Bioenergy for Sustainable Local Energy Services and Energy Access in Africa

Demand Sector Report 5: Horticulture
Focus Country: Kenya

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Cover photo: Biogas plant at Olivado (EPZ) Ltd, Murang'a County, Kenya (credit: Hannes Muntingh).

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In particular, we would like to thank Hannes Muntingh and the rest of the team at Olivado for their support in providing information on their biogas plant in Murang'a County, which represents the commercial flagship project for this report.

EXECUTIVE SUMMARY

NIRAS-LTS partnered with Aston University, E4tech and AIGUASOL to research the opportunities and constraints for bioenergy development in sub-Saharan Africa (SSA) across seven shortlisted industries, through five interlinked themes: biomass resources, technology, economic competitiveness, commercial viability and institutional, market and regulatory frameworks. This report, the fifth in the series, focuses on the bioenergy opportunities in the horticulture sector in Kenya.

Kenya has a large and diverse horticulture industry. Large quantities of residues are generated during grading, cleaning and processing fruits and vegetables. While solid residues are generally composted or fed to livestock, liquid residues can create disposal problems. This presents an opportunity for anaerobic digestion (AD) for bioenergy as both a waste management and energy supply solution. Despite the potential for using horticulture residues for bioenergy for CHP at commercial scale, and a strong regulatory framework for small-scale electricity generation, only a handful of horticulture companies have installed AD systems based on these feedstocks. The research therefore analysed the commercial opportunities for wider adoption of AD in Kenya's horticulture sector, based on the experiences of Olivado EPZ, an avocado oil processor in Murang'a County.

The research found that the potential for AD adoption is highest in centralised facilities in rural areas that require both a cost-effective waste management system and an energy supply option, and which are dependent upon relatively unreliable and expensive grid electricity. An assessment of biomass resources suggests that the potential is particularly high in the pineapple, mango and avocado (oil) sub-sectors.

The research also found that the high cost and operational sophistication of biogas technology is a barrier to wider uptake. These challenges can be overcome through adaptation and localisation of technology to reduce costs, and on-the-job staff training by specialised technology providers and project developers, to build competency for installing and operating such technologies.

Analysis of the Olivado operation suggests that high on-site energy requirements, high costs of waste management and high expenditure on diesel (owing to weak and unreliable grid power) are important factors in boosting the economic and environmental case for investment in AD. However, few fruit and vegetable processors in Kenya have similarly large onsite energy demands. Where these demands do exist, solar PV is likely to represent a cheaper 'turnkey' option than AD. Many processors are also located close to urban centres, where reliable grid electricity is accessible. While waste disposal can be a challenge - hence an opportunity for AD - it is often not a critical cost factor for horticulture enterprises. Securing finance is another bottleneck to replication, owing to the low or non-existent familiarity of local banks with commercial-scale AD projects. The investment environment is further impeded by the unattractive policy and regulatory framework for AD-based electricity generation and supply. A low grid feed-in-tariff, the absence of incentives for the national utility to upgrade its grid infrastructure to handle new electricity generation and high import duties on AD further disincentivise uptake.

While there is a large untapped opportunity for AD-based bioenergy generation in the horticulture sector in Kenya and other SSA countries, there is a need to support Africa-based technology developers to continue developing cost-effective local solutions, to develop more innovative local financing mechanisms and to offer more viable feed-in tariffs for biogas-derived electricity.

Contents

LIST OF ACRONYMS

ABEX	abandonment expenditure
AD	anaerobic digestion
AFA	Agriculture and Food Authority
BSEAA	Bioenergy for Sustainable Local Energy Services and Energy Access in Africa
CAPEX	capital expenditure
CHP	Combined Heat and Power
EPRA	Energy and Petroleum Regulatory Authority
EPZ	Export Processing Zone
FiT	Feed-in-Tariff
G&I	Gender and inclusion
GAVEX	Ghana Association of Vegetable Exporters
GDP	Gross Domestic Product
HCD	Horticulture Crops Directorate
IPP	Independent Power Producer
KALRO	Kenya Agricultural and Livestock Research Organization
KES	Kenyan Shilling
KHE	Kenya Horticultural Exporters
KPLC	Kenya Power and Lighting Company
LCC	Life Cycle Cost
LCOE	Levelized Cost of Energy
MCA	Multi-Criteria Analysis
MEB	Mass-Energy Balance
MoE	Ministry of Energy
NEMA	National Environment Management Authority
OPEX	operational expenditure
PPA	Power Purchase Agreement
REREC	Rural Electrification and Renewable Energy Corporation
SSA	Sub-Saharan Africa
TAHA	Tanzania Horticultural Association
TEA	Transforming Energy Access
USD	United States Dollar
VEPEAG	Vegetable Producers & Exporters Association of Ghana
VS	Volatile solids
ZEGA	Zambia Export Grower's Association

1 INTRODUCTION

NIRAS-LTS partnered with Aston University, E4tech and AIGUASOL to implement a 2-year project - 'Bioenergy for Sustainable Local Energy Services and Energy Access in Africa-Phase 2' (BSEAA2). BSEAA2 was part of the Transforming Energy Access (TEA) programme, which is funded with UK aid from the UK government. TEA is a research and innovation platform supporting the technologies, business models and skills needed to enable an inclusive clean energy transition. TEA works via partnerships to support emerging clean energy generation technologies, productive appliances, smart networks, energy storage and more. It increases access to clean, modern energy services for people and enterprises in sub-Saharan Africa (SSA) and South Asia, improving their lives, creating jobs and boosting green economic opportunities.

BSEAA2 was intended to identify and support the development of innovative, commercial bioenergy pathways and technologies to accelerate the adoption of bioenergy in SSA. Building upon BSEAA Phase 1, which took place in 2016/17, the second phase focused on opportunities for the development of anaerobic digestion (AD) and combustion for electricity and/or heat generation in the range 10 kW to 5 MW, with a Technology Readiness Level of 5+. That is, technologies that had been successfully piloted in a representative commercial setting.

The research team investigated the challenges and opportunities affecting the commercial deployment of these technologies in ten focus countries in SSA (Ethiopia, Ghana, Kenya, Mozambique, Nigeria, Rwanda, South Africa, Tanzania, Uganda and Zambia), investigated through six relevant themes: biomass resources, technology, economics, business models, institutional, market and regulatory frameworks, and gender and inclusion (G&I). The research targets bioenergy entrepreneurs, investors and policymakers, aiming to catalyse action for the further development of commercial bioenergy in SSA.

Commercial opportunities and constraints for bioenergy development were assessed within seven shortlisted industries, referred to as 'demand sectors'. These demand sectors and their associated bioenergy pathway and focus countries are presented in Table 1-1. This report, the fifth in the series, focuses on the AD opportunity in the horticulture sector in Kenya.

Table 1-1. Shortlisted demand sectors for BSEAA2 research

No.	Demand sector	Biomass resource	Technology	Country
1	Cement manufacturing	Biomass residues, part-replacing fossil fuel	Combustion for heat	Nigeria
2	Tea processing	Biomass briquettes, part-replacing fuelwood		Kenya
3	Wood processing	Wood processing residues	Combustion for CHP	Tanzania
4	Palm oil processing	Palm oil mill effluent	AD for CHP	Ghana
5	**Horticulture**	**Fruit & vegetable processing residues**		**Kenya**
6	Dairy	Cattle manure		South Africa
7	Sisal processing	Sisal processing residues	AD for electricity	Kenya

2 METHODOLOGY

2.1 OVERALL METHODOLOGY

During a 6-month preliminary assessment (2019-20), the research team screened a range of bioenergy 'pathways' in SSA involving AD or combustion, comprising a specific biomass feedstock, conversion technology, end use and demand sector. The aim was to identify the most promising pathways for the adoption of bioenergy-based combustion or AD across the target countries, for which the existence of at least one operational venture could be verified. This resulted in the shortlisting of the seven priority demand sectors in five countries. During the following 12 months (2020-21), these demand sectors were investigated in detail across the five research themes, to explore the experiences of both adopters and non-adopters of bioenergy technology.

Information was gathered from site visits to representative commercial operations and from other stakeholders active in bioenergy in SSA, from published literature and from partners of the TEA Programme, UK Energy Catalyst and Innovate UK. A bibliography is in Appendix 1 and a list of people consulted is in Appendix 2.

For each Demand Sector, a 'Base Case' and a 'Bioenergy Case' were identified:

- The **Base Case** refers to the industry standard for energy use in the given demand sector in the target country; that is, the default heat, power or combined heat and power (CHP) solution used by a majority of similar businesses.
- The **Bioenergy Case** refers to a specific enterprise (or 'flagship project') that has transitioned to the use of bioenergy for heat and/or electricity generation in the target demand sector, using either combustion or AD.

The Base Case and Bioenergy Case for the horticulture sector are defined in Table 2.1.

Table 2.1: Base Case and Bioenergy Case for the horticulture sector

Base Case	Bioenergy Case
Fruit or vegetable processors meeting their electricity and heat requirements from the grid	Fruit or vegetable processors meeting part of their electricity and heat requirements from AD-based CHP generation **Flagship project: Olivado EPZ Ltd, Murang'a, Kenya**

This report analyses the Bioenergy Case flagship project across the five study themes of biomass resources, technology, economics, commercial viability, governance frameworks and G&I to identify the factors that have enabled the adoption of sustainable bioenergy. The findings are compared with Base Case examples to identify the opportunities and constraints for other enterprises in the same demand sector to adopt similar solutions. Based on this analysis, the potential and requirements for wider adoption of the Bioenergy Case in the chosen demand sector are assessed, both for the target country and for the other BSEAA2 countries.

2.2 Institutional, market and regulatory framework assessment

The institutional, market and regulatory framework assessment for bioenergy in Kenya's horticulture sector was based on web-accessed reports, journal articles, news reviews and interviews with government, private sector and development partner informants. Trade publications, industry statistics and data on trade, finance and investment in the fruit and vegetable sector proved particularly valuable, supplemented by team members' own expertise. Consultations took place with government agencies and regulatory bodies responsible for agriculture, horticulture, environmental management and the electricity sector, and with representatives of horticulture companies, including KHE, AAA Growers and Mara Farming Group. The AD plant at the avocado oil company Olivado, in Murang'a County, was researched extensively, as the flagship project for this demand sector, both remotely and via its biogas plant manager, who was a member of the study team.

2.3 Biomass resource assessment

The objective of the resource assessment was to determine resource availability, bioenergy potential, feedstock-technology interface and mass-energy balance (MEB) for relevant feedstocks in each demand sector. Existing data on agri- and horticultural processing were used, adopting biomass feedstock categories from FAO (2004) and IEA & FAO (2017). Country- and industry-specific resource potential was calculated based on the amount of primary product generated, residue-to-product ratios, recoverable fractions, the fraction available (considering other uses) and its bioenergy potential (see data in Appendix 3). An MEB model was developed to simulate the energy system, using validated performance and efficiency data. Based on the known feedstock inputs of the flagship project, the model quantifies expected material flows and outputs of heat and power under optimised performance conditions, allowing replication potential to be estimated based on the biomass resource assessment.

2.4 Technology assessment

The objective of the technology assessment was to determine the technological implications of bioenergy use, in this case for CHP in Kenya's horticulture sector, based on technical considerations and practical experiences at the Bioenergy Case flagship project at Olivado. Olivado has pioneered the use of AD to generate electricity to run its avocado oil processing facility and is one of very few companies in SSA[1] trialling biogas upgrading for transport fuel. Exploring Olivado's experiences from a technical perspective and interacting with a sample of other horticulture companies, enabled the team to characterise the current technology and its supply chain landscape, and the opportunities and requirements for replication linked to technology.

2.5 Economic competitiveness analysis

The objective of the economic viability analysis was to compare energy costs under the Base Case and the Bioenergy Case, to investigate potential economic drivers for wider adoption of bioenergy in this demand sector. A 10-year discounted cash flow analysis was carried out using an Excel-based Life-Cycle Cost (LCC) modelling toolkit

[1] Novo Energy (S.Africa) trialled landfill gas for vehicles: mg.co.za/article/2010-12-07-billionrand-biogas-saving-for-the-taking

developed by AIGUASOL (see Appendix 4).[2] The main economic indicator considered was the Levelized Cost of Energy (LCOE), in USD/MWh. LCOE comprises CAPEX (upfront investment and other amortizable costs), OPEX (personnel, consumables and operating costs) and ABEX (abandonment expenditures). For this demand sector, LCOE was calculated for electricity only, as heat was previously being generated using an electrical immersion heater. The LCC model was also used to perform sensitivity analyses on LCOE, considering a range of values for relevant input parameters.

2.6 Commercial viability assessment

The objective of the commercial viability assessment was to determine the commercial case for bioenergy in each demand sector, the factors affecting its successful adoption at the flagship project and the potential for wider uptake in the same sector, based on barriers, enablers, market potential and finance. The Bioenergy Case at Olivado was first analysed to identify the elements for commercial success linked, for example, to internal demand for heat and electricity, potential for grid export and factors such as waste disposal, supply chains, and financing. Information about the operation was obtained from the biogas plant manager and literature review. This was followed by an analysis of the wider commercial potential of AD in the horticulture sector, analysing the barriers and enablers for supplying heat and electricity under various scenarios. Following this, the team undertook an assessment of energy requirements and potential market size for the most promising horticulture sub-sectors, to indicate commercial replication potential. Finally, potential sources of finance and their relevance for bioenergy projects such as this were assessed.

2.7 Gender and inclusion assessment

The objective of this assessment was to identify G&I-related issues and to highlight potential areas for improved awareness, inclusion and participation of women. The research framework was adapted from a UNDP (2004) toolkit and was structured around: access to assets; beliefs and perceptions; practices and participation; and institutional laws and policies. The research focused mainly on the production and supply of feedstocks and, where applicable, the bioenergy conversion process. A literature review was also carried out, and further information was gathered through interviews with informants working in G&I and at the flagship project.

2.8 Multi-Criteria analysis

A multi-criteria analysis (MCA) was carried out to summarise the degree to which each the study's five thematic strands are conducive or detrimental to the successful adoption of the particular bioenergy solution in each demand sector. Each theme was given an average 'score' from 1 to 10, based on the degree to which various sub-factors under each theme make a positive contribution (high score) or act as an impediment (low score) to the viability of the Bioenergy Case. The MCA results are presented in the concluding chapter as a multi-point spider diagram, providing a graphical summary of the factors most likely to support or impede successful adoption of bioenergy in the target demand sector. The MCA input data are in Appendix 7.

[2] 10 years is a standardised period chosen for economic analysis based on an averaging of longer periods generally applicable for sustainability assessments and shorter periods applicable for investors consideration, and is not necessarily indicative of the functional lifetime of a particular project.

3 Overview of the horticulture sector

3.1 Sector landscape

Agriculture is the main economic sector in Kenya, contributing 26% to the gross domestic product (GDP) and employing over 40% and 70% of the entire and rural population, respectively (FAO, 2021b). In 2018, about 198,000 ha was under vegetable production and 185,000 ha under fruits (AFA, 2021).

Kenya has become one of the world's most successful horticultural producers and exporters over the past four decades (World Bank, 1989). Horticulture employs over 200,000 people in centralised production, processing and shipping, and up to 2 million in the sector as a whole. The sector is experiencing rapid growth, generating important employment opportunities and income for small-scale farmers, given that 80% of horticultural products are produced at small scale (Jalang'o, 2016).

About 95% of horticultural products are sold into domestic markets, and about 5% are exported. However, exports generate 60% of sector revenue (Research Solutions Africa, 2015), of which 74% comes from flowers, 18% from vegetables and 8% from fruits (AFA, 2021). Kenya is Africa's largest exporter of cut flowers and second largest exporter of fruit and vegetables. Kenya earned nearly USD 18 million in fruit exports and USD 24 million in vegetable exports in 2020 (FPEAK, 2021). These exports comprise both fresh produce that requires little processing and packaging, and a growing share of ready-to-eat and ready-to-cook products that have been prepared for higher-value markets, and which generate significant residues during processing.

Kenya also has a thriving domestic market for high value horticultural crops, with vegetables contributing about 36% and fruit about 26% to the domestic value of horticulture (Embassy of the Netherlands, 2017). There is also a rapidly growing domestic market for processed produce, with about 10% of domestically-consumed horticulture produce now frozen, canned, juiced or otherwise processed (Research Solutions Africa, 2015).

3.2 Bioenergy in the horticulture sector

Over the past 20 years, there has been significant interest in using AD to generate energy from horticulture residues, which include wastes from floriculture and from fruit and vegetable processing. Most of this interest has focused on small-scale installations for cooking gas in homes and institutions, such as schools and hospitals. Despite great potential for using such residues to produce bioenergy for CHP at commercial scale, and a strong regulatory framework in Kenya for small-scale electricity generation (see below), only a handful of commercial horticulture processors in niche sub-sectors have installed AD systems to generate either heat or electricity. These include Tropical Power at the VegPro horticulture operation in Naivasha, and Olivado Kenya (EPZ) Ltd, at its avocado oil processing facility in Murang'a County. Olivado represents the flagship project for the Bioenergy Case in this demand sector, and this report explores Olivado's experiences and the implications for wider adoption of AD in the horticulture sector in Kenya.

3.3 Institutional, regulatory and finance framework

3.3.1 Institutional framework for the horticulture sector

Kenya's Ministry of Agriculture, Livestock, Fisheries & Cooperatives is responsible for policymaking, technical, legal and financial support, promotion and advocacy for the horticulture sector (Figure 3.1). Its Horticultural Crops Directorate (HCD) is the main support and regulatory body for the sector and provides 'farm to fork' training geared towards sustained traceability.

Under HCD's charter, it works with key stakeholders and their representative bodies (including the Kenya Horticulture Council and the Kenya National Chamber of Commerce and Industry) to accelerate development of the horticulture sector (HCD, 2018). The HCD is part of the Agriculture and Food Authority (AFA), which supports a number of research directorates, agencies and institutes in the sector, as mandated under the Agriculture, Fisheries and Food Authority Act (Republic of Kenya, 2013) and the Crops (Horticultural Crops) Regulations (Ministry of Agriculture, Livestock, Fisheries and Irrigation, 2019). Also under the AFA, the Kenya Agricultural and Livestock Research Organization (KALRO), through the Horticultural Research Institute, provides development and capacity building support for developing, expanding and improving the sector (AFA, 2021).

The National Horticulture Policy (ASCU, 2012) has been the blueprint for horticultural development and expansion for nearly ten years, and mentions the essential nature of energy to the success of horticulture, even citing the need for 'green energy'. But it is telling that this Policy does not mention the possibility of using plant residues as a source of that energy, and instead cites hydropower and grid extension as key to the sector's development.

The Ministry of Industrialization, Trade and Enterprise Development and the Kenya Trade Network Agency (KenTrade) are the primary bodies regulating the industrial (e.g. processing) and commercial (e.g. marketing) aspects of the horticulture sector. The Kenya National Chamber of Commerce and Industry is a membership-based trade support institution that works to protect and promote commercial and industrial interests of the Kenyan business community. It has offices in all 47 counties and its membership constitutes enterprises of all sizes, including over 250 horticulture companies and industries.

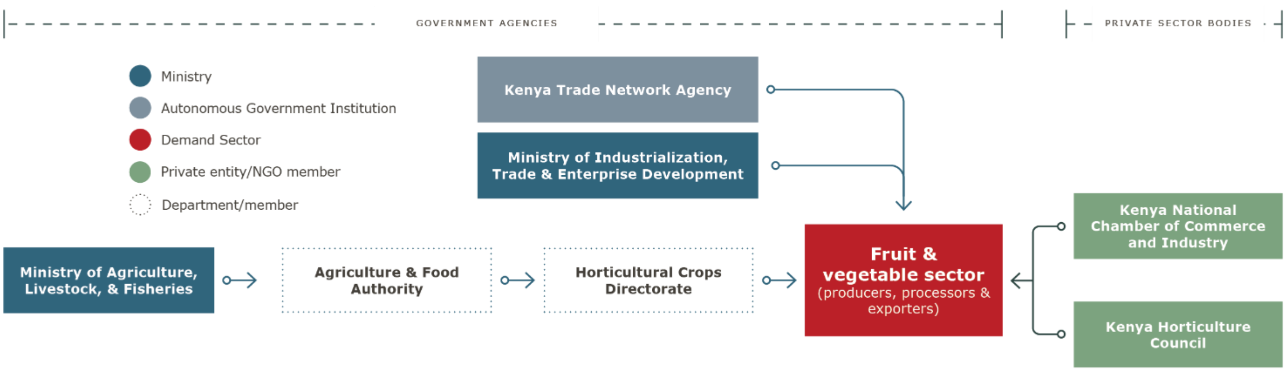

Figure 3.1: Institutional framework for marketing, trade & export in Kenya's horticulture sector (Source: authors' compilation)

Under the Horticultural Crops Regulations (Republic of Kenya, 2019b), the national Horticulture Technical Working Group is the paramount stakeholder forum that brings together public and private horticulture stakeholders to promote private-public sector dialogue, provides capacity building, accredits business support facilities, raises awareness, develops common strategies, carries out risk assessments and supports adoption of international codes of practices, regulations and market diversification (Figure 3.2). The national Working Group supports County Horticulture Technical Working Groups (HTWG) to accelerate horticulture activity in Kenya. Further, it provides support to the Ministry of Agriculture, the Horticultural Research Institute (under the AFA) and KALRO to provide technical support and guidance to the horticulture sector.

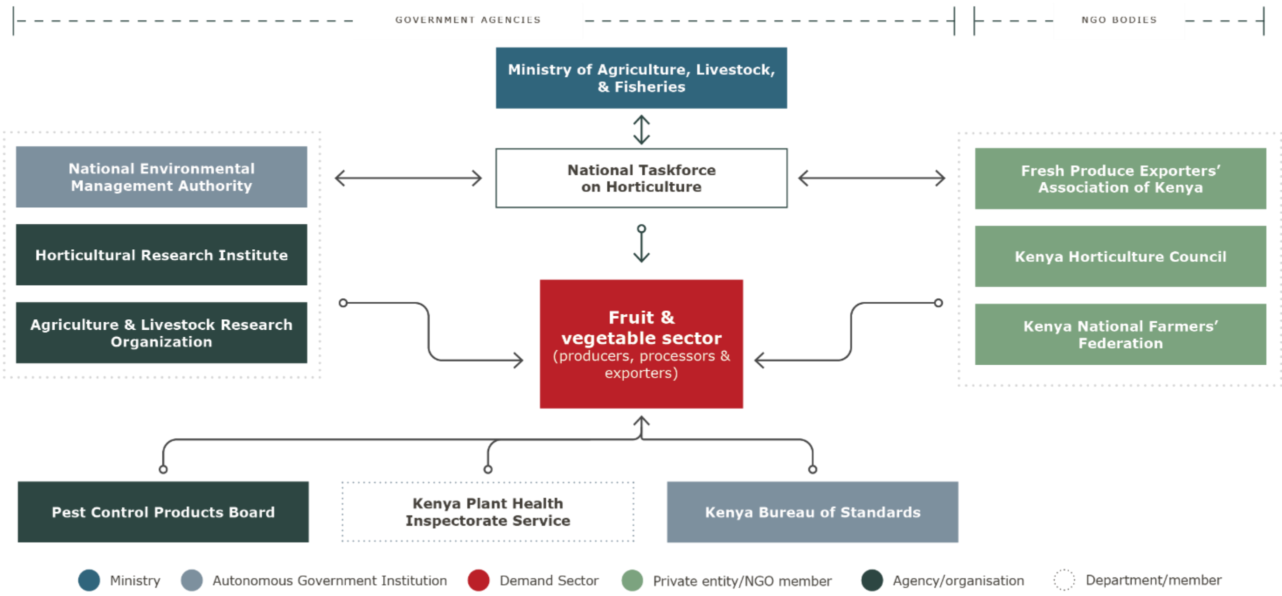

Figure 3.2: Institutional framework for research, quality, standards and health in Kenya's horticulture sector (Source: authors' compilation)

The Kenya Plant Health Inspectorate Service and the Pest Control Products Board are jointly responsible for enforcing regulations and standards for ensuring quality and hygiene in the sector. The Kenya Bureau of Standards is Kenya's national standards body and has developed standards for the horticulture sector, particularly the Horticulture Industry Code of Practice, namely the Kenya Standard KS 1758-2:2016 (SOCCA Kenya, 2018), which sets out best practice in the horticultural (fruit and vegetable) industry.

The National Environment Management Authority (NEMA) is Kenya's paramount environmental enforcement agency guided by the Environmental Management and Co-Ordination Act/EMCA, Chapter 387 (Republic of Kenya, 2012a). NEMA has offices in all 47 counties and is responsible for licensing (e.g. Effluent Discharge Licence/EDL) and enforcing regulations concerning air quality/pollution, water quality, waste management, waste disposal and utilisation from horticulture production, processing, storage and transport.

3.3.2 Institutional and regulatory framework for bioenergy in the horticulture sector

The institutional set up for electricity and heat generation from horticulture processing includes institutions from both the environment and energy sectors. Environmental entities regulate and support horticulture as a source of residues for bioenergy (Figure 3.2), while energy sector entities define the framework for bioenergy (particularly electricity) generation and sales from biomass, including from AD (Figure 3.3).

The Ministry of Energy (MoE) is responsible for policy, planning and oversight in Kenya's energy sector. MoE's Rural Energy Directorate is responsible for renewable electricity policy formulation, review, planning, promotion, development, M&E and Feed-in Tariff (FiT) formulation and review. The Kenya Power & Lighting Company (KPLC or Kenya Power) is the power off-taker from all power generators, including independent power producers (IPP) under the Kenya Generation Corporation (KenGen), based on negotiated Power Purchase Agreements (PPA) for transmission, distribution and supply to consumers.

The Energy & Petroleum Regulatory Authority (EPRA) is responsible for regulating electricity and the use of biogas for energy (EPRA, 2012) . Generating biogas for self-consumption (other than small-scale household or institutional use) or sale to other parties requires an EPRA-led 'Team Assessment' involving NEMA, the Kenya Bureau of Standards and relevant county/municipal authorities, with a focus on safety.

A new Bioenergy Strategy for 2020-2027 (Ministry of Energy, 2020) was released in late-2020. The strategy was developed by high-level experts from various ministries, supported by GIZ, the World Bank, ICRAF and others. It is endorsed by the Principal Secretary, MoE, and written by the MoE's Rural Energy Directorate.

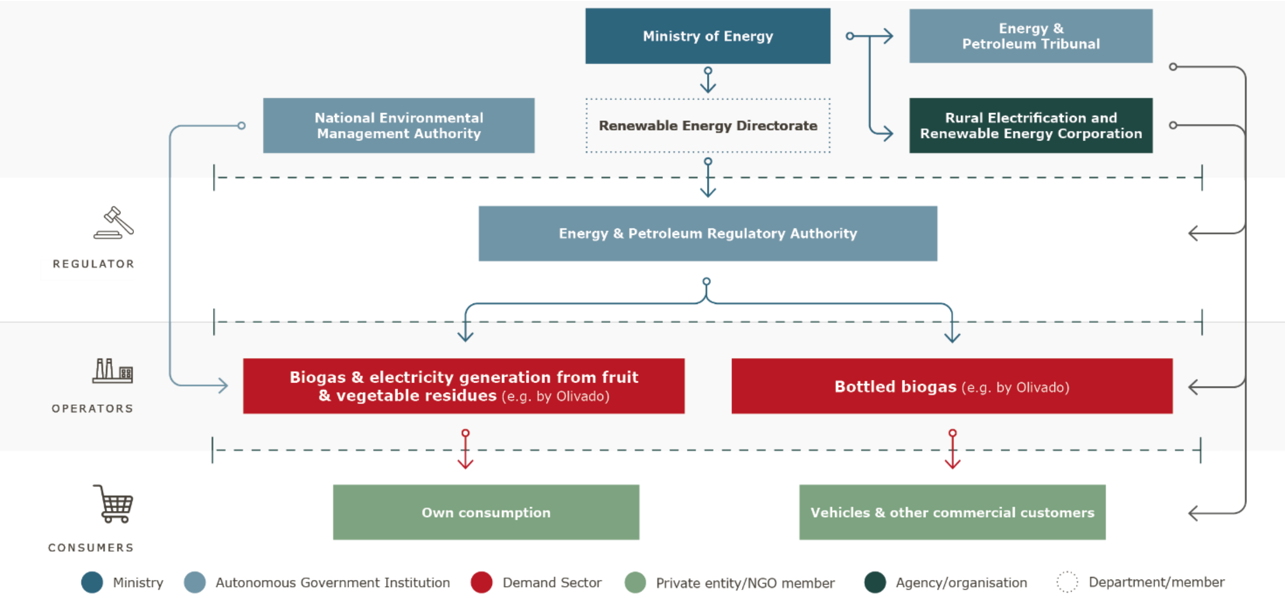

Figure 3.3. Institutional & regulatory framework for bioenergy in horticulture in Kenya (Source: authors' compilation)

The Strategy sets the parameters for a policy and regulatory framework to support bioenergy development from various bioenergy sources - including solid, liquid and gaseous biofuels. It sets out a schedule of actions to build consensus, raise finance, provide training and support technology development, among others. It is ambitious in scope and aims, and it remains to be seen how its implementation will be financed. But, as noted, it was developed with high level participation. The Rural Energy Directorate is responsible for renewable electricity policy formulation, review, planning, promotion, development and M&E of biogas electricity generation support through FiTs. It sets eligibility for biogas projects to benefit from the FiT, which is set at USD 0.10/kWh for projects that generate electricity in the range 200 kW to 10 MW (EPRA, 2012; Ministry of Energy, 2012a). There is no FiT for electricity from biogas below or above this range. Kenya Power is the off-taker from all power generators on the basis of negotiated PPAs for generation and distribution to consumers. The Rural Electrification and Renewable Energy Corporation (REREC) [3] is the successor to the Kenya Rural Electrification Authority (Ministry of Energy, 2006) and was established under the 2019 Energy Act (Republic of Kenya, 2019a). REREC implements rural electrification projects and leads Kenya's green energy drive. Its responsibilities also include the development, use and operation of biogas (among other renewable energy sources) through the EPRA. The Energy Act (Republic of Kenya, 2006a) promoted the use of biogas for electricity for the first time, as well as the creation of the Electricity Regulatory Commission, which was changed to EPRA by the Energy Act of 2019 (Republic of Kenya, 2019a). A FiT for biogas-generated electricity was first introduced in 2008 (Ministry of Energy, 2012b) and revised in 2012 (Republic of Kenya, 2012b). The Energy Act (2019) expanded the scope for bioenergy generators to sell their electricity to third parties, and to use the national grid to 'wheel' renewable electricity from the point of generation to the point of consumption, upon payment of a wheeling charge.

Under the Energy Act (2019), all electricity generating projects above 200 kW must be registered with the EPRA. Generation from 200 kW to 1 MW for own use does not require an EPRA licence, but any sale to third parties or export to the grid does require such a licence to be obtained, with a tariff that is approved by the EPRA. Projects generating more than 1 MW require licences from the EPRA, whether the power is for self-consumption or grid sale.

EPRA sits on the FiT Committee. The FiT process is currently being reviewed for simplification by a national committee set up to operationalise third party electricity sales and wheeling on the national grid.

Environmental legislation on the treatment and disposal of horticultural processing residues should provide an incentive for horticulture companies to invest in AD for biogas production. In the mid-to-late-2000s, there was considerable interest in using AD to generate electricity in agri-processing. However, a combination of the very low FiT, which is unchanged since 2008, and Kenya Power's poor infrastructure in many rural areas where horticultural processors are located, has provided few additional incentives, and most producers and processors have found more cost-effective means of treating and disposing of their wastes.

3.3.3 Finance

Kenya is East Africa's financial hub, and farmers and factories can draw upon major financial institutions such as the Commercial Bank of Africa (Kenya's largest

[3] http://www.rerec.co.ke/

commercial bank), Kenya Commercial Bank (accredited with the GCF), the Cooperative Bank of Kenya, the National Bank of Kenya, the Diamond Trust Bank, and Chase Bank among others, all of whom provide equity and debt finance in the agricultural, industrial and renewable energy sectors. Most have funded renewable energy projects through AFD's (Agence Française de Développement) SUNREF [4] programme. In addition to Chase, international banks active in the agricultural sector and renewables include Stanbic Bank (Kenya's first green bond) and Barclays (GVEP), among a number of others.

However, given the fact that commercial-scale AD is not widely used in Kenya, borrowing from commercial banks for such projects is likely to be difficult. This proved the case with Olivado, the flagship project for this demand sector. Supplier finance/credit/guarantees/insurance is often available for top-of-the-line equipment from such agencies as EH Group, Germany; COFACE, France; Denmark's Export Credit Agency (EKF); UK Export Finance; the US Development Finance Corporation (ex-OPIC); the US Export-Import Bank; and SACE (Gruppo CDC), Italy's export credit agency, among many others, when equipment is sourced from these countries.

3.3.4 Summary

Discussions with the private sector, government agencies and development partners suggest that the very low FiT of USD 0.10 per kWh available for electricity from biogas and the inability to access that FiT for generation below 200 kW are two of the main barriers to investment. Power would only be sold to the grid at a rate this low if it was surplus to the requirements of an enterprise's own consumption, meaning that the primary driver for an investment in AD will be to meet a company's own energy and waste management needs. The sale of power also requires a reliable connection to the national grid, but the weak condition of the grid in many rural areas, where much horticulture processing takes place, is a further impediment to investing in horticulture residue-based AD. High import duties on AD equipment is an additional barrier. Simply put, Kenya's electricity policy, regulatory, tax and institutional environment provides essentially no incentive to invest in horticulture-based AD, even for own consumption.

[4] www.sunref.org/en/

4 Overview of Bioenergy Case

4.1 Project summary

Olivado [5] operates an avocado processing plant in a small Export Processing Zone (EPZ) at the eastern edge of Murang'a County, close to the Tana River (Figure 4.1). The company buys fruit from organically certified farmers for the production of export-grade edible avocado oil. The oil extraction process generates significant quantities of solid and liquid residues, which are difficult and costly to dispose of safely so as to comply with NEMA specifications. NEMA requires an Effluent Discharge License (EDL) for any facility generating effluents that could harm ground water, surface water or coastal waters, and effluent tests to ensure compliance is carried out at least annually by NEMA (Republic of Kenya, 2006b). While the solid waste could be composted, space permitting, the liquid waste would have to be separated from oil residues and disposed of at a NEMA-approved landfill, all at considerable cost.

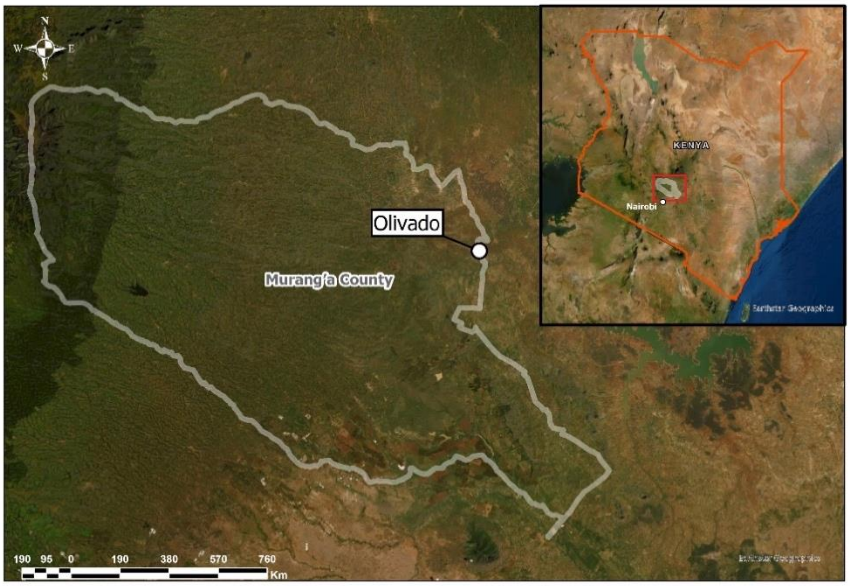

Figure 4.1. Location of Olivado EPZ Ltd, Murang'a County, Kenya

The waste disposal challenge, together with Olivado's commitment to become carbon positive by 2022, prompted interest in setting up an AD plant to convert its avocado residues to biofertilizer, and in the process generate heat and power for the factory operations, as well as upgraded biomethane for use in the company's vehicle fleet. Construction got underway in 2016 and the AD plant has been fully operational since late 2019.

The technical information provided below comes mainly from Olivado's biogas plant manager, except where otherwise referenced. A selection of photos from the site are in Appendix 8.

[5] www.olivado.com/the-story/olivado-in-kenya

4.2 TECHNICAL DETAILS

4.2.1 Plant design

The layout of the Olivado AD plant is illustrated in Figure 4.2

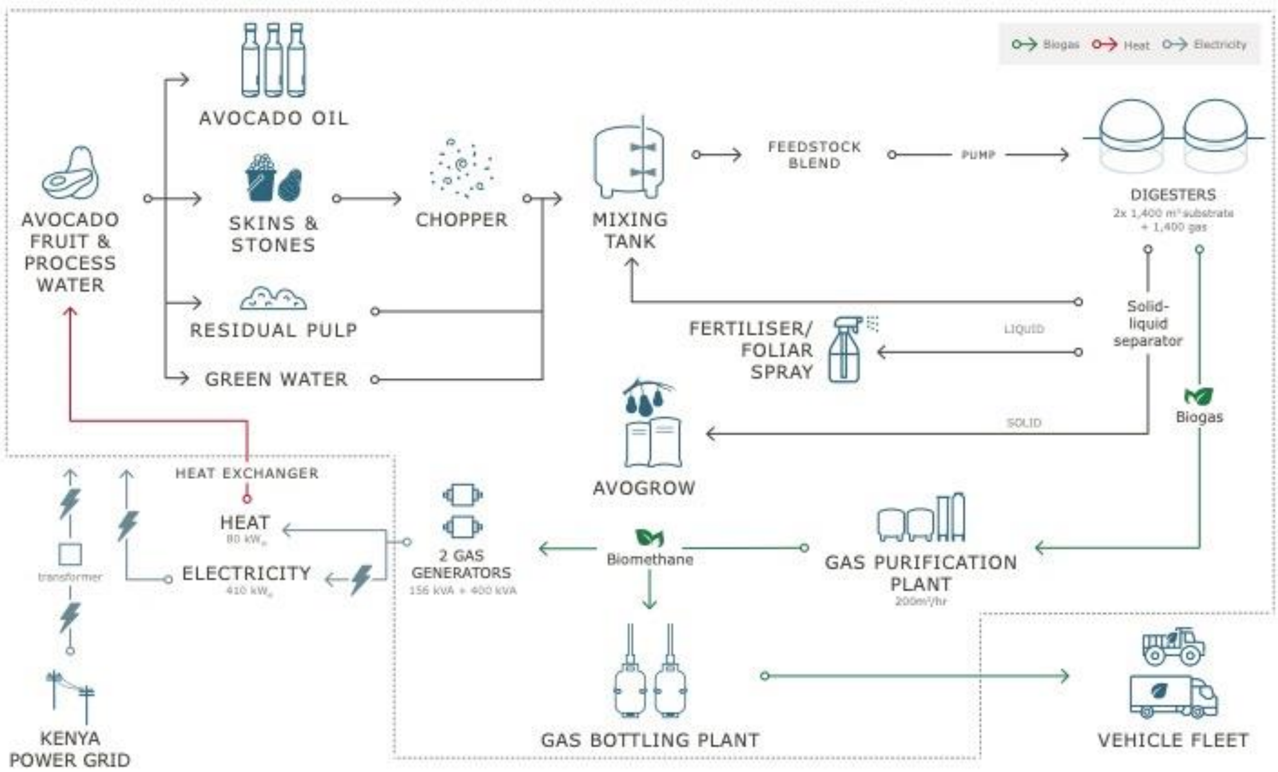

Figure 4.2. Schematic diagram of the AD plant at Olivado EP Ltd, Murang'a County, Kenya

4.2.2 Feedstock

Avocado oil is extracted from the fruit flesh and comprises 11% of the whole fruit, with the remaining 89% discarded in the form of stones, skins and pulp. Process water adds an additional waste stream containing pulp particles and residual oil. Olivado processes around 4,000 t of avocado fruit per year. This generates around 3,560 t of stones, skins and pulp. An additional 800-1,000 litres of water is used per tonne of fruit processed, adding a further 3,200-4,000 t/yr to give total feedstock for the AD system of at least 6,760 t/yr. Solids content of the feedstock mix is kept at around 8%.

A chopper at the processing facility crushes the stones and a conveyor combines them in a mixing tank with the skins and residual pulp, plus the green processing wastewater. Feedstock pH and temperature are monitored, and samples are taken for regular analysis to monitor other characteristics of the feed. Level sensors in the mixing tank control the mixing range and manage the pumping of the blended material to the digesters.

4.2.3 Reactor design

Olivado's AD plant comprises two anaerobic digesters, each with 1,400m³ substrate capacity. The tanks are below-ground and consist of two circular, excavated and lined basal sections. At ground level, a circular wall acts as a fixing point for two doublemembrane gasholders mounted on top of the tanks. The wall also provides for the necessary digester viewing ports and fittings. Each digester can store 1,400m³ of biogas, with both over and under-pressure relief protection.

The digesters can operate in series or in parallel, and this is manually controlled via valves in the feeding lines. This configuration allows flexibility for optimisation of the AD process during different times of the year, in response to variations in feedstock quantities.

Mixing is achieved by means of substrate recirculation. No heating system is installed, as the ambient temperature is sufficiently high at the plant location (90 km from the equator), but there is some cooling over time of the feedstock, from an initial 35-40°C at the point of entry to a stable 27-30°C in the digesters. The layout of the installation allows effluent to flow out of the digesters by gravity as it is displaced by new substrate being fed in, and avoids the need for additional pumping.

4.2.4 Gas upgrading and CHP generators

The AD plant produces up to 3,000 normal cubic metres[6] (Nm^3) of raw biogas (with 64% methane) per day during the peak avocado processing season (March to September; occasionally also October to December), with an annual potential of up to 472,000 Nm³. This has exceeded the system's conservative design specification, which would have predicted 354,000 Nm³ for 4,000 t/yr of fruit throughput.

The facility includes a gas upgrading plant with a 200 m^3/hr capacity that purifies the biogas to a methane content consistently above 94%. The upgraded biomethane is fed to two natural gas CHP generators. There is one 400 kVA MTU generator and a smaller 156 kVA Liebherr generator,[7] both with cooling water and exhaust heat exchangers, for a combined output capacity of around 410 kW_e[8] and at least 600 kW_{th}. Sophisticated load management capabilities mean that one or both generators can be run in any combination.

A plate heat exchanger on the larger generator supplies 75-80 kW_{th} to heat process water to 45°C for the avocado oil operation, replacing a 120 kW electric immersion boiler that previously accounted for 44% of the factory's entire power consumption, and which is still maintained as a backup. The exhaust heat is not yet used, though the necessary heat exchangers are in place.

Olivado requires 411 MWh_e p.a. for processing 4,000 t of fruit. This demand can be met with less than 40% of the biogas produced, so there is considerable excess capacity in the system. Olivado has ruled out the sale of power to the national grid as the FiT of USD 0.10/kWh is not deemed sufficiently attractive and significant bureaucracy was envisaged with the process of negotiating a PPA with Kenya Power. The minimum allowable supply under a PPA for a small-scale producer is also 200 kW_e, which would be right at the upper limit of Olivado's likely surplus electricity capacity.

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[6] While a standard cubic metre is the volume occupied by a gas at prevailing pressure and temperature, a normal cubic metre is a standardised measure that would be the volume occupied by the gas under 'normal' conditions, i.e. 0°C and 1 atmosphere pressure (101.3 kPa).

[7] The smaller unit was intended to meet the demands of the office and the biogas plant during the off-season when processing is suspended (usually October to February), but has not yet been required.

[8] With a standard power factor of 0.8, a combined output of 445 kW_e would be expected, but at the site altitude of 1,100m, this is closer to 410 kW_e (~300 kW_e and ~100 kW_e for the larger and smaller generator, respectively).

4.2.5 Gas bottling

The excess biomethane will be compressed, stored on site and dispensed as vehicle fuel. A bottling plant has been installed and tested, with the intention of using the upgraded gas for employees' vehicles and avocado picking trucks. Vehicle conversion and the construction of a dispensing facility was scheduled for 2020, but was delayed due to COVID-19 travel restrictions.

Upgraded biomethane can be transferred to specially adapted vehicles using either a 'slow fill' or 'fast fill' method. With slow fill (typically overnight while the vehicles are parked in a depot), low pressure stored biomethane can be directly compressed and filled into onboard cylinders. Olivado has opted for the more flexible fast fill approach, in which the biomethane will be compressed and bottled at the biogas plant, and the bottles can then be transferred to the vehicles as required. The company had also considered supplying bottled gas to industries or institutions, but determined that it was more commercially expedient to use the gas internally, rather than transporting it to clients as an LPG replacement.

The bottling plant for vehicle use is believed to be the only one of its kind in Africa,[9] and Olivado has determined that it will be an economically viable solution for making productive use of excess gas, while fulfilling its wider commitment to environmental sustainability.

The bottled gas could also potentially be used cooking staff meals, but this was not deemed cost-effective in relation to the CAPEX outlay. Raw biogas could alternatively be piped directly from the digester to the staff kitchen, but the distance is significant and a gas blower would be required to achieve satisfactory combustion performance. Again, the capital outlay makes this a less expeditious option than upgrading the gas and using it as a fossil fuel replacement in company vehicles.

4.2.6 System by-products

Much of the liquid portion of the digestate can be recycled back to the mixing tank to water down the feedstock and facilitate pumping. Recirculation also allows the active bacteria in the effluent water to continuously re-inoculate the digesters, enhancing the stability and efficiency of the digestion process.

The solid fraction of the digestate has the potential to add significant additional value to the project. Olivado is developing a bio-fertiliser called 'Avogrow'. Trials have shown good results as a bio-fertiliser and soil conditioner. Analysis of the digestate has revealed high quantities of boron and zinc, both of which are lacking in soils in central Kenya and Tanzania, offering additional potential to supply this material as a source of minerals for farmers in the region.

Any portion of the liquid effluent not recycled or sold as liquid fertiliser/foliar spray runs through a constructed wetland system for further filtering and removal of nutrients. Being able to fully utilise all components of the digestate would complete the cycle and maximise the potential from the avocado oil production process.

[9] Novo Energy in South Africa was trialling the use of upgraded landfill gas for vehicles, but the current status of this project is unknown. See: mg.co.za/article/2010-12-07-billionrand-biogas-saving-for-the-takingzx

4.2.7 Project design and equipment sourcing

The Olivado project is interesting for its technological approach. From the outset, the aim was to develop a system that would be both economically and technically viable for replication in SSA. Local expertise and locally available materials were therefore used wherever possible. In many aspects of the installation, Kenyan contractors were engaged and local capacity for project-specific works was built.

While the digestion concept based on excavated, lined frusta with a top to bottom digestion process came from Germany, the actual tank design is unique to Olivado. By modifying proven designs to facilitate mostly local installation and using cost-competitive materials, Olivado has achieved significant reductions in build cost.

Despite various unforeseen challenges, the owners estimate that the plant has cost less than half that of a similar European system bought 'off the shelf', and can pay for itself in under four years, without valorising the fertiliser output. This assumes utilisation of all the gas for site supply of electricity, heat and vehicle fuel, and quantifies the avoided costs of waste management.

The Olivado project is also interesting from a management angle. In contrast with companies that have out-sourced installation to specialist AD providers, Olivado opted to design, build and manage the project internally. A biogas specialist was recruited to lead the process from start to finish. He spent 18 months running digester tests to establish the biogas yield from avocado waste, prior to the company's investment in a full-scale system.

It was not possible to find suitably qualified technicians in Kenya, but the lengthy construction period gave the employees an opportunity to receive extensive on-the-job training, resulting in a reliable and capable team who can now maintain and operate the plant efficiently. Olivado probably has the most qualified and experienced team for installing and operating industrial biogas plants in East Africa, if not further afield. Staff training continues on a daily basis and new challenges bring more experience, constantly improving the skillsets of the team.

4.2.8 Main challenges

Delays with equipment imports were a major challenge. The biogas purification/upgrading plant, compressors and various pumps came from a company with experience of 25 successful bottling plant installations, but manufacture and delivery was handled by a third party who proved slow and unreliable.

The digesters were deliberately designed to use basic construction materials available locally. However, for certain pipes and fittings that are specific in their application and design, procurement proved more challenging – though this experience will be invaluable for future projects.

As this was a pilot project, Olivado purchased a used gas engine. This had been configured to operate grid-parallel, i.e. always supplying a constant load to the grid. In island operation, it has had to cope with load fluctuations, inrush currents and other site-specific challenges. At future operations of this nature, a new engine and gas train would be procured and configured for the specific demands of the site, to avoid such teething problems.

The seasonality of avocado processing brings challenges for continuous operation, and Olivado is exploring options for using additional or stored feedstock to keep the system running through the off-season. Fortunately, the demand for energy largely coincides with the availability of waste.

4.3 Economic assessment

Table 4.1 summarises the data used in the LCC model for Olivado, as the Bioenergy Case, comparing it with a Base Case operation relying on grid power to meet all its electricity and heat requirements.

Table 4.1: Key project data for economic modelling

Category	Parameter	Value
General parameters	Discount rate	10%
	General growth rate	8% (Consumer Price Index)
	Energy price growth rate	8% (Energy Price Index)
	Electricity retail price	USD 158.8 /MWh (from Olivado electricity bills)
	Currency exchange rate	102.33 KES/USD (3-year average)
Base Case	Annual processing capacity	4,000 t/yr of fresh fruit
	Capacity factor	90%
	Specific energy consumption	0.1023 MWh_e/t processed fruit
	Cost of diesel for genset and utilisation rate	USD 0.95/l and 10% utilisation rate, complementing 90% power purchase from grid
	Specific waste generation	1.29 t per t of fruit processed
	Waste management costs	USD 32/t of processed fruit, equivalent to USD 24.8/t of waste
Bioenergy Case	Specific biogas production	118 Nm^3/t of processed fruit (based on annual output of 472,000 Nm^3 from 4,000 t of fruit)
	Biogas methane content	64%
	CAPEX (for AD+CHP)	USD 1,350,000[10]
	OPEX reduction	Main OPEX reduction is from avoided costs of waste management and power purchase.

Under these operating parameters, Figure 4.3 compares the cost of electricity for the Bioenergy Case (based on AD) with the cost for the Base Case (using grid power plus gensets). The model confirms that the Bioenergy Case is economically viable, with an $LCOE_{electricity}$ of USD 753 per MWh, compared with USD 1,001 per MWh under the Base Case.

[10] For reasons of commercial confidentiality, this is an industry-specific cost estimate for a locally built plant, not an exact figure from Olivado. It excludes the cost of the bottling plant.

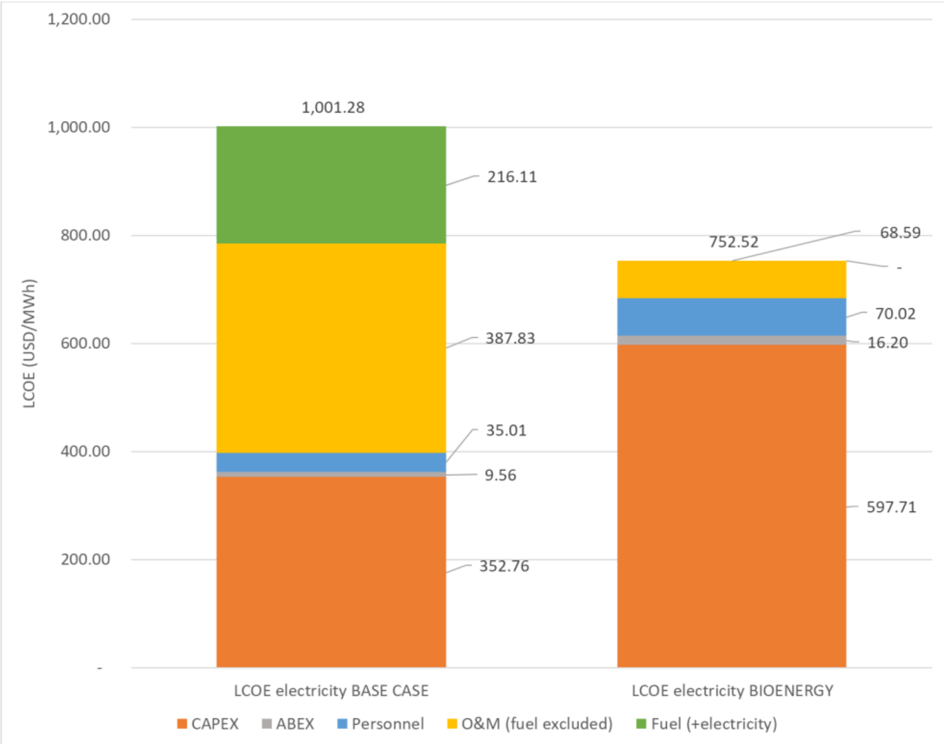


Figure 4.3: LCOE comparison of Base Case vs. Bioenergy Case

Taking into account that current operations at the plant use only about 40% of the biogas being produced, there is potential to make the operation even more economically attractive by valorising the remaining biogas, e.g. as vehicle fuel, or by generating additional electricity for export to the grid.

4.4 Commercial success factors

Figure 4.4 summarises the ownership of the different stages of the supply chain for the bioenergy case.

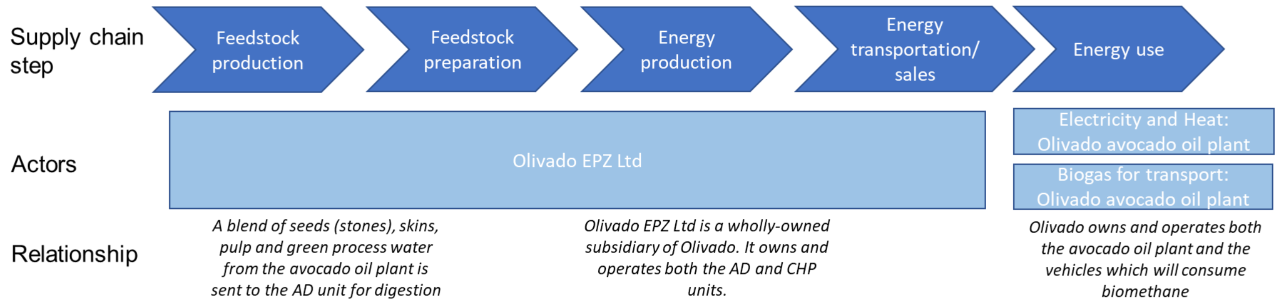


Figure 4.4. Overview of the Olivado supply chain

The following factors have been important for the commercial viability of this venture:

- **Significant onsite demand for both heat and power:** The Olivado plant has significant power requirements for processing machinery, cold storage, a water heater and administrative operations. This provides an important anchor load for the energy produced by the AD system.
- **Biogas use for transport:** A significant proportion of the upgraded biogas is intended for use as vehicle fuel, which caters to a second important source of energy demand and will enable Olivado to save on transport costs.

- **Adaptation of AD equipment to local context:** Olivado claims a 50-75% cost saving compared with AD systems of similar size and performance, having custom-designed the plant to the company's specific needs, using local parts where possible.
- **Waste disposal needs:** Olivado generates large quantities of waste (90% by mass of the avocado, plus process water). Even though landfill is approved by NEMA, the company owner preferred to pursue AD as a waste management option, given the lower environmental impact and the cost-savings on energy.
- **Supply chain control:** Olivado Kenya (EPZ) Ltd owns and controls the supply chain, ensuring a stable supply of feedstock and a constant, reliable demand for energy from its avocado oil factory.

While it is too soon to conclude that the Olivado venture will be a commercial and technological success, the indications are certainly positive, given the leadership of a well-qualified project manager, the vision of the Olivado Group CEO and the combined savings from avoided waste disposal and the on-site production of both electricity and heat.

Olivado set out not only to build an AD plant to meet its own needs at the Murang'a site, but also to gain the necessary expertise and institutional capacity to replicate the model at other locations in East Africa. As such, it kept the design, construction and operation in-house rather than contracting an external technical service provider. The hands-on experience gained in designing and realising the project has given the team the necessary skills to undertake new projects, and gives them confidence in their ability to efficiently deliver a reliable service to prospective clients. This approach to commercial replication contrasts with other projects investigated under BSEAA-2, in which specialised technology developers have recommended that their clients focus on their core business, while they handle the installation and operation of the AD plant, sometimes charging a fee to the project owner for the power provided. Managing the operation internally has not only enabled Olivado to build experience and skills for replication, but has also saved the company a significant amount of money.

Some of the notable achievements reported are:

- The time taken to train staff on the job, resulting in a team with an excellent understanding of all aspects of installing the biogas system from start to finish;
- Fine-tuning of the design and installation process to reduce costs and simplify any future installations;
- The ongoing development of a fertiliser product, with the potential to add significant value to the AD package;
- Learning first-hand about the potential pitfalls of such a project, and how to avoid them in future;
- Gaining experience in dealing with suppliers of key equipment and narrowing them down based on reliability; and
- Gaining experience in dealing with local financing institutions

5 Potential for wider adoption

This section assesses the replicability potential of the Bioenergy Case in the horticulture sector, considering the five research themes of biomass resources, technology, economic benefits, commercial potential and the institutional and regulatory framework.

5.1 Biomass resource assessment

5.1.1 Biomass potential from the horticulture sector

The main agricultural crops in Kenya are sugarcane, maize, roots and tubers, fruits and vegetables (FAO, 2021a). The main vegetables produced in Kenya are potatoes, various pulses, cabbages, indigenous and Asian vegetables (e.g., snow peas, kales, broccoli, runner beans, French beans), tomatoes, carrots, spinach (FAO, 2021a). The main fruits are bananas, mangoes, pineapple, avocados, watermelons and various other citrus and tropical fruits (FAO, 2021a) (Figure 5.1). Most fruits tend to be seasonal, while vegetables, especially green and leaf vegetables, are often harvested continuously throughout the year (Embassy of the Netherlands, 2017).

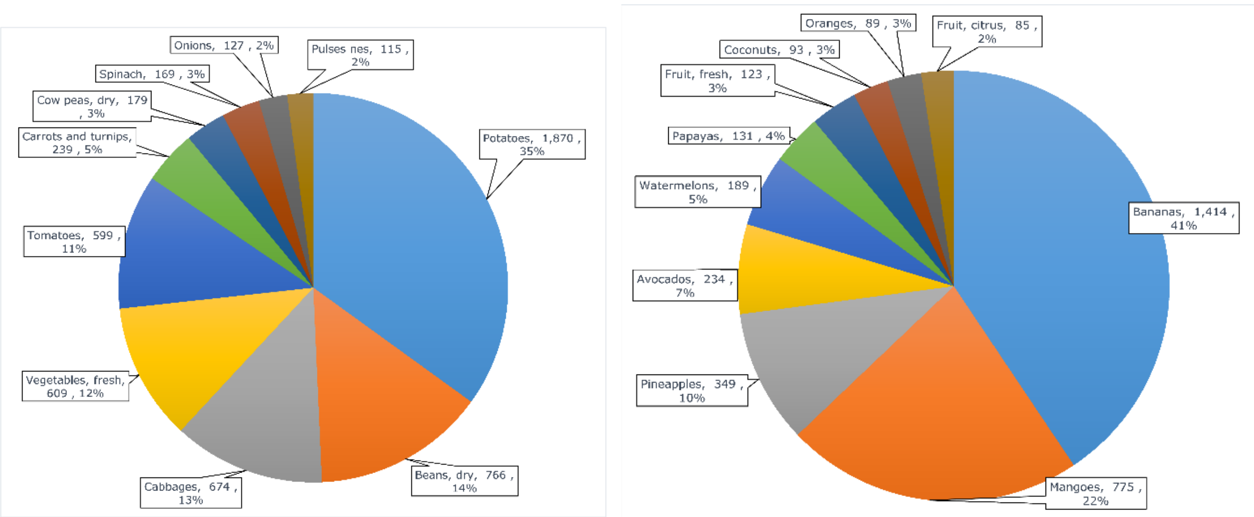


Figure 5.1: Top-10 vegetables (left) and fruits (right) in Kenya (kilo-tonnes and percentages) (FAO, 2021a)

The processing of vegetables and fruits generates streams of organic residues in the form of peels, cut-offs, pulp and wash water (IRENA, 2017). 20% product-to-residue ratios are not uncommon, rising to 40% or more for some ready-to-eat or ready-to cook produce.

Most of the fruits and vegetables produced in Kenya are traded in local markets and shops (Embassy of the Netherlands, 2017; Wiersinga & de Jager, 2007). While public marketplaces can generate significant quantities of waste, mainly spoilt or rotten produce, ownership is unclear and there is no reliable and sustainable waste management infrastructure. When considering feedstocks with potential for AD, it is important that they are aggregated at centralised processing locations, under clear ownership.

Many solid residues from the horticulture sector are converted to compost and used by the growers in their own operations, which is straightforward, low-cost solution for waste disposal and nutrient recycling. In general, it is therefore only liquid effluents and moisture-rich residue streams that offer potential for AD, as they are more troublesome to dispose of and offer higher biogas yields. The most viable horticulture waste streams in Kenya come from the processing of main commercial fruits i.e avocado, mango and pineapple and are therefore assessed in more detail as part of this study. Given that potatoes are the main vegetable grown in Kenya, the bioenergy potential from this sector is included as part of this assessment.

Avocado is widely grown by small-scale farmers and is one of the main high-value crops, with a rapidly growing export market for 10-20% of all fruit (Amare et al., 2019; Embassy of the Netherlands, 2017; Wiersinga & de Jager, 2007). It is thought that less than 10% of Kenya's avocadoes are processed, mainly for the high-value oil that makes up around 11% of the fresh fruit weight (Costagli & Betti, 2015). 0.8 to 1.0 l of water is required per kg of fruit processed, giving a final waste mix of green water, skin, residual pulp and crushed stone (H. Muntingh, personal communication, 5 September 2020).

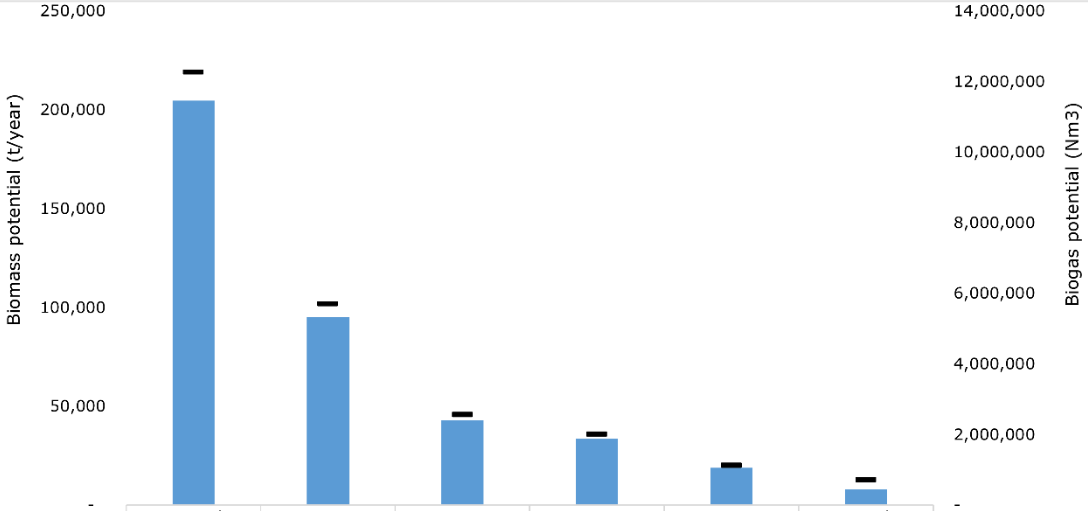
Mangoes are mainly produced by small-scale growers and most fruits are marketed whole, both domestically and internationally (Embassy of the Netherlands, 2017; Wiersinga & de Jager, 2007). 8-10% of mangoes are processed (mostly juiced) (FSD Kenya, 2015; International Trade Centre, 2014), generating 20-45% waste in the form of peels and seeds (Maisuthisakul, 2009). These residues are often composted and used as fertilizer and soil enhancer, but are also suitable for AD, with the digestate providing a fertiliser alternative.

Pineapple is a highly commercialised and mechanised crop, of which 90% is produced by large integrated plantation processors, mainly for the export market (Ndungu, 2014). They process 10-15% of the fruit for juice and canned fruits (Ndungu, 2014), resulting in discard of 50-65% of the fresh fruit in the form of skin, fibre and pulp (Eight-Japan Engineering Consultants, 2010; Sukruansuwan & Napathorn, 2018). Large amounts of processing water potentially add to the available waste stream.

Potatoes are the main vegetable grown in Kenya. 5-10% is processed into potato crisps and French fries (NPCK, 2018), generating 20-40% residues in the form of peels, slivers and nubbins (Ahokas et al., 2014; IRENA, 2017).

Bananas are Kenya's main fruit and are predominately sold unprocessed (Embassy of the Netherlands, 2017; Wiersinga & de Jager, 2007), although bananas could be used for juicing or dried fruit, generating peels as residues for composting or AD.

Based on these assumptions, and applying crop production, residue-to-product ratios and removable fractions that are detailed in Appendix 3, horticulture in Kenya generates 402,296 t/yr of biomass feedstock suitable for AD, with a biogas potential of 24.4 million Nm^3 (Figure 5.2).



	Pineapple processing residues incl wastewater	Mango processing residues incl wastewater	Fresh vegetables residues	Fresh fruit residues	Potato processing residues	Avocado processing residues incl wastewater
Biomass potential (t wet basis)	204,417	94,966	42,789	33,467	18,704	7,954
Biogas potential (Nm3)	12,265,028	5,697,941	2,567,312	2,008,004	1,122,225	715,835

Figure 5.2: Theoretical biomass and biogas potential from the horticulture sector in Kenya

5.1.2 Mass-energy balance

Table 5.1 shows the mass-energy balance (MEB) parameters for using avocado processing residues to produce biogas and generate electricity and heat. The input data are based on the specifications of the Olivado plant.

Table 5.1: Mass-energy balance, bioenergy for electricity in horticulture sector

Parameter	Units	Value
Biomass feedstock		Avocado processing residues
Feedstock mix ratio	Stones:pulp:wash water	1:2:3
Moisture content	Stones % Pulp % Wash water %	50 20 6
Model input parameters		
Energy installed	kW_e	410
Capacity factor	%	11.5[11]
Annual operational hours	hrs	1,003
Process	CHP to generate electricity	
CH4 content of biogas	%	64%, upgraded to 94%
Moisture content as received	%	82%
Volatile matter content	%	95%
Electrical efficiency	%	35%
Model outputs		
Biomass flow	kg/s (wet basis)	0.77
	t/yr (wet basis)	2768

[11] 11.5% capacity factor is based on installed generator capacity of 410 kW_e producing 411 MWh_e/year.

Parameter	Units	Value
MWh electricity/ t biomass	MWh/t (wet basis)	0.15
Biogas production (upgraded to biomethane)	Nm^3/s	0.05 (biomethane 0.03)
	Nm^3/yr	184,758 (biomethane 125,792)
Energy		
Electricity	MW	0.4
	MWh/yr	411
Heat supply via exchanger and losses	MW	0.8
	MWh/yr	764

The MEB is illustrated graphically in Figure 5.3, indicating flows of materials and energy through the system.

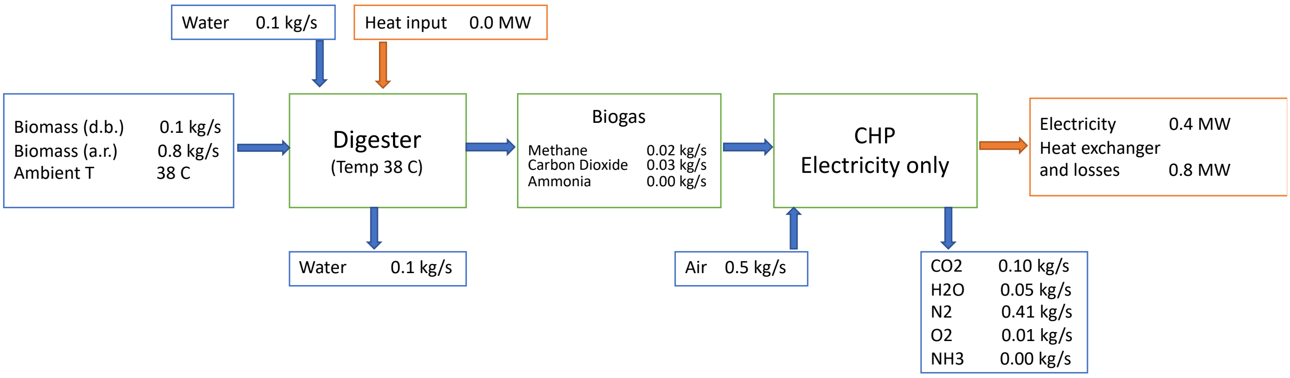


Figure 5.3: Mass-energy balance for energy generation for avocado processing, based on Olivado input specifications

Olivado currently produces 411 MWh of electricity per year from the AD plant to meet its electricity demand for onsite processes. According to the MEB model, this should require 125,792 Nm^3 of upgraded biomethane. This in turn requires 184,758 Nm^3 biogas with a CH_4 content of 64% from 2,768 t of feedstock (taken as a mix of avocado pulp, skins, crushed stones and processing waste water).

With about 3,600 t p.a. of solid residues (pulp and stones) and up to 3,600 m^3 of processing waste water (800-1,000 l per tonne of fruit processed), about 7,200 t p.a. of feedstock are available. Based on the MEB model results, this could yield 480,660 Nm^3 of raw biogas or 327,256 Nm^3 of upgraded biomethane, with the potential to provide 1,070 MWh of electricity annually. Olivado intends to use this significant excess of upgraded biomethane as vehicle fuel, catering to a second important source of energy demand.

5.2 Technology

The processing of fruits and vegetables generates both solid and liquid residues in significant quantities. The standard industry solutions are to compost the solid wastes and to treat the liquid wastes before safe discharge. With relatively low electricity demands, little or no requirement for process heat and a bureaucratic and uneconomic process for achieving grid feed-in, few companies in the horticulture sector have found it attractive to install new technology such as AD for CHP. Solar power is proving a cheaper and more reliable substitute for diesel generators, to complement grid electricity. For most players in the industry, there are therefore more dependable solutions for their waste disposal and power sourcing challenges.

But for certain types of horticulture processing that generate significant residue streams and require a reliable supply of heat, AD may offer a solution. Avocado oil production is one such example. AD has also been adopted at the site of VegPro, a horticulture concern in Naivasha, at HPW Fresh and Dry in Ghana and at several fruit and vegetable processors in South Africa.

Drawing on their experiences, barriers to wider adoption of the technology include the high cost of AD technology, challenges in dealing with local financing institutions for unfamiliar AD investments and the operational sophistication of biogas technology. The investment cost challenge was tackled by Olivado through the adaptation of German design concepts to use simpler and more affordable components. This is a key strategy for replication that Olivado and other biogas developers must pursue, to keep costs competitive in the non-subsidised renewable energy environment that exists in most SSA countries. The operating challenge has been addressed by conducting significant in-house training and capacity building of staff to become competent technicians. This now enables Olivado to develop a business opportunity by pitching to build, own and operate future plants on behalf of clients, to demonstrate that the concept is commercially viable with a variety of alternative feedstocks at mid-sized agribusinesses and processors in the region.

5.3 Economic viability

The economic viability of the Bioenergy Case is influenced by many factors, such as avoided costs of effluent treatment, genset utilisation rate and CAPEX requirements. In this section, the impact of these parameters on LCOE is investigated through sensitivity analysis. The charts below show linear best-fit regression lines for the results from hundreds of simulated scenarios.

Figure 5.4 shows the result of modelling $LCOE_{electricity}$ for a range of wastewater treatment and disposal costs, ranging from zero to USD 40 per tonne of processed fruit (compared with the current estimate of USD 32/t). The analysis indicates that the Bioenergy Case is economically competitive for electricity generation for avoided costs of waste water treatment higher than USD 18 per tonne of processed fruit.

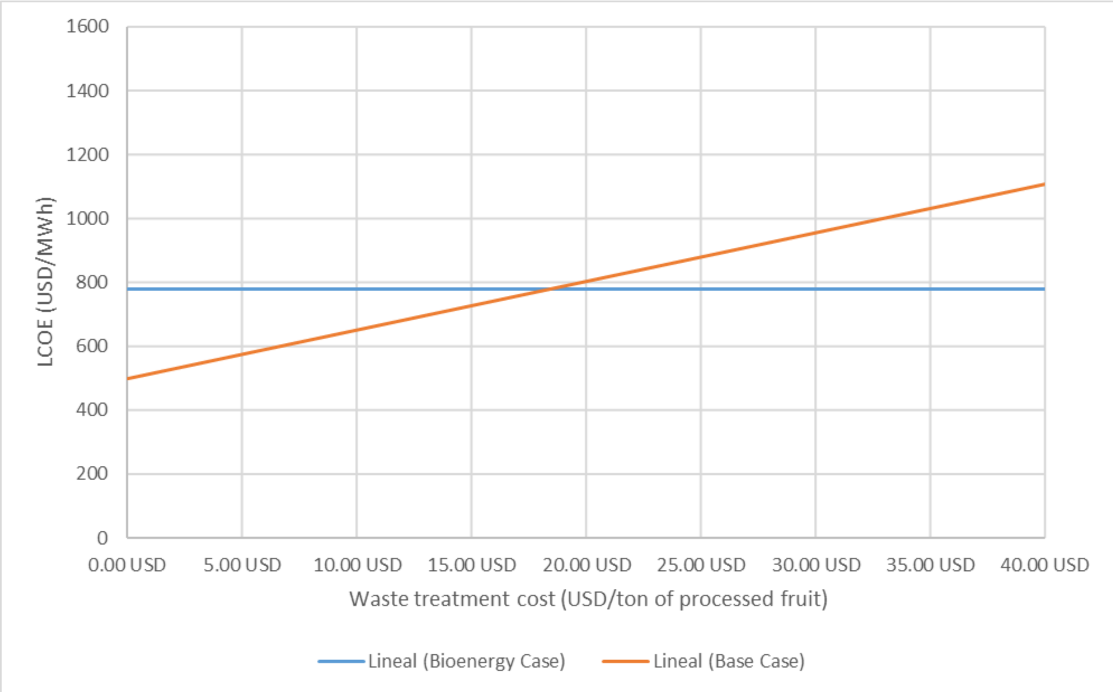


Figure 5.4: Sensitivity of LCOE to waste treatment costs

The LCC modelling in 4.4 above assumed that 10% of electricity was drawn from diesel gensets, prior to the installation of the AD plant. In order to determine the effect of grid power supply becoming more reliable or less reliable, genset utilisation rates ranging from zero to 25% were explored. Figure 5.5 illustrates the results, which indicate that even if the Base Case operation was able to rely fully on the grid, with zero genset use, the Bioenergy Case $LCOE_{elecricity}$ would still be lower.

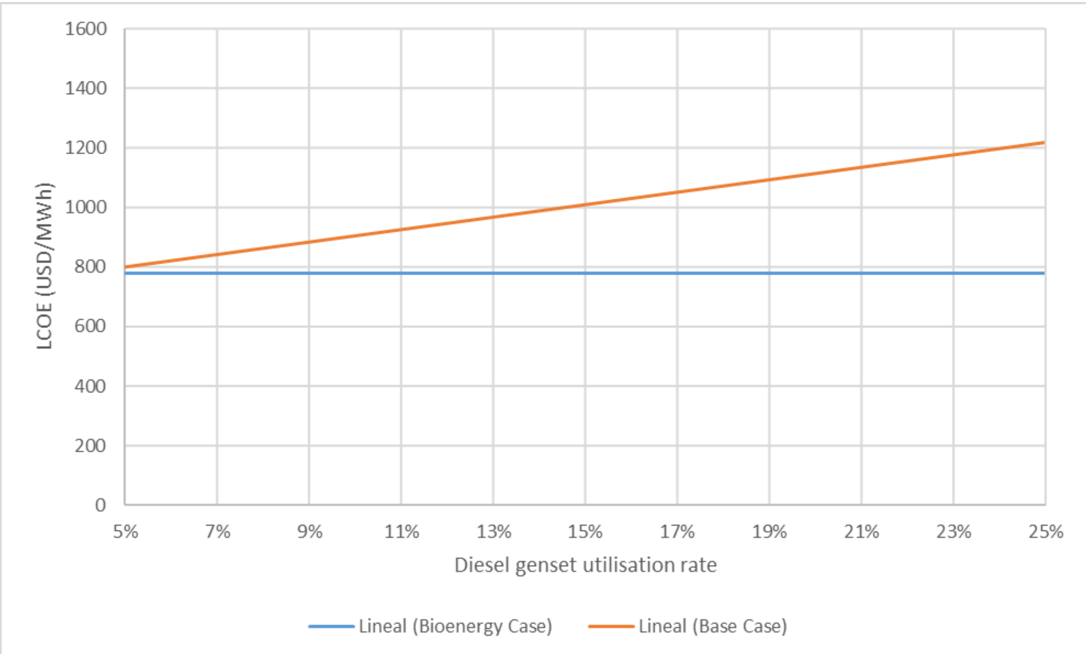


Figure 5.5: Sensitivity of LCOE to diesel genset utilisation rate

Finally, Figure 5.6 illustrates the effect of CAPEX on the LCOE comparison. The results show that the tipping-point for the viability of the Bioenergy Case is around 155% of the actual CAPEX value, indicating that Olivado has successfully achieved economically competitive electricity supply by actively addressing technology cost reductions, and has managed to do so by a significant margin. These results further show that the Bioenergy Case would be viable for any investment CAPEX below USD 5,110 per kW of installed capacity (compared with the current ratio of USD 3,293 per kW for the Olivado facility).

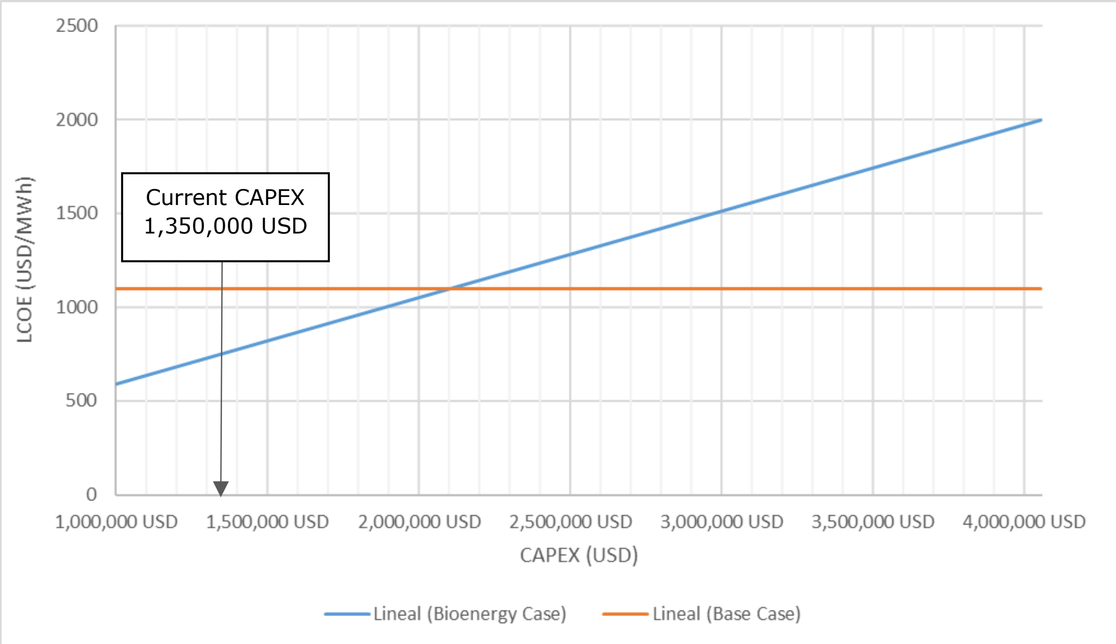


Figure 5.6: Sensitivity of LCOE to CAPEX increment

These values are in line with the CAPEX references published by IRENA (from the IRENA Renewable Cost Database), which indicate a range of total installed costs from USD 2000 to 6000 per kW for vegetal and agricultural waste based power generation projects (below 10MW) in Europe (IRENA, 2020).

5.4 Commercial prospects for replication

5.4.1 Market potential

Olivado has achieved the goals it set for this project and others to come, having designed and successfully installed an AD system that costs a fraction of similar systems in the region, and having developed the local skills required to operate and maintain such a facility. This realisation led to the establishment of Olivado Biogas Africa Ltd, with the aim of exploring commercial opportunities to replicate the project. A similar venture is going ahead at Olivado's Tanzanian operation, and commercial discussions are well advanced with at least one other fruit processor in Kenya.

Unlike other demand sectors considered under BSEAA2, the horticulture sector comprises numerous sub-sectors, each with unique processing residues, energy needs and approaches to waste disposal and/or reuse, making it impractical to undertake an analysis of the entire sector. An assessment of the sector was instead narrowed down to two value chains – pineapple processing and mango processing - based on their size, processing requirements and waste potentials.

As noted in Section 5.1, other fruit and vegetable processing sub-sectors in Kenya, such as banana processing for making juices or potato processing for crisps and chips, also produce wastes that are suitable for AD. But such processors are likely to be located in urban and peri-urban areas with reliable electricity connections, limited space and existing markets for their peels as animal feed or compost. Nevertheless, although these additional sub-sectors have not been explored in this analysis, there may be niche potential for AD-based energy generation, to be determined on a case-by-case basis.

5.4.1.1 Pineapple processing

350,000 t of pineapples were harvested in Kenya in 2018, most of which were produced and processed at Del Monte Kenya (FAO, 2021a). The country exported 15,000 t of pineapple juice and 30,000 t of canned pineapple in the same year. Typical processes for juicing and canning of pineapple require a lot of water, in addition to numerous steps that require both heat and electricity. An overview of the steps involved in pineapple canning and juicing processing and corresponding energy requirements at each step is provided in Appendix 5, based on calculations made by Masanet et al. (2008).

From stakeholder engagement, the pineapple processing sector typically produces both canned and juice products from the same feedstock stream: the canned pineapple product is produced, and the leftover fruit is then juiced. Much of the pineapple's weight is left as waste from processing. Peels account for 30-40%, and the core accounts for approximately 10% of the weight (Roda & Lambri, 2019). Juicing uses approximately 50% of the fruit weight, while canning uses only 25% (ibid.), leaving an estimated 25% of the pineapple available for AD. Pineapple juicing is also estimated to be more energy intensive, requiring 582 kWh of heat and 79 kWh electricity per tonne of product, compared to 495 kWh heat and 78 kWh electricity per tonne of canned product (Masanet et al., 2008).

For this study, pineapple waste is assumed to have a biogas yield of 670 m^3/kg volatile solids (VS), based on values for ensilaged pineapple waste (Rani & Nand, 2004). In Table 5.2, this yield factor is used to estimate the potential energy production from processing residues, as compared to the sector's energy demand. Energy generation potential is given only as a total, as both processes are considered to be part of a single process stream, and therefore produce a single waste stream.

Table 5.2: Energy potential and demand from pineapple processing

Parameter		Pineapple - Juice	Pineapple - Canned	Total
Energy demand				
Demand per tonne product	Heat (kWh)	582	496	**1,078**
	Electricity (kWh)	79	78	**157**
Total energy demand	Heat (GWh)	7.4	14.9	**22.3**
	Electricity (GWh)	1.2	2.3	**3.5**
Energy generation potential				
Energy potential per tonne pineapple processed	Heat potential (CHP) (kWh)	-	-	**503**
	Electricity potential (CHP) (kWh)	-	-	**302**
Total energy potential	Heat potential (GWh)	-	-	**60.3**
	Electricity potential (GWh)	-	-	**36.2**

Assuming that all waste from the processing of exported pineapple products could be utilised for AD, this could produce a total of 60.3 GWh heat and 36.3 GWh electricity per year, far more than the estimated 22 GWh heat and 3.5 GWh electricity demand of the industry. Pineapple waste-based AD therefore has the potential to meet not only the heat and electricity requirements of the pineapple processing industry, but also to produce a significant excess that could be sold to the grid or nearby off-takers.

5.4.1.2 Mango processing

Mango is the second most grown fruit in Kenya. Approximately 775,000 t of mangoes were grown in 2015, of which roughly 60,000 t were processed (FAO, 2021a). As with pineapple, water is required for mango processing, although electricity requirements are lower, as energy-intensive peeling and coring is not required. An overview of the steps involved in mango canning and juicing processing and corresponding energy requirements at each step is provided in Appendix 5, based on calculations made by Masenet et al. (2008).

The majority of the waste from mango is peel, which accounts for 15-20% of the weight of the fruit (Serna-Cock et al., 2016). A significant difference between the canning and juicing processes is the yield: mango juicing uses an estimated 52.5% of the fruit weight (Hegger & Haan, 2015), while canning uses approximately 80% (Shahidi & Alasalvar, 2016). Similar to pineapple processing, mango juicing is more energy-intensive than canning: requiring 582 kWh_{th} and 73 kWh_{e} per tonne of juice, compared to 496 kWh_{th} and 69 kWh_{e} per tonne of canned product (Masanet et al., 2008).

Table 5.3 shows, the energy demand per tonne of product and the energy generation potential from the two streams of mango processing wastes.

Table 5.3: Energy potential and demand from mango processing

Parameter		Mango - Juice	Mango - Canned	Total
Energy demand				
Demand per tonne product	Heat (kWh_{th})	582	496	**1,078**
	Electricity (kWh_{e})	73	69	**142**
Total energy demand	Heat (GWh_{th})	17.5	14.9	**32.4**
	Electricity (GWh_{e})	2.2	2.1	**4.3**
Energy generation potential				
Energy potential per tonne product	Heat potential (CHP) (kWh_{th})	283.5	184.3	**467.8**
	Electricity potential (CHP) (kWh_{e})	170.1	110.6	**280.7**
Total energy potential	Heat potential (GWh_{th})	8.5	6.9	**15.4**
	Electricity potential (GWh_{e})	5.1	3.3	**8.4**

Although electricity potential from mango processing residues (8.4 GWh_{e}/year) is greater than the estimated demand of the industry (4.3 GWh_{e}/year), the heat potential (15.4 GWh_{th}/year) is much lower than industry demand (32.4 GWh_{th}/year). Mango processing has lower energy potential than pineapple processing as residue volumes are smaller and biogas yield is lower (at 270 m^3/t of peel) (Gebreeyessus & Demessie, 2014). This confirms that AD is only viable for energy self-supply for value chains that generate high percentages of waste or wastes with a high energy-generating potential.

5.4.2 Market barriers

Based on the experiences of the flagship project at Olivado, and discussions with other potential adopters of AD in Kenya (see Appendix 6), the key barriers and enablers to the further adoption of AD in Kenya's horticulture sector are summarised in Table 5.4 below.

Table 5.4: Barriers and enablers to the use of processing residues for AD in Kenya's horticulture sector

	Barrier to business model	Enabling conditions
Electricity for self-consumption	**Minimal onsite electricity demand** Many fruit and vegetable processing plants do not have significant onsite electricity demands, particularly those that are mainly packing (rather than processing), so can absorb the costs of grid power without major impacts on profitability, even if it is at times unreliable.	**Significant onsite electricity demands** Olivado has significant power requirements for operating processing machinery, cold stores, a water heater and administrative operations. It was dependent on unreliable grid power, via a rural transmission line, with costly diesel backup generators, and the situation was worsening as the grid had reportedly become more unreliable in recent years. The need for reliable power was a key motivation for adopting AD.
	Solar PV is a cheaper RE solution than AD As an alternative to unreliable grid power, solar PV is likely to represent a cheaper 'turnkey' option than AD, e.g. Kenya Horticultural Exporters have chosen to install 1.2 MW of solar supply at their production and processing sites, along with demand adjustment to move some electricity loads (e.g. irrigation) to hours of peak sunshine.	**AD needs to be more reliable and cost-competitive** For other horticulture companies to adopt AD, the technology package needs to be cost-competitive and reliable, so processors can be confident that it will work as advertised. Other potential projects may learn from the Olivado example, wherein cost-savings were achieved by adapting the plant to the local context, using locally sourced parts where possible. Fiscal incentives are needed that match those offered to solar PV (e.g. zero duty on imported AD components such as engines, pumps, valves, gas membranes and monitoring systems). An alternative concept that could be explored is a hybrid system combining AD and PV, which could potentially allow for more cost-competitive economics, whilst still retaining AD's ability to provide despatchable power.

	Barrier to business model	Enabling conditions
	Being close to cities gives access to grid electricity Many fruit and vegetable processors (e.g. mango juicing) are close to Nairobi, and thus likely have access to grid electricity. Having access to reliable electricity therefore reduces the need for onsite electricity production.	**Grid unreliability** Most of the horticultural processors interviewed noted that the reliability of Kenya's grid has been getting worse which could provide an additional incentive to consider electricity produced from biogas.
Electricity for grid export	**Lack of regulatory provision for small power producers to sell into the grid** Kenya's energy regulator (EPRA) does not permit independent power producers (IPPs) with less than 200 kW generating capacity to sell power to the grid.	**Regulatory reform** Although improbable in the near future, if EPRA lowered the threshold for IPPs or made it easier for small generators to enter into wheeling agreements to sell electricity to third parties, the business case for AD at fruit and vegetable processing facilities would be significantly strengthened.
	Non-viable feed-in tariff The FiT for power from biogas is only 0.10 USD/kWh, which is not high enough to justify investing in AD purely for export, nor likely to be large enough to justify the marginal cost of increasing AD capacity.	**Review feed-in tariffs for power from bioenergy** Although improbable in the near future, if EPRA and Kenya Power made it easier for small generators to enter into wheeling agreements to sell electricity to 3rd parties, this could significantly strengthen the business case
Heat for self-consumption	**Limited onsite heat demand** With some exceptions, (see 5.4.1), fruit and vegetable processors tend to have minimal demands for heat, which means this important energy stream cannot be valorised.	**Requirement for process heat** At Olivado, the primary use of the heat from the CHP unit is to heat process water for avocado oil extraction, as a substitute for an existing immersion boiler that consumed close to 45% of the operation's entire electricity before the AD system was installed. This heat demand constitutes an important part of the investment case for AD.

	Barrier to business model	Enabling conditions
Waste management	**Waste can be disposed of in other environmentally-compliant ways** Whilst AD can be an effective method to deal with large volumes of wet waste, there are other, environmentally compliant, lower cost options available. For example, the waste may be spread on the land as a fertilizer, or aerobic digestion ponds may be employed for residues with high moisture content.	**Valuing the enhanced environmental benefits of AD** Even though landfill is approved by NEMA, the owner of Olivado preferred to pursue AD as a waste management option, given the lower environmental impact and the potential to reduce transport/energy costs.
Transport fuel demand	**The upfront costs of converting an existing vehicle fleet to run on CNG can be highly costly** Most corporate vehicle fleets in Kenya run on diesel, making it costly to convert fully to use CNG.	**Fleet owners needing to purchase a new fleet or replace an ageing fleet** Olivado was previously leasing its vehicles but wanted to purchase their own. Since they did not own their own vehicles and were going to purchase vehicles anyway, this meant that the marginal cost differential between CNG and diesel trucks, could be legitimately considered when analysing of the investment case, which significantly improved the project economics. This approach is replicable amongst start-ups in fruit and vegetable processing or existing fruit and vegetable processors with sufficient financial capacity to purchase their own CNG-based vehicles (if currently leasing). For others, it is possible – and significantly cheaper - to part replace diesel with 15-40% CNG in existing vehicles, without major modifications.

In addition to the above energy-specific barriers, there are sector-specific challenges to replication, depending on the type of processing required, the characteristics of the residues and existing competing uses. For instance, there is a global trend toward fresh fruit and a declining demand for canned fruit, which could lead to reduced feedstock availability, low energy demand and, as a result, reduced technical and commercial potential for using AD. Feedstocks may additionally have pre-existing uses. For example potato peels, are highly digestible due to their protein and starch content, and are commonly used as animal feed.

5.4.3 Finance

In the case of Olivado, it proved extremely challenging to obtain financing from local banks for an AD investment, in the absence of a risk guarantee. Even when such a guarantee was provided, via the French AFD-funded 'SUNREF' programme, the first bank that offered finance delayed signing an agreement for nearly a year, eventually pulling out after nine months of negotiations. An alternative loan facility was then agreed with Chase Bank, but that bank collapsed. When Chase eventually found a buyer, the loan was reinstated. The project also received a German DEG grant and a contract with UNIDO (GEF-5), the latter only payable after the AD plant was built.

These experiences highlight the low or non-existent familiarity of banks regarding commercial-scale AD technology. In order to build confidence in the market, some form of external validation, cost-sharing or guarantee scheme is likely to be key if AD projects are to obtain financing from local institutions in SSA.

5.5 Gender and inclusion

Kenya, like other East African countries, has gendered ideologies that determine behaviours in agriculture and horticulture. There are differences in gender inequalities depending on the specific fruit and vegetable categories. This analysis looks at G&I issues with respect to the Bioenergy Case, i.e. avocado production and processing, in order to identify the key issues and barriers to meaningful inclusion of women in this sector.

Avocado trees are predominantly owned by male heads of household at the smallholder level. They make decisions on production, marketing, and income, as well as negotiating avocado contract farming agreements. Commonly within avocado value chains, women's participation is not valued or recognised due to lack of tree ownership. Generally, male ownership rights means women are more likely to be excluded from avocado agronomy and from Good Agricultural Practice certification trainings and export value chains (Johnny et al., 2019). Extending the analysis to the role of gender in avocado contract farming, the literature suggests that women are now involved in avocado production activities that were traditionally done by men, with Olivado reporting that about 35% of their contracted farmers are female. However, the limited participation of women farmers in marketing is an indication that women are not well integrated in all aspects of avocado production chains. A study conducted in Murang'a County (Johnny et al., 2019) suggests that educational qualifications in Kenya don't necessarily correlate with involvement, in terms of total numbers, but with the quality and seniority of roles. The study concluded that although more females had avocado farming as their main occupation, male workers in the value chain received three times as much contractor-provided training as women.

When assessing the commercial avocado processing sector, some practical findings were contradictory to the literature findings. For instance, Olivado is actively engaging with SheTrades, demonstrating awareness and active engagement on the issue of gender inequality. SheTrades supports gender engagement, the development of fair policies, assistance to help market access and unlocking of financial services. This has filtered into Olivado's policies towards protection of women's rights within the company, for example via a gender committee that advises on hiring and management decision and social impact reporting, and which monitors the development of female and young staff in the company. In terms of employment of skilled, semi-skilled and unskilled labour, women made up an average of 30% of skilled and semi-skilled, and 0% of unskilled roles within Olivado.

5.6 Institutional, market and regulatory framework

In the late 2000s, there was significant optimism regarding the prospects for commercial AD in Kenya, with German development assistance programmes taking a particularly keen interest in the sector, in part seeing the opportunity for German firms to supply technology and expertise. While the AD opportunity in the horticulture sector was estimated at less than 5 MW_e, the Kenyan investment climate was evaluated as positive, and the local market was described as "an interesting entrance to the East-African biogas market for investors" (Fischer et al., 2010). This optimism was based on the expected introduction of an attractive FiT system by the Government of Kenya, and a range of FiTs up to 18 US¢/kWh were proposed for AD installations - but these did not materialise.

15 years later, it is ironic that Kenya, which has one of the largest and most successful horticultural sectors in SSA, still has only two operational AD units using horticultural residues. These bioenergy ventures are highly specialised and produce electricity primarily, if not exclusively, for their own consumption.[12]

The regulatory framework for horticulture-derived electricity is governed by the EPRA, while any grid sales are on Kenya Power's technical, operational and power purchase terms. While Kenya Power has PPAs with a number of large renewable energy IPPs (e.g. geothermal, wind, solar photovoltaic), it has only two PPAs for biogas-generated electricity.[13] While the regulator has set a framework for feed-in-tariffs for biogas since 2008, both the terms of the PPA and the low FiT rate provide practically no incentive for investment in AD for selling to the grid, whether in the horticulture sector or in other agribusinesses.

Further, Kenya Power's network is poor in many rural areas where horticultural crops are produced, and Kenya Power is averse to adding embedded generation to its network (i.e. not being able to despatch the electricity generated by an IPP). The weakness and unreliability of the grid, which was cited by several of the larger horticultural producers, necessitates investment in diesel standby generators. While this could potentially provide an incentive to use horticultural wastes for AD to cover self-consumption of electricity, there is little awareness of AD and interest in its adoption, and alternative sources of renewable electricity generation (primarily solar PV) appear cheaper and more reliable.

On 30th June 2021 the Government of Kenya gazetted in the new Finance Bill that 'pre-fabricated biogas digesters' and the sale of 'biogas' are now exempt from VAT. This could possibly stimulate further interest and possibly investment in AD for horticulture in Kenya (Republic of Kenya, 2021).

[12] Of the horticulture AD plants in Kenya, only Tropical Power has an offtake agreement with Kenya Power, although its primary load and sales are to VegPro. Although Olivado generates a surplus of electricity beyond its own needs, it decided not to negotiate a PPA with Kenya Power due to the low feed-in-tariff (USD 0.10/kWh) it would receive.

[13] The PPAs are with Kilifi Plantations (from AD based on sisal processing residues) and Tropical Power (from AD based on horticulture residues).

The key recommendation to change the market environment is for the Government of Kenya to double its FiT for biogas-derived electricity, with the EPRA making this a priority. The MoE and the EPRA should require Kenya Power to 1) prioritise biogas electricity; 2) put in place the mechanisms for doing so; and 3) strengthen the grid (particularly medium voltage), including transformers, inductors (for power factor correction) and basic distribution network wiring to improve reliability of supply. Imposing fines on Kenya Power for not meeting minimum standards in these areas would go a long way in ensuring that small-to-medium scale renewable electricity generators have good access to the grid, both for supplying electricity and for improving the reliability of the supplies they take.

While wide-ranging legislation and regulation is in place for liquid waste treatment and disposal,[14] NEMA's enforcement of these regulations in the horticulture sector is fairly light for most crops. Waste management controls do not provide sufficient incentives to invest in AD, unless the size of the horticulture facility and the amount of liquid waste is substantial enough to affect the local water catchment area or contaminate the soil around the facility, as determined by NEMA. As noted above, this was the case with Olivado, which found transporting avocado waste to a designated disposal facility more expensive than installing an AD system to treat the effluent and other residues.

Lower equipment costs and locally adapted technology could further boost the prospects for replication, notwithstanding the significant impediment presented by the low FiT.

5.7 Replication potential in other target countries

5.7.1 Introduction

This section explores the potential for wider adoption of the Bioenergy Case in the other BSEAA2 target countries. The intention is to summarise the prospects for replication of the model, based on the commercial environment in each of those countries and their respective horticulture sectors, where applicable, but not to quantify either total energy demand in the sector, or the potential scale of the replication opportunity.

Horticulture is of growing economic importance in most of the BSEAA2 target countries, with Ethiopia, South Africa, Tanzania, Uganda, Rwanda and Zambia showing the greatest growth, in order of economic and export importance, driven by rising domestic income and by exports. Almost all of the target countries are promoting increased and improved vegetable and fruit markets by supporting organisation of the sector into associations and encouraging producers to meet international quality standards.

Given the potential for positive impacts on rural development, income generation, economic diversification, increased exports and export earnings, coupled with reduction of regional trade barriers (e.g. Economic Community of West Africa, East African Community, Southern Africa Development Community [SADC] Free Trade Area and the Common Market for East and Southern Africa [COMESA]), there has been a

[14] See (Ministry of Environment, 2006, 2009; NEMA, 2008, 2019), Environmental Management, Co-ordination (Water Quality) Regulations (Ministry of Environment, 2006) and Environmental Management, Co-ordination Act (Republic of Kenya, 2012a).

significant reduction in barriers to trade and expanded economic incentives and business opportunities for fruit and vegetable producers in all target SSA countries.

However, even though Kenya is second among these horticultural producers, there is little to demonstrate to horticulture operators and investors in other countries from Kenya's experience.

5.7.2 Country fruit and vegetable sector profiles

Ethiopia: Ethiopia is currently SSA's largest exporter of vegetables, primarily to Europe and the Middle East, thanks to a favourable climate, proximity to major markets, cheap labour and a vast area of fertile land. While smallholders account for over 95% of agricultural production, a rapidly growing number of enterprises have moved into high value fruit and vegetable production aimed at export markets and to meet rising middle-class demand in Addis Ababa and other rapidly growing urban areas (Oduya, 2016). The second phase of the National Biogas Programme supports the government's efforts to develop household biogas in rural areas (EREDPC & SNV, 2007), although there is no government or development partner support for commercial biogas AD in the horticulture sector.

The Ethiopian Horticultural Development Agency was established in 2008 to support the development of the horticulture sector. It has coordinated with other government bodies to develop a favourable, export-led support framework for fruit and vegetables over the past decade, including access to good land, new roads to export-oriented farms, reliable and low-cost electricity connections and easy acquisition of export licences. Investors have responded quickly and are organised around the Ethiopia Horticulture Producers and Exporters Association, with nearly 120 members. Exports are mainly supported by the Upper Awash Agro-Industry Enterprise and Horticulture Development Enterprise, which were state-owned companies privatised in the late-2000s (Weirsinga & de Jager, 2009). There are currently no operational fruit or vegetable AD-based energy plants operating in Ethiopia.

Ghana: Fruit plays a crucial role in Ghana's economy and is a major source of export earnings, contributing about 16% of GDP in 2015. Ghana has suitable climatic conditions and land resources and is a leading African producer of a variety of fruits such as pineapple, mango, banana, citrus, papaya, passion fruit and coconut. The country produces about 20 million t per year of fruits, but with limited processing facilities (Weirsinga & de Jager, 2009). Ghana exports a significant quantity of fresh fruits to the EU, North America and the Middle East. Market liberalization and a trend towards export diversification have played an important role in stimulating exports of high-value fruit crops. Local demand for fresh fruits is also growing, with rising urbanisation and incomes (Wageningen University et al., 2019).

Ghana's fruit and vegetable sub-sector is organized under the Ghana Association of Vegetable Exporters (GAVEX)[15] and the Vegetable Producers & Exporters Association of Ghana (VEPEAG).[16] GAVEX's main activities are to organise exhibitions and conferences to promote and display Ghana's agricultural, primarily horticultural offerings. It is totally focused on exports. Ghana's other main horticulture association

[15] https://www.virtualmarket.fruitlogistica.de/en/Ghana-Association-of-Vegetables-Exporter-GAVEX,c44840
[16] http://www.vepeag.org/

is VEPEAG, a national organization established in 1997 by individual farmers and exporters who came together to increase exports and to meet quality standards set by European buyers. Membership currently stands at 260, with each member having 6 to 10 out-growers. VEPEAG's main activities and operational areas are producing vegetables for international and local markets, supply of seeds and agro-chemicals to producers.

There is an AD-based 400 kW CHP plant at HPW Fresh and Dry, a fruit processor in Adeiso, which uses mango, pineapple, papaya and coconut waste, palm kernel cake and poultry manure, and which was profiled in a case study analysis available in BSEAA Part 1 reports (LTS International, 2017).

Nigeria: Nigeria, with its population of 190 million, is SSA's largest producer of fruits and vegetables. While fruit and vegetable exports are not significant, Nigeria's domestic market, dominated by Lagos (with nearly 24 million inhabitants) and its rapidly growing monied middle class, have stimulated Africa's fastest growing fruit and vegetable sector (van der Waal, 2015). Nigeria's dynamic entrepreneurial class has been encouraged by a government shift in the past decade towards improved cash crop agricultural production, which is supported by easier access to credit, concessionary finance, improving infrastructure and export support for the country's fruit and vegetable sector. But poor road, rail and electricity infrastructure are still a major hindrance to growth and modernisation. And in contrast with other SSA countries with a horticulture sector, producers and processors in Nigeria are not well organised or coordinated. The investment climate for bioenergy in the sector is therefore weak, and there are currently no commercial scale fruit or vegetable AD-based energy systems in Nigeria.

Rwanda: Rwanda's National Agricultural Export Development Board is a public institution established to promote fruit and vegetable production for export and, increasingly, for local markets. Expanding Rwanda's commercial fruit and vegetable sector is a government priority, with tax incentives, infrastructure (roads, electricity, water, waste management) and financial support provided to fruit and vegetable exporters (Dijkxhoorn et al., 2016). Rwandafresh[17] is the government's commercial support and marketing arm, working with over 20 horticultural product exporters. Effectively, it is a government-supported clearinghouse for Rwandan horticulture, primarily for export. Very little of Rwanda's fruit and vegetables is processed, with the bulk being refrigerated or frozen for export. Several types of high-quality horticultural products grown in the country are in demand in Europe, the Middle East and other African markets. Fruits (including avocado, mango, pineapple, passion fruit, banana and strawberry) and macadamia nut are increasingly in demand in these international markets, and from Rwanda's own rapidly growing urban population.

There are no fruit and vegetable commercial AD projects operating in Rwanda.

South Africa: South Africa's horticulture sector employs 300,000 people and makes an increasingly important contribution to the country's agricultural exports, with about 72% of total production exported (Infomineo, 2016). South Africa is a key supplier of deciduous and citrus fruits to markets in the northern hemisphere. Only about a

[17] naeb.gov.rw/index.php?id=31

quarter of the produce in the country is processed, so fruit processing is regarded as a residual industry that handles fall-out or downgraded fruits from the fresh fruit market. The vegetable sector is primarily driven by local demand and focused on fresh produce.

South Africa's fruit and vegetable industry is well-organised, and there is a dynamic, well-organised set of organisations with a primary objective of increasing exports, while improving their members' horticultural practices, quality and health. The largest is the Agricultural Produce Agents Council[18] which regulates the occupations of fresh produce, export and livestock agents, and maintains and enhances horticulture activities. The Fresh Produce Exporters Forum of South Africa and the SA Fruit & Vegetable Canners' Export Council are particularly active in the horticultural sector. Fruit South Africa and Wines of South Africa aggressively market South African products locally and internationally.

There are several commercial-scale AD projects in South Africa's horticulture sector, including:

- *Greenway Farms Biogas (Krugersdorp):* A 3.5 MW biogas thermal plant using vegetable residues from food processing and grass silage. Commissioned in 2015, it comprises a biogas plant for the supply of raw biogas for their food processing factory's steam boiler.
- *Tshwane Food and Energy Centre / Biogas Power (Tshwane):* A 100 kVA plant commissioned in 2016 to supply biogas-generated electricity to the off-grid Centre, which has agri-processing and retail facilities, using discarded vegetables, sweet sorghum grass silage and other farm residues as feedstock.

Tanzania: Tanzania's horticulture industry employs 2.5 million people and is the fastest growing agricultural sub-sector, with average annual growth of 9-12%. Approximately 10% of the country's fruit and vegetables are exported, while high value produce demand is growing rapidly in large urban areas, particularly Dar es Salaam, Arusha and Mwanza. Most large-scale growers are located in northern Tanzania, primarily around Arusha and Manyara, with air shipment via Kilimanjaro International Airport (Match Maker Associates, 2017). Some producers have formed groups to serve as contract farming operations to large-scale export groups.

The Tanzania Horticultural Association (TAHA) is Tanzania's paramount horticulture support and trade organisation, with membership of over 700 individuals, companies and organisations.[19] TAHA statistics shown an increase in horticulture export earnings in Tanzania from USD 64 million in 2004 to over USD 779 million in 2019 (TAHA, 2021a). TAHA is an advocacy and support organisation that is very active in working with government to promote policies favourable to the industry (TAHA, 2021b).

There are no fruit or vegetable AD energy projects operating in Tanzania in the BSEAA2 scale range.

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[18] www.apacweb.org.za/

[19] TAHA members are categorised as comprehensive members (16) namely large producers, exporters and processors of horticultural products, allied members (26) include suppliers of agro-inputs and other service providers in the industry including financial and credit providers, consultancy companies, business development service providers and, finally, associate members (677), which include smallholder farmer groups and associations and individuals taking part in horticultural activities (www.taha.or.tz/).

Uganda: Uganda has a favourable climate, fertile soils and good rainfall for producing a number of fruits and vegetables. The sector is dominated by smallholders, with production widely dispersed from west to east across the country's southern half. The sector is one of the largest contributors to GDP, with most fruits and vegetable consumed locally. Fruit and vegetable processing is limited in Uganda (Dijkxhoorn et al., 2019) .

Most exporters supply international ethnic markets, focusing on specific fruits and vegetables for the Asian and African diaspora in Europe, North America and the Middle East (ibid.). As with Rwanda (and other East and Southern Africa BSEAA2 target countries), Uganda has benefited significantly from trade liberalisation under the East African Community and COMESA. Exporters are particularly active and the Uganda Fruits and Vegetables and Exporters Association is their biggest international promoter. The Uganda Flowers Exporters Association is a non-profit organization established in 1993 as an umbrella organization to bring together stakeholders in the flower industry in Uganda. It is mainly an advocacy and capacity-building association (Uganda Flowers Exporters Association, n.d.).

However, there are currently no operational AD-based CHP installations in Uganda's horticulture sector.

Zambia: Despite favourable agro-ecological conditions for domestic production, Zambia imports significant quantities of fruits and vegetables, primarily from South Africa's thriving horticultural sector. The country has about 1.5 million smallholder farmers who engage primarily in small-scale production for local consumption (African Centre for Biodiversity, 2015).

However, over the past ten years, Zambia's exports of fruit and vegetables has been growing, particularly within the SADC and COMESA trade areas. The Zambia Export Grower's Association (ZEGA) was formed in 1984 as a non-profit association to promote the interests of all growers wishing to export fresh horticulture produce (ZEGA, n.d.). With the influx of large-scale Zimbabwean farmers over the past 20 years, high quality fruit and vegetable production and exports have grown, particularly through the efforts of ZEGA. The Organic Producers and Processors Association of Zambia is a dynamic, successful group of several hundred farmers set up in 1999 as a body affiliated to the Zambian National Farmers Union (OPPAZ, n.d.).

The Rural Energy Agency/Fund, with support from the World Bank and Swedish aid, in particular, have made grid-extension to high value crop areas a top priority through Zambia's aggressive Rural Electrification Master Plan (Ministry of Energy & Water Development, 2019). This is part of the Government's growing focus on improving infrastructure for large agriculture operations, particularly in the horticulture sector, seeking to take advantage of free-trade agreements with SADC and COMESA that have 'levelled the playing field' considerably, particularly with South Africa and Kenya

There are currently no operational fruit or vegetable AD-based energy plants operating in Zambia.

5.7.3 Potential for replication of Kenya's AD experience in the fruit and vegetable sector

Given Kenya's limited success with horticultural residue-based bioenergy, even with its enormous horticultural export and processing facilities, the enabling environment has not been conducive to promoting horticulture-based bioenergy, specifically AD. There are many reasons for this, including low FiTs, poor electricity infrastructure in many rural areas and high duties on imported equipment for the bioenergy sector, as well as lack of tax relief.

It should be noted that these same factors apply in most other target SSAs. However, in South Africa, which comes closest to Kenya in terms of private investment in horticulture AD, a weak grid in many areas represents an opportunity for electricity sales to the grid. However, the electricity policy framework in South Africa is in a state of major, positive change for small-scale generators (100 kW plus). New legislation offers generators with the ability to supply 100 kW or more the possibility to wheel electricity via the grid to willing customers, if grid conditions permit. It is not clear how open Eskom will be towards supporting horticulture-based AD electricity generators in this range, but the regulatory regime is in a period of encouraging transition that could likely support such sales.

In Uganda and Tanzania, two other target SSA countries with strong and growing horticultural sectors, electricity policy is non-supportive at the scale of generation that horticultural AD investments could realistically generate. Uganda has not approved any new FiTs for larger renewable energy-based electricity generation since early 2019.[20] Tanzania's energy regulator and national electricity utility (TANESCO) are also unwilling to sign PPAs with FiTs that would encourage investment in AD electricity generation, except in exceptional circumstances (e.g. island grids where TANESCO depends upon expensive diesel generation).

Ethiopia's Government provides a supportive regime for horticulture, which is highly centralised, served with good infrastructure (roads, electricity, water) and lies within several hundred kilometres of the capital city and main airport. With good electricity and sewerage infrastructure, however there is little incentive for horticulture producers to develop AD for energy generation from waste/residue treatment.

[20] While there is still a Uganda FiT programme supported by the REA/REF, it is understood that all FiT contracts awarded since 2019 have been for small, off-grid renewable energy projects, almost exclusively based on solar PV, for households, clinics, hospitals, schools, community water pumping and small commercial enterprises. All the large FiT projects under the REFiT programme were closed out in 2019 after the Get.FiT project exceeded its targets for new renewable electricity projects.

6 SUMMARY AND CONCLUSIONS FOR REPLICATION

Based on the analysis of Bioenergy Case at Olivado and its wider replication potential, a multi-criteria analysis (MCA) was carried out to summarise the degree to which each of the study's five thematic strands are conducive or detrimental to the successful adoption of bioenergy in the horticulture sector (DS5) in Kenya. The results are presented in Figure 6.1, with a low score indicating an impeding factor and a high score indicating an enabling factor (see Appendix 5 for scoring details).

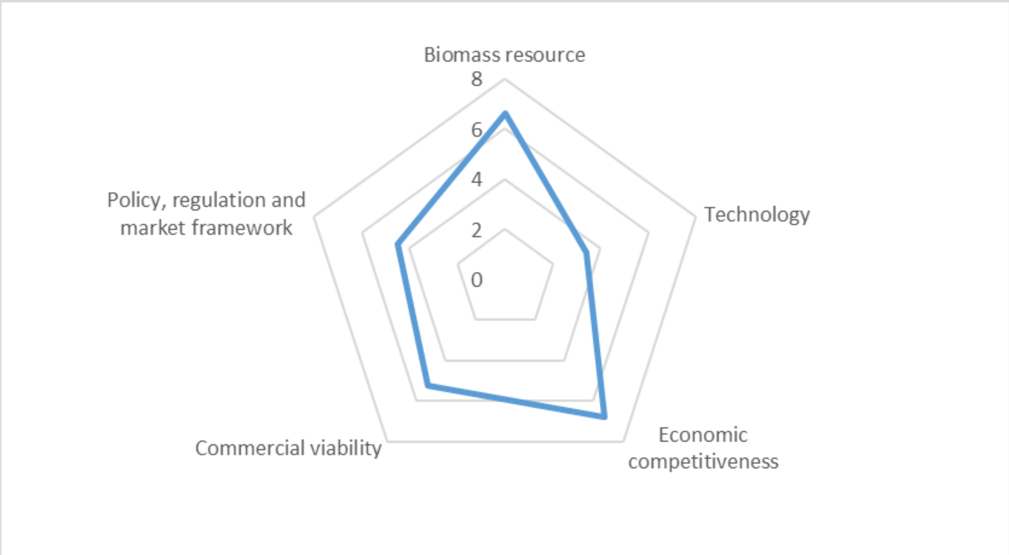

Figure 6.1: Impact of key factors on wider adoption of Bioenergy Case

Kenya has a large and diverse horticulture industry, including an important export sector that supports significant employment and value addition. Large quantities of residues are generated during grading, cleaning and processing of fruits and vegetables. While solid residues are generally composted and returned to the land or fed to livestock, liquid residues can create disposal problems and present an opportunity for AD as a waste management solution, e.g. in mango, pineapple and avocado (oil) processing. Despite great potential for using such residues for bioenergy for CHP at commercial scale, and a strong regulatory framework for small-scale electricity generation, only a handful of processors in niche sectors have installed commercial-scale AD systems to generate heat and electricity from these feedstocks, which include wastes from both floriculture and from fruit and vegetable processing.

Resource assessment indicates that availability and access to suitable horticultural residues is generally not a bottleneck to wider adoption of AD in fruit and vegetable processing enterprises in Kenya that generate liquid effluents and moisture-rich residue streams. The potential is highest in centralised facilities in rural areas that require both a cost-effective waste management system and an energy supply option, where they are dependent upon relatively unreliable and expensive grid electricity. While there is theoretical potential for using wastes from local fruit and vegetable markets for AD, unclear ownership and lack of aggregation hampers the opportunity for conversion to bioenergy. While the Kenyan horticultural sector has been slow to adopt AD, the assessment indicates potential to expand capacity from processing residues, particularly within the pineapple, mango and avocado (oil) sub-sectors, although this potential is lower for mango processing, given its lower waste production and biogas yields. Existing uses for residues need careful consideration, so as not to negatively impact the return of nutrients and organic matter to fields, irrigation or livestock.

An assessment of technology supply chains, on the other hand, indicates that technology selection, sourcing and operation are a constraint to wider adoption of AD in Kenya's horticulture sector. Where there is a requirement for generating electricity on site, solar power is seen as a cheaper and more reliable substitute for diesel generators, to complement grid electricity. But for certain types of processing that need a reliable supply of heat, AD may offer a solution. Technological barriers to wider adoption include the high cost and operational sophistication of biogas technology. Olivado's experience indicates that these challenges can be overcome through adaptation and localisation of technology to reduce costs, and on-the-job training of staff to build competency for installing and operating such technologies. This may be a daunting challenge for potential adopters and speaks to a need for experienced technology developers to offer an outsourced package of customised technology and a management team to operate and maintain the facility on behalf of the investors or owners.

The economic assessment demonstrates the high economic viability of investing in a plant with similar processing and waste management requirements as Olivado. The key factors contributing to its economic success are the significant onsite demand for heat and power, and the company's success in building an AD system cheaply (compared with turnkey European AD systems of similar size and performance), avoided liquid waste disposal costs and the ability to valorise multiple outputs (e.g. from the potential sale of digestate as a fertiliser and the bottling of biogas as vehicle fuel). Sensitivity assessments indicate that the Bioenergy Case would be viable for any CAPEX below USD 5,110 per kW of installed capacity (compared with around USD 3,300/kW for the Olivado facility).

From a **commercial perspective**, there **can be a case for wider adoption of AD** based on the experiences of Olivado. However, a number of barriers are holding back deployment in the Kenyan horticulture industry. Few processors have large onsite energy demands and where these demands do exist, solar PV is likely to represent a cheaper 'turnkey' option than AD. Many fruit and vegetable processors (such as mango or potato processing companies) are also located close to Nairobi and other urban centres where access to reliable electricity is not a constraint. While waste disposal can be a challenge and hence an opportunity for AD, it is often not seen as a critical cost factor. The standard industry solutions are to compost solid wastes and to treat liquid wastes before safe discharge (though this may be sometimes difficult in urban settings). Securing finance is another bottleneck for many developers owing to the low or non-existent familiarity of local banks with commercial-scale AD projects. In order to build confidence in the market, some form of external validation, cost-sharing or guarantee scheme is likely to be required, if AD projects are to obtain financing from local institutions in Kenya.

A key barrier to wider adoption of AD within the fruit and veg industry in Kenya is the unattractive policy and regulatory framework for electricity generation and supply at the FiT of USD 0.10/kWh for projects with a generating capacity of 200 kW to 10 MW.

This FiT has failed to stimulate significant investment from horticultural producers. Moreover, Kenya Power lacks the incentives to invest in upgrading its distribution infrastructure to handle new electricity generated from rural generators to feed into the grid, further disincentivising investment into AD based power generation. While the recent exemption of biogas and pre-fabricated biodigesters from VAT, is a step in the right direction, high import duties on AD equipment (such as engines, pumps, valves, gas membranes and monitoring systems) is still a major impediment to such investments. Simply put, Kenya's electricity policy, regulatory, tax and institutional environment provides very little incentive to invest in horticulture-based AD, even for own consumption.

The replication potential of horticultural residue-based AD in other target countries exists but is currently untapped. This is because many of the limiting factors identified in Kenya, such as very low electricity feed-in tariffs, poor electricity infrastructure in many rural areas, high duties on imported bioenergy equipment and a lack of tax relief, also exist in many of the other target countries with significant horticulture sectors, such as Uganda, Tanzania and South Africa. Ethiopia on the other hand does provide an overall more supportive regime. However, its horticulture sector is highly centralised, served with good infrastructure (roads, electricity, water) all within several hundred kilometres of the capital city, thereby limiting the incentive for investing in electricity generation.

In sum, there is a largely untapped opportunity for AD-based bioenergy generation in the horticulture sector in Kenya, and the flagship project at Olivado demonstrates potential for improving the commercial case in other sub-sectors. Local technology developers should be supported to continue developing cost-competitive alternatives to imported AD technology and the Government of Kenya should double its FiT for biogas-derived electricity, with the energy regulator (the EPRA) making this a priority. Furthermore, the Ministry of Energy and the EPRA should require Kenya Power to 1) prioritise developing biogas electricity PPAs; 2) put in place the mechanisms for doing so; and 3) strengthen the grid to improve reliability of supply and grid export. Stricter enforcement of waste treatment and disposal regulations by the National Environment Management Authority (NEMA), together with minimization or removal of duties on import of biogas equipment, could further help boost the attractiveness of AD in Kenya's horticulture sector.

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Appendix 2: People consulted

Organisation	Name	Position	Mode of contact
AAA Growers	Neville Ratemo	Group Operations Director	Call
Agriculture and Food Authority	Benjamin Tito	Managing Director, Horticultural Crops Directorate	Call
Agricultural and Livestock Research Organization	Dr. Lusike Wasilwa	Director Crop Systems, Horticulture Research Institute	Call
Electricity and Petroleum Regulatory Authority	Caroline Kimathi	Acting Director Electricity	Call
	Nickson Bukachi	Senior Renewable Energy Officer	Call
	Fenwicks Musonye		Call
Delegation of German Industry and Commerce for Eastern Africa (AHK)	Thilo Gabriel Vogeler	Former project manager	Call
	Valerie Leisten	Current project manager	Call
Fresh Produce Exporters Association of Kenya (FPEAK)	Apollo Owuor	Chairman	Call
	Boniface Mulandi	Director, Training, Standards & Compliance	Call
Kenya Horticultural Exporters	Shamal Patel	COO	Call
Kenya Horticulture Council	Josephine Songa	Coordinator	Call
Mara Farming Group	Franz Swanepoel	CEO	Call
Ministry of Agriculture, Livestock, Fisheries and Co-operatives	Joshua Oluyali	Head of Horticulture Division	Call
National Environment Management Authority	Annastacia Vyalu	Plastics and Waste Management Compliance Officer	Call
	Kennedy Odhiambo	Research and Planning Officer	Call
Olivado Biogas Africa Ltd	Hannes Muntingh	Project Manager	Call
Renewable Energy Directorate, Ministry of Energy	JJ Gitonga	Deputy Director for Renewable Energy & Biogas	Call
	Eng. Kihara Mungai	Principal Renewable Energy Officer & FiT Specialist	Call

Appendix 3: Assumptions in biomass resource assessment

The country-specific residual biomass potential was calculated based on amount of crop or primary product generated, the residue-to-product ratio, the recoverable fraction and the fraction of biomass available, considering other uses:

$$BMP=Cp*RPR*RF*OF$$

Where:
BMP = available residual biomass in tonnes per year
Cp = crop production in tonnes per year
RPR = residue-to-product ratio in tonnes of residues per tonnes of product
RF = recoverable fraction per tonnes of product
OF = biomass fraction available after considering other uses per tonne of product

The theoretical bioenergy potential of this biomass resource was calculated considering the available residual biomass and its energy content.

$$BEP= BMP*(1-MC)*HHV$$

Where:
BEP = bioenergy potential in GJ
BMP = available residual biomass in tonnes per year
MC = moisture content
HHV = higher heating value in GJ per tonne

Biomass resource assessment

Crop	Feedstock	Production of crop (t) [1]	Area of crop (ha/yr) [1]	Total biomass (t)	Recoverable fraction	Biomass potential (t wet basis)	Biogas potential (m3/t fresh matter) [8, 9]	Biogas potential (Nm3)	Moisture content as received (wt%) [2, 3, 4, 5, 6, 7, 8]	Volatile matter (wt%) [2, 3, 4, 5, 6, 7, 8]
Pineapple	Pineapple processing residues incl wastewater	349,431	9,757	1,022,086	0.2	204,417	60	12,265,028	90	79
Mango	Mango processing residues incl wastewater	775,230	50,737	189,931	0.5	94,966	60	5,697,941	70	75
Vegetables, fresh	Fresh vegetables residues	4,278,853	78,557	85,577	0.5	42,789	60	2,567,312	90	85
Fruit, fresh	Fresh fruit residues	3,346,674	11,008	66,933	0.5	33,467	60	2,008,004	90	85
Potatoes	Potato processing residues	1,870,375	217,315	37,408	0.5	18,704	60	1,122,225	85	77
Avocadoes	Avocado processing residues incl wastewater	233,933	14,497	7,954	1.0	7,954	90	715,835	83	95

Biomass resource assessment (continued)

Crop	Feedstock	Production scale	Current use	Existing supply chain	Mobilisation
Pineapple	Pineapple processing residues incl wastewater	Large scale (dominant) & small scale	Water from processing treated and used for irrigation, solid waste given to locals as animal feed, some composted and returned to fields	yes	Utilisation as part of processing supply chain
Mango	Mango processing residues incl wastewater	Small and large scale	Water from processing treated disposed, solid waste composted and returned to fields	yes	In the case of small-scale processing lacking infrastructure and resources for collection and transport. More feasible in large-scale commercial processing
Vegetables, fresh	Fresh vegetables residues	Small and large scale	Solid waste composted and given to locals as animal feed. Lots of residues outside control of processors, traders	yes	In the case of small-scale processing lacking infrastructure and resources for collection and transport. More feasible in large-scale commercial processing
Fruit, fresh	Fresh fruit residues	Small and large scale	Solid waste composted and given to locals as animal feed. Lots of residues outside control of processors, traders	yes	In the case of small-scale processing lacking infrastructure and resources for collection and transport. More feasible in large-scale commercial processing
Potatoes	Potato processing residues	Small and large scale	Solid waste composted and given to locals as animal feed. lots of residues outside control of processors, traders	yes	In the case of small-scale processing lacking infrastructure and resources for collection and transport. More feasible in large-scale commercial processing
Avocadoes	Avocado processing residues incl wastewater	Small and large scale	Solids and liquid waste disposed or composted; some already used for biogas	yes	Utilisation as part of processing supply chain

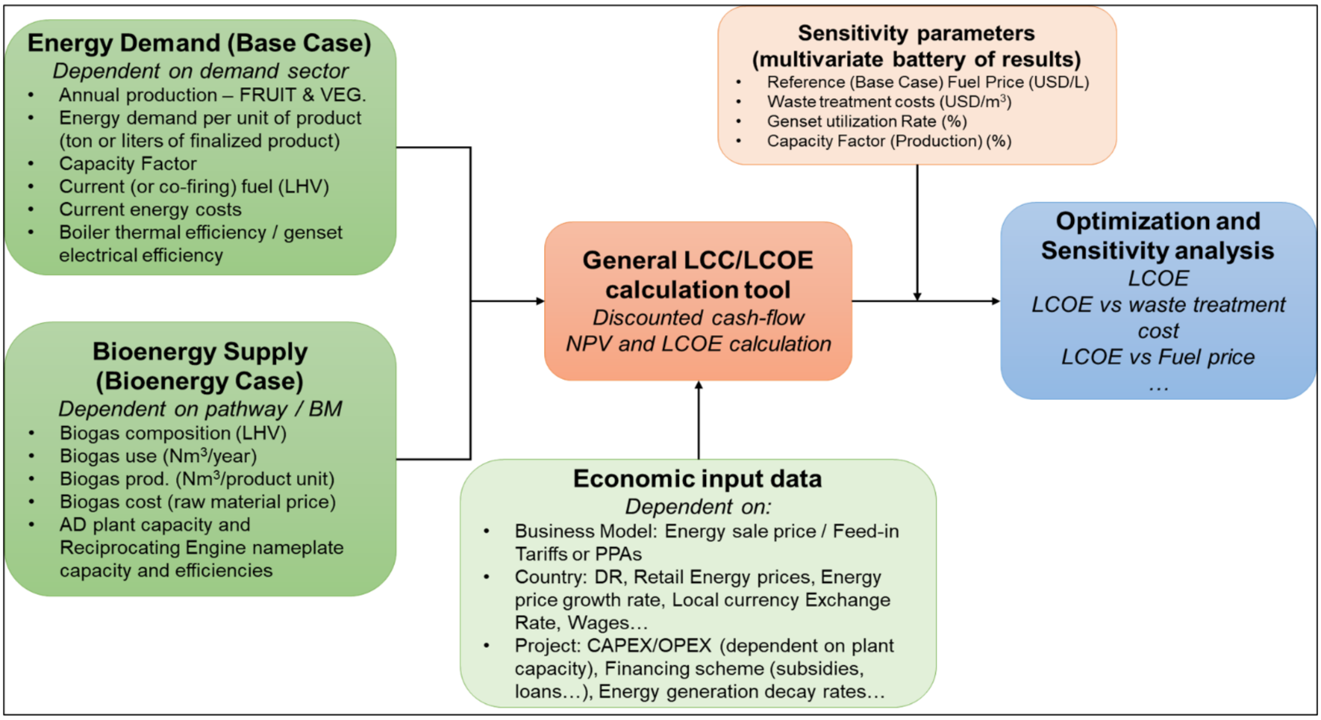
Residue-to-product ratios (RPR)

Crop	Residue type	RPR	Note
Pineapple	Pineapple processing residues incl wastewater	0.5 19	50% of fruit are residues in the case of juicing and canning [10, 11] 19 m3 waste water per tonne of processed fruit [10, 11]
Mango	Mango processing residues incl wastewater	0.45 2	45% processing residues including peels, fibre, stone [12] 1.5-2.5 m3 waste water per tonne of processed fruit [12]
Vegetables, fresh	Fresh vegetables residues	0.2	10-40% residues/waste from processing/packaging fresh vegetables [13, 14]
Fruit, fresh	Fresh fruit residues	0.2	10-40% residues/waste from processing/packaging fresh vegetables [13, 14]
Potatoes	Potato processing residues	0.2	20-28% processing residues [14]
Avocadoes	Avocado processing residues incl wastewater	0.9	10-15% of fruit are oil, rest residues after extraction [8, 15] 0.4-1 m3 waste water per tonne of processed fruit [8, 15]

1 (FAO, 2021a); 2 (TNO, 2021); [3] (Adeniyi et al., 2019); [4] (Bharath et al., 2020); [5] (Inna et al., 2015); [6] (Liang et al., 2015); [7] (Jorge et al., 2015); [8] H. Muntingh, personal communication, 5 September 2020; [9] (LfL, 2021); [10] (Sukruansuwan & Napathorn, 2018); [11] (Eight-Japan Engineering Consultants, 2010); [12] (Maisuthisakul, 2009); [13] Project field notes; [14] (IRENA, 2018); [15] (Costagli & Betti, 2015).

Appendix 4: Life-Cycle Cost toolkit functions

A flow diagram of AIGUASOL's Life-Cycle Cost (LCC) modelling toolkit functions is provided below:



The main economic indicator considered is the Levelized Cost of Energy (LCOE), in USD/MWh:

$$LCOE = \frac{\sum_{t=1}^{n} \frac{C_t}{(1+DR)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+DR)^t}(1+IR)^t}$$

Where: C_t = costs incurred in year t
DR = discount rate
E_t = energy consumed in year t
IR = annual inflation rate

Appendix 5: Energy requirements in pineapple and mango processing

Process flow and energy requirements for mango canning (Source: (Masanet et al., 2008))

Mango canning	kWh/tonne product		
	Steam	Hot water	Electricity
Sorting	0.0	0.0	34.9
Washing	0.0	140.2	4.5
Peeling	0.0	0.0	4.5
Cutting/slicing	0.0	0.0	7.8
Cooking	129.2	0.0	0.0
Can filling	0.0	0.0	6.5
Can exhausting	64.6	0.0	0.0
Can sealing	21.3	0.0	6.5
Cooling	0.0	0.0	4.5
Heat sterilisation	140.2	0.0	0.0
Totals:	355	140	69

Process flow and energy requirements for pineapple canning (Source: (Masanet et al., 2008)

Pineapple canning	kWh/tonne product		
	Steam	Hot water	Electricity
Sorting	0.0	0.0	34.9
Washing	0.0	140.2	4.5
Peeling	0.0	0.0	6.5
Coring	0.0	0.0	6.5
Cutting/slicing	0.0	0.0	7.8
Cooking	129.2	0.0	0.0
Can filling	0.0	0.0	6.5
Can exhausting	64.6	0.0	0.0
Can sealing	21.3	0.0	6.5
Cooling	0.0	0.0	4.5
Heat sterilisation	140.2	0.0	0.0
Totals:	355	140	78

Process flow and energy requirements for mango juicing (Source: (Masanet et al., 2008))

Mango juicing	kWh/tonne product		
	Steam	Hot water	Electricity
Inspection and grading	0.0	0.0	3.2
Washing	0.0	140.2	4.5
Pulping	0.0	0.0	4.5
Deaeration	0.0	0.0	33.6
Heat sterilisation	140.2	0.0	0.0
Can washing (juice)	0.0	140.2	0.0
Can filling	0.0	0.0	6.5
Can sealing	21.3	0.0	6.5
Heat sterilisation	140.2	0.0	0.0
Cooling	0.0	0.0	4.5
Packaging	0.0	0.0	9.7
Totals:	302	280	73

Process flow and energy requirements for pineapple juicing (Source: (Masanet et al., 2008))

Pineapple juicing	kWh/tonne product		
	Steam	Hot water	Electricity
Inspection and grading	0.0	0.0	3.2
Washing	0.0	140.2	4.5
Peeling	0.0	0.0	6.5
Pulping	0.0	0.0	4.5
Deaeration	0.0	0.0	33.6
Heat sterilisation	140.2	0.0	0.0
Can washing (juice)	0.0	140.2	0.0
Can filling	0.0	0.0	6.5
Can sealing	21.3	0.0	6.5
Heat sterilisation	140.2	0.0	0.0
Cooling	0.0	0.0	4.5
Packaging	0.0	0.0	9.7
Totals:	302	280	79

Appendix 6: Perspectives of other horticulture companies in Kenya

Kenya Horticultural Exporters (KHE) cultivate 4,000 acres at three sites and around 500 out-growers and three packhouse facilities. They produce ~10 t/day of fruit and vegetable processing residues, which is trucked to their Nanyuki farm and composted. Wastewater goes into the sewage system at their Nairobi packhouse, or into sump pits at the farms. Their largest power demands are for water pumping (at the farms) and cooling (at the packhouses). They have diesel gensets for standby power and are installing 1.2 MW of solar PV capacity across their operation. They have no major heat requirements. They are familiar with AD but were discouraged after hearing that VegPro (Naivasha) were operating their system at low capacity due to feedstock shortages (unverified). So although KHE generate significant quantities of waste suitable for AD, these residues are safely disposed of by composting. Their power needs are meanwhile being supplemented by their new solar systems. They might consider AD if a significant heat demand was to arise in the future, or if NEMA deemed their disposal arrangements for wastewater unsatisfactory or if a more attractive FiT became available with a minimum of red tape.

AAA Growers cultivate ~700 ha at four sites for fruits, vegetables and flowers, mainly for export. The main site of interest for AD is Hippo Farm near Thika, where the feasibility of biogas was explored in 2013 (Muntingh & Albertsson, 2013). Hippo Farm covers 100 ha, of which 10 ha is under cover, and has an on-site packhouse. Waste comprises vegetable rejects and offcuts, which are composted and returned to the land. The 2013 study estimated 8-9 t/day of solid wastes in the low season and 12-13 t/day in the high season. Additional liquid wastes from the flume, wash tanks and spinning operation enter a wetland filtration system and eventually discharge into a pond, monitored by NEMA-certified auditors. A drip irrigation system is the largest power consumer, followed by cold storage and processing machinery. There is no requirement for heat. The 2013 study estimated annual power demand of 1,100 MWh for the processing plant and 730 MWh for the irrigation system, of which a biogas plant could have supplied 560 MWh (30%), to supplement the grid plus two standby diesel generators. Several companies have approached them offering solar PV solutions, but the payback period is too long and the solutions have seemed complex. Kenya Power is increasingly unreliable and is felt to be exploiting its monopoly position and companies do want alternative forms of energy, but require turnkey solutions that actually work. Prospects for biogas at AAA Growers are limited, as their residues already have satisfactory disposal solutions. The absence of viable grid feed-in options and the lack of on-site heat requirements also remove the 'pull factor'.

Mara Farming Group cultivate 400 ha at three sites and buy vegetables from around 400 out-growers. They export ~100 t/week of prepared vegetables. Waste is generated both at the farms and at a Nairobi packhouse, where residues are perhaps 40 t/week. It is assumed that the solid wastes are trucked to a dump site and liquid wastes go into the urban sewage system. Power demands are mainly for irrigation at the farms and for cold storage and processing machinery in Nairobi. There are no heat or steam requirements. The company management are broadly familiar with biogas, but the opportunity is constrained by the limited space at the Nairobi plant (in an urban EPZ) and the difficulties of securing a PPA and viable FiT from Kenya Power.

Appendix 7: Multi-Criteria Analysis input data

Criteria	Score	Scoring criteria (Min=1)	Scoring criteria (Max=10)
Biomass			
Availability	7	low	high
Seasonality	9	short	long
Aggregation	6	scattered	centralised
Proximity	5	far	close
Technical feasibility	6	low	high
Average	**7**		
Technology			
Technology track record in same sector	4	low	high
Availability of a turnkey technology solution	3	limited	well established
Ease of operation and maintenance with in-house capacity	3	limited	well established
Supplier reputation, engagement and partnership	4	not engaged	engaged
Access to technical support & spares	3	low	high
Average	**3**		
Business model			
Energy self-consumption drivers	6	limited	significant
Grid and 3rd party export drivers	4	limited	significant
Waste disposal drivers (based on cost for disposal)	6	limited	significant
Market potential (replicate business model)	5	low	high
Average	**5**		
Policy, regulation and market			
Bioenergy policy	4	unsupportive	supportive
Bioenergy policy implementation	2	not implemented	implemented
Agriculture/Forestry policy	7	unsupportive	supportive
Agri/Foresty policy implementation	7	not implemented	implemented
Demand sector specific policy	3	unsupportive	supportive
Environmental policy	5	unsupportive	supportive
Environmental policy implementation	4	not implemented	implemented
Technology-specific fixed price (e.g. FIT)	3	unattractive	attractive
Demand sector specific governance practice	4	weak	strong
Biomass/processing specific governance practice	6	weak	strong
Average	**5**		
Cost			
LCOE electricity total	7	cost increase	cost reduction
LCOE electricity Capex	1	cost increase	cost reduction
LCOE electricity OPEX non-fuel	9	cost increase	cost reduction
LCOE electricity OPEX fuel or electricity	10	cost increase	cost reduction
Average	**7**		

Appendix 8: Photos of Olivado AD plant, Kenya

Waste avocado stones & skins
(Matthew Owen)

Timber formwork for casting the digester walls
(Hannes Muntingh)

Twin digesters and gasholder control room
(Hannes Muntingh)

Gas purification and bottling plant
(Hannes Muntingh)

Containerised generator unit
(Hannes Muntingh)

Exhaust heat exchanger, buffer tank and emergency cooler
(Hannes Muntingh)