Bioenergy for Sustainable Local Energy Services and Energy Access in Africa

Demand Sector Report 3: Wood Processing
Focus Country: Tanzania

SEPTEMBER 2021

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Cover photo: Combined heat and power plant at Tanganyika Wattle Company, Njombe. Tanzania. Credit: Emmanuel Michael Biririza.

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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 third in the series, focuses on the bioenergy opportunities in the wood processing sector in Tanzania.

Tanzania has East Africa's most extensive forest resources and some of the region's largest plantation management and wood processing companies. Only two of these currently use wood processing residues for CHP to meet their internal electricity and heat demands and sell excess electricity to the grid. Others use their residues only to generate heat for wood drying. Given the availability of suitable feedstock and the environmental benefits that adoption of bioenergy could offer for this sector, the landscape for residue-based CHP use in Tanzania's wood processing industry was explored to identify the opportunities and barriers for wider adoption.

Biomass resources and technological considerations were not found to be barriers to the adoption of wood-residue based CHP. There is significant underutilised biomass potential from wood processing residues, and supply is expected to increase as the industry continues to grow. With respect to technological considerations, biomass boilers and steam turbines are a proven combination at 1-5 MW scale, with several (mainly Asian) suppliers providing equipment of quality and cost that now out-compete European and North American manufacturers.

Economic analysis suggests that combustion-based CHP is cost-competitive if an enterprise has significant internal heat demand. But it is not necessarily attractive if electricity is the main requirement of the enterprise, unless surplus electricity can be valorised through external sale.

Besides the two current adopters of CHP, other wood processing industries in Tanzania have therefore refrained from investing in CHP. A combination of low internal heat and power demand, relatively cheap and relatively reliable grid power, low feed-in-tariffs and a government focus on large-scale hydropower, discourage new investments in bioenergy technology. Except in South Africa, the policy and market environments in the other countries researched do not favour investment in wood residue-based bioenergy, beyond the direct production of heat for processing timber.

In sum, electricity generation from wood residues has the potential to develop strong rural embedded generation, support sustainable local development and reduce demand for fossil fuels for electricity generation to meet climate change targets. However, replication in Tanzania under current political and economic circumstances is unlikely unless there is practical government support for bioenergy, particularly from more attractive feed-in tariffs and long-term power-purchase agreements.

CONTENTS

LIST OF ACRONYMS

ABEX	Abandonment expenditure
AD	Anaerobic digestion
BSEAA	Bioenergy for Sustainable Local Energy Services and Energy Access in Africa
CAPEX	Capital expenditure
CDC	Commonwealth Development Corporation
CHP	Combined Heat and Power
EWURA	Energy and Water Utilities Regulatory Authority
FBD	Forestry and Beekeeping Division
FiT	Feed-in Tariff
G&I	Gender and Inclusion
IPP	Independent Power Producer
KVTC	Kilombero Valley Teak Company
LCC	Life Cycle Cost
LCOE	Levelized Cost of Energy
MCA	Multi-Criteria Analysis
MEB	Mass Energy Balance
MPM	Mufindi Paper Mills
NEMC	National Environment Management Council
OPEX	Operational expenditure
PPA	Power Purchase Agreement
REA/F	Rural Energy Agency/Fund
SHI	Sao Hill Industries
SPP	Small Power Producer
SSA	sub-Saharan Africa
TANESCO	Tanzania Electric Supply Company
TANWAT	Tanganyika Wattle Company
TEA	Transforming Energy Access
TEDAP	Tanzania Electricity Development and Access Project
TFS	Tanzania Forest Services Agency
TREEP	Tanzania Rural Electrification Expansion Programme
TZS	Tanzanian Shilling
URT	United Republic of Tanzania
USD	United States Dollar

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_e to 5 MW_e, 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 third in the series, focuses on the bioenergy opportunity in the wood processing sector in Tanzania.

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 wood processing sector are defined in Table 2.1.

Table 2.1: Base Case and Bioenergy Case for the wood processing sector

Base Case	Bioenergy Case
Wood processing facilities that meet their heat requirements from combustion of wood processing residues and their electricity requirements from grid supply.	Wood processing facilities that meet both their heat and electricity requirements from combustion-based CHP technology. **Flagship project: Tanganyika Wattle Company, Njombe, Tanzania**

This report analyses the Bioenergy Case flagship project across the six 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 assessment employed web-based reviews and interviews with government, private sector and NGO informants working in bioenergy in Tanzania. The team examined the institutional, policy, regulatory, market and finance framework for forestry, wood processing, wood energy, electricity and heat. Interviews were conducted with representatives of the Tanzania Forest Services Agency, the Rural Energy Agency, the Tanzanian Electricity Supply Company, the Energy and Water Utilities Regulatory Authority and the Ministry of Energy's Renewable Energy Directorate, on the government side, and with the CEOs or MDs of Kilombero Valley Teak Company, Kisiwa Farming, Sao Hill Industries and others in the private sector. Two visits took place to the Tanganyika Wattle Company (TANWAT), as the Bioenergy Case flagship project for this demand sector. Discussions were also held with the Embassy of Finland, which has supported forestry in Tanzania since the 1970s.

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 the relevant feedstocks in each demand sector, in this case wood processing residues. These are defined as woody biomass by-products originating from the wood processing industry (FAO, 2004) and were taken to include wood chip, sawdust, offcuts and debarked logs from the tannin industry. Existing data on forestry and forest 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 crop or primary product generated, the residue-to-product ratio, the recoverable fraction, the fraction available (considering other uses) and its bioenergy potential (see source data in Appendix 3). An MEB model was also 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 preceding assessment of the biomass resource.

2.4 Technology assessment

The technology assessment aimed to determine the technological implications of bioenergy use for heat and/or power production in each demand sector, in this case the wood processing sector in Tanzania, based on technical considerations and practical experiences at the Bioenergy Case flagship project at TANWAT. The TANWAT CHP operation has been widely profiled in the bioenergy literature, being one of the first such facilities in Tanzania. Exploring TANWAT's experiences from a technical perspective also required interaction with company staff through both remote contact and site visits. The technology and its supply chain landscape were characterised, and opportunities and requirements for replication linked to technology were assessed.

2.5 Economic competitiveness analysis

The objective of the economic competitiveness 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 the demand sector. A 10-year discounted cash flow analysis was carried out using an Excel-based Life-Cycle Cost (LCC) modelling toolkit developed by AIGUASOL (see Appendix 4).[1] 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). LCOEs were calculated for both electricity and heat. The 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 outline determine the commercial case for bioenergy use 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 TANWAT was first analysed to identify the elements for commercial success linked, for example, to supply chain ownership, demand for heat and electricity, and other factors such as waste disposal and financing. Information about the operation was obtained from stakeholder interviews and literature review. This was followed by an analysis of the wider commercial potential in the wood processing sector, analysing the barriers and enablers for supplying both heat and power under various scenarios. Taken together with an assessment of market size and conditions, the barrier analysis gave an indication of wider market 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 the gender and inclusion research was to identify G&I-related issues in each demand sector, 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 of the study's five key themes are conducive or detrimental to the 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 factors (non-weighted) under each theme make a positive contribution (high score) or are an impediment (low score) to the viability of the Bioenergy Case. The MCA results are presented in the report's concluding chapter as a multi-point spider diagram, to provide a graphical summary of the factors most likely to support or impede successful adoption of bioenergy in the demand sector in question. The input data for the MCA are in Appendix 5.

[1] 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 wood processing sector

3.1 Sector landscape

Tanzania has some of the most extensive forest resources in East Africa, with around 47 million ha (half of the country's land area) under forest, woodland and bush land (FAO, 2015) (FAO, 2021). Approximately 70% of this area is in productive use, while the rest is protected. Plantations cover only about 280,000 ha, but provide the majority of the country's industrial wood for construction and furniture, poles for housing and electricity distribution, and feedstock for pulp and paper (FAO, 2015). The main species grown are pine (~65%) and eucalyptus (~20%), with rotations of 10-20 years (Unique Forestry & Landuse, 2017).

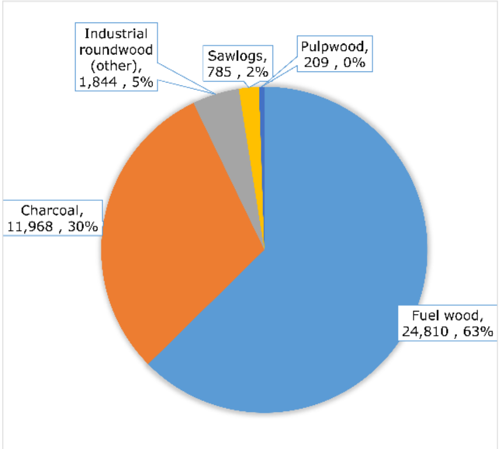

Figure 3.1, Main wood products in Tanzania (kt/yr; % of products) (FAO, 2021)

The breakdown of the main wood products in Tanzania is summarized in Figure 3.1. Woodfuel (fuelwood and charcoal) is dominant, mainly from natural forests and to a lesser extent from plantations, and accounts for close to 93% of production by tonnage, with plantation-grown industrial wood making up the balance.

Figure 3.2. Main wood processing companies in Tanzania (Source: authors' compilation)

Approximately 80% of Tanzania's forest plantations are located in the Southern Highlands, with the largest at Sao Hill covering around 50,000 ha. These areas are home to most of the country's important forest sector companies, which are some of the largest and most successful plantation management and wood processing concerns in the East African region (Figure 3.2).

These enterprises provide substantial rural employment and account for significant foreign exchange earnings. About 60% of plantation area is under small-scale ownership (Unique Forestry & Landuse, 2017) and there are also many small sawmills in the north of the country (e.g. in the Usambara Mountains) and throughout the centre and south.

3.2 Bioenergy in the wood processing sector

Bioenergy is Tanzania's dominant source of energy, accounting for 83% of primary energy consumption, mainly in the form of fuelwood and charcoal for household use, mostly for cooking (Camco Clean Energy, 2014; IEA, 2020; IRENA, 2017). Bioenergy is also used commercially for thermal applications, e.g. bagasse in sugar mills, sawdust in sawmills and processing residues in the sisal, cotton, coffee, cashew, rice and coconut sectors.

Many forest plantations have low yields and produce poor quality wood, but the opportunities to improve yields and diversify products and services are increasingly recognised (Unique Forestry & Landuse, 2017). One option for optimisation and diversification is to develop CHP production based on wood processing residues. CHP commenced at Mufindi Paper Mills (MPM) in 1986, followed by TANWAT in 1995. Two other large wood processing enterprises, Kilombero Valley Teak Company (KVTC) and Sao Hill Industries (SHI), use sawmill wastes to generate heat for wood drying. Kisiwa Farming Ltd. (located on Mafia Island in the Indian Ocean) is developing a small CHP plant to be fuelled with coconut wood from plantations under rehabilitation, as well as sawmill residues.[2] A zoomed-in map of these facilities is in Appendix 6.

Among the numerous other small wood processing facilities, some may be using their residues for heat production, but none are thought to be producing both heat and power. If not used for energy, residues from wood processing are usually given away or sold cheaply as fuel or are dumped or burned. Productive use of the biomass for heat and electricity production therefore brings additional environmental benefits in terms of reduced greenhouse gas emissions (through avoided burning or disposal, avoided use of diesel generators during periods of grid instability or in areas where grid is not available) and more environmentally friendly handling of wastes.

This research explores the current landscape for bioenergy use in Tanzania's wood processing industry, to identify the potential for adoption of CHP within the sector, and the opportunities and barriers for wider adoption. The analysis is grounded in the experiences of TANWAT in Njombe, which is the flagship venture representing the Bioenergy Case for this demand sector.

3.3 Institutional, regulatory and finance framework

3.3.1 Institutional framework for energy and wood processing

The main institutions governing bioenergy in Tanzania are the Ministry of Energy, the Electricity and Water Utilities Regulatory Authority (EWURA), the Tanzania Electric Supply Company (TANESCO) and the Rural Energy Agency/Fund (REA/REF). See Figure 3.3. The Ministry of Energy's Electricity and Renewable Energy Division is responsible for bioenergy policy and strategy. It facilitates the development of new sources of electricity generation such as mini-hydro, wind, geothermal, biomass and solar photovoltaic, for both on- and off-grid networks.

[2] Kisiwa Farming is a joint venture between the owners of Ng'ombeni Coconut Estates Ltd. and EnergiDrop, a South African company, to generate electricity through gasification of coconut wood chips for own use and sale to TANESCO..

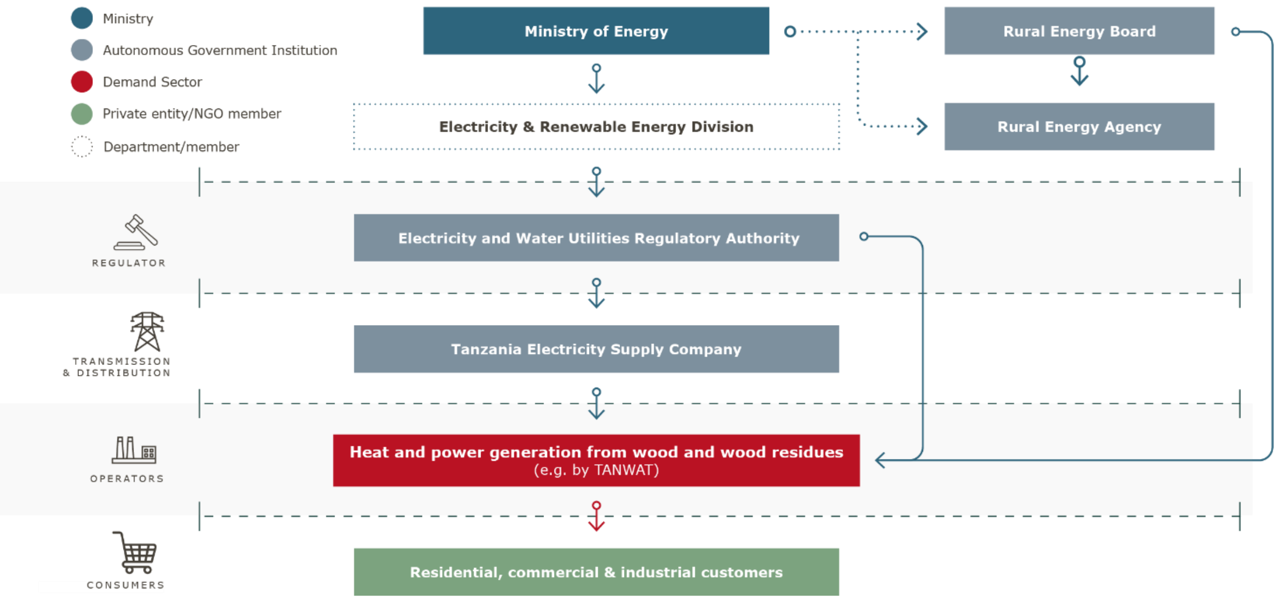

Figure 3.3. Institutional framework for bioenergy in Tanzania (Source: authors' compilation)

Tanzania's wood processing sector meanwhile falls under the Forestry and Beekeeping Division (FBD) of the Ministry of Natural Resources and Tourism, with technical support from the Tanzania Forest Services Agency (TFS), formed under the Executive Agencies Act (URT, 1997), see Figure 3.4. The TFS, together with the FBD's Forestry Utilization Section and Forest Development Section, works with communities and the private sector to support the commercial wood energy sector in forest management, harvesting and utilisation, on both private and state-owned land.

The wood processing sector consists of two main groups:

1) small-scale, informal sector rural wood workers, often operating hand saws or mobile motorised saws, producing timber primarily for local consumption; and
2) larger-scale forestry plantations and processors, often established with international development funding and primarily supplying urban or international markets.[3]

3.3.1 Policy and regulations for wood processing and bioenergy

Forestry: Tanzania's Forest Act (URT, 2002), Forest Regulations (URT, 2017) and Forest Regulations Supplements (URT, 2019b) promote sustainable, commercial forestry through a licensing system for wood processing industries, including sawmilling and forest products. The Forest Act provides the legal basis for the operations of Tanzania's large, plantation-based forestry concerns.

Environment: Tanzania's National Environment Management Council (NEMC) was created by the Environmental Management Act (URT, 2004) and is the paramount agency overseeing and administering environmental laws and policies. While the FBD and TFS focus on silvicultural practices, the NEMC is responsible for ensuring that these activities comply with environmental legislation.

[3] Key examples are TANWAT, established by the British Commonwealth Development Corporation (CDC); KVTC, also established by the CDC, Sao Hills Forest Estates and SHI, established by the Tanzania Government as a joint venture with the Norwegian Government, later Green Resources AS; and MPM, established by a consortium of international donors including the World Bank, the OPEC Fund for International Development and the African Development Bank.

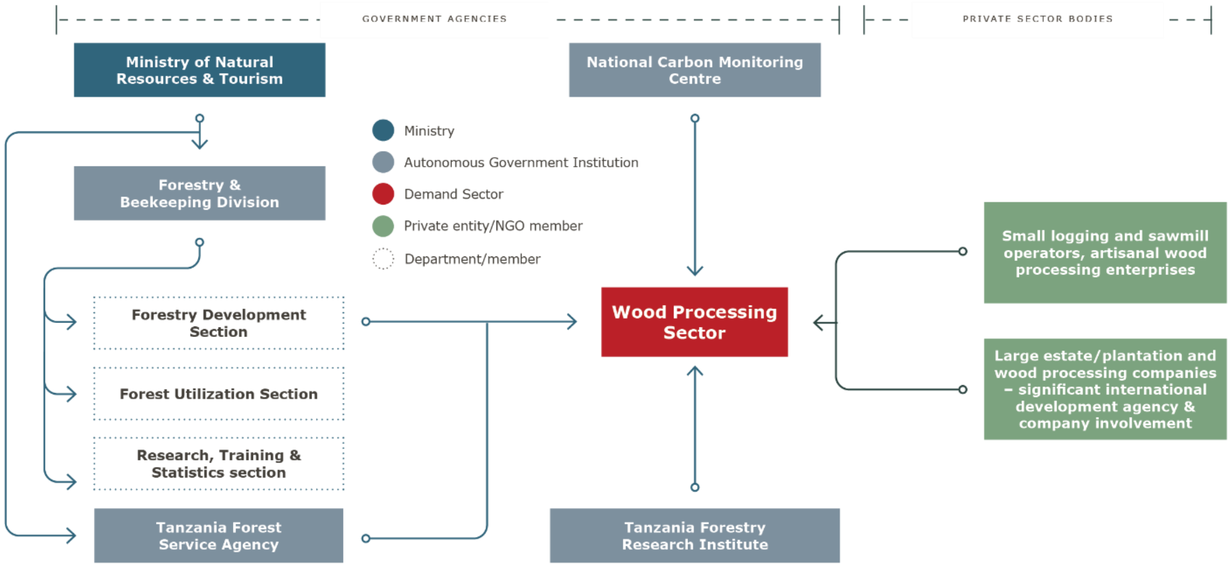

Figure 3.4. Institutional framework for wood processing sector in Tanzania (Source: authors' compilation)

Wood-based bioenergy: Tanzania's National Energy Policy (MEM, 2015) highlights the role of various energy sources in developing the forestry sector, including biomass for power generation. The policy stresses the role of private investment in local energy sources, including bioenergy from wood processing residues.

Electricity: The Tanzanian government embarked upon major electricity sector policy liberalisation and institutional reform during the early 2000s. This started with the passage of the Energy and Water Utilities Regulator Act (URT, 2006), which led to the establishment of the energy regulator, EWURA. The Rural Energy Agency (REA) started operations in 2008 after passage of the Rural Energy Act (URT, 2005). The same Act led to the establishment of the independent Rural Energy Board (REB) to provide oversight of the REA and to approve projects to finance REA activities and projects. The REA (and its Rural Energy Fund/REF, managed by the REB) is a major recipient of World Bank, IFC, AfDB, European Commission, Swedish, Norwegian, US Government (e.g. Powering Africa), and, until recently, UK aid (via FCDO). The FCDO provided REA with funds primarily to finance off-grid renewable energy electricity activities.

The most important development in the electricity sector was the passing of the landmark Electricity Act (URT, 2008), supplemented by the Electricity Rules (URT, 2019a), which brought about liberalisation of the electricity sector to allow independent power producers (IPPs) to participate in electricity generation, distribution and sales. All these built a strong foundation for the National Energy Policy of 2015.

These developments set the framework for unbundling the state-owned TANESCO. For example, the Electricity Act allows EWURA to license independent power generation by Small Power Producers (SPPs) generating less than 10 MW, particularly in the renewable electricity sector. The framework for structuring power purchase agreements (PPAs) and granting licences followed quickly after the Electricity Act became law.

Even though the Act liberalised the electricity sector from a state monopoly to allow the private sector to participate in power generation and electrification, national electricity transmission and the distribution infrastructure and the bulk of electricity generation remain with TANESCO, the state-owned utility, making it the only grid-based off-taker.

3.3.2 Finance

The World Bank's Tanzania Rural Electrification Expansion Programme (TREEP) commenced in 2016 and is administered through the REA. It follows on from the previous World Bank-funded Tanzania Electricity Development and Access Project (TEDAP), which ran from 2008 to 2015. Bilateral development agencies have also provided considerable finance for particular activities of the REA/REF, including grid-connected renewable energy (Sweden), off-grid renewable electricity (UK), technology-focused support (US Power Africa) and TANESCO grid extension and connections (where over 80% of development partner funds have been invested).

Beyond national electricity grid extension, the TREEP (and the earlier TEDAP) provides funds to Tanzanian banks for concessional lending to eligible renewable energy projects, including bioenergy projects. Tanzania has a vibrant financial sector with a number of international banks (e.g. Stanbic, Standard Chartered, Bank of Baroda, CitiBank), national banks (e.g. CRDB, National Bank of Tanzania, Diamond Trust Bank) and development banks, of which only TIB Development Bank and Bank of Baroda have provided finance for bioenergy projects over the past decade. The finance that has come from the Rural Energy Fund (REF) went through TIB Development Bank for one project. Other finance has been concessionary (i.e. donor-financed) for bioenergy projects, including three biomass gasification-hybrid solar projects (non-operational at present) and one small (1.5 MW) wood-fired thermal electricity project on an isolated grid on Mafia Island, which operated for two years (2015-2017).

A developer's own finance and, in the case of imported equipment and machinery, export 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; the US Export-Import Bank; and SACE (Gruppo CDC), Italy's export credit agency; among a number of others, when equipment is sourced from these countries. However, none of these entities have provided finance for Tanzania's bioenergy projects. Only an Indian-Tanzania bank has provided finance for a new generator for an existing 26-year old wood processing plant in Southern Tanzania.

The financing of bioenergy-based electrification has been limited primarily because the feed-in-tariffs (FiTs) that EWURA administers to SPPs are so low that they do not enable small-scale bioenergy projects to be profitable (see Table 3.1 for current FiTs for biomass-fuelled power plants). Commercial lending and finance for bioenergy projects is therefore virtually non-existent.

Table 3.1: Approved FiTs for biomass-based projects in Tanzania (Ministry of Energy, 2019)

Output range (MW)	Feed-in-tariff (US¢/kWh)
0.1 - 0.5	10.15
0.51 – 1	9.34
1.01 – 5	8.64
5.01 - 10	7.60

Despite the availability of TREEP finance for eligible projects through Tanzanian commercial banks, with biomass (bioenergy) FiTs being the lowest of all FiTs, commercial lending to developers of wood-based energy projects has not occurred under the auspices of the TREEP or the previous TEDAP.

4 Overview of Bioenergy Case

4.1 Project summary

The adoption of wood processing residue-based CHP at TANWAT is a flagship project for the adoption of bioenergy technology, and the Bioenergy Case for this demand sector. This successful example can be used to explore the opportunities and constraints facing other wood processing companies considering similar investments.

TANWAT is an integrated forestry plantation and processing company located in Njombe, southwest Tanzania. The company was founded in 1949 by the Commonwealth Development Corporation (CDC) and sold in 2007 to the Rai Group, a Kenya- and Mauritius-based agro-forestry conglomerate.

Production of tannins from the bark of the black wattle tree (*Acacia mearnsii),* also known as mimosa, was TANWAT's main source of revenue until the late 1960s, when a decline in demand for leather goods prompted diversification into other forest product opportunities (Ledoga, 2020). Today, in addition to tannin extract in solid and powdered forms, TANWAT produces eucalyptus power poles, sawn pine timber and pine plywood from its own forest estate, which comprises 13,500 ha of wattle (50%), pine (35%) and eucalyptus (15%).

In 1995, growing internal demand for electricity and a large surplus of residues from its wood processing operations led the company to set up a plant for the cogeneration of process heat and electricity. TANWAT installed Tanzania's second commercial wood-fired power plant, with a capacity of 2.5 MW_e.[4] The plant was initially off-grid and the electricity was used internally for company operations. It was later connected to TANESCO's regional isolated grid serving the Njombe area, to supplement three diesel generators and a small hydro plant (UNIDO, 2009). Njombe eventually became connected to the national grid, and TANWAT is now one of eight SPPs licensed to sell electricity to TANESCO (EWURA, 2019).[5] The company has not sold any power to the grid since 2018, however, due to progressive reduction in power output and planned replacement of the CHP plant in March 2021 with a new 2 MW_e turbine and generator. It is this new CHP plant that forms the flagship project and Bioenergy Case for this demand sector.

The information provided below comes from two site visits (August 2020 and January 2021) and other sources as referenced. A selection of photos is in Appendix 7.

4.2 Technical details

The layout of TANWAT's CHP plant is summarised in Figure 4.1.

[4] MPM installed Tanzania's first wood processing residue-based CHP facility (7 MW_e).
[5] The others being Mwenga (4 MW), TPC (9 MW), Yovi (1 MW), Darakuta (0.24 MW), Tulila (5 MW), Andoya (0.5 MW) and Matembwe (0.5 MW).

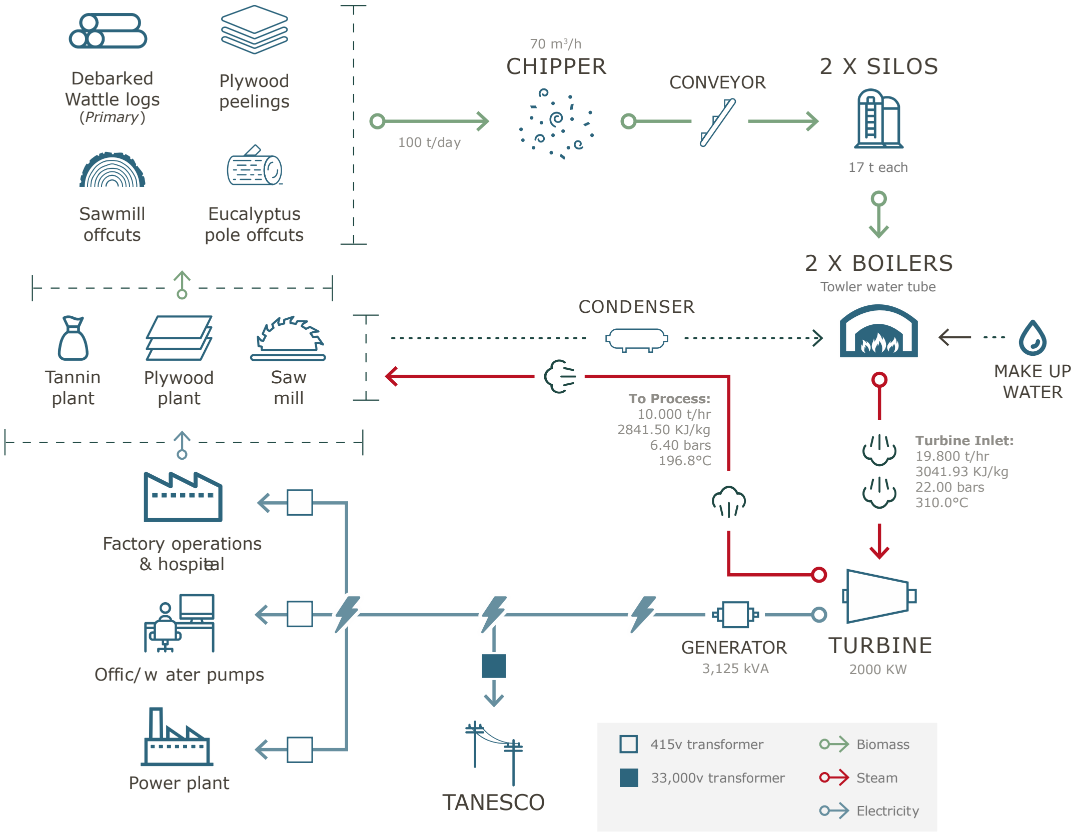

Figure 4.1. Schematic diagram of TANWAT's CHP plant (Source: authors' compilation)

Note: This represents the arrangement after the installation of the new turbine and generator, scheduled for March 2021. In the interim, the plant was operated on a heat-only basis using one boiler at a time, with electricity drawn from the TANESCO grid and back-up diesel generators.

4.2.1 Technology description

Most of the fuel for TANWAT's CHP plant comes from debarked wattle logs, of which the company generates around 60,000 t/yr from its tannin operation. The tannin season runs from late January to early November, with a 2-3 month break during the rains when access to the plantations becomes difficult and the wet bark is harder to strip. The de-barked logs are dried in the plantations for 6-8 weeks before being brought to the TANWAT central yard, where they are stacked and dried further, in readiness for chipping and combustion.

Eucalyptus pole offcuts, plywood peelings and sawmill residues provide supplementary boiler fuel, but make up less than 10% of total supply. Wattle is the preferred feedstock by virtue of its high quality, relative homogeneity and ease of handling. Additional fuel previously came from spent wattle bark and sawdust, but these lightweight materials were too easily blown up the furnace flues and are no longer used.

The logs are chipped to 25 mm using a 70m^3/hr drum chipper from Kloeckner (Germany). The chips are mechanically conveyed to two 17 t storage silos, from where they are gravity-fed to the plant's boilers (RECP, 2014; Ulomi, 2009; UNIDO, 2009). TANWAT has two Towler water tube boilers manufactured by Mechmar Cochran (Malaysia) in 1994, each originally consuming 60-80 t/day of wood chip for a rated output of 15 t/hr of steam at 330°C and 30 bar pressure. Fuel consumption and steam output have both been reduced under the new CHP configuration (see below).

Under the original set-up (1995 to 2018), the steam was split into two streams: superheated steam (30 bar at 200°C) was used to generate electricity via a 2.5 MW Terry condensing steam turbine from Dresser Rand (USA), connected to a generator from AVK (Germany) (RECP, 2014; Ulomi, 2009), while a second stream was depressurised to 10 bar at 100°C to provide process heat for tannin processing, plywood production and timber drying.

Under the new arrangement, the plant uses a smaller, 2 MW back-pressure turbine connected to a 3,125 kVA generator, both sourced from Triveni Turbines (India). This will provide up to 1.5 MW of power for the company's own operations and the surplus of up 0.5 MW will be sold to the TANESCO grid. TANWAT's power demands have reduced, with the cutting of a former transmission line to a nearby tea factory,[6] so the smaller turbine is a better fit for current needs. The configuration of the CHP system will be changed so that all the steam is directed to the turbine under high pressure, with low pressure steam drawn from the turbine for the factory operations. This will be more efficient than the previous arrangement, which saw energy being wasted by depressurising some of the superheated steam after it exited the boilers.

The boilers are now over 25 years old and must be managed carefully. They will be operated at lower (25 bar) pressure and the steam will be fed to the turbine at 22 bar (19.8 t/hr, 310°C), giving a margin of comfort for uninterrupted operation. The process heat will be drawn from the turbine at 10 t/hr, 6.4 bar and 198.8°C, which will mean lower pressure but higher temperature than before. The plant will supply steam to the tannin plant (for water heating), the sawmill (for timber drying) and the plywood plant (for heating a log bath, operating hydraulics, running a dryer and warming a glue press). Condensate will be recycled and topped up with make-up water, before being pumped to a thermal deaerator and from there back to the boilers.

4.2.2 Power and heat distribution

The upgraded power plant will distribute electricity through TANWAT's four existing lines, as summarized in Table 4.1.

Table 4.1. TANWAT power distribution

Demand centre	Transformer
1. Power station own consumption	1,000 kVA, 3,300/415 V
2. Tannin plant, sawmill, pole plant, plywood plant, staff housing, company hospital	600 kVA, 3,300/415 V
3. Water intake pumps, company offices	2,000 kVA, 3,300/11,000 V
4. TANESCO interconnector	2,000 kVA, 3,300/33,000 V

Surplus electricity will be sold to TANESCO under a long-standing PPA at the EWURA-approved tariff of US¢8.64/kWh. This electricity sale price may not cover the cost of electricity production (see section 4.3), but there are important mitigating factors: first,

[6] A previous 11 kV connection to the Kibena tea factory (6 km away) became redundant in the late 2000s when Kibena secured its own connection to the national grid.

TANWAT should no longer need to buy power from the grid, for which it currently pays TZS 157 (US¢6.84) per kWh[7]; second, the power plant will help TANWAT avoid costly reliance on its two 540 kVA diesel generators during frequent periods of grid outage; and third, the system produces steam that is vital for the company's various wood processing operations much more economically (see section 4.3).

4.2.3 Plant maintenance

TANWAT's previous CHP system ran without major interruption for 24 years, so was clearly robust and well maintained. But power output declined over time, before the rising costs of maintenance led to eventual shutdown in 2018. The longevity of operation is testament to the company's emphasis on preventive maintenance and on ensuring adequate stocks of spare parts (Ulomi, 2009). Routine maintenance entailed general cleaning, lubrication and programmed part replacement, while the plant was shut down once or twice a year, usually for no more than 12 hours, for cleaning of the cooling and feed water systems, or to replace components in the chipping plant, conveying system or alternator lubricating system. Most maintenance was carried internally by TANWAT technicians in a well-equipped workshop, with the exception of boiler tube replacement, for which a specialist service provider is required. This will continue to be the case with the new plant, though a higher degree of automation will require adjustments to operation and maintenance procedures. The factory management do not anticipate major challenges, as the Triveni equipment is robust and market-proven. TANWAT's organisational strength and its team of well qualified and dedicated staff have been important factors in the success of the CHP plant (UNIDO, 2009).

Annual checks are carried out by government inspectors on the boilers, high pressure vessels and lifting tackles to ensure legal compliance. The boiler check involves physical inspection, a hydraulic test and a steam test, while the pressure vessel inspection involves wall thickness measurements and relief valve testing.

4.3 Economic viability assessment

Table 4.2 summaries the data used in the LCC model for the TANWAT CHP plant, as the Bioenergy Case, comparing it with a Base Case scenario generating heat-only and drawing its electricity from the grid.

Table 4.2: Key data for economic modelling

Category	Parameter	Value
General parameters	Discount rate	7% (CIA, 2020)
	Electricity price	TZS 157,000 (USD 68.48) per MWh (TANESCO T3-MV tariff)
	General growth rate	5.3% p.a. (Consumer Price Index)
	Energy price growth rate	0% p.a.
	Exchange rate	2,293 TZS/USD (3-yr average)
Base Case	CAPEX	USD 4.9 M for low pressure boiler + civil works (~USD 472/kW_{th})
	Wood chip cost	Zero (internally generated)
	Wood chip LHV	15.4 GJ/t (wattle logs @ 20% MC)
	Nominal power	10 MW_{th} (1 x low pressure boiler)

[7] www.tanesco.co.tz/index.php/customer-service/tariffs/7-bei-za-umeme-zilizoidhinishwa/file

Category	Parameter	Value
	Genset for backup power	5% of electricity demand; 187,714 l of diesel per year
	Capacity factor	80%
Bioenergy Case	CAPEX	USD 10.7 M for 2 high pressure steam boilers + turbine + generator + civil works (USD 463/kW$_{th}$ + USD 674/kW$_e$)
	Nominal power	20 MW$_{th}$ + 2 MW$_e$
	Annual energy demand	56,000 MWh$_{th}$ + 10,512 MWh$_e$
	Electricity sales to grid	25% of power sold @ FiT of USD 86.4/MWh

Using these input parameters, Figure 4.2 shows the LCOE for heat and power in the Bioenergy Case compared with the Base Case. The LCC model shows that TANWAT's CHP plant delivers a significant cost reduction for thermal energy and modest cost reduction for electrical energy. TANWAT is estimated to have achieved a reduction in LCOE$_{heat}$ from around USD 23.5 to USD 19.0 per MWh$_{th}$, and a small reduction in the LCOE$_{electricity}$ from USD 87.7 to USD 87.6 per MW$_e$.

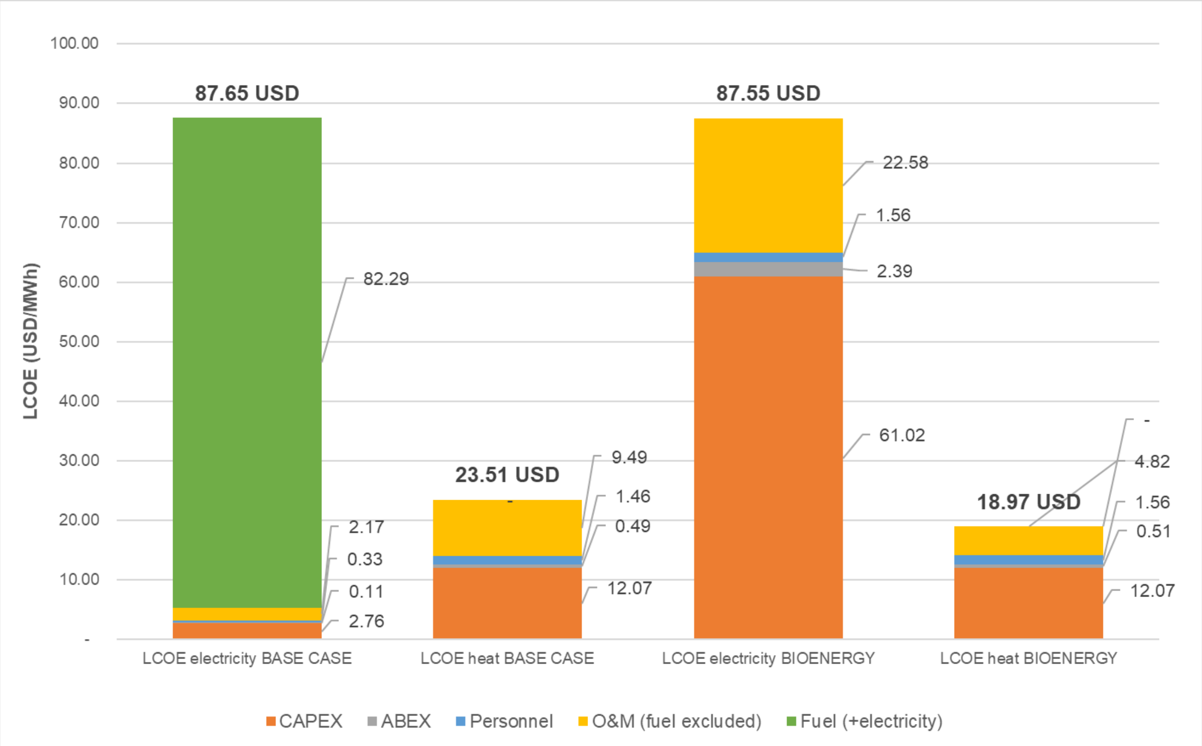

Figure 4.2: LCOE comparison for heat and power at TANWAT, Base Case vs. Bioenergy Case

Figure 4.3 below explores the consideration of potential revenues from surplus electricity export from TANWAT's CHP plant to TANESCO; in that case, the current OPEX would be almost fully offset in the Bioenergy Case, and an overall 25% reduction in the net cost of electricity supply would be achieved. The extra revenue from electricity sales to TANESCO is therefore an important part of the economic case, on top of the savings on the cost of heat.

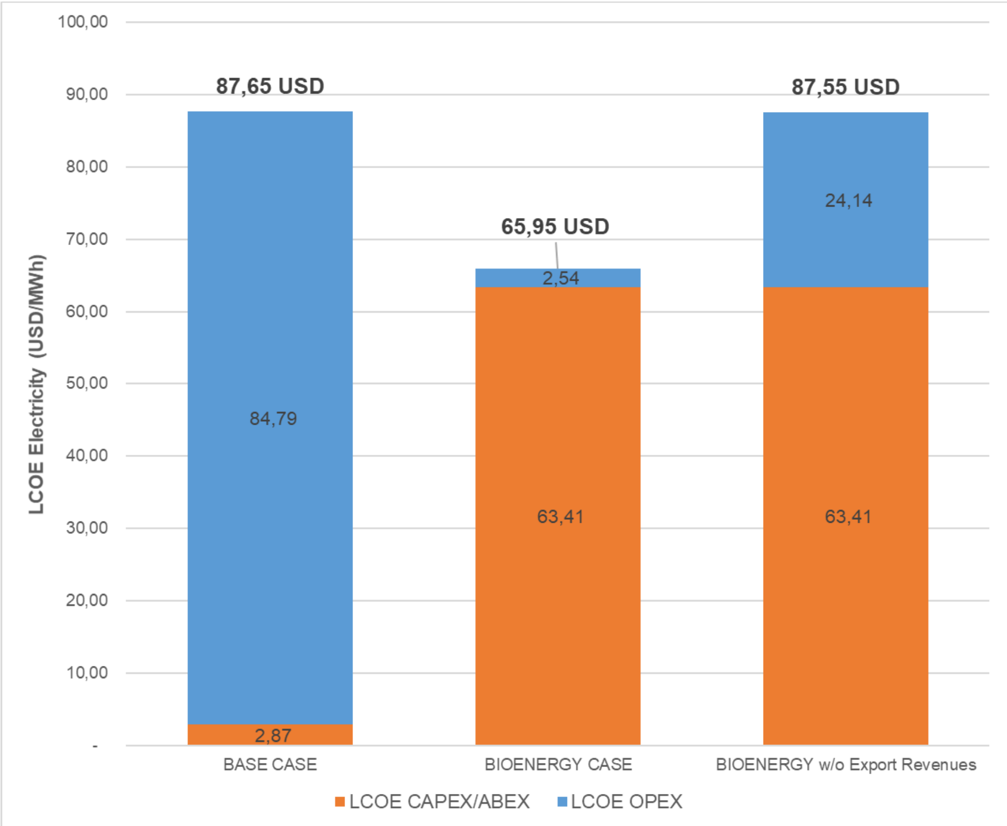

Figure 4.3: LCOE comparison for electricity at TANWAT, with and without power sales to TANESCO

4.4 Commercial success factors

The business model for TANWAT's CHP operation is summarised in Figure 4.4.

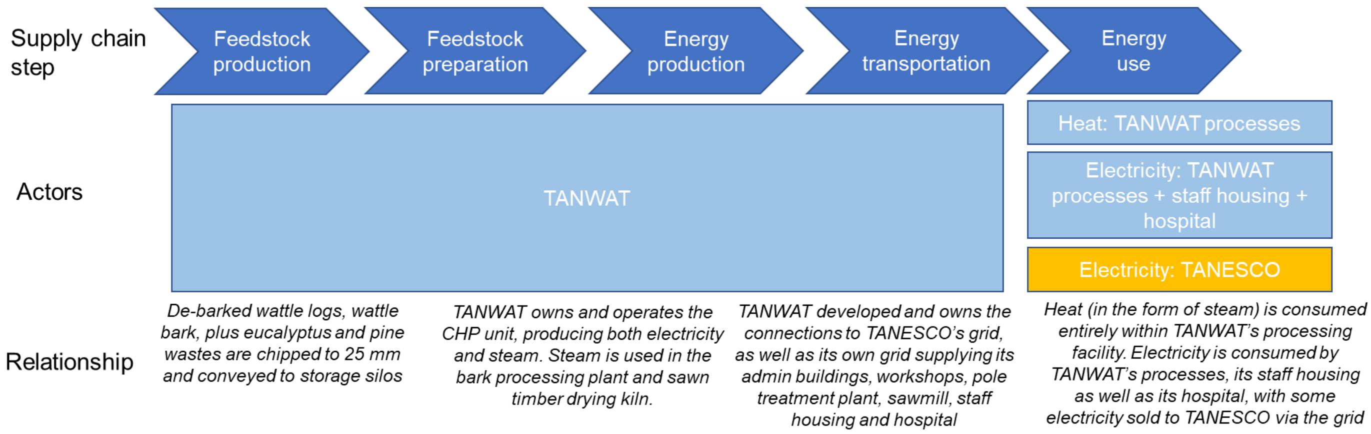

Figure 4.4. Overview of TANWAT supply chain

An analysis of supply chain archetypes during an earlier stage of the research suggested that having onsite supply of feedstock, together with onsite demand for heat and electricity, have been key reasons for the success of the TANWAT CHP venture. Electricity sales provide useful supplementary revenue, as the previous section has described, and the ability to secure finance has also been important. These factors are discussed below:

a) **Onsite feedstock supply:** TANWAT owns and controls each stage of the bioenergy supply chain, from feedstock production and supply through to energy consumption (with the exception of some electricity export to TANESCO).

Feedstock is available in ample quantities at no cost. This has minimised supply-side and demand-side risks.

b) ***Self-consumption of heat:*** TANWAT is a diversified forestry company requiring process heat for tannin extraction, plywood production and timber drying, resulting in significant aggregated demand within its own factory complex. This demand for heat has been a key driver for the investment in CHP, and contrasts with other wood processing companies that have less diverse product lines and generally require heat only for drying sawn timber.

c) ***Self-consumption of power:*** The integrated nature of TANWAT's operations results in high internal demand for electricity. Since 2018, TANWAT has been reliant on grid import from TANESCO, while awaiting the arrival of the new CHP turbine. In the case of TANWAT, the grid is unreliable and cumulative downtime is up to one day per week. Rather than switching over fully to costly power from its two back-up generators, the company often chooses to suspend most of its operations until grid power returns, and runs the generators to support only its lighting and core administrative functions. Grid reliability has, therefore, significantly affected the continuity of commercial operations and this has been a further driver for the decision to invest in a replacement CHP turbine.

d) ***Grid export of power:*** When the original CHP turbine was operating, TANWAT exported excess electricity to TANESCO. This arrangement will resume once the new turbine is commissioned. However, EWURA's gazetted FiT for bioenergy power producers is relatively low and TANESCO's standard payment terms are reported to be three months, often with further delays. Grid export is, therefore, a useful supplementary benefit, but not the key motivating factor for the CHP investment.

e) ***Ability to secure finance:*** This was key to the success of the original CHP project, and has facilitated the investment in the replacement turbine. TANWAT was originally established by CDC, which financed the installation of the first CHP unit and benefitted from UK government-backed development financing. Since the facility is now under private ownership through the Rai Group, it was difficult to ascertain the financing arrangements for the new turbine. From the evidence gathered, however, it appears that no significant financing challenges were encountered. Rai Group is a well-resourced forestry company, with a significant presence in the region. The purchase of the new CHP system was a straightforward commercial transaction. Proven equipment from a dependable supplier was chosen and a commercial loan from a bank is understood to have been secured.

5 Potential for wider adoption

This section assesses the replicability potential of the Bioenergy Case in the wood processing sector in Tanzania, considering the six research themes of biomass resources, technology, economic viability, commercial potential, the institutional and regulatory framework and gender and inclusion.

5.1 Biomass resource assessment

5.1.1 Biomass potential from wood processing residues

Around 2.8 million m^3 of industrial roundwood, sawlogs and pulpwood are produced annually in Tanzania (FAO, 2021). For this assessment, only residues (offcuts and chips) from industrial roundwood and sawlog processing are considered as sources of biomass feedstock, as paper mills have their own means of utilising biomass and waste streams. Tanzania produces about 1.8 million m^3 of industrial roundwood and 0.79 million m^3 of sawlogs per annum. This can generate 270,446 t/yr of processing residues (on a dry basis, d.b.). An additional biomass source is wattle logs after removal of the bark for tannin extraction, as seen at TANWAT (Malimbwi & Zahabu, 2008). Taken together, these available wood residues total 299,246 t/yr (d.b.) with energy potential of 5.7 million GJ (Figure 5.1).

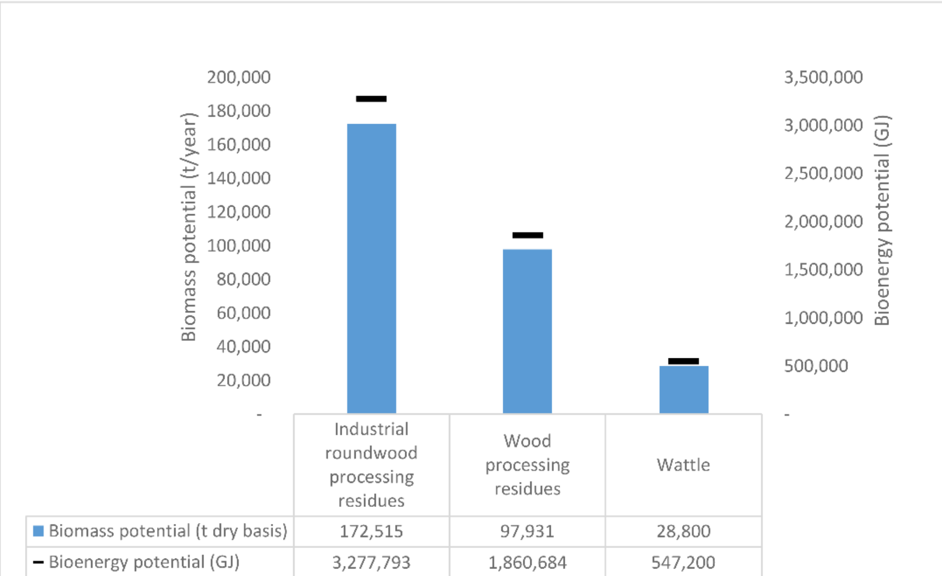

Figure 5.1. Biomass and bioenergy potential from wood processing residues

5.1.2 Mass-energy balance

Table 5.1 shows the mass-energy balance (MEB) parameters for a CHP plant in the wood processing sector. The input data are based on the specifications of the TANWAT facility.

Table 5.1: Mass-energy balance, wood processing CHP

Parameter	Units	Value
Biomass feedstock		Wood processing residues
Input Parameters		
Energy installed	MW_e	2
Capacity factor	%	80%
Annual operational hours	hrs	7,008
Process		Combustion to CHP
LHV of feedstock	MJ/kg	15.4
Moisture content, as received	%	20%
Efficiency	%	Elec: 12%; Heat: 47%
Output of MEB model		
Biomass flow	kg/s (d.b.)	0.4
	t/yr (d.b.)	22,426
Electricity produced	MWh_e/t (d.b.)	0.5
Heat produced	MWh_{th}/t (d.b.)	1.2
Steam produced	kg/s	5.6
	t/yr	138,225
Energy		
Electricity	MW	2.0
	annual MWh	14,016
Heat	MW	7.8
	annual MWh	54,896
Loss	MW	6.8
	annual MWh	47,888

Figure 5.2 shows the results of the MEB model based on these input specifications, indicating biomass flows and energy production, including losses. Based on the model results, such a CHP facility requires 22,426 t (dry basis) of wood residue feedstock per year (d.b.). The quantity of wood processing residues available in Tanzania (299,246 t/yr) could provide sufficient feedstock for around 13 facilities of this size.

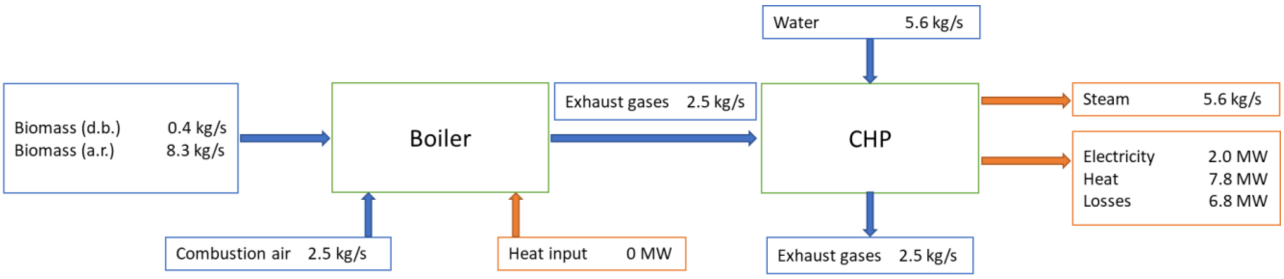

Figure 5.2: Mass-energy balance heat and electricity generation for a CHP plant, based on input specifications at TANWAT

TANWAT is currently using 32,500 t/yr of biomass (equal to about 26,000t/yr, dry basis). Considering the specification described in Table 5.1, this quantity of biomass can potentially generate 2.3 MW_e and 9.0 MW_{th} , which is a 16% increase in electricity and heat each over what is currently understood to be produced. Considering the biomass available nationally from the wood processing sector, operating at this level of performance could provide a total of 31.7 MW_e and 123.5 MW_{th}.

5.2 Technology

5.2.1 Technology supply chain

This section explores the role of technology in replication of the Bioenergy Case in Tanzania's wood processing sector, and any constraints to adoption by other companies that relate to technology or technology supply chains.

Combustion-based steam turbines are an industry standard for large-scale CHP in wood processing plants. This is a mature and competitively priced technology, and is more tolerant of feedstock variability than alternatives such as gas engines.

When TANWAT's previous CHP plant eventually stopped functioning, it was natural that the company would seek a replacement to restore its self-reliance in electricity generation, in addition to meeting its ongoing needs for process heat. While the original (1995) turbine and generator were sourced from the USA and Germany, respectively, the development of Asian manufacturing capacity over the last 30 years, possibly together with a corporate orientation towards India after the Rai Group purchase, led TANWAT to consider Indian equipment suppliers for its turbine replacement. Triveni staff reportedly made several promotional visits to TANWAT and it is a well-established company with over 4,000 steam turbine installations up to 100 MW.[8]

There are numerous reputable suppliers of boilers, turbines, generators and ancillary components for CHP plants designed for solid biomass, with John Thompson, Mechmar, Dresser-Rand, Vyncke and Shinko having strong track records in SSA. Any large-scale forestry processing company will have the means to identify, procure and install such equipment, and – with appropriate training and support – the capacity to operate and maintain it. There is no evidence that access to suitable technology was a constraint, either to the original CHP investment at TANWAT or the recent turbine upgrade, or that it is a barrier to the adoption of similar technology at other forest processing industries in Tanzania and the wider region. Put simply, the barriers to adoption are not technological, but relate more to the need for internal heat demand and Government policy towards electricity prices, FiTs and PPAs.

5.2.2 Steam turbines vs. other CHP technologies

Steam turbines are a proven CHP solution and offer excellent efficiency at the higher end of the BSEAA2 scale range. A 3 MW back pressure turbine, for example, can achieve total CHP efficiency of almost 80% (Energy and Environmental Analysis, Inc., 2015). This is the preferred technology for TANWAT and has also been adopted at MPM. But at smaller (sub-1 MW) scale, there are alternative biomass-based CHP technologies such as reciprocating engines, micro gas turbines, Organic Rankine Cycle turbines and Stirling engines, that are more efficient, especially for generating electricity, rather than CHP (Dong et al., 2010; Energy and Environmental Analysis, Inc., 2015; Gonzalez et al., 2014; OPET Network, 2003).

For enterprises whose main requirement is electricity, it could therefore be logical to consider a reciprocating engine or micro (gas) turbine connected to a biomass gasifier. A gas turbine has been the technology choice of Kisiwa Farming, whose aim is to

[8] www.triveniturbines.com/sites/default/files/uploads/investor/clean-energy-turbine-solutions.pdf

generate electricity for self-consumption and build up the system modularly to sell power into the isolated Mafia Island grid based on demand. Their starting investment in a 35 kW plant has yet to be commissioned, however, and it remains to be seen if their novel approach based on gasification proves to be economically and operationally viable, given the known challenges around gas quality with this technology.

5.3 Economic viability

Adjustments were made to selected parameters in the LCC model to determine their impact on LCOE, and the implications of these changing costs for the replication potential of the Bioenergy Case. For this demand sector, the chosen parameters for the sensitivity analysis were the plant capacity factor, the TANESCO FiT and the power plant size.

5.3.1 Sensitivity of LCOE to Capacity Factor

The LCOE was investigated for a range of different typical plant capacity factors from 60% to 90% (Figure 5.3). This reveals that a minimum capacity factor of 79% is needed to reach an $LCOE_{electricity}$ equal to the Base Case. At lower capacity factors, the cost of electricity is higher than it is under the Base Case. The situation is more positive for thermal energy, with the $LCOE_{heat}$ for the Bioenergy Case being lower than the Base Case across the full range of capacity factors considered.

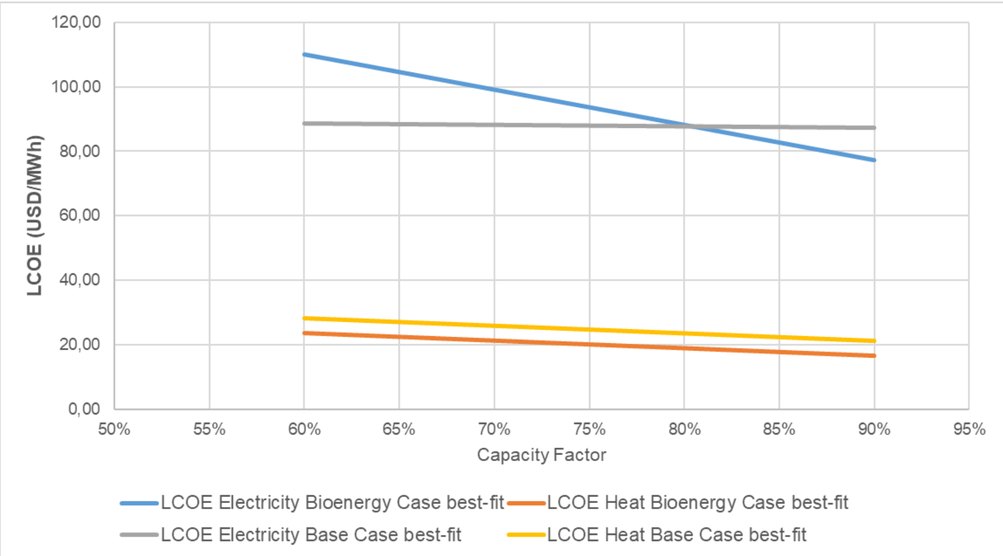

Figure 5.3. Sensitivity of LCOE electricity and LCOE heat to plant capacity factor

5.3.2 Sensitivity of LCOE to Feed-in Tariff

The 'net' cost of electricity supply (defined as the $LCOE_{electricity}$ minus revenue from sales to TANESCO) is shown in Figure 5.4 , for a range of potential FiT values from USD 60-100 per MWh (versus the current FiT of USD 86.4/MWh). Accounting for these sales into the grid, the net cost of electricity supply is consistently lower than the Base Case, even for FiTs as low as USD 60/MWh. The ability to sell surplus electricity into the grid is clearly an important enabler of the Bioenergy Case, even at lower FiT values.

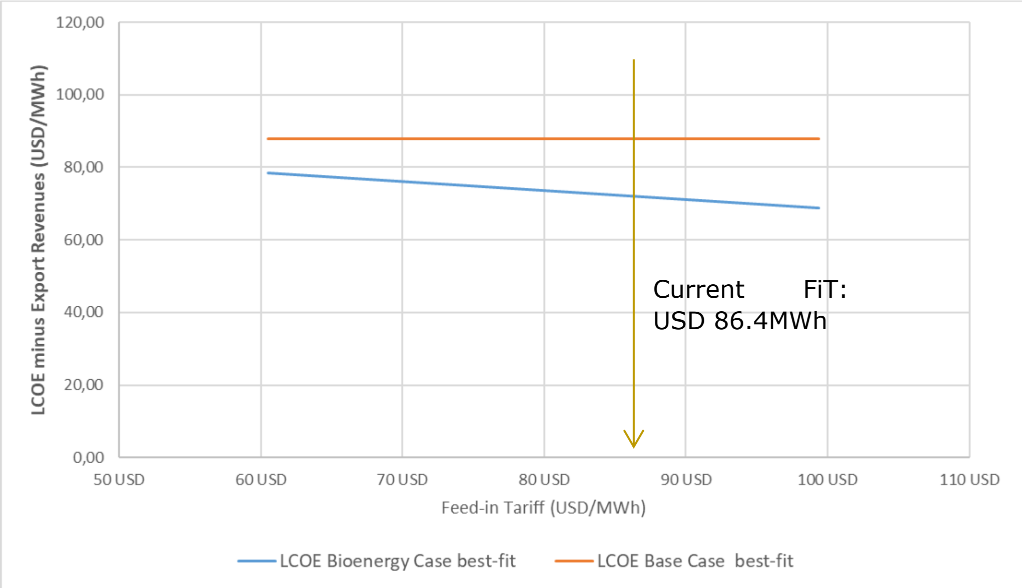

Figure 5.4. Sensitivity of net electricity costs to feed-in tariff

5.3.3 Sensitivity of LCOE to power plant size

The sensitivity of $LCOE_{electricity}$ was explored for a range of CHP plant sizes from 0.5 to 5 MW_e (Figure 5.5). The actual electricity demand is met with a 1.5 MW_e CHP plant, which defines two different ranges (i) 0.5 to 1.5 MW, where all the CHP generation is consumed on site and additional needed power purchased[9] from the grid, and (ii) 1.5 to 5MW, where surplus generation is sold to the grid; at the current FiT level, the modelling shows that the optimum CHP size for a facility with TANWAT's size on-site power demand of around 10,500 MWh/yr, is 4.5 to 5 MW, in order to achieve the lowest net electricity cost compared with the Base Case. Despite this economic advantage of a larger system and the lack of feedstock constraints, TANWAT opted for a smaller 2 MW plant, perhaps because of the high CAPEX required for a larger plant, a desire to use the existing fuel feeding system and boilers, and the risks of relying on consistent payment from TANESCO for power sold, as discussed in sections 5.4.3 and 5.6.

[9] TZS 157,000 (USD 68.48) per MWh (TANESCO T3-MV tariff), see Table 4.2

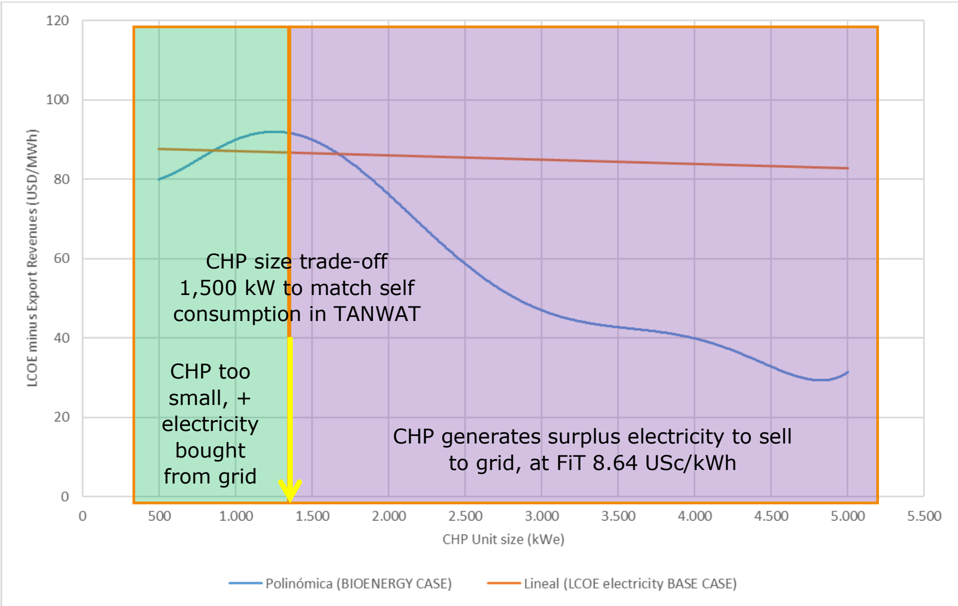

Figure 5.5. Sensitivity of net electricity costs to CHP generator size

5.4 Commercial prospects for replication

5.4.1 Overview

The commercial potential for replication of the Bioenergy Case (CHP in the wood processing sector) depends in part on the size of the sector and the demand for heat and power within its constituent companies. As noted above (and in Figure 5.6a), Tanzania produces 2.8 million m^3 of industrial roundwood each year for sawn timber and veneer, paper manufacturing and other uses such as transmission poles (FAO, 2021). The construction industry consumes large quantities of softwood (mainly pine) sawnwood and eucalyptus poles. Tanzania additionally has a large transmission pole industry, with a production capacity of 500,000 poles per annum (Unique Forestry & Landuse, 2017). These industries together account for roughly 75% of wood product consumption (Figure 5.6b). Although Tanzania has only one paper mill, the pulp and paper industry accounts for around 20% of industrial roundwood consumption.

Tanzania's wood processing sector is growing rapidly as demand for finished wood products rises. In response, it is projected that output from plantations and managed forests could increase to ~2 million t of sawn logs per annum by 2050, which could generate an additional 600,000 t of residues (URT & MFA, 2018).

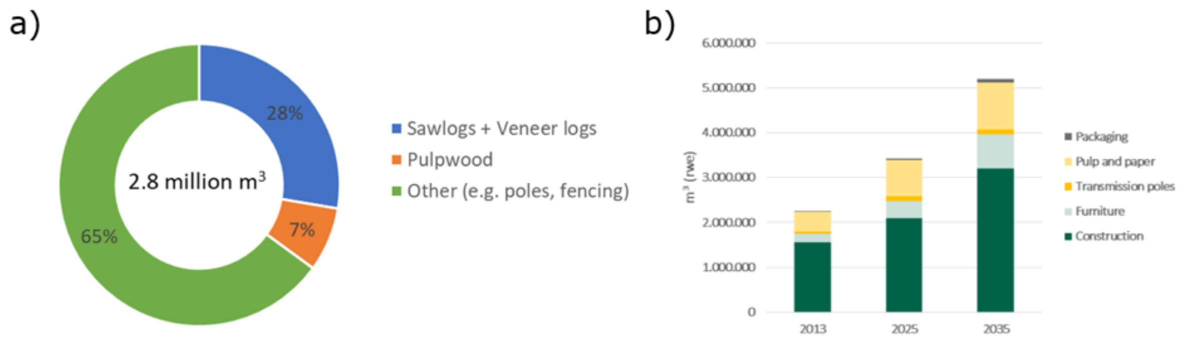

Figure 5.6. a) Industrial roundwood production in Tanzania (2018); b) Consumption of wood products in Tanzania by market segment (2013-2035) (IEA, 2019)

Feedstock in the wood processing sector is generated on-site and is readily available in sufficient quantities for CHP. The replicability of the business model in this sector therefore depends mainly on barriers relating to the demand for both heat and electricity, and the enablers that can help overcome these barriers.

5.4.2 Market barriers

For heat and electricity, the barriers and enablers depend upon whether the demand comes from *self-consumption* and, additionally for electricity, from demand from *grid export* and *self-consumption* (Table 5.2).

Table 5.2. Summary of demand-related barriers and enablers

Demand	Barrier	Enabler
Heat for self-consumption	**Heat demand is low at most wood processors:** Other processing operations, beyond TANWAT, have a small range of products and limited requirements for heat thereby reducing the incentive to invest in CHP system, e.g. KVTC air-dries most of its teak and kiln-dries just 20% using a small boiler; SHI uses ~10% of its residues for limited wood drying.	**Diversification of wood processing industry:** If the industry becomes more sophisticated, with more processors developing value-added products like plywood, medium-density fibreboard and heat-treated pallets, the demand for heat within individual processors would increase. However, no evidence was found of such evolution, and the current foreign investment climate in Tanzania is perceived as risky, so existing wood processing industries do not seem keen to expand and upgrade their operations.
Electricity for self-consumption	**Electricity demands are relatively low:** Power requirements are low at most wood processing plants, as they are engaged in basic re-sizing and milling of standardised logs	**Integrated wood processing industries:** The bioenergy business model has better prospects where there are diverse power demands in addition to a core sawmilling operation. This is likely to develop as the country's wood processing sector modernises, though no firm evidence was found of such diversification in Tanzania's wood processing industry.
Electricity for grid-export	**Grid power has become relatively accessible, cheap and reliable:** While grid reliability was an issue for TANWAT, TANESCO's grid has expanded to areas such as Sao Hill and KVTC, and the quality and reliability of grid power has reportedly improved.	**Cost reflective electricity tariff:** In order to incentivise adoption of renewable energy (including bioenergy), a more realistic, cost-reflective power tariff must be charged to industrial consumers. However, there is no evidence that this is likely to occur in the near future.

Demand	Barrier	Enabler
	Grid FiTs are unattractive, with poor terms of payment: Tanzania's FiT range for renewable power producers is low, and TANESCO is regularly in payment arrears. For TANWAT, the heat and power demands from its own facilities were the primary driver for the investment in CHP. Supplementary demand from the grid was not crucial to the business case, though has significantly improved the commercial proposition.	**Cost reflective FiTs:** If the government wishes to encourage continued growth in renewable power generation, then FiTs need to be raised to competitive commercial levels, and payment terms improved to IPPs. There is, however, no evidence that the FiT might be increased, at least in the short term. The model can be more easily replicated in isolated power grids (e.g. islands using diesel power), where higher FiTs can be negotiated. This is the case for Kisiwa Farming on Mafia Island.

5.4.3 Market potential

In order to determine whether there are niches where opportunities might exist, the market was assessed in more detail by production sub-sector (from Figure 5.6b) for pulp and paper, transmission poles and poles and sawn timber for construction.

While **pulp and paper** production requires significant process heat, MPM is the only paper mill in the country and already has a biomass-fuelled CHP system producing 7 MW of electricity self-consumption using residues such as small tree tops, branches, bark and leaves (Camco Clean Energy, 2014). As a result, there appears to be no replication potential within the pulp and paper sector in Tanzania.

Most processors of **poles and sawn timber** have low heat and electricity requirements. SHI, for example, operates two sawmills and a pole plant in Mufindi District. The company considered investing in a 15 MW_e CHP plant based on 212,950 m^3 (170,360 t) of biomass residues per annum, which could supply 10 MW_e for grid export or load balancing, and 5 MW_e for own use (UNFCCC, 2012). The CEO of Green Resources, the parent company, reports that the project did not proceed as SHI's internal heat demands are relatively small (and can be satisfied by burning just 10% of the plant's wood residues), there are no nearby opportunities for heat export, grid power is cheap and has become more reliable, and the TANESCO FiT is unrealistically low. This example indicates that, even for larger wood processing companies, the commercial motivation to adopt CHP using processing residues is minimal. Similar considerations apply to KVTC and to the country's smaller wood processors.

TANWAT is an exceptional case because of its unusually diverse product lines and a significant need for process heat. But even here, a large quantity of wood feedstock goes unused because the commercial case for a larger power plant is weak. The company commissioned a feasibility study for upgrading to a 6 MW CHP plant (and the preceding economic analysis showed optimal financial benefit at 4.5-5 MW scale), but payment terms were deemed too risky, and the Government has signalled its intention to focus on large-scale power investments (such as the 2,115 MW Stiegler's Gorge hydropower project) and has reduced interest in buying electricity from IPPs, except in areas served by isolated grids. The market for the power and the price offered for that power would not guarantee recovery of the investment, and TANWAT made the decision to install the smaller 2 MW turbine instead, and to focus on producing heat and power primarily to meet its own needs.

Opportunities exist only in specific cases, where excess heat or power export is possible or energy demand is exceptionally high, but these are not representative of the wider industry.

5.4.4 Finance

TANWAT is understood to have financed its CHP investment through its international banks in India and their subsidiaries in Tanzania. MPM received significant funding for its own CHP plant from the OPEC Fund for International Development, the World Bank and the African Development Bank.

While it is difficult to speculate what sources of finance might be available for additional CHP projects in the wood processing sector, as this will depend on the particular company involved and the site-specific conditions, it seems unlikely that finance would be an impediment to this type of investment. For companies whose financial situation is healthy and/or are backed by financially stable owners, the companies themselves are likely to be able to invest in such projects – an example being the fact that the replacement turbine at TANWAT will be financed by the company's owners, Rai Group, who are a well-resourced international forestry concern. Such owners, given their financial situation, are also more likely to be able to access commercial loans.

The degree of perceived technology risk for combustion-based CHP is low, given that CHP is a mature and commercially proven technology. This may increase a project's likelihood of raising finance from commercial sources, relative to other options.

5.4.5 Conclusion

While the wood processing industry in Tanzania is growing and generates significant quantities of solid residues that are ideal for combustion-based CHP and are readily available as a secure feedstock source, a combination of low internal heat and power demand at processing plants, relatively cheap grid power, low FiTs and poor payment terms for biomass-based electricity mean that there is little or no potential for wider adoption of residue-based CHP within the sector under current conditions.

5.5 Gender and inclusion

Tanzania has experienced rapid and sustained economic growth, with marked improvements in poverty and human development. However, inequality, especially gender inequality, still remains (World Bank, 2019). It is often the case that social and cultural norms determine the specific roles women can engage with, in both formal employment and within households. Inequalities can be observed as women face high-level barriers such as customary law, inheritance and land rights which have historically created barriers to entry (Mwamakimbullah, 2016). This study highlights areas of concern and makes recommendations for organisations considering bioenergy investments similar to those at TANWAT.

There are few examples of basic gender mainstreaming in the wood processing sector. The field research suggests that there are limited incentives for wood processing enterprises to consider gender or social inclusion in their work, due to: limited need for transparency in the supply chain; lack of decision-maker understanding of the issue; misconceptions of the difference between quality and quantity of jobs; and an assumption that gender inclusion is limited to a headcount of the number of women employed. One example of better practice was found within a company which produces fuel briquettes. Charcoal Briquettes Tanzania Ltd claims to have made concerted efforts to ensure equality for women within all aspects of the energy value chain (Gaia Consulting & ARTI-TZ, 2016). It is therefore clearly possible to take positive steps within the bioenergy sector.

For organisations wishing to expand or invest in bioenergy, the following recommendations can ensure that G&I considerations are incorporated from the outset:

- Incorporate gender-sensitive policies, which are not only centred around affirmative action (i.e. setting employment quotas for under-represented groups such as women), but also ensure quality and fair treatment of men and women in all operations. This would include policies on sexual harassment as well as basic labour requirements.
- Consider capacity building for decision-makers and staff, including men, on the need for gender mainstreaming and on the potential unintended (negative) impacts of not empowering women in the workforce.
- Include a detailed assessment of gender and social inclusion impacts, including unintended consequences, in feasibility studies before investments are finalised.
- In any investments made by a donor, ensure transparency in G&I throughout the supply chain. Within wood processing operations in Tanzania, there seem to be minimal incentives for organisations to promote gender equity in the workplace. An outside force would therefore be required to ensure that even a basic level of equality is considered. Companies would need to be accountable to an external agency, such as a donor, which could introduce a requirement for reporting on inclusion and the upholding of G&I principles.

5.6 Institutional, market and regulatory framework

Tanzania has developed a policy and regulatory framework that is, on paper, more supportive of bioenergy electricity development in the BSEAA2 scale range (10 kW_e to 5 MW_e) than all of the target SSA countries, except South Africa. Far-sighted legislation, from the Rural Energy Act (2005) to the Energy and Water Utilities Regulatory Act (2006), to the pioneering Electricity Act of 2008 and its 2019 update (see 3.3.1, above), have established an institutional and regulatory framework that is highly conducive to the development of wood residue-based electricity projects. It should have stimulated serious investment, particularly in Tanzania’s southern regions where large-scale commercial forestry is concentrated.

When this framework was set out during the early 2000s, TANWAT, SHI and other forestry companies developed plans for new and expanded projects for wood residue electricity generation. Some of these projects went ahead. For example, through the REA Programme of Activities under the UNFCCC’s Clean Development Mechanism, N’gombeni Power on Mafia Island obtained a licence from EWURA, with a commercially viable PPA and FiT, to operate as an IPP for nearly four years, selling electricity from coconut wood residues to TANESCO's Mafia Island isolated grid. Other projects supported by the REA and international development partners (including US Power Africa, Sida, FCDO and the EEP Africa programme) invested in biomass gasification.

However, none of these projects are generating electricity today. This is partly due to technological factors, especially for the gasifier installations. Late payment by TANESCO for electricity sales was also a factor in the shutdown of, for example, N'gombeni Power. But the main reason for the absence of wood residue CHP is the lack of demonstrated commitment from TANESCO to purchase the electricity these projects generate, coupled with EWURA's limited interest in independently exercising its regulatory mandate to force TANESCO to negotiate PPAs that meet the requirements of the SPP support framework. Such factors led to SHI shelving a plan for a 12 MW cogeneration facility at Sao Hill using wood processing residues, and to TANWAT downscaling its planned refurbishment of its Njombe CHP plant from 6 MW to 2 MW, after commissioning a feasibility study in 2015-16.

Put simply, TANESCO has not demonstrated interest in wood residue cogeneration projects. The REA and its primary support institution, the World Bank, are focused on rural electrification through grid extension, with ambitious targets for transmission line extension into rural areas and new grid connections to rural enterprises, institutions and households. Almost all of the World Bank's funds (through TADEP and TREEP) have supported grid extension and the addition of new connections, and only marginally on supporting investment in renewable energy, particularly bioenergy project development and generation.

This lack of Government interest is clear in EWURA's FiT schedule, Table 3.1 (Ministry of Energy, 2019) for non-bagasse biomass electricity generation, with the highest FiT set at US¢10.15 per kWh and the lowest at just US¢7.25. No new investment in biomass renewable generation could go ahead with tariffs this low. They reflect a clear lack of interest on the Government's part in stimulating investment in bioenergy electricity.[10]

To reverse this situation:

1. EWURA, with its regulatory mandate, should consider increasing its FiTs to reflect actual commercial costs for renewable energy generation from biomass. Sector experts estimate that the FiTs need to be doubled, in line with international best practice;
2. TANESCO, under the prevailing regulatory requirements, should commit to PPAs that guarantee the purchase of electricity from new, or expanded, wood residue energy electricity projects such as TANWAT and SHI; and
3. PPAs must be of sufficient duration to enable capital costs to be recovered and a commercial profit to be realised.

These actions would facilitate investment in electricity generation in one of Tanzania's most important rural economic sectors and would bring additional benefits from embedded generation and grid stability.

[10] This is further demonstrated on EWURA's website, where model PPAs are set out for hydropower, wind, solar and geothermal projects, but not for biomass projects: www.ewura.go.tz/power-purchase-agreements

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 nine 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 wood processing sectors, where applicable, but not to quantify either total energy demand in the sector, or the potential scale of the replication opportunity.

5.7.2 Country analysis

The wood processing sector is important in all ten of the BSEAA2 target countries. In addition to Tanzania, it is commercially most active in South Africa, Nigeria, Ghana, Kenya, Uganda, Mozambique and Zambia. It also plays a major role in Ethiopia and Rwanda. Wood processing residues are widely used for heat production in these countries, mainly for wood drying and pole treatment, and also for generating electricity in Ghana, Kenya, Nigeria, South Africa and Uganda, in addition to Tanzania.

Tanzania's legal, regulatory, licensing and institutional framework provides other SSA countries with an excellent model of how to support the development of bioenergy, particularly for electricity generation and sales. This framework includes technical assistance and finance from the REA/REF, the regulator's (EWURA's) ground-breaking one-stop-shop and a simplified licensing and regulatory framework for small- and medium-scale IPPs, particularly for power purchase pricing and electricity sales. It is unfortunate that this excellent framework has not been successfully implemented due to factors already highlighted, primarily the lack of opportunity to sell electricity to TANESCO and FiT rates so low that they have failed to stimulate any successful commercial investment in bioenergy electricity in the 15 years that they have been in place.

Ethiopia: Ethiopia has more than 17 million ha of forests, including just over 1 million ha of plantations, primarily *eucalyptus spp* (FAO, 2020a). The wood processing sector includes sawmilling and furniture industries. There is no wood residue-based CHP production.

Ghana: During the 2000s, Ghana suffered severe droughts which significantly reduced hydroelectricity generation and overall availability of electricity in the country. The Government encouraged and supported a major drive to attract investment in thermal electricity generation. So much thermal electricity capacity was built that today Ghana has a surplus generation capacity that is nearly double its national demand. Its electricity regulator, the Energy Commission, has put a halt to supplies of any new renewable energy to the grid since 2018, including bioenergy from wood processing facilities. This has effectively stopped any investment in electricity generation from such sources.

Kenya: Most sawmills procure their raw materials from government plantations, for which harvest and utilization levels are established by the Kenya Forest Service (Ototo & Vlosky, 2018). Kenya is not thought to have any operational wood residue CHP plants, only wood treatment plants using heat generated from wood residues. Previously, the East African Tannin Extract Company (EATEC) was a major company owned by Lonrho with a 5 MW CHP plant, extracting tannin primarily for export and producing charcoal for domestic use and export (including to Hima Cement in Uganda from the 1950s to 1970s (Kapchanga, 2008)). EATEC was bought out by Timber Treatment International[11] who produces a range of timber and poles, but do not generate electricity. For over 30 years Kenya had the largest pulp and paper mill in East Africa (Pan African Paper Mills in Webuye), funded by the International Finance Corporation. Pan Paper had a large CHP plant, but the company closed in 2009 (IFC Compliance Advisor/Ombudsman, 2010). There are no wood processing CHP plants currently operating in Kenya.

Mozambique: There were at least three coconut residue CHP plants in Zambezia (owned by Grupo Madal, now Rift Valley Corporation) and Inhambane, until Coconut Lethal Yellowing Disease nearly wiped out Africa's largest commercial coconut industry (ESD, 2007). Mozambique has considerable forest resources (FAO, 2020b) and there are several South African and Mauritian forestry companies operating, although none use wood processing residues for more than timber drying. Rift Valley and Green Resources AS have timber concessions, but no forest residue CHP.

Nigeria: Nigeria has a well-developed wood processing sector, dominated by small-scale sawmillers producing wood panels, furniture and matches (Larinde et al., 2010). UNIDO supported the local government to develop a 5 MW_e wood processing residue-based CHP plant using gasification at Okwor Ngbo in Ebonyi State, though lack of commercial orientation has led to cessation of operations (LTSI, 2017).

Rwanda: Rwanda's forests and other woodland cover ~537,000 ha, or ~20% of total land area (EUEI-PDF, 2009; Ministry of Infrastructure, 2019). Natural forests account for just 23% of the country's tree cover, while plantations cover 28% and the rest is other woodland (FAO, 2020c). Rwanda has a small but emerging wood processing sector. The New Forest Company has plantations for sawn timber, transmission poles and develops products such as charcoal, wood chips and pellets from wood waste (New Forest Company, 2020). There is no wood residue CHP production in Rwanda.

South Africa: South Africa is a leading commercial forestry producer and is one of the world's top five forest plantation countries in terms of land area and wood production (Barua et al., 2014). It has, by far, the largest and most advanced wood processing sector in Africa, with associated industries ranging from logging and sawmilling, to pulp and paper and wood panel manufacturing

Ngodwana Energy, a subsidiary of South Africa Pulp & Paper Industries (Sappi), along with KC Africa and African Rainbow Energy and Power, has started constructing a 25 MW biomass power plant at Sappi's Ngodwana Mill in Mpumalanga. The plant will use waste wood recovered from surrounding plantations and screened waste material from the mill production to generate electricity for the national grid through a Power Purchase Agreement for projects over 1 MW_e under the South African Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), administered by the Department of Mineral Resources and Energy in conjunction with the Development Bank of Southern Africa and the South African Treasury. While this project is beyond the scale of the BSEAA2 research, it demonstrates how government action can stimulate the use of wood processing residues for CHP.

[11] http://www.ttieatec.co.ke/?page_id=4

In 2014, the MTO Group, working with the GEF, entered into a contract between its George sawmill and the textile factory Tradelink, located 200 m away, to retire Tradelink's oil boiler and purchase steam from the George sawmill instead. A pipeline was installed between the two firms to deliver about 9,100 t/yr of steam, generated from 3,300 t of biomass residues. They are currently completing Phase II of this project, with a major rehabilitation of the sawmill and expansion of the heat pipeline (Stehle, 2016).

Uganda: Uganda has more than 70,000 ha of tree plantations (FAO, 2020d). Its wood processing sector includes sawmilling and wood panel manufacturing. Most tree growers are small-scale farmers, with a handful of large companies, notably Busoga Forest Company (a subsidiary of Green Resources of Norway – the same company that operates SHI in Tanzania and has operations in Mozambique), New Forest Company, Global Wood and Nile Ply. Busoga Forest Company produces sawn timber, fence posts and utility poles, while the New Forest Company converts wood wastes from its pole plant and sawmill into energy products such as charcoal, wood chips and pellets. There is no wood residue CHP production in Uganda.

Zambia: Zambia Forestry and Forest Industries Corporation (ZAFFICO) is a state-owned enterprise and a member of the Industrial Development Corporation Group (IDC, 2021; ZAFFICO, 2021). It establishes and manages pine and eucalyptus plantations, harvesting and processing timber for local and foreign market. The New Forest Company converts wood wastes from its pole plant and sawmill into energy products, notably, charcoal, wood chips and pellets. Rainlands Timber is a successful timber company operating a sawmill, producing various timber products and has a wood-fired kiln system for drying and curing quality timber and wood products. There is no wood residue CHP production in Zambia.

5.7.3 Summary of replication potential

Most of the target SSA countries have a history of using wood residues from industrial timber production going back many years. There were pulp and paper mills in Ghana, Nigeria and Kenya 30 years ago that generated CHP and none of these mills or their CHP plants are operational today. Before widespread grid extension into rural areas in the ten target SSA countries, pulp and paper mills and the largest wood industries were not close to the national grid. So, generating electricity was essential for their operations (as it has been for most sugar factories in Africa). However, with extensive grid extension to previously-isolated rural areas, most of these large wood/timber processors have resorted to generating only the heat they require for processing.

Out of the ten target SSA countries, only South Africa and Tanzania currently use wood residues for CHP. South Africa uses wood residue CHP fairly extensively in both its large pulp and paper sector and commercial timber sector. Tanzania uses it in one paper mill (MPM) and one industrial wood processing and timber facility (TANWAT).

The rest of the target SSA countries do not use wood processing residues for CHP for a number of reasons, primarily because they are connected to the national electricity grid where the industrial price of electricity is relatively low, and, more fundamentally, they either cannot get a licence and/or PPA to sell to the grid or wheel their electricity on the grid to a buyer, and/or the purchase price from the grid is too low to warrant investment in CHP for electricity.

6 Summary and conclusions for replication

Based on the analysis of TANWAT's experiences, 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 residue-based CHP in the wood processing sector in Tanzania. 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).

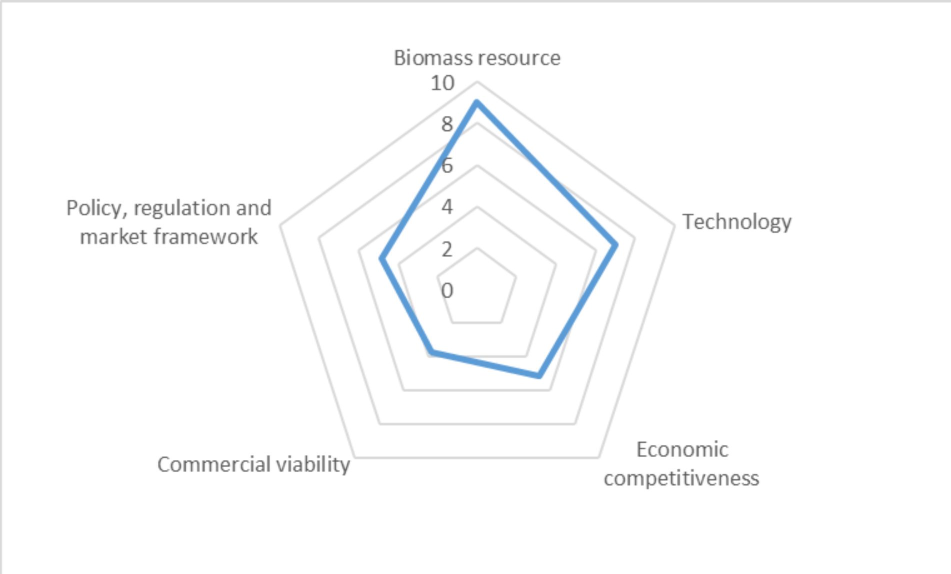

Figure 6.1: Impact of key factors on wider adoption of bioenergy case

The MCA analysis shows that the availability and access to suitable forestry bioenergy residues is not a bottleneck to wider adoption of CHP in the wood processing industry. Tanzania has some of the most extensive forest resources in East Africa and some of the region's largest, most successful wood processing industries. There is significant underutilised biomass potential from wood processing residues and supply is expected to increase as the industry continues to grow. That growth could provide a valuable bioenergy resource for heat and power generation to meet Tanzania's growing electricity demand, in line with the country's focus on expanding rural access to electricity, strengthening the national grid and reducing GHG emissions in the electricity sector.

Based on experiences from TANWAT, technology selection, sourcing and operation are not constraints to the wider adoption of bioenergy in this sector. Biomass boilers and steam turbines are a proven combination at 1-5 MW scale, with several (mainly Asian) suppliers providing equipment of quality and cost that now out-compete European and North American manufacturers. While there is some scope for process enhancements and the use of more modern CHP systems, the key barriers to wider adoption are not technical or operational.

The economic analysis indicates a significant cost-saving for heat from a residue-based CHP system, compared with a stand-alone low-pressure boiler, and a modest saving for electricity compared with reliance on the grid and stand-by generators. That saving is much improved if revenue from sales of surplus electricity to the grid is factored in. The positive economic case arises due to TANWAT's uniquely diverse production lines for timber, poles and tannin that result in high demand for process heat, which underpins the economic case for combustion-based bioenergy. Even with a significant need for electricity, a minimum capacity factor of 79% is required to achieve a cost reduction in electricity, indicating that combustion-based CHP is not necessarily economically attractive if electricity demand is the main requirement of the enterprise.

Overall, while there is some scope for process enhancements and the use of more modern CHP systems, the key barriers to wider adoption are not technical or operational, but rather commercial and policy related.

In reality, the opportunity for bioenergy-based CHP production in the wood processing sector is highly constrained, with no new wood processing CHP project commissioned in the past five years. Only one other wood processing company (Mufindi Paper Mills) uses bioenergy-based CHP production, and (like TANWAT) sells power to the grid through a legacy power purchase agreement (PPA) with TANESCO. Other wood processors in Tanzania have insufficient internal requirements for heat and power to justify a CHP investment. Several have considered investing, with an eye on exporting surplus power to the grid, but have refrained from doing so as their internal heat and power demands are insufficient, new PPAs for sale of surplus electricity to TANESCO are not available, and they would only be eligible for commercially unviable feed-in tariffs.

The other key barrier restricting wider adoption of CHP in the wood processing industry is policy-related. Aggressive grid development and major investment in natural gas, hydropower, solar PV and wind generation have led to significant grid extension and stabilisation over the last 10 years. While Tanzania's current policy and regulatory framework is, on paper, more supportive of bioenergy electricity development in the BSEAA2 scale range (10 kW_e to 5 MW_e) than all the target SSA countries except South Africa, the utility is not incentivised to procure electricity from small independent power producers. A lack of practical government support for bioenergy, particularly from more attractive feed-in tariffs (FiTs) and long-term PPAs, has thus significantly reduced the incentives for generating and selling electricity from wood processing residues and other biomass. Given Tanzania's large territory, dispersed rural population and significant distances to transmit electricity to relatively few major load centres, a strong case should exist for baseload embedded power generation - such as from small-to-medium-sized wood industry CHP to strengthen the grid in remote areas. Unfortunately, this case has not been successfully made.

Of the other target countries in SSA, only South Africa uses wood residues for CHP, in both its large pulp and paper sector and its commercial timber sector. The policy and commercial enabling environments in the other eight target countries do not favour investment in wood residue-based bioenergy, beyond the production of heat for processing timber or other wood products, despite the potential benefits of generating useful energy from wastes, supporting inward commercial investment in the forestry sector, generating sustainable rural development impacts and contributing to grid stability and climate change mitigation and adaptation objectives.

In sum, while the wood processing industry in Tanzania generates considerable (and growing) quantities of residues, a combination of low internal heat and power demand at processing enterprises, relatively cheap and relatively reliable grid power, low FiTs and a government focus on large-scale hydropower, discourage new investments in bioenergy technology. Thus, while the TANWAT model has the potential to develop strong rural embedded generation, support local sustainable development objectives and reduce demand for fossil fuels for electricity generation to meet Tanzania's climate change targets, replication in today's political and economic circumstances is unlikely.

To promote the more widespread use of wood residues for bioenergy in Tanzania's wood processing sector:

1. EWURA, the energy regulator, should increase its FiTs for wood bioenergy CHP generation to ~US¢20 per kWh, to reflect actual commercial costs;
2. TANESCO should commit to PPAs that guarantee the purchase of electricity from new, or expanded, wood residue energy CHP projects;
3. The Rural Energy Agency and its development partners should support the development of wood residue CHP projects; and
4. PPAs commissioned by TANESCO should be of sufficient duration to enable capital costs to be recovered and a commercial profit to be realised.

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Appendix 2: People consulted

Organisation	Name	Position	Mode of contact
EWURA	Victor Labaa	Senior Engineer	Call
Embassy of Finland	William Nambiza	Coordinator, Development Cooperation	Call
Green Resources AS (owner of SHI)	Hans Lemm	CEO	Call
Kisiwa Farming Ltd	Darius Boshoff	Operations Manager	Call
KVTC	Irvine Kanyemba	CEO	Call
Ministry of Energy, Office of Electricity Development	Styden Rwebangira	Assistant Commissioner, Electricity Development	Call
Ng’ombeni Coconut Estates Ltd.	Richard Stanley	Owner & JV Partner with Kisiwa Farming Ltd, Director Stanley Farming Ltd. & H.W. Stanley Ltd.	Call
Rural Energy Agency	Advera Mwijage	Market Development & Technologies Manager	Call
SCC Industries	Tobias Löwe	CEO	Call
TANWAT	Arun Mudgil	Factory Operations Manager	In person
	Naftali Mtemi	Power Plant Manager	In person
	Antery Kiwale	Chief Forestry Manager	In person
Tanzania Renewable Energy Association	Matthew Matimbwi	Executive Secretary	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:

$$BMP=Cp*RPR*RF$$

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 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

The table below provides a detailed description of the biomass resource assessment undertaken for the key biomass resources identified for this demand sector

Biomass resource assessment data

Crop	Feedstock	Production (t/yr)[1]	Area of crop harvested (ha/yr)	Total feedstock (t)	Removable fraction	Biomass potential (t wet basis)	MC as received (wt%)[3]	Biomass potential (t dry basis)	HHV (MJ/kg)[4]	Bioenergy potential (GJ)
Industrial roundwood (other)	Industrial roundwood processing residues (chips/ off-cuts)	912,780	n/a	410,751	0.6	246,451	30	172,515	19	3,277,793
Sawlogs	Wood processing residues (chips/ off-cuts & sawdust)	388,614	n/a	233,168	0.6	139,901	30	97,931	19	1,860,684
Plantation wood	Wattle	64,000 [2]	800 [2]	57,600	1.0	57,600	50	28,800	19	547,200

Biomass resource assessment table (continued)

Crop	Feedstock	Production scale	Current use	Existing supply chain	Mobilisation
Industrial roundwood (other)	Industrial roundwood processing residues	Small and large scale	Used during wood processing (kiln drying); used by other industries and commercial sector for processing energy; unused residues disposed to land or burned	yes	Mobilisation depends on scale of wood processing facility and demand from other sectors
Sawlogs	Wood processing residues	Small and large scale		Yes	
Plantation wood	Wattle	Small and large scale	Residues from tannin production; limited other uses, e.g. as a community relations exercise, plantations allow charcoal producers and firewood gatherers access to any surplus wood	Yes	

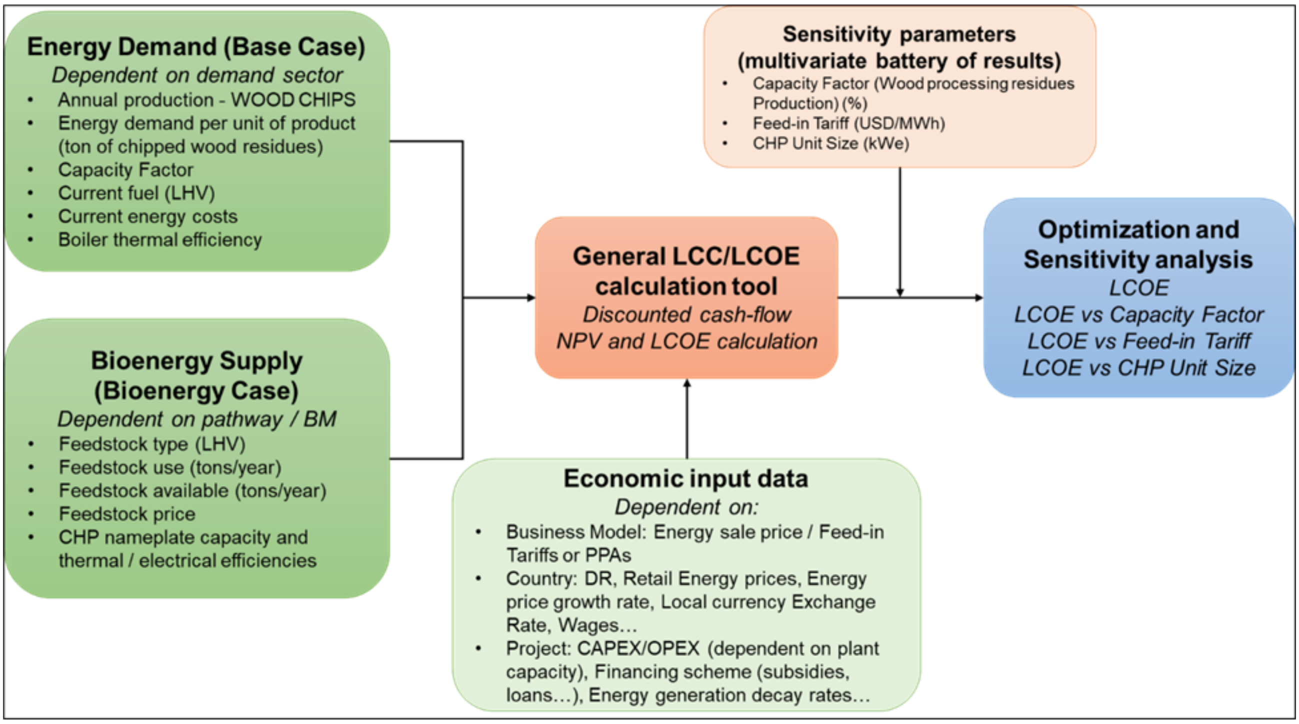
Residue-to-product ratios (RPR)

Feedstock	Residue type	RPR	Note
Sawlog/roundwood[5]	Wood chips/off-cuts	0.45	~40% of logs are sawn wood, 30% chips, 15% offcuts, 15% sawdust
Sawlog/roundwood[5]	Sawdust	0.15	~40% of logs are sawn wood, 30% chips, 15% offcuts, 15% sawdust
Sawlog/roundwood[6] (hardwood)	Sawnwood	0.60	Average density 600 kg/m^3 for tropical hardwood
Sawlog/roundwood[7] (softwood)	Sawnwood	0.39	Average density 390 kg/m^3 for softwood
Wattle[2]	Processing residue	0.90	90% of tree left for fuel after bark removed for tannin production

Sources: [1](FAO, 2021); [2] (Malimbwi & Zahabu, 2008); [3] (TNO, 2021); [4] (Forest Research, 2021); [5] (Aebiom, 2012); [6] (Reyes, G., Brown, S., Chapman, J., Lugo, A. E., 1992); [7] (FAO, 1997)

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:

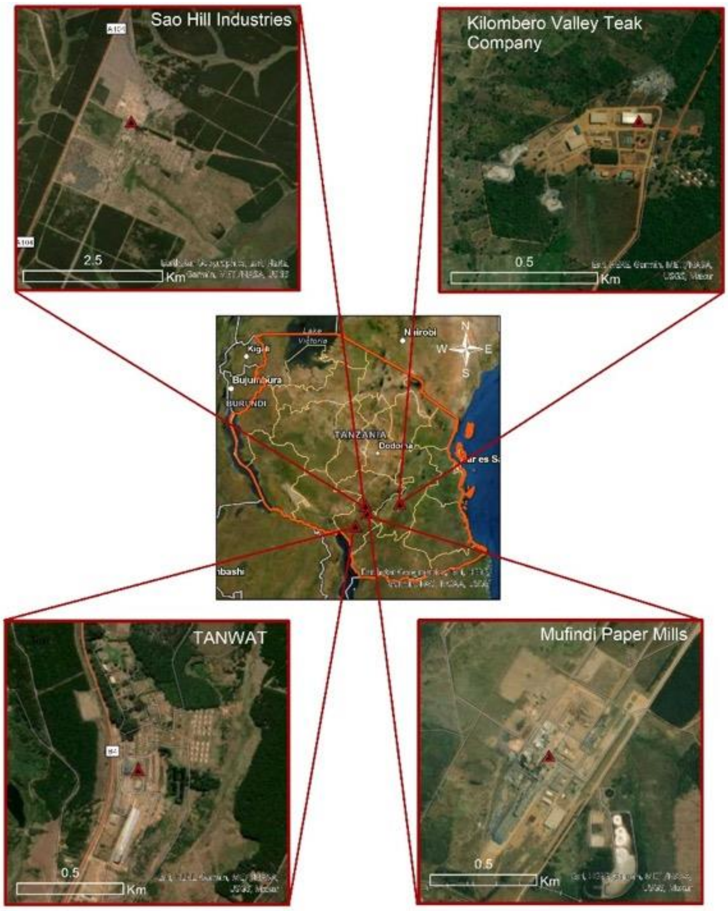
$$\mathrm{LCOE} = \frac{\sum_{t=1}^{n} \frac{C_t}{(1+DR)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+DR)^t}(1+IR)^t}$$

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

Appendix 5: Multi-Criteria Analysis input data

Criteria	Score	Scoring criteria (min=1, max=10)	
Biomass			
Availability	10	low	high
Seasonality	9	short	long
Aggregation	10	scattered	centralised
Proximity	10	far	close
Technical feasibility	6	low	high
Average	**9**		
Technology			
Technology track record in same sector	7	low	high
Availability of a turnkey technology solution	8	limited	well established
Ease of operation and maintenance with in-house capacity	7	limited	well established
Supplier reputation, engagement and partnership	8	not engaged	engaged
Access to technical support & spares	5	low	high
Average	**7**		
Business model			
Energy self-consumption drivers	4	limited	significant
Grid and 3rd party export drivers	5	limited	significant
Waste disposal drivers (based on cost for disposal)	4	limited	significant
Market potential (replicate business model)	2	low	high
Average	**4**		
Policy, regulation and market			
Bioenergy policy	5	unsupportive	supportive
Bioenergy policy implementation	3	not implemented	implemented
Agriculture/Forestry policy	8	unsupportive	supportive
Agri/Forestry policy implementation	8	not implemented	implemented
Demand sector specific policy	7	unsupportive	supportive
Environmental policy	4	unsupportive	supportive
Environmental policy implementation	4	not implemented	implemented
Technology-specific fixed price (e.g. FIT)	3	unattractive	attractive
Demand sector specific governance practice	3	weak	strong
Biomass/processing-specific governance practice	3	weak	strong
Average	**5**		
Cost			
LCOE electricity total	3	cost increase	cost reduction
LCOE electricity Capex	1	cost increase	cost reduction
LCOE electricity OPEX non-fuel	1	cost increase	cost reduction
LCOE electricity OPEX fuel or electricity	10	cost increase	cost reduction
LCOE heat total	7	cost increase	cost reduction
LCOE heat Capex	5	cost increase	cost reduction
LCOE heat OPEX non-fuel	9	cost increase	cost reduction
LCOE heat OPEX fuel or electricity	5	cost increase	cost reduction
Average	**5**	cost increase	cost reduction

Appendix 6: Maps of prominent wood processors in Tanzania



Wood processing enterprises in the Southern Highlands

Kisiwa Farming (Mafia Island)

Appendix 7: Photos of TANWAT and CHP plant

Credit: Emmanuel Michael Biririza

CHP Plant

Biomass chipping and loading area

Boiler fire chambers

Location for the new turbine

Electrical transformers

Stand-by generators

Tannin plant

Sawmill

Plywood plant

Pole plant

Sawn timber

Company hospital