production in Rwanda is compatible with these ambitions. Approximately 20% of Rwandans are reported to be food insecure with low consumption of healthy foods (Republic of Rwanda, 2021), while 35.8% of the population is characterised as being undernourished (FAO et al., 2022).

Important initiatives in the agriculture sector aim to increase productivity through the consolidation of small landholdings, provision of infrastructure (irrigation, improved roads, cold storage), and agro-industrialisation through greater mechanisation and use of agricultural inputs such as inorganic fertilisers. Recent yield improvements in key cereal and root crop production in Rwanda demonstrate some success towards improving food security (Figure 6).

Total production of cereal and root crops has increased at a compound annual growth rate of 3.6% from 2017 to 2022, which exceeds the annual population growth rate of 2.4% during that time period. There is a longer-term potential of increasing food crop production to meet food security challenges and, beyond this point, to potentially identify land and/or crop outputs that could be used for energy applications, including SAF production.

As part of the 2018 Rwanda Strategic Plan for Agriculture Transformation 2018-24, the production of key food crops is aimed to increase relative to 2018 outputs from 56% (rice) up to 164% (cassava). This is intended to be achieved through a range of interventions in the agricultural sector including: improved land productivity, through improved varieties, increased irrigation, fertiliser use, and reducing soil erosion/degradation;

improving markets and supply chains, including cold chains, to reduce food waste; and creating an enabling environment to achieve these ambitions. By increasing agricultural production, the population's food needs would be exceeded in terms of calories (by 2022/23), with 441 kcal/person/day surplus by 2024, and protein (by 2020/21), with 24 g/person/day surplus by 2024. A deficit in fats production per person is expected to persist beyond 2024. The food calorie surplus projected for 2024 is equivalent to ~620,000 t maize or 2,020,000 t cassava, indicating a future potential to produce feedstocks for SAF on cropland without negatively impacting food security.

Recent production trends, however, lag behind targets set by the Ministry of Agriculture in its 2018 Strategic Plan (MINAGRI, 2018) (Figure 7). In total for these key food crops, the gap between actual production in 2020 and the Strategic plan targets is equivalent to approximately 260 kcal/person/day.

Until agricultural food crop production can be demonstrated to exceed the food needs of the population, diversion of land or crop outputs for SAF is unlikely to avoid negatively impacting food security and thus would be in conflict with the principle that biofuel production is not undertaken with detriment to local food security (RSB, 2018).

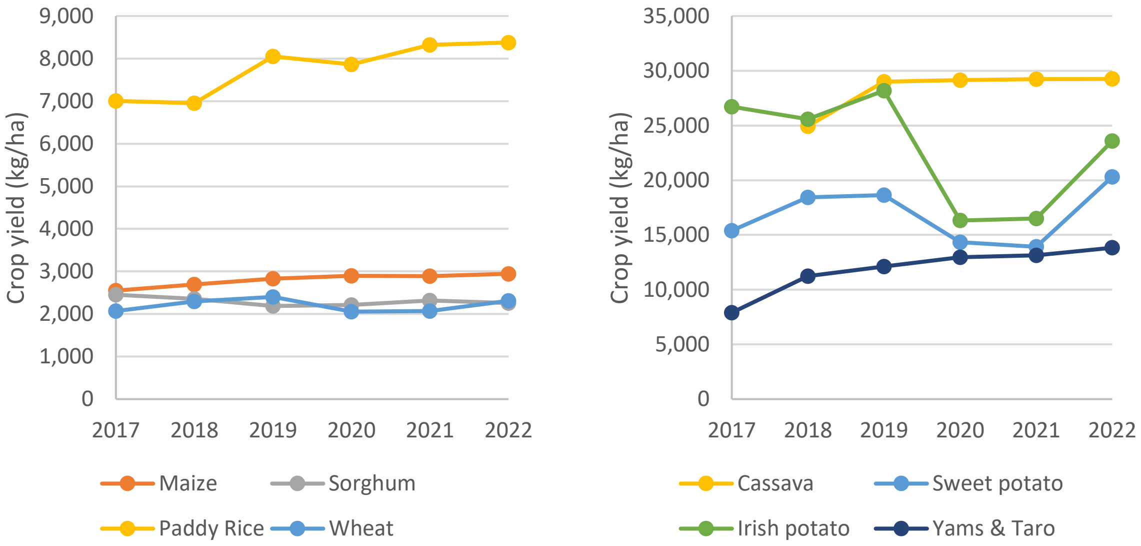

Figure 6. Trends in yield of key agricultural crops in Rwanda a) cereal crops; b) root starch crops. Data from NISR (2019) and NISR (2022).

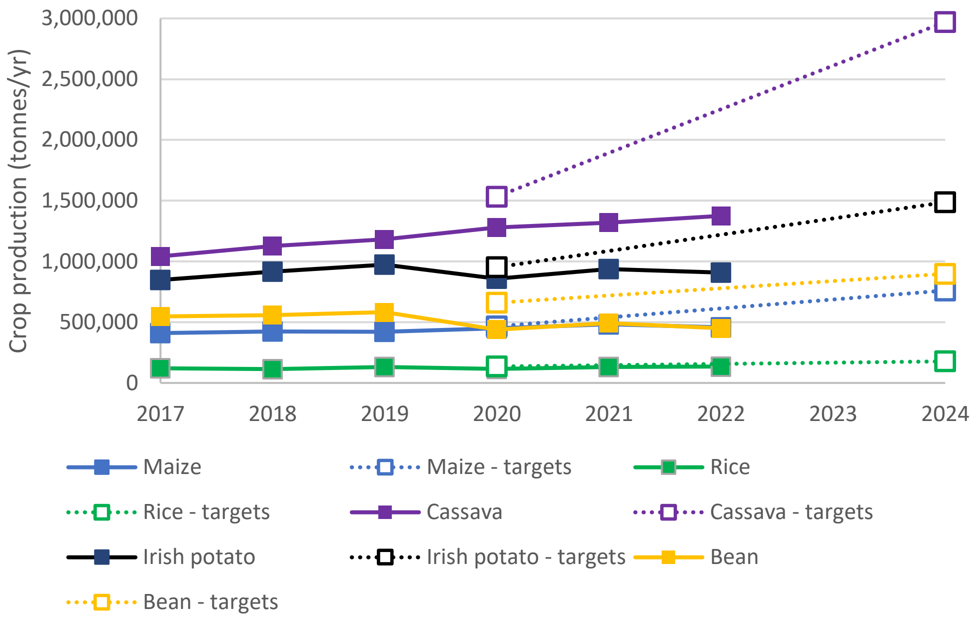

Figure 7. Trends in production of key agricultural crops, and interim/future targets set in the Rwanda Strategic Plan for Agriculture Transformation 2018-24 (MINAGRI, 2018) and actual production data from NISR (2019) and NISR (2022).

2.2 AGRICULTURAL NON-FOOD CROPS

2.2.1 Feedstock-related information

Given the priority of utilising fertile land for food production to meet food security challenges, dedicated crop production for SAF is only suitable where production of feedstock can take place on degraded and marginal/underutilised lands that are unsuitable for staple conventional crops, or without sacrificing food crop production.

Several oil crops have been proposed in recent years, such as jatropha and castor oil, with the potential to achieve reasonable yields on marginal and underutilised lands. Previous experience with jatropha cultivation in Rwanda was not successful. To support domestic biodiesel production, a network of small-scale jatropha producers was established, but anticipated yields were not realised. Investigation into this failure found that the vast majority of surveyed plantation owners reported low yields (1.1-2.9 tonnes per hectare per year, 63% of respondents) and very low yields (0-1 tonnes per hectare per year, 33% of respondents) (Ntaribi, 2018), far below estimated minimum yield of 7 tonnes per hectare per year to be profitable to growers in Rwanda (Ntaribi, 2019).

Failure of jatropha plantations to achieve expected yield was not isolated to Rwanda. Similar experience was reported in Kenya (Iiyama, 2013) where 79% of surveyed growers reported yields of less than 0.1 kg per tree, far below expected yields of up to 2 kg per tree. In Tamil Nadu, India, jatropha cultivation was found to be unviable due to low yields (Ariza-Montobbio and Lele, 2010). Efforts continue to develop higher yielding jatropha varieties, and to add value to non-oil byproducts through briquetting for solid fuel applications and detoxification to enable use as an animal feed (JOil, 2016).

There are ongoing initiatives to identify oil seed varieties and cultivation practices that can achieve commercially viable yields in Rwanda. Italian energy company Eni is collaborating with the National Industrial Research and Development Agency (NIRDA) in a pilot project aimed at producing viable castor oil crops in a precision farming approach with the use of drones for soil analysis and crop monitoring (RDB, 2022). However, estimates are not yet available as to the production potential of castor oil or other oil seed crops on non-crop lands in Rwanda.

Brassica carinata, also known as "Ethiopian mustard" has been proposed as a potential oil seed feedstock, including for SAF production (RSB, 2022). As the plant leaves are edible – they are commonly consumed in Ethiopia – it may be possible for co-production of food and SAF feedstock. In other world regions, *brassica carinata* has been considered as a winter cover crop (instead of leaving fields fallow), being found to not impact productivity of main crops while offering a financial benefit to growers (e.g, Karami et al., 2022).

Non-oilseed crops have also been considered for production on marginal and underutilised lands. Elephant grass, also known as Napier grass, has been promoted as a resilient biofuel crop that can withstand a wide range of growing conditions including intermittent drought, and that requires a minimal of inputs following establishment (Mohammed at al., 2019).

There is some experience with this crop in Rwanda as a forage grass for the dairy sector, although a requirement for high soil fertility and susceptibility to disease has been noted in this context (Negawo et al., 2017). There may be opportunities to integrate Napier grass production in farm boundaries and terraces where erosion risk is high, and to attract pests from food crops (Paul et al., 2020). The potential to integrate Napier grass with food production, to provide a fuel feedstock without compromising food productivity, requires investigation.

2.3 AGRICULTURAL RESIDUES

2.3.1 Feedstock-related information

A significant quantity of agricultural residues is generated in Rwanda, estimated at 1.12 million tonnes/year (MININFRA, 2018). This estimate is in line with academic literature, where Rwanda's agricultural residue production was estimated at approximately 1 million tonne/year (Rocha-Meneses et al., 2019). Key sources of agricultural residues include cereal straws (rice, wheat, millet), and corn stover. There is very limited information available about current management of these residues, and it is not possible to estimate what fraction of this total resource might be surplus to current uses in energy, materials, and feed applications. Competing uses for straws include the production of briquettes as a solid fuel substitute for wood-based fuels and low carbon building materials (Zero Carbon Designs, 2023).

Corn stover is commonly used as animal feed, or as a solid fuel alternative to wood-based fuels. Significant quantities of residues are generated from banana and plantain production (Eliasson and Carlsson, 2020) however these are retained on soil to fertilise trees and maintain productivity. Given current competing uses, it is unlikely that significant quantities of agricultural residues would be available for SAF production in the near term without diverting from these uses.

It is possible that the availability of agricultural residues for SAF production could increase in the future. Efforts to consolidate land holdings would enable larger areas to be dedicated to a single crop, making collection of residues more efficient. Consolidation, alongside intensification of agriculture through increasing irrigation, mechanisation, and use of agricultural inputs including fertilisers, are key to achieving gains in crop yields (see Section 2.1), which correspondingly would increase the production of agricultural residues. However, to date there are no projections of future agricultural residue production and availability for emerging uses. Future utilisation of agricultural residues for SAF production would have to ensure that residue removal was done at a level that does not compromise soil quality, carbon stocks, and crop productivity.

Residues derived from the processing of food crops could be suitable for SAF production, although only a small fraction of Rwanda's agricultural production is processed (not exceeding 6.5% of food crop output) (FAO, 2023). A key benefit of food processing residues is that, in comparison with crop residues, the material is already collected at a production site. Through surveys of food processors, it is indicated that nearly all residues are currently being utilised, either to provide energy at the processing facility (cassava peelings, sugarcane bagasse), sold on as a fuel (coffee husks, maize cobs, rice husks), or as a compost (coffee pulp) (Carne 2022). Recent projects have investigated the utilisation of food processing residues for energy, including a pilot rice husk gasification project for off-grid electrification (RGF, 2023).

2.3.2 Sustainability aspects

If managed correctly, agricultural residues can be a sustainable and low carbon feedstock for the production of SAF, by ensuring the rate of residue removal does not negatively impact soil carbon stocks and future agricultural productivity (REF). The default CORSIA life cycle GHG emissions for SAF production from agricultural residues is 7.7 gCO_2eq/MJ, based on the assumption that residue removal does not require nutrient replacement for the primary crop.

A key risk for SAF production from agricultural residues in Rwanda is the diversion of these materials from current uses. As discussed in Section 1.3.1, biomass fuels are the predominant energy source in Rwanda, representing 90% of energy supply, of which 91% is used by households for cooking and heating. Agricultural residue-derived solid fuels are an alternative to forestry biomass, and thus contribute to Rwanda's objective of reducing demand pressures on wood-based fuels. Diverting from this application to SAF production risks exacerbating existing challenges in meeting demand for these fuels.

2.3.3 Economic and market aspects

Based on the total generation of agricultural residues, there is potential for significant SAF production. If all generated residues (1.12 million tonnes/yr) were utilised, approximately 160 kilotonnes of SAF (195 million liters) could be produced annually. This is more than double recent aviation fuel demand in Rwanda (59 kilotonnes in 2019). However, it is unlikely that such quantities would be available for SAF production, due to current competing uses.

Data specific to Rwanda related to the cost of agricultural residue collection is not available. Similarly, there are no data on current market prices for residues, and so it is not clear what price would be required to divert these materials from their current uses. Agricultural residue feedstock cost of USD 110 per tonne (range USD 78 to USD 175 per tonne) are indicated in the literature cited by the ICAO Rules of Thumb (ICAO, 2023). It is likely that feedstock supply costs will be higher in Rwanda than in other regions, due to highly fragmented land holdings, low levels of mechanisation to enable efficient collection of residues, and underdeveloped supply chains capable of aggregating feedstock supply.

2.3.4 Summary

Key opportunities:

- Significant quantities of agricultural residues are produced in Rwanda

Key challenges:

- Insufficient data about residue generation and current uses, which introduces uncertainty when assessing potential applications
- Requires diversion from current uses, which would require alternative supply of solid fuels, distributed electricity generation, animal feed, and compost
- Fragmented land holdings, low levels of mechanisation, and underdeveloped supply chains likely to result in higher feedstock costs than in other regions

2.4 WASTE OILS

2.4.1 Feedstock-related information

Waste oils, including used cooking oil (UCO) and tallow (a byproduct of beef and mutton production), are potential SAF feedstocks via the HEFA production route (see Table 2). There are limited data on used cooking oil (UCO) availability in Rwanda. Per capita edible oil consumption has been estimated at 2.5 L/person, resulting in national consumption of 25,000 tonnes/year in 2010 and projected to increase to 90,000 by 2030 (Vijaraghavan, 2012).

This is an order of magnitude less than the edible oil consumed in neighbouring countries Kenya and Tanzania, due to lower per capita edible oil consumption (approximately 40% that of the East Africa region average, Vijaraghava (2012), and smaller population size. It is uncertain what fraction of edible oil consumption would be available as UCO. A 2017 survey of UCO generation in Rwanda estimated potential UCO availability of approximately 26,000 L/month from food processing, hotels, and bars/restaurants (unpublished). Of this total, approximately 15,000 L/month are estimated to be generated in the City of Kigali. The main source of UCO is food processing facilities. Food processing is a small sector but with the potential for significant growth, which could increase the availability of UCO in future.

Secondary markets for UCO exist within Rwanda, where it is sold for household food preparation, used within other food production at hotels/restaurants, added to animal feed, and used for soap production. Reuse of UCO in food preparation and animal feed poses health risks, due to degradation of the oil at high temperatures, and animal feed applications are banned in the European Union (Riera and Codony, 2000). Diverting UCO from uses within the food value chain could thus achieve health co-benefits.

Based on the results of the unpublished 2017 survey, approximately one quarter of UCO is disposed of as waste, and so could be available for SAF production and avoid competition with current uses. If UCO is available for fuel production, biodiesel production would be a key competitor, using the same production process. HVO/HEFA biodiesel has similar advantages as SAF, being a drop-in fuel that can directly replace conventional diesel in road transport and electricity generation applications. With very limited resource availability, it would be important for Rwandan stakeholders to prioritise future energy applications from UCO.

Data related to tallow byproduct outputs of beef and mutton production and use in Rwanda are not collected. Tallow byproducts are understood to be currently used for food (edible tallow) and for soap production (inedible tallow), and is unlikely to be available for SAF production. Expansions of meat production for export, in particular beef, will increase the availability of such byproducts with potential to supply new markets. In the period of July 2022 to December 2022, meat exports of approximately 4,700 tonnes were realised (NAEB, 2023) a rapid increase from a year earlier when only 700 tonnes were exported during the same six month window. Future projections of meat production for export are not available. As with UCO, it is important to improve understanding of competing uses for tallow, including its use for other fuel and energy applications, and for Rwandan stakeholders to prioritise future uses.

2.4.2 Sustainability aspects

Life cycle greenhouse gas emissions associated with SAF production from UCO and tallow would be expected to be low. The default CORSIA emissions factor for these production routes are 13.9 $gCO_2eq./MJ$ and 22.5 (UCO and tallow, respectively), assuming production in a stand-alone facility (ICAO, 2022a). As UCO and tallow are byproduct streams of the food sector, there are minimal environmental impacts expected from its transformation to SAF as GHG emissions associated with the production of oil crops and livestock are attributed to the primary food product markets.

The hydrotreatment process requires an input of hydrogen, which is commonly produced from fossil fuel sources but could be produced from renewable (green hydrogen) utilising on-site electrolysis.

Diverting UCO and tallow from current uses in food preparation, animal feed, and soap manufacture poses socio-economic trade-offs if SAF or other energy uses of UCO and tallow are prioritised over current uses, alternative oil sources would be required to supply current uses, thus inducing an increased demand for oils – and corresponding impacts associated with increasing primary production – or depriving current users who would be forced to go without.

2.4.3 Economic and market aspects

Fuel production in the City of Kigali, making use of UCO available within the city, would avoid transport costs required to aggregate supply from other provinces. Up to 32 tonnes SAF/year could be produced from the UCO currently disposed of, compared with a maximum production potential of 140 tonnes SAF/year if all UCO were used for fuel production. From a national perspective, if all currently wasted UCO could be utilised for SAF production, 54 tonnes SAF/year could be produced, or approximately 0.1% of current aviation fuel demand in Rwanda. This increases to 236 tonne SAF/year if all UCO is utilised, or 0.4% of current aviation fuel demand.

A greater quantity of tallow is potentially available from export meat production. On an annual basis, meat production for export in the second half of 2022 would yield approximately 850 tonnes tallow (calculations based on Campbell, 2023; USDA, 2015). If this was fully used for SAF production, it would yield approximately 700 tonnes SAF/year, equivalent to 1.2% of recent in-country aviation fuel demand.

The quantities of UCO and tallow are insufficient on their own for a commercially viable SAF production facility, which would be expected to have fuel production capacity of 1 billion litres of distillate fuel/year (550 million litres SAF/yr) (ICAO, 2023), requiring an input of approximately 910,000 tonnes oil/year. UCO and tallow can only be considered to potentially make a marginal contribution to feedstock supply for a future

HEFA process, at most providing 1,086 tonnes per year or 0.2% of required oil supply when diverting from current uses. Producing SAF only from available waste oils would not be economically feasible.

While UCO is a byproduct of food preparation, it has current uses and so has an existing market value. The 2017 survey indicated a median price of 500 to 600 Rwanda Francs (RWF) per litre, equivalent to USD 465 to USD 560 per tonne. Higher UCO prices, within a range of 750 to 1000 RWF per litre (USD 700 to 930), were reported by food processors, which typically use higher value sunflower oil (unpublished data). Additional costs would be associated with the collection of UCO and delivery to a fuel production facility. Current UCO prices are in line with expected feedstock prices of USD 580 per tonne (ICAO, 2023), and so it is possible that SAF production could compete favourably with current uses of the feedstock to secure this supply. No data is available regarding feedstock price for edible or inedible tallow.

2.4.4 Summary

Key opportunities:

- Waste oils to SAF is a proven fuel production route
- Waste oils could provide a small portion of feedstock supply to a larger HEFA facility

Key challenges:

- Limited data on waste availability
- Existing estimates indicate a very small quantity of UCO currently unutilised; greater quantities of tallow may become available with planned expansion of meat exports
- Competing uses for waste oils as feedstocks for biodiesel for road transport

2.5 MUNICIPAL SOLID WASTE

2.5.1 Feedstock-related information

Data on municipal solid waste (MSW) generation are very limited. Preliminary estimates in Kigali (based on counting collection trucks) indicate that approximately 400 tonnes per day are collected and landfilled (MININFRA, 2022). Similar data are not available outside of Kigali. Regarding waste composition, several sampling studies have been conducted, typically indicating 60-80% organic material in urban collections and >90% in rural collections (MININFRA, 2022). There are no data available for quantities or compositions of commercial and industrial solid waste.

Waste collection is undertaken by private companies, who bid on tenders to collect household waste within defined geographical areas. Within urban areas, 46% of survey respondents had access to waste collection services, contrasting with only 1.7% of rural households (data as of 2017) (MININFRA, 2022). Collected waste is delivered directly to landfill, while transfer stations do not yet exist to aggregate waste from local collections. There are ambitions to create a network of transfer stations that would then feed provincial landfills and waste management facilities, which is expected to increase the rate of solid waste collection (upcoming National Integrated Water Supply and Sanitation Master Plans, referred to in MININFRA, 2022).

With limited collection, especially in rural areas, most waste is currently deposited to land. Landfill sites in Rwanda are privately operated, and most are classed as semi-controlled dump sites. Nduba (Kigali) is classed as a controlled landfill. At dump sites, any separation and recovery of materials is done based on market drivers, for example, to recover plastics or for compost production.

Landfilling of organic materials results in the generation of methane-rich landfill gas. Methane is a potent GHG with a global warming potential approximately 30 times that of carbon dioxide over a 100 year time frame. Diverting solid waste from landfill and, in longer-term, using waste as a feedstock for energy generation is a priority strategy for mitigating greenhouse gas emissions under Rwanda's National Determined Contributions (Republic of Rwanda, 2020). Near term actions will focus on implementing improved waste collection and construction of sanitary landfills where landfill gas can be captured and used for energy recovery.

Longer term, the deployment of waste-to-energy systems, via waste incineration for electricity generation, is seen as a costlier waste management route but one that avoids fugitive landfill gas emissions and therefore can further reduce GHG emissions. SAF production from MSW could align with future waste-to-energy ambitions, as a higher value route to utilising waste as a feedstock. SAF production has the additional benefit of displacing imported aviation fuels, whereas alternative renewable electricity generation sources are available in Rwanda (see Section 1.3). There are near-term opportunities to produce fuels, such as refuse-derived fuel, from mixed waste, for utilisation in cement production and potentially in incineration facilities for electricity generation. These opportunities may compete with SAF production even in the longer term.

MSW is a challenging feedstock: due to its heterogeneous nature, pre-treatment/sorting and drying may be required to achieve a suitable process input. Advanced gasification processes for SAF production from MSW are not yet in commercial operation. The technology readiness level has been estimated at ranging from 6 to 8 (Knowledge Transfer Network, 2021), where a level of 9 indicates commercial operation. To de-risk SAF production from MSW, demonstration of viable gasification processes, capable of producing an adequately clean syngas output suitable for downstream synthesis, may be appropriate. This would have the additional benefit of creating a supply chain for MSW collection, aggregation, and pre-gasification processing, which in turn would help to better understand requirements, opportunities, and challenges with sourcing significant quantities of MSW for a fuel/energy production process.

2.5.2 Sustainability aspects

Production of SAF from MSW is likely to be characterised by low GHG emissions. ICAO default values for MSW to SAF, via gasification and Fischer-Tropsch synthesis, are 5.2 $gCO_2eq./MJ$ for organic waste. Within the organic content range of Kigali MSW (60% to 80% organic), default GHG emissions of 39 to 73 $gCO_2eq./MJ$ would be expected, compared to conventional jet kerosene emissions of 84.5 $gCO_2eq./MJ$ (ICAO, 2022a).

Diverting MSW from landfill to SAF production will avoid significant GHG emissions, primarily by avoiding the generation of methane-rich landfill gas. These emissions are significant in sanitary landfill systems, which aim to minimise the environmental impacts of landfilling, capture and flaring of landfill gas, but greater in uncontrolled landfills. In sanitary landfill sites, GHG emissions of nearly 400 $kgCO_2eq$ arise for each tonne of landfilled organic waste over a 100-year decomposition period (Nordahl, 2020) due to landfill gas leakage. Without capture and flaring at an uncontrolled site, each tonne of food waste deposited in a landfill would contribute 2,100 $kgCO_2eq$ due to landfill gas generation and emission over this period (NSWEPA, 2022). Most existing landfills in Rwanda are semi-controlled, and it is noted that most sites in Rwanda do not follow RURA's Standards for Waste Disposal Sites or meet international standards of sanitary landfilling (MININFRA, 2022).

There is an ongoing initiative to convert the Nduba landfill site in Kigali to a sanitary landfill with landfill gas management (MININFRA, 2022).

In addition to GHG emissions reduction, the diversion of solid waste from current landfills would have further environmental benefits. Controlled and semi-controlled landfills have no, or partial, leachate management, resulting in pollutants leaking into surrounding soils and ultimately into waterways. Landfill leachate contains dissolved organic matter, inorganic components, heavy metals, and other pollutants, which risk contaminating soils and water near the dump site.

2.5.3 Economic and market aspects

Household waste collection and transport tariffs in Kigali are overseen by Rwanda Utilities Regulatory Authority. These costs vary by neighbourhood and by household income, ranging from RWF 1,000 to 2,200 per week for low income households (USD 0.8 to 1.8), from RWF 3,300 to 7,500 for assisted living households (USD 2.8 to 6.3), and from RWF 5,000 to 11,200 for high income households (USD 4.2 to 9.4) (RURA, 2012). An average waste collection and transport cost cannot be accurately determined from this data, due to uncertainties in quantities of waste collected and the shares of waste collected at each cost band. Based on per capita waste generation in urban areas ranging from 0.56 to 0.70 kg per person per day (Global Green Growth Institute, 2019; REMA, 2021) and average urban household size of 3.7 persons (NISR, 2023), a range of waste collection costs can be estimated, from USD 45 per tonne (low income collection cost, high waste generation rate) to USD 650 per tonne (high income collection cost, low waste generation rate).

A SAF production facility utilising MSW as a feedstock may be burdened with the cost of waste collection, as this cost is currently borne by the waste producers (households, commercial and industrial sources). Diversion of MSW to SAF production can avoid current dumping/landfilling costs, but this does not provide a significant financial incentive at current gate fee[2] RWF 1,000 per tonne (0.8 USD) (The East African, 2017b) to deposit solid waste at current dumping sites. Provided further supply aggregation is not required for SAF production, an MSW feedstock cost of approximately nil might be expected at present.

Future waste disposal costs at anticipated sanitary landfill sites are unknown, and could be higher than present disposal fees. Landfill fees range from USD 10 to 30 per tonne in low income countries (Matheson, 2019). If similar landfill costs are seen in the future in Rwanda's cities, this would provide a greater driver to divert solid wastes to SAF production. It is possible that a gate fee (or tipping fee) could be applied to MSW received by the SAF production facility, which would correspondingly reduce the minimum fuel selling price of manufactured SAF.

Estimating the SAF production potential from solid wastes in Rwanda is uncertain, due to limited data on the composition of wastes and resulting uncertainty in assessing potential fuel yields. Diversion of all Kigali solid waste currently collected (estimated at 146,000 tonnes MSW/yr) to SAF production could be expected to yield approximately 23,000 tonnes distillate fuels per year, of which SAF would comprise 9,000 tonnes/year (11 million litres SAF/yr).[3] This is equivalent to 15% of aviation fuel consumption in Rwanda in 2019 (US EIA, 2023). While this estimate indicates a significant potential of SAF from MSW, the scale of potential SAF production utilising only this feedstock would be more than ten times below that expected for future mature

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[2] A "gate fee" is the rate paid to a waste treatment facility to accept wastes.

[3] Assuming a feedstock-to-fuel energy efficiency of 54% (ICAO, 2022b) and waste fraction specific energy contents (Meng et al., 2019).

production facilities (300 million litres distillate fuels/year, including 120 million litres SAF). The ICAO Rules of Thumb (ICAO, 2023) consider a facility of similar capacity, at 25 million litres SAF/yr, resulting in fuel minimum selling price of USD 2.9 per litre (pioneer plant) and USD 1.5 per litre (nth plant). This compares with a minimum fuel selling price of USD 2.1 per litre (pioneer plant) and USD 0.9 per litre (nth plant) at the expected larger capacity of 500 million litres per year.

2.5.4 Summary

Key opportunities:

- Waste to SAF is compatible with waste management and climate change strategies
- Diversion from landfill will have significant GHG emissions benefits. This will still be the case if waste is destined for sanitary landfill, due largely to the high biogenic content
- There is a priority to address solid waste management in Rwanda, so potential for quick implementation of new ways of managing this waste

Key challenges:

- Insufficient data about waste and its management, which introduces uncertainty into assessing potential uses
- Limited quantity of waste available, due to lack of collection and transport infrastructure. Too little feedstock for the expected scale of a commercially viable facility
- Current strategy aimed towards sanitary landfilling, which may preclude other waste uses such as SAF in the near- and medium-term
- Technology risk, especially related to the gasification of MSW due to the high heterogeneity of solid wastes

2.6 ELECTRICITY-BASED FUELS

2.6.1 Feedstock-related information

Resource requirements for the production of electricity-based fuels (e-fuels, or eSAF in the context of aviation fuels) are a carbon source, in the form of carbon dioxide (CO_2) and/or carbon monoxide (CO), and hydrogen. CO_2 can be utilised from point sources – industrial processes that generate significant quantities of CO_2 at a high concentration, such as large-scale fermentation processes and combustion of fossil fuels or biomass-based fuels. Alternatively, CO_2 can be captured from the air via direct air capture (DAC) process, an emerging technology to separate CO_2 from ambient air. Compared to point sources of CO_2, DAC requires greater energy inputs to capture CO_2 from this more dilute source.

Potential point sources of CO_2 in Rwanda are limited, due to the lack of large capacity thermal electricity generation facilities and other industrial sources. One potential source of CO_2 is the cement sector. Domestic cement production was 480,000 tonnes in 2022, providing approximately half of demand (950,000 tonnes per year). A new cement facility opened in August 2023, Anjia Cement, is expected to increase capacity by up to 1 million tonnes per year once fully operational and become the largest capacity facility in the county (The New Times, 2023). At full capacity, this facility would generate approximately 600,000 tonnes CO_2 per year (based on 0.6 tonnes CO_2 per tonne cement; Fennel et al., 2021). Aggregating supply from multiple point sources to achieve a higher capacity eSAF facility would require requisite infrastructure for the storage and transport of CO_2 and entail associated costs.

The availability of low cost and low carbon electricity is a requirement for viable eSAF production, both as an input to the fuel production process and for the generation of low carbon hydrogen. Already renewable sources provide over 60% of electricity supply (IRENA, 2022). There is potential to significantly expand renewable electricity generation within the country. Rwanda has abundant solar resources, with a practical photovoltaic generation potential of 4.1 kWh/kWp per day (ESMAP, 2020). This is a significant resource, although less than the most solar-abundant nations including many in the Middle East and North Africa, Chile, and Southern Africa (ESMAP, 2020).

2.6.2 Sustainability aspects

Default life cycle GHG emissions values for eSAF are not available from ICAO (ICAO, 2022a). Existing studies of these fuels indicate the potential for very low GHG emissions where renewable electricity is used hydrogen production and as energy input to the CO_2 capture and fuel production processes. For example, CONCAWE and Saudi Aramco estimate GHG emissions for synthetic kerosene produced via FT at 5.5 gCO_2eq per MJ, a 93% reduction compared with conventional kerosene (CONCAWE, 2022).

Under the CORSIA LCA methodology, point sources of CO_2 are treated as a waste of the process from which they are captured. As such, zero emissions are attributed to the resulting eSAF product from the CO_2 source “waste, residue, or byproduct” of the process from which they are captured. At the point of combustion, CO_2 emissions are not considered to increase atmospheric GHGs, based on the assumption that this CO_2 would have been emitted by the point source if not captured for SAF production. There is no differentiation between the origin of the CO_2 - whether it is fossil based (e.g., from combustion of fossil fuels at an industrial facility), biogenic (e.g., from a biofuels production facility), or captured from the atmosphere.

Recently agreed rules for e-fuels under the European Union’s Renewable Energy Directive place further restrictions on fossil CO_2-based fuels. Fuels produced from CO_2 originating from fossil fuels used for electricity generation will no longer be eligible after 2035, and from CO_2 originating from other fossil fuel applications after 2040 (European Commission, 2023). Fossil CO_2-derived fuels are seen as an intermediate step towards a net-zero economy (Ordonez, 2022), with EU policy specifically noting that long-term utilisation of CO_2 originating from non-sustainable fuels is not compatible with a trajectory towards climate neutrality by 2050 in the region (European Commission, 2023). Therefore, longer term, identifying routes to supply CO_2 from biogenic sources (e.g., through bioenergy with carbon capture) or direct air capture will be a longer-term objective if this pathway is developed in Rwanda.

2.6.3 Economic and market aspects

The CO_2 output of a 1 million tonne cement plant – approximately 600,000 tonnes CO2/yr – is sufficient for the production of 180 million litres/yr of e-fuels, of which SAF would comprise 36 million litres SAF (29,000 tonnes) (ICAO, 2023). This is approximately half that of in-country aviation fuel demand in 2019 (US EIA, 2023). However, this production scale is less than one fifth that of the expected scale of future commercial eSAF production (ICAO, 2023).

The production of eSAF requires substantial quantities of electricity, primarily for the production of low carbon hydrogen as well as for operating the CO_2 capture and fuel production processes. In the preceding example of 180 million litres/yr of e-fuels output, the electricity requirement would total approximately 3.8 TWh.[4] If provided exclusively from solar PV generation, this would require an installed generation capacity of 2.4 GW.[5] In comparison, the total electricity generation capacity in Rwanda in 2023 is reported as 332.6 MW (REG, 2023).

The costs of eSAF production are dominated by the price of electricity, representing 50-60% of total costs in existing studies (CONCAWE, 2022). Renewable electricity costs from photovoltaics in Rwanda are estimated at USD 0.10 per kWh (ESMAP, 2020). This results in an electricity input cost of USD 2.30 per litre eSAF. Future generation costs are expected to decrease by 40% by 2050 (DNV, 2023), while improvements in hydrogen production efficiency will also serve to reduce electricity demand (CONCAWE, 2022), resulting in electricity costs of USD 1.30 per litre eSAF by 2050.

Even at anticipated nth plant capacity, eSAF is likely to be more costly than other SAF sources. The viability of fuel production by this route will ultimately depend on future market conditions, and the national regulatory context. Regions with lower renewable electricity costs may be capable of producing eSAF at a lower price, creating competition between domestically produced eSAF and imported fuels.

2.6.4 Summary

Key opportunities:

- Potential to utilise waste CO_2 gases from cement production
- Abundant solar resources

Key challenges:

- Less proven SAF production route, entailing significant technology risk
- Scale of electricity demand is greater than total national electricity generation in Rwanda
- High production costs when compared with conventional fuels

2.7 OVERALL ASSESSMENT

Limitations on feedstock availability for SAF production in Rwanda are an important barrier. Fertile croplands are prioritised for food production to improve food security. It is uncertain what area of land unsuitable for staple crop production may be available for SAF feedstock cultivation. Agricultural residues, including crop residues (cereal straws) and food processing residues, are not available for SAF production due to current uses as animal feed and in energy applications. Waste feedstocks offer some promise. In particular, SAF derived from MSW could provide a significant share of current aviation fuel use in Rwanda. The commercial viability of this route, however, is hindered by the relatively small quantity of feedstock when compared with the scale of expected production facilities.

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[4] Calculation based on electricity consumption data in CONCAWE (2022).

[5] Calculation based on ESMAP (2020) data for average practical solar photovoltaic generation potential in Rwanda, 4.1 $kWh/kW_p/day$.

Table 3. Summary of opportunities and challenges related to the use of domestic feedstocks for the production of SAF.

Feedstock considered	Conversion pathway	Feedstock evaluation (supply)	Sustainability evaluation	Economic/market evaluation	Overall
Starch and sugar crops	ATJ	Very Low • Lack of suitable area for cultivation, competition with food production	Very low • High risk of competition for land with food production – food security	Low • Unlikely to secure adequate feedstock for viable production scale	Very low
Oil crops	HEFA	• Very Low (Uncertain)Lack of suitable area for cultivation, competition with food production • Unknown potential for cultivation of oil seed varieties on marginal lands	Very Low • High risk of competition for land with food production – food security	Very Low (Uncertain) • Low productivity demonstrated on marginal lands to date • Unknown potential of new oil seed varieties	Very low
Agricultural residues (crop, food processing)	FT ATJ	Low • Competing uses for animal feed, energy, and materials applications • Fragmented land holdings and lack of mechanisation will make residue supply aggregation difficult	Medium • Risk of competing with existing energy, materials, and animal feed uses	Low • Feedstock collection cost is likely to be high • Available resource is too little on its own for SAF production facility	Low
Waste oils (used cooking oil, animal fats)	HEFA	Low • Limited availability, but could be input to SAF production	Medium • Risk of competing with existing uses for UCO	Low • Available resource is very small compared with feedstock demand for HEFA process	Low

Municipal solid waste	FT	Medium - Use for SAF aligns with waste management objectives - Available quantity too little for the required scale of SAF production - Lack of collection and supply aggregation infrastructure	High - GHG emissions benefit by avoiding landfilling, dumping - Addresses land and water pollution impacts of current waste management	Low - Available resource too little on its own for SAF production facility	Medium
CO_2 + renewable electricity	FT	Low - CO_2 is not currently captured in Rwanda - Electricity requirement far exceeds current total national generation capacity	High - Potential to mitigate current industrial CO_2 emissions	Low - Relatively high electricity cost when compared with other markets	Low

SECTION 3. IMPLEMENTATION SUPPORT AND FINANCING

3.1 CAPACITY-BUILDING NEEDS

3.1.1 Feedstock supply chains

Efficient supply chains, capable of aggregating large quantities of feedstock at low cost, are a prerequisite for SAF production at a commercially viable scale. Currently, SAF-relevant feedstocks such as agricultural residues and MSW are managed at a local scale. Creating the infrastructure to allow more efficient aggregation of feedstocks is an important step to enabling future SAF production. Current ambitions in MSW management are aligned to address this current capacity gap.

There are plans to develop a network of transfer stations to encourage higher rates of waste collection and supply regional waste management facilities (landfills). This will be applicable to future SAF production, albeit requiring further aggregation of wastes to achieve a commercially viable production scale.

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

In-country experience with biofuel production is limited to a pilot biodiesel facility, with no commercial scale production of liquid transport fuels to date. The pilot facility utilised vegetable oils, with a capacity of 730,000 litres/year, based on a transesterification process. In contrast, a commercially viable HEFA facility converting oil feedstocks to SAF could be expected to have a 1,000 times greater production capacity (ICAO, 2023). The HEFA process for SAF production includes additional fuel petrochemical refining process technologies (catalytic cracking; separation of product streams), which are not currently in operation in Rwanda. In addition, the HEFA process requires an input of hydrogen.

Recent data indicates no domestic hydrogen production, and minimal imports valued at less than USD 1,000 per year (World Bank, 2023a), and so skills related to hydrogen production, storage, handling, and use are unlikely to be available domestically at present.

Production of SAF via Fischer-Tropsch synthesis is based on feedstock gasification and subsequent thermochemical conversion and separation processes. Experience with gasification technologies to date is focused on agricultural feedstocks, such as the RGF-supported rice husk gasification project for off-grid electricity generation (RGF, 2023) (See Section 2.3.1). Utilising MSW as a gasification feedstock is more challenging, due to the heterogeneity of wastes in general, and their higher moisture and ash contents compared with feedstocks such as agricultural residues.

To date, waste gasification has not been undertaken in Rwanda. Conversion of the output syngas to SAF, as opposed to combustion for electricity generation, requires “clean” syngas. In particular, sulphur compounds can deactivate catalysts even at very low concentrations of 0.2 parts per million (Spath and Dayton, 2003), and so their removal via a desulphurisation process is required. Halides (10 parts per billion) and nitrogen compounds – ammonia (10 parts per million), nitrous oxides (0.2 parts per million), and hydrogen cyanide (10 parts per billion) – must also be carefully controlled to avoid catalyst poisoning (Spath and Dayton, 2003). Downstream fuel synthesis and separations process technologies are not currently in operation in Rwanda.

3.1.3 Fuel blending and certification

At present, all aviation fuels are imported into Rwanda as finished fuels. There is existing capacity and know-how in the country to store and distribute aviation fuels. Domestic production of SAF would require the provision of infrastructure to blend fuels within the country. The capacity to test and certify fuels would also be needed.

3.1.4 Summary of capacity-building needs

To successfully deploy SAF production at a commercially viable scale in Rwanda, there are requisite infrastructure, technical, and labour skills that need to be addressed.

Infrastructure needs:

- Road improvements and a transfer site network capable of efficiently aggregating supply of feedstocks to scale required for commercially-viable SAF production
- Reliable access to process inputs, including electricity
- Fuel blending, testing and certification facilities

Technology needs:

- Process technologies related to feedstock conversion, SAF production processes, and downstream separations
- Production, storage, transportation and handling of hydrogen

Skills needs:

- Design, construction, operation and maintenance of systems within the SAF value chain, from feedstock collection, storage and transport, to fuel production and downstream activities related to fuel blending, testing and certification
- Training capacity to develop skilled workers in the above areas

3.2 FINANCING

Private investment in the green economy in Rwanda is supported by the Ireme Invest programme. The programme was launched in 2022 at the UN Climate Change Conference (COP27) with an initial capitalisation of USD 100 million (BRD, 2022). Ireme Invest comprises two components, a Project Preparation Facility delivered by Rwanda Green Fund (RGF), and a Credit Facility at the Development Bank of Rwanda (BRD).

Projects must meet eligibility requirements to be considered for funding. Regarding biomass-based fuels, ineligible fuels include food crops or feedstocks grown on otherwise arable land. Support is therefore only available to crops that are grown on non-arable lands, or where feedstocks are derived from agricultural residues, byproducts, and wastes, or other waste sources such as UCO or MSW.

Project preparation focuses on advancing projects from feasibility to bankability. At RGF, Innovation Grants are targeted to research and development, proof-of-concept, and demonstration activities. Support of up to USD 300,000 is available to private companies to support these activities, through recoverable grants with zero interest typically over a two to five year period. Equity financing at below market rates can also be provided by RGF, up to USD 1,000,000. In addition to private investment support through Ireme Invest, RGF provides additional funding facilities, including support for public institutions through the Intego facility (grants up to USD 5,000,000).

To date, RGF has not supported projects related to renewable liquid fuels such as SAF, although projects utilising biomass resources have been delivered. A rice husk to power project in Nyagatare District developed a 70 kW pilot facility based on rice husk gasification for electricity generation (RGF, 2023a). A second project focused on sustainable building materials, utilising agricultural residues to fabricate building panels, was delivered with Strawtec Rwanda (RGF, 2023b).

This Project Preparation Facility may be an appropriate route to build technical capacity and de-risk deployment of key technologies related to SAF production at a smaller scale. Such a strategy could be of benefit to the gasification of solid wastes, where the capacity to address known technical challenges related to the heterogeneity of the feedstock could begin to be established.

Through the Credit Facility, Ireme Invest provides credit to private sector companies at below market rates. The BRD issues bank guarantees that can cover up to 50% of commercial bank collateral requirements (capped at EUR 1,500,000) and loans (capped at USD 5,000,000). Further support for private investment is provided by the Rwanda Development Board (RDB).

The RDB provides fiscal and non-fiscal mechanisms in key sectors, including energy, manufacturing, and the green economy. Examples of fiscal support include the reduction of import duties, where domestic value addition is significantly high; exemptions of import duty for equipment and machinery; and preferential corporate income tax rates. (RDB, 2021).

Non-fiscal incentives include the provision of work permits to facilitate skilled labour where capacity needs are identified. Regional initiatives provide additional funding and financial support to advance SAF production and use in Rwanda. The African Development Bank (AfDB), as detailed in its Climate Change and Green Growth Strategic Framework (AfDB, 2023), has set out an action plan to support climate adaptation, mitigation and investment in the green economy in Africa.

The AfDB aims to mobilise USD 25 billion in climate finance between 2020 and 2025, maintaining 40% of bank finance as climate finance over this period. Key investment priorities for climate mitigation are related to agriculture/land use, energy, and transport sectors.

Related initiatives of relevance to SAF include: Sustainable Energy Fund for Africa, which aims to improve access to renewable energy and efficient energy services; African Circular Economy Facility to build the case for circular economy business models; Africa NDC Hub, to build capacity, finance, and technology development/transfer and support efficient climate mitigation and adaptation actions; and Africa Climate Change Fund supports a wide range of projects focused on addressing greenhouse gas emissions and building climate resilience in member states. Globally, the Green Climate Fund (GCF) supports developing countries' ambitions towards climate change mitigation and adaptation. To date, GCF supports 10 projects in Rwanda, with USD 127 million in total financing (GCF, 2023).

Key projects focus on addressing investment gaps (in energy, productivity, mobility/logistics), supporting sub-national mitigation solutions, and improving access to energy services. Rwanda is a current beneficiary of funding from the World Bank International Development Association, including 21 national and regional projects valued at USD 2.83 billion (World Bank, 2023b). Current focus areas include infrastructure, agricultural productivity and commercialisation, and improving human capital.

SECTION 4. ACTION PLAN

4.1 POLICY AND REGULATORY FRAMEWORK

4.1.1 Encouraging feedstock supply chains for SAF production

Sufficient and suitable feedstock access is a key challenge for future SAF production. Policy support is required to encourage the establishment of feedstock value chains to support future SAF production.

Regarding solid wastes, the existing waste management strategy is expected to make important progress in increasing waste collections, establishing infrastructure to aggregate supply through a network of transfer stations, and – in the longer term – encouraging value addition to waste streams. The immediate sectoral objective is the safe disposal of solid wastes via sanitary landfilling, with the potential to greatly reduce the negative environmental impacts of waste dumping by avoiding a significant fraction of associated greenhouse gas emissions (via landfill gas collection and energy recovery) and mitigating pollution impacts of leachate on soils and water. In the future, diverting organic wastes from landfill to energy applications such as SAF production will have additional GHG benefits by addressing unavoidable landfill gas emissions that remain significant in sanitary landfills.

At that point, drivers to divert wastes from landfill will be required, and could take the form of a landfill tax (as in the UK, HM Revenue and Customs, 2023), or regulatory requirements to reduce the quantity of waste destined to landfill (as in the EU Landfill Directive, Council of the European Union, 1999). Competition for waste feedstocks with other energy applications, including for electricity generation, or the use of refuse-derived fuels for cement manufacture, will exist. Which use(s) of wastes would be expected to deliver the greatest strategic or socio-economic benefit to Rwanda would need to be determined.

With limited information on the availability of solid waste, waste oils, and agricultural residues, a necessary first step is to improve data collection of these feedstocks. Data gaps exist related to the quantities of solid waste collected and its composition, agricultural field and food processing wastes and byproducts, as well as insights on the current uses of these materials. Initiating data collection to inform feedstock availability could address this gap. For agriculture and food processing wastes and byproducts, collecting relevant statistics alongside other agricultural statistics such as crop production and yield, would be beneficial. Going forward, once greater certainty has been made regarding the availability of residual materials, it will be necessary to prioritise applications for these limited materials to deliver the greatest socio-economic benefit, or provide a strategic opportunity, and provide appropriate fiscal and non-fiscal supports to achieve these potential benefits.

The use of limited productive land resources to produce biomass crops is likely at present to compete with food production. There is a longer-term potential for yield improvements in the agricultural sector to achieve food security and generate a surplus of crops or cropland that could be used for biomass production. Ongoing monitoring of food production and initiatives to increase yield and reduce food wastage through investments in the supply chain needs to continue, in order to identify the possibility in the future for productive capacity to exist for biofuel feedstock production.

4.1.2 Encouraging the use of SAF

SAF is more costly than current fuels, and so a policy or regulatory driver is required to incentivise or require the use of SAF. Fiscal support for SAF would have to ensure that the cost to the State is balanced by the wider socio-economic benefit to Rwanda of the SAF production value chain. This is only likely to be achieved where significant value-add takes place within Rwanda, through the production/processing of feedstocks, the manufacture of fuel, fuel blending and certification, and/or export of fuel.

Regulatory support, such as through mandating a share of SAF within the Rwanda aviation fuels market or applying a “carbon tax” mechanism to penalise GHG emissions of fuels, would require regional alignment to avoid potential market effects. If not subsidised, regulations requiring the blending of SAF within aviation fuel supply or taxing GHG emissions will increase the cost of fuel. Competitiveness with the region for international flights may be negatively impacted as a consequence of unilateral actions that increase the cost of aviation fuel supply in Rwanda.

4.2 CRITICAL SUCCESS FACTORS

A range of critical success factors have been identified for the implementation of SAF production in Rwanda:

Establishing feedstock supply chains: The availability of feedstocks – oils, solid waste, agricultural residues – at a scale suitable for SAF production is an important barrier. The collection of data on the production of these materials, their current uses, and projections of future production will improve understanding of their potential to supply SAF production. Current ambitions to improve waste collection rates, and to aggregate waste sources at transfer sites, will increase the quantity of material entering formal waste management that may prove suitable for future SAF production. Further investigation over the next few years of the conditions (technical, economic and environmental) that would be required for the establishment of feedstock supply chains in Rwanda that are sufficient for SAF production is needed as a precursor to industry establishment.

De-risking process technologies and developing skills: Rwanda has limited industrial experience with process technologies necessary for SAF production, via the HEFA process for oil-based feedstocks, or via the FT process for solid wastes and agricultural residues. In the case of FT, developing technical capacity around gasification from a range of feedstocks including heterogeneous solid wastes is a necessary step. Smaller scale and lower risk intermediate projects – for example, solid waste gasification and combustion of syngas for electricity generation – would further develop local expertise in this technology area. Longer-term, a strategy for technology transfer and for developing a workforce with the necessary skills to design, operate and maintain facilities for fuel production, blending and testing/certification is needed.

Demonstrating financial viability and GHG emissions reduction potential: Waste diversion from semi-controlled dumpsites and future sanitary landfills will significantly reduce GHG emissions associated with methane-rich landfill gases. SAF production from solid wastes can thereby make a substantial contribution to Rwanda’s Nationally Determined Commitments (Republic of Rwanda, 2020). Prospective assessments of the financial viability and the net GHG emissions impacts of waste-to-SAF, based on high quality data regarding the quantity and composition of wastes, will help to make the strategic case for developing this fuel production route.

Creating SAF certification capacity: Domestic production of SAF would necessitate the capability to blend and to certify aviation fuels within Rwanda. At present, finished fuels are imported into Rwanda, with certification taking place outside of the country.

Establishing an appropriate regulatory framework to encourage investment: SAF production costs exceed those of conventional aviation fuels, and so drivers are needed to encourage or require the use of SAF. A review of policy and regulatory options, and an assessment of the potential success of such measures and their wider economic impacts, is needed. With limited feedstock available for low carbon fuels production in Rwanda, there is a need to identify and encourage priority uses capable of delivering strategic and socio-economic benefits. Attracting investment to develop infrastructure and productive capacity will require long-term certainty of policy and regulatory support for the production and use of SAF in Rwanda.

Developing a regional strategy for SAF production and use: The need for regional co-operation is apparent. The capacity expected for a commercially viable SAF production facility exceeds both the current availability of domestic feedstocks to supply the facility, and the current demand for aviation fuels in Rwanda to utilise the outputs. Co-operation with regional partners could help to increase the magnitude of feedstock supply, while ensuring a market for produced fuels. Regional co-ordination of SAF policies and regulations will also help to ensure that competitiveness is not negatively impacted by measures to mandate the use of SAF.

4.3 ACTION PLAN

The current section describes recommended actions to support the future production and utilisation of SAF within Rwanda. The intention is to provide insights as to how an expansion from the results of this study into specific supportive actions can take place. The State, following its own review, should decide on whether to complete particular actions, determine additional actions to take, decide on the timing of undertaking actions, and to identify relevant stakeholders to deliver the actions.

Table 4. Overview of the opportunities and challenges of identifying and establishing viable SAF supply chains in Rwanda.

Vision: To identify and establish viable SAF supply chains in Rwanda	
Opportunities:	Challenges:
• Strong government commitment in developing the Green Economy • Diversion of solid wastes from dumpsites to fuels production, including SAF, is aligned with climate change mitigation actions and waste management strategies • Potential for social benefits through adding value and diversification of agriculture and waste management sectors	• Waste collection systems are limited or non-existent in many areas • Lack of technical expertise in relevant technology areas • Fuel refining, blending and testing/certification infrastructure is lacking • Competition for waste and byproduct streams with animal feed, electricity, and solid fuel applications • Agricultural land required for food production and cannot be diverted to biomass crops

Table 5. Description of recommended actions to identify and establish viable SAF supply chains in Rwanda

Recommended Actions	Timeline	Potential Responsible Entity
Aim 1: Provide an enabling policy and administrative environment to develop opportunities for SAF production and build relevant capacity		
1.1 Include consideration of advanced biofuels, including SAF, in relevant policies and strategy documents, including future Energy Sector Strategic Plan	By 2028 (5 years)	MININFRA, and others
1.2 Draft a biomass fuels strategy, identifying opportunities and priorities for the use of biomass and waste feedstocks for energy and materials applications	By 2025 (2 years)	MININFRA, and others
1.3 Investigate the potential for regional cooperation, in developing and advancing SAF supply chains and coordinating policy and regulatory mechanisms for encouraging the use of SAF	From 2024, ongoing.	tbc
1.4 Include SAF as a strategy for mitigating GHG emissions within Rwanda's Climate Change Strategy, and consider inclusion of SAF within future revisions of the Nationally Determined Commitments	By 2025	Ministry of Environment
Aim 2: Develop in-country capacity for waste-to-SAF		
2.1 Continue ongoing strategies to improve collection rates of solid wastes from household, commercial and industrial sources and establishment of a transfer station network to aggregate waste sources	Current	MININFRA, Ministry of Environment, REMA
2.2 Improve data collection related to the quantity and composition of solid wastes, building on existing efforts in Kigali, Huye and Muhanga, to expand data collection in urban and non-urban areas and to improve understanding of feedstock variability	Current	MININFRA, Ministry of Environment, REMA
2.3 Conduct a sustainability and techno-economic feasibility study for MSW gasification for electricity generation at a technology pilot facility	By 2025 (2 years)	NIRDA, MININFRA, WASAC, GGGI
2.4 Following successful findings in action point 2.3, establish an MSW gasification pilot facility to build expertise in waste gasification and de-risk the technology	By 2028 (5 years)	NIRDA, MININFRA, WASAC, GGGI
2.5 Conduct a sustainability and techno-economic feasibility study for SAF production from MSW considering inter-province supply chain opportunities	By 2028 (5 years)	NIRDA, MININFRA, WASAC, GGGI
2.6 Conduct a comparative assessment of alternative uses for MSW to identify options that deliver the greatest socio-economic, sustainability, and strategic benefit	By 2030 (7 years)	NIRDA, MININFRA, WASAC, GGGI
Aim 3: Improve understanding of potential feedstock supply from agriculture and food sector		
3.1 Assess marginal land availability and potential utilisation options for biomass cropping, and conduct initial sustainability and economic feasibility study	By 2028 (5 years)	RAB
3.2 Assess the feasibility of expanding the Seasonal Agricultural Survey to include: i) production/collection of agriculture (field) residues from key crops – cereal and maize straws; legumes; ii) uses/markets for agriculture (field) residues; iii) quantities of food crops sent to processing activities; iv) production and current uses of food processing residues	By 2025 (2 years)	NISR, RAB

3.3 Conduct a sustainability and techno-economic feasibility study for agricultural and food processing residue gasification for electricity generation at technology pilot facility	By 2028 (5 years)	NIRDA, RAB
3.4 Following successful finding in action point 3.3, establish agricultural and food processing residue gasification pilot facility to demonstrate upscaling of supply chain and further build expertise in gasification technology	By 2033 (10 years)	NIRDA, RAB
Aim 4: Assess regional opportunities for feedstock supply aggregation and SAF production		
4.1 (Following from action point 1.3) conduct regional feedstock feasibility assessments within region and neighbouring countries, leading to feedstock supply cost and sustainability studies	By 2028 (5 years)	tbc
4.2 Conduct sustainability and techno-economic feasibility study/studies for SAF production from promising feedstocks (action point 4.2)	By 2028 (5 years)	tbc
Aim 5: Assess options and implications of SAF import to Rwanda		
5.1 Identify potential supply chains for SAF import to Rwanda, including estimates of the timeline of potential SAF availability from regional/international suppliers and the potential cost of imported SAF	By 2025 (2 years)	SP Aviation, MININFRA, RURA

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