



Bioenergy for Sustainable Local Energy Services and Energy Access in Africa

Demand Sector Report 2: Dairy
Focus Country: South Africa

SEPTEMBER 2021



Transforming Energy Access

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Cover photo: Biogas CHP plant at Uilenkraal dairy farm, Darling, South Africa. Credit: Darius Boshoff

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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 sixth in the series, focuses on the bioenergy opportunities for anaerobic digestion (AD) in the dairy sector in South Africa.

South Africa has the largest commercial dairy industry in SSA. The sector is undergoing consolidation, presenting an opportunity for producing energy from cattle manure in farms where large herds are stalled indoors. However, despite South Africa's leadership in SSA's biogas industry, there has been limited adoption of AD within its dairy sector.

Resource assessment indicates that the opportunity for AD in South Africa's dairy sector exists mainly on large commercial dairy farms with at least 400 stalled, lactating cows (implying herds larger than 800 in total, as only 50% of cows are usually in-milk). About 240 dairy herds in SA meet this requirement, with a combined minimum of around 180,000 lactating cows. The power generation potential from manure-based AD and the electricity demand from the dairy sector are both highest in Western Cape, Eastern Cape, KwaZulu-Natal and Free State Provinces, where milk production is concentrated, making these the most promising regions for further AD-based electricity production.

Much of the AD technology used for large-scale AD was developed in subsidised European environments, and replication in SSA is hampered by high cost and technical complexity. This has motivated a number of specialist South African companies to develop locally-manufactured alternatives to European technology, which cuts costs and can stimulate wider adoption. These companies offer installation and management services that permit the investor to focus on their core business, leaving the complex management of the AD system and associated CHP plant to the technology provider.

Economic analysis reveals a favourable reduction in the net cost of electricity for a 400 kW biogas-powered CHP plant at a dairy farm. However, further adoption in South Africa's dairy sector is likely to be limited to those few large farms that have significant on-site power demands, either because they have their own milk processing plants or have a co-located enterprise such as a feed mill. But the number of combined milk producer/processors has been falling, with production being predominantly rural and processors mostly located in towns and cities, so the opportunity is limited.

Other key barriers to replication relate to electricity policy. For most potential adopters, low internal heat and power requirements mean that commercial viability of an AD investment relies on the ability to sell surplus power at an attractive tariff, with minimal bureaucracy. While there have been encouraging recent amendments to the electricity regulations that mandate Eskom, the national utility, to work with municipalities and large industries to procure electricity directly from small-scale producers, uptake has been limited owing to high costs and administrative requirements for 'wheeling' electricity using Eskom's grid. For more dairy farms to become interested in generating and selling power from AD, Eskom will need to significantly reduce its wheeling charges and administrative requirements, and improve its rural network infrastructure to accommodate smaller scale embedded generators.

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LIST OF ACRONYMS

ABEX	abandonment expenditure
AD	anaerobic digestion
AFD	Agence Française de Développement
BBBEE	Broad-Based Black Economic Empowerment
BSEAA	Bioenergy for Sustainable Local Energy Services and Energy Access in Africa
CAE	Cape Advanced Engineering
CAPEX	capital expenditure
CFA	Climate Finance Accelerator
CHP	combined heat and power
DALRRD	Department of Agriculture, Land Reform and Rural Development
DBSA	Development Bank of Southern Africa
DFFE	Department of Forestry, Fisheries and the Environment
DMRE	Department of Mineral Resources and Energy
DPE	Department of Public Enterprises
FiT	Feed-in Tariff
G&I	Gender and Inclusion
IPP	Independent Power Producer
IRP	Integrated Resource Plan
LCC	Life Cycle Cost
LCOE	Levelized Cost of Energy
MCA	Multi-Criteria Analysis
MEB	Mass-Energy Balance
Milk SA	Milk South Africa
MPO	Milk Producers' Organisation
Mt	mega tonne (1 million tonnes)
NERSA	National Energy Regulator of South Africa
OPEX	operational expenditure
PPA	Power Purchase Agreement
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
SAMPRO	South African Milk Processors' Organization
SANEDI	South African National Energy Development Institute
SSA	Sub-Saharan Africa
SSEG	Small Scale Embedded Generators
SUNREF	Sustainable Use of Natural Resources and Energy Finance
TEA	Transforming Energy Access
USD	United States Dollar
ZAR	South African Rand

1 INTRODUCTION

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

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

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

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

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 dairy sector are defined in Table 2-1.

Table 2-1 Base Case and Bioenergy Case for the dairy sector

Base Case	Bioenergy Case
Dairy farms meeting their electricity requirements from the grid	Dairy farms meeting part of their electricity requirements from AD-based combined heat and power (CHP) generation. Flagship project: Uilenkraal Dairy, Western Cape, South Africa

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 involved extensive web-based research and interviews with government, private sector and NGO informants working

in bioenergy in South Africa. The methodology focused on: a) the dairy sector, within the context of South Africa's overall agricultural development; b) the electricity sector and its growth and evolution; and c) the renewable energy policy and regulatory framework. Interviews were held with the national energy regulator (NERSA), the state-owned power utility (Eskom), the Independent Power Producer (IPP) Office under the Department of Mineral Resources and Energy, and other national and provincial government representatives. Interviews were also conducted with Metier Private Equity, Mergence Capital, SUNREF/AFD, the Development Bank of Southern Africa, the Southern African Biogas Industry Association and other private sector dairies and bioenergy stakeholders active in South Africa (full list in Appendix 2). A remote interview plus a field visit took place to the Uilenkraal dairy farm in the Western Cape.

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 dairy cattle manure in South Africa.¹ Existing data on livestock and manure production were used, adopting biomass feedstock categories from FAO (2004) and IEA & FAO (2017). Country-specific resource potential was calculated based on the amount of manure generated, the fraction recoverable at large centralised dairies and its bioenergy potential (see 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 dairy sector in South Africa, based on technical considerations and practical experiences at the Bioenergy Case flagship project at Uilenkraal dairy farm. The Uilenkraal AD operation has been widely profiled in the bioenergy literature, being one of the first such facilities in SSA. Exploring their experiences from a technical perspective also required interaction with the farm's owners through both remote contact and a site visit. 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 this 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).² The main economic indicator considered

¹ The term 'manure' means cattle excreta, while 'slurry' refers to excreta plus urine, and 'wash water' refers to the water used to clean stalls and milking parlours. For readability, 'manure' is used in much of this report as a catch-all term, but strictly speaking the dairy residue stream comprises cattle slurry plus wash water.

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

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). LCOE in this case was calculated for electricity only. The LCC model was also used to perform sensitivity analyses on LCOE considering a range of values for relevant input parameters.

2.6 COMMERCIAL VIABILITY ASSESSMENT

The objective of this assessment was to outline 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 Uilenkraal was first analysed to identify the elements for commercial success linked, for example, to supply chain ownership and 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 for AD in the dairy sector, analysing the barriers and enablers for supplying electricity 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 thematic strands are conducive or detrimental to the successful adoption of the particular bioenergy solution in each demand sector. Each theme was given an average 'score' from 1 to 10, based on the degree to which various factors (non-weighted) under each theme make a positive contribution (high score) or act as an impediment (low score) to the viability of the Bioenergy Case. The MCA results are presented in the 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.

3 OVERVIEW OF THE DAIRY SECTOR

3.1 SECTOR LANDSCAPE

South Africa is SSA's leading dairy producer and has the largest and most commercialised dairy processing industry on the continent. Milk output has grown at an average rate of 5% p.a. since 2000. South Africa's national cattle herd numbers just below 13 million, of which 20% are dairy cows. Most of the milk supply comes from the Eastern Cape, Western Cape and KwaZulu-Natal Provinces (Figure 3.1).

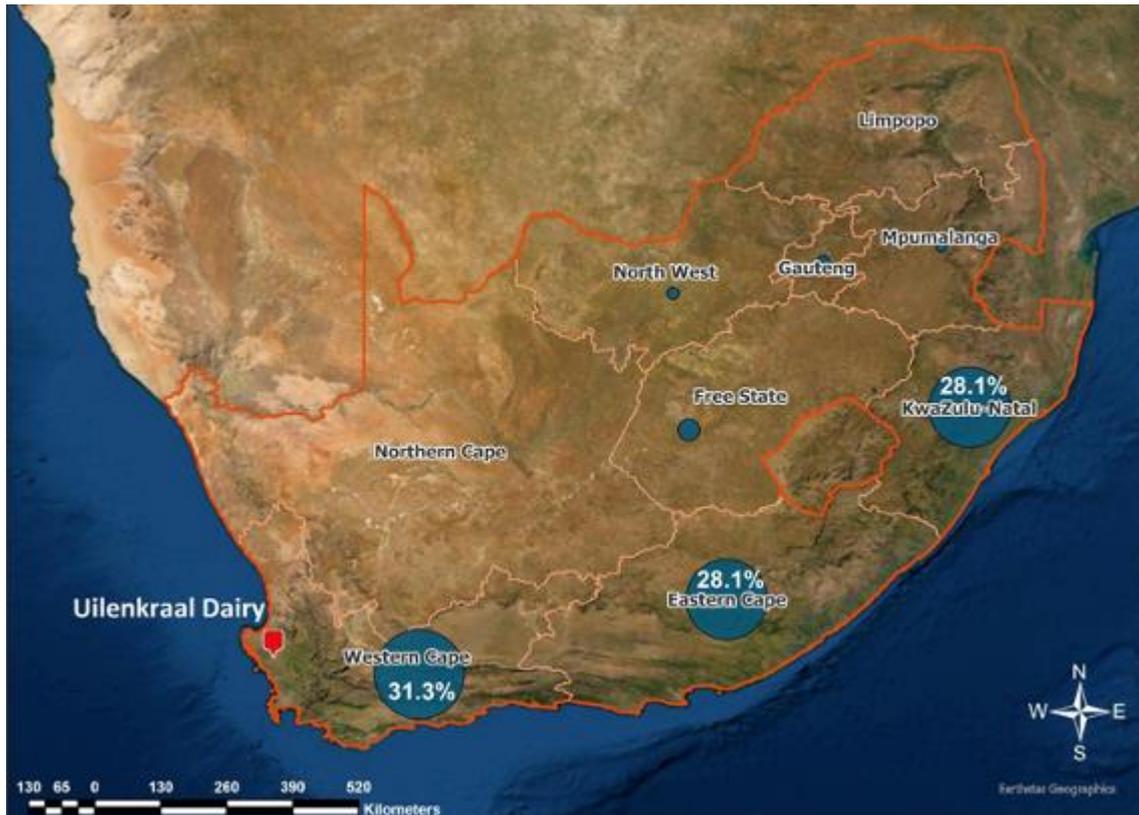


Figure 3.1: Milk output of main milk-producing provinces (Source: authors' compilation with data from Milk SA (2020a))

Milk production is important for income and employment at both small and large scale, employing more than 40,000 people (Milk SA, 2020a). The sector is well organised, with several national industry bodies, sophisticated commercial marketing and adherence to international quality, hygiene and animal husbandry standards. This enables South African dairy farmers to export their products all over the world.

South Africa's dairy industry has seen considerable consolidation over the past two decades, with the number of dairy farms decreasing from 50,000 in 1997 to just under 1,200 in 2020, with an average herd size of 459 in 2019, and some 170 farms now having more than 1,000 head of dairy cattle (ibid.).

3.2 BIOENERGY IN THE DAIRY SECTOR

South Africa dominates the commercial biogas landscape in SSA and accounts for 23 of the 51 commercial-scale AD projects identified in the ten BSEAA target countries (BSEAA2 Stage 2 report). South Africa has pioneered AD innovation, with several 'first

of a kind' projects. For instance, the use of novel feedstocks (e.g. Napier grass tested by Sucropower), novel technologies (e.g. an induced blanket reactor developed by Renen) and novel business models (e.g. a 4.6 MW plant built and operated by Bio2Watt at a cattle feedlot to supply power to an industrial off-taker).³

Greater adoption of this bioenergy solution has the potential to deliver environmental benefits by reducing greenhouse gas emissions linked to the use of grid-based electricity (given South Africa's reliance on coal-fired power plants), avoiding methane emissions and potential eutrophication from spreading cattle manure on fields. But while South Africa is a leader in SSA's biogas sector, there has been very limited successful adoption of AD within the country's dairy sector. Uilenkraal in the Western Cape is the only dairy farm with an operational AD plant using cattle manure as feedstock for CHP.

With the ongoing concentration of dairy farming into a smaller number of ever-larger concerns, it might be expected that the economic and technical potential for using cattle manure and slurry for AD-based heat and power production would be growing, due to economies of scale and improving access to manure from modern facilities with indoor milking. But while dairy farms are becoming larger and fewer in number, a smaller proportion are processing their own milk, so they have lower electricity requirements and hence less motivation to self-generate power. In fact, the number of 'producer distributors' has decreased by two thirds over the past 11 years, from 170 in 2009 to 68 in 2020 (Milk SA, 2020a). The commercial opportunity for AD is therefore mixed.

This research explores the landscape for AD in South Africa's dairy industry, and the potential for further adoption within the sector.

3.3 INSTITUTIONAL, REGULATORY AND FINANCE FRAMEWORK

3.3.1 Institutional framework

The institutional framework for South Africa's **dairy sector** is summarised in Figure 3.2. The main support and regulatory body is the Agricultural Production, Health & Food Safety Branch of the newly created (2019) Department of Agriculture, Land Reform and Rural Development. The Agricultural Research Council provides development and capacity-building support for dairy farmers and for dairy products. The Chemicals and Waste Management Branch of the Department of Forestry, Fisheries and the Environment (DFFE) is responsible for regulating the management, disposal and use of cattle and milk processing wastes, while the Food Control Section of the Department of Health is responsible for dairy product quality, standards and hygiene. The Department of Trade, Industry & Competition regulates commercial aspects of the dairy sector.

The commercial dairy sector is well-organised and represented by Milk South Africa (Milk SA), founded in 2002 as a non-profit company to address the needs of the entire industry, whose members comprise the Milk Producers' Organisation (MPO) and the South African Milk Processors' Organisation (SAMPRO). MPO represents producers of unprocessed milk and provides training and support for sustainable dairy farming, while SAMPRO is a membership organisation for the secondary dairy industry (e.g. UHT milk, yoghurt and other milk-based products), with an active training subsidiary. Milk SA

³ See www.ibert.co.za/reference/sucro-power-mandini ; renen.co.za ; www.bio2watt.com

brings MPO and SAMPRO together to promote South Africa’s dairy producers, processors and exporters, and to train them to the highest international standards.

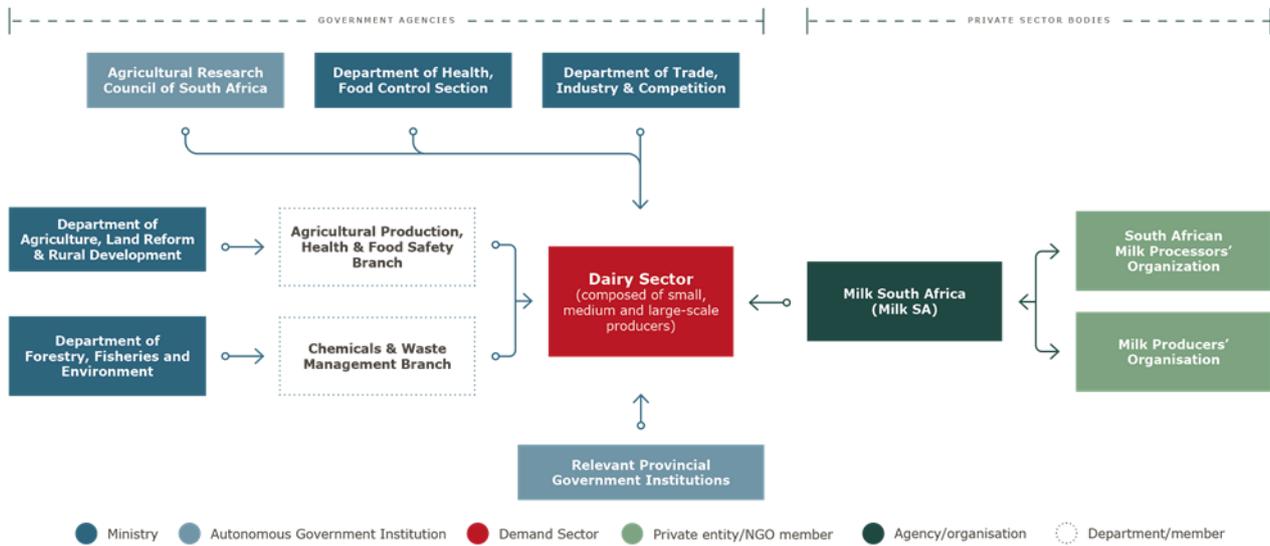


Figure 3.2. Institutional framework for dairy sector in South Africa

The institutional framework for South Africa’s **electricity sector** is summarised in Figure 3.3. Eskom is the national electricity utility and owns over 90% of the country’s generation capacity, the entire transmission system and 60% of the distribution network. In 2002, Eskom was converted from a statutory body into a public company as Eskom Holdings Limited, in accordance with the Eskom Conversion Act (2001). Municipalities and private companies own and manage the other 40% of electricity distribution. Over 200 municipalities and large corporations have their own independent electricity companies, some with their own generation capacity, and all with their own distribution networks (Baker & Phillips, 2019).

The Department of Public Enterprises (DPE) oversees Eskom.⁴ South Africa’s electricity sector is regulated under the National Electricity Regulatory Authority (NERSA). The Department of Minerals Resources and Energy (DMRE) oversees the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), which was set up in 2011, based upon the first Integrated Resource Plan (2010), to promote investment in renewable electricity. The REIPPPP is run in conjunction with the National Treasury and the Development Bank of Southern Africa (DBSA).⁵ It includes a Small Renewables Independent Power Producer Procurement Programme covering procurement of 400 MW from projects between 1 and 5 MW (IPP Office, 2021).

⁴ See dpe.gov.za/about/

⁵ See www.ipp-renewables.co.za/

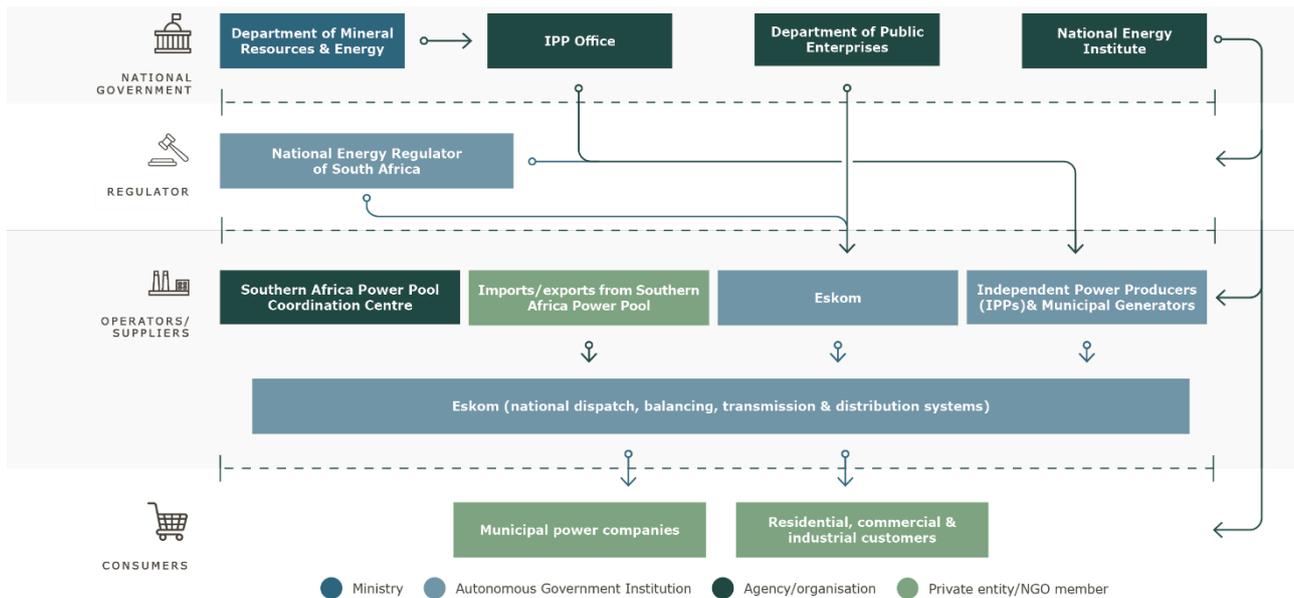


Figure 3.3. Institutional framework for electricity sector in South Africa

The REIPPPP is designed to stimulate innovative, commercially viable renewable energy investments, both to meet South Africa's rapidly growing electricity demand and to contribute to the country's aggressive climate change reduction targets, by replacing coal-based power generation. Biogas is one of five eligible technologies.⁶ It has a target of 17,800 MW of renewable energy by 2030 and has so far contracted 6,422 MW of generation.⁷ While this accounts for only 6% of national capacity, the REIPPPP has helped to increase renewable energy generation capacity from less than 700 MW in 2011 to an installed capacity of some 3,876 MW in 2019, with the remaining contracted generation (2,546 MW) to be installed by 2021 (Republic of South Africa, 2019).

The REIPPPP is operated by the DMRE's Independent Power Producer (IPP) Office,⁸ which runs a series of bid windows targeting specific renewable energy resources and technologies.⁹ Bidders propose projects that meet the specified capacity, resource and power purchase prices most competitively. The IPP Office negotiates Power Purchase Agreements (PPAs) for successful applicants, working with the National Energy Regulator of South Africa (NERSA) and Eskom.

Since the launch of the REIPPPP, 6,422 MW has been procured from 102 renewable energy projects. The programme has been a success due to clarity in procurement requirements and knowledge that procurement offers will be commercially bankable. But because the REIPPPP sets an eligibility threshold of >1 MW generation capacity, small-scale power producers generating ≤ 1 MW are not eligible. Thus, while the REIPPPP has been very successful in increasing renewable electricity generation capacity, it has excluded small-scale renewable electricity producers, particularly those using bioenergy, including dairy wastes.¹⁰

⁶ See www.ipp-smallprojects.co.za

⁷ Bioenergy constitutes 51 MW of REIPPPP-procured capacity from four projects (all based on sugar cane bagasse).

⁸ The IPP Office, while under the DMRE, is separately located and is jointly funded by the DMRE, the National Treasury and the DBSA. See: www.ipp-projects.co.za

⁹ The REIPPPP has had five rounds of bid windows (BW): BW1 (2011), BW2 (2012), BW3 (2013), BW3.5 (2014) and BW4 (2014). A fifth window is imminent as there has been nearly a 7-year delay in the bidding schedule.

¹⁰ Small-scale solar PV is an exception. By Dec 2019, >250 MW of small-scale solar PV had been installed in South Africa.

On the consumer level, increasing numbers of large power users are starting to buy directly from non-Eskom suppliers, or at least limit their exposure to Eskom. Given Eskom's growing fragility and unreliability, both in generation and distribution, South Africa's President and its Minister of Mineral Resources pledged in late 2020 to open generation to non-Eskom sources. This marked the start of a major transformation of the power sector, as set out in the DMRE's 2019 Integrated Resource Plan (IRP).

In October 2020, the DMRE Minister gazetted amendments to the 'Electricity Regulations on New Generation Capacity', in terms of Section 35(4) of the Electricity Regulation Act of 2006 (DMRE, 2020b). These amendments opened the way for 'municipalities in good financial standing to develop their own power generation projects' for generating up to 100 MW of electricity. This must be in accordance with the IRP and the municipality's own Integrated Development Plan. The amendments extend the procurement of new renewables, cogeneration, baseload, mid-merit, peak load, energy storage and cross-border generation capacity to organs of State 'active in the energy sector', which includes municipalities.

The amended legislation also allows private, corporate and municipal power generators to sell to the grid if they generate more than 100 kW and allows new generators to invest in generation up to 100 MW with minimal paperwork.

On 10 June 2021, following an extensive public consultation process by the DMRE, President Ramaphosa allowed these producers to sell excess electricity to the grid through agreements with Eskom and municipal authorities. Schedule 2 of the Electricity Regulation Act will be amended for this purpose. The final version of the amendment and associated rules are expected to be published in August 2021 (Republic of South Africa, 2021). It is anticipated that the above process will be much quicker than obtaining licences (Burkhardt & Mbatha, 2021).¹¹

Large generators are the first to realise the opportunities of these pledges (Winning, 2021). The framework for Small Scale Embedded Generators (SSEGs) has also been set up within Eskom (Eskom, 2021) and within many municipalities (including the Cities of Cape Town, Ekurhuleni and Johannesburg). However, smaller-scale renewable electricity generators and SSEGs have yet to realise anything tangible from the recent announcements. SSEGs are typically <1MW and do not export power to Eskom, except in special cases of net metering and/or banking of energy. Yet in these cases the customers always remain a net user of electricity.

However, the electricity policy framework in South Africa is in a state of major, positive change for small-scale generators (100 kW plus). New legislation offers generators with the ability to supply 100 kW or more, the possibility to wheel electricity via the grid to willing customers, if grid conditions permit. It is not clear how open Eskom will be towards supporting bioenergy-based AD electricity generators, specifically dairy AD electricity generators in this range. However, the regulatory regime is in a period of encouraging transition that will likely support such sales.

This is potentially a game-changer for encouraging small-scale bioenergy producers, like Uilenkraal, to negotiate contracts directly with municipalities, industrial estates,

¹¹ Private generators will still need to have their registration approved by NERSA and meet the associated requirements, including grid connection approval from Eskom. The generators will be allowed to sell electricity to one or more end-use customers, given that they are registered and have secured grid connection approval.

residential estates, for selling electricity as 'willing buyer-willing seller' contracts. It is important for NERSA to help promote such a development.

3.3.2 Policy and regulations

Dairy waste management: The disposal or use of manure, milk processing waste and effluents associated with cleaning and disposing of those wastes are covered by national and provincial laws and regulations under the Department of Agriculture, Land Reform and Rural Development (DALRRD)'s Agricultural Production, Health & Food Safety Branch and its Food Control Section; DFFE's Chemicals and Waste Management Branch; and the Department of Health. There are no regulations governing the spreading of manure on fields. Similarly, no permits or licences are required if a farm gives animal waste away, according to the Fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act (Department of Agriculture, 1947). However, if a farm sells digestate as an organic fertiliser, it needs to register with the above-mentioned DALRRD. This implies that a farm can spread cattle manure as it wishes, but if it is upgraded to AD digestate, then a licence is needed for its sale.

Electricity management: On the electricity side, South Africa has produced two IRPs, the latest in 2019 (Republic of South Africa, 2019). The IRP is the National Electricity Plan for the expansion of electricity supply, designed to identify investments required for the country to meet its forecast electricity demand at the minimum cost.¹² The IRP is developed and overseen by the DMRE, which sets the policy framework and works closely with NERSA. South Africa's National Development Plan 2030 provides overarching guidelines for the energy policy and regulation, and sets a target of procuring at least 20,000 MW of electricity from renewables by 2030 by implementing the IRP (National Planning Commission, 2011).

Over the past two years, shortages of electricity, reduced grid reliability, insufficient firm generation capacity, and other problems with the national grid system have led South Africa's President and Minister of Mineral Resources and Energy to call for considerable new investment in generating capacity from a number of sources.¹³

3.3.3 Finance

The REIPPPP has greatly facilitated the financing of renewable energy projects. A project selected by the REIPPPP can obtain debt or equity financing with virtually any large bank (such as Nedbank or Standard Bank) and with investment finance institutions (such as Investec, ABSA Corporate & Investment Banking or Rand Merchant Bank) and development finance institutions (such as DBSA or the Industrial Development Corporation). A number of equity investors (both South African and international) have invested in REIPPPP-qualified projects, including Globeleq, Loreko Metier Sustainable Capital and Africa Infrastructure Investment Managers, among others.

For renewable energy projects that do not qualify for REIPPPP support, particularly projects under 1 MW, securing finance is more difficult and more expensive. That said, a non-REIPPPP project that has a PPA with Eskom, a municipal electricity company or a major off-taker (e.g. a large mining concern or industry) will almost certainly still be

¹² The 2019 IRP envisages the development of over 16.3 GW from a mix of sources, including 2 GW of emergency power to meet short-term electricity gaps to be connected to the grid by June 2022, 6.8 GW from solar and wind, 513 MW from energy storage, 3 GW from gas and 1.5 GW from coal. There is no mention of bioenergy. (Republic of South Africa, 2019).

¹³ See, for example, "Minister Gwede Mantashe gazettes amendments to Electricity Regulations on New Generation Capacity" www.gov.za/speeches/dmre-16-oct-2020-0000#

bankable. There are a number of programmes in South Africa that provide finance and technical support to renewable energy projects to help them reach bankability.

The Climate Finance Facility is a specialized lending facility of the DBSA that provides financing for climate-related infrastructure projects in the Southern African Development Community, of which South Africa is a member. The Facility provides financing for mini-grid solar and urban solar farms in the range USD 5-10 million, through instruments such as long-term subordinated debt and credit enhancement, including tenor extension (up to 15 years) (DBSA, 2019).

The Embedded Generation Investment Programme supports the development and upscaling of embedded generation projects in solar PV and wind energy, developed by IPPs operating in South Africa. Funded by the DBSA and the Green Climate Fund, this programme offers a credit support mechanism that enables funding of embedded generation renewable energy projects, through the provision of risk capital for projects implemented by private sector entities and local municipalities (DBSA, 2021).

The Sustainable Use of Natural Resources and Energy Finance (SUNREF) programme, developed by the French Agence Française de Développement (AFD) Group with financial support from the Swiss Government, mobilises South African banks to finance investments to increase the use of renewable energy technologies. One area of SUNREF focus is agro-processing. It partners with South African National Energy Development Institute (SANEDI) and South Africa's Industrial Development Corporation (IDC). AFD's credit line is a debt fund only, but can be combined with the IDC's equity products in some cases. SUNREF aims to facilitate access to affordable sustainable energy, to allow companies to acquire higher quality equipment, to make cost savings, and to be more competitive through better energy management and improved environmental performance. SUNREF II is currently underway and includes a credit facility and technical assistance (Zyl, 2020).

On 3 June 2021, the British High Commission, together with the National Business Initiative and GreenCape, launched the Climate Finance Accelerator (CFA) with a call for proposals for low carbon projects. The CFA is designed to help South Africa achieve its 'green' targets (primarily in renewable energy, but also energy efficiency) set out in its Nationally Determined Contributions under the UNFCCC's 2015 'Paris Agreement'. Beyond finance, the CFA provides a range of services to potential green investors, ranging from access to other investors, to networking and coaching on best practices (British High Commission, 2021). While no dairy AD projects have received finance from the facilities and programmes highlighted above, these programmes do offer technical assistance. Interviews with the South African Biogas Industry Association, SUNREF and SANEDI did not, however, indicate any technical assistance for dairy AD, although there was some interest in large-scale AD in the agro-industrial sector.

Finally, developers' 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; UK Export Finance; the US Development Finance Corporation (ex-OPIC); the US Export-Import Bank; and SACE (Gruppo CDC), Italy's export credit agency, among a number of others, when equipment is sourced from these countries.

4 OVERVIEW OF BIOENERGY CASE

4.1 PROJECT SUMMARY

The adoption of manure-based AD at the Uilenkraal dairy farm in the Western Cape is a flagship project for the adoption of bioenergy technology and can be used to explore the opportunities for other South African dairy farms considering similar investments.

Uilenkraal is a total mixed ration¹⁴ dairy cattle feedlot located 20 km north of Darling, Western Cape. The farm is owned by the Basson family and has around 3,000 Holstein Friesian cows and 800 oxen. Fresh milk is chilled at the farm and trucked offsite for processing. While most dairy farms have only limited electricity requirements for milking and chilling, Uilenkraal has additional power needs to run an onsite feed mill that produces concentrated animal feed, under the Nutrikor brand.

In 2013, the farm owners went into partnership with Cape Advanced Engineering Ltd (CAE), in nearby Atlantis, to install an AD system fed with cattle manure and wash water for CHP production. The operational details below were kindly provided by Uilenkraal and CAE, except where separately referenced. Appendix 6 contains a selection of photos.

4.2 TECHNICAL DETAILS

The layout of Uilenkraal’s AD system is summarised in Figure 4.1.

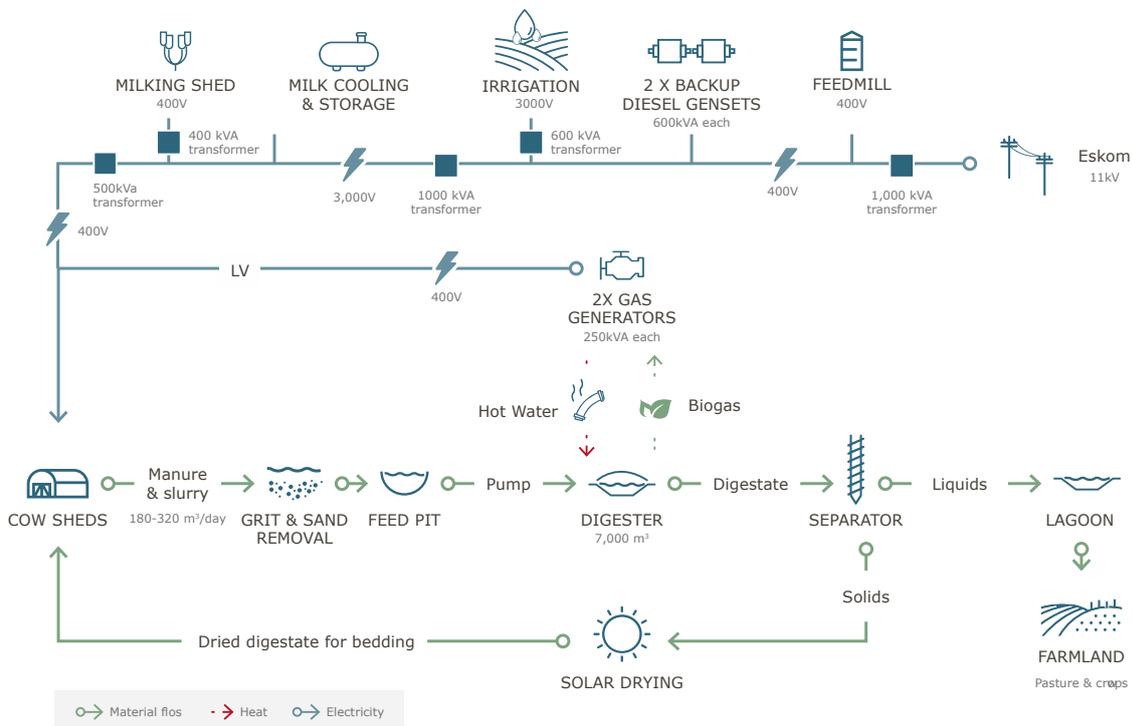


Figure 4.1. Schematic diagram of Uilenkraal AD plant

¹⁴ Total mixed ration is the dominant method globally for feeding high producing, indoor-housed dairy cows. The cattle are fed a nutritionally balanced ration, allowing them to consume as close to their actual energy requirements as possible and maintaining the right physical characteristics for proper rumen function.

4.2.1 Technology description

50% (1,500) of Uilenkraal's dairy cows are usually in-milk and are confined indoors on concrete floors, where their manure can be collected for biogas production. The other dairy cows are with calves in outdoor pens with dirt floors, from which the waste is not suitable for AD due to contamination with sand. Half of the farm's 800 oxen are also confined on concrete floors and their manure adds to that of the in-milk dairy cows, giving a total of 1,900 cattle generating collectable and usable manure.

Uilenkraal initially used hydraulic scrapers for collecting the wastes. These broke down due to sand abrasion and manure is now scraped using a tractor, three times per day, after each milking session. The manure is blended with milking parlour wash water and pushed into a concrete channel. This is angled at about 3 degrees to facilitate separation of wind-blown sand as the manure/slurry blend flows to a holding tank, from where it is pumped to the biogas digester at a rate of 180-320 m³ per day. The feed rate varies significantly, according to CAE's flow rate monitors, from zero to as much as 400 m³ per day.

The balloon-type digester has a 7,000 m³ capacity and is built over a U-shaped pit that is 6 m deep with sloping sides. While it resembles a standard lagoon digester, the installation incorporates a heating and mixing system (the latter added around 2017). It has an uninsulated single membrane with a water seal around the edges, weighted down with sandbags. If there is no gas in the membrane it lies flat. Rainwater then has a tendency to accumulate and has to be pumped off.

The digester has internal piping to circulate hot water from the gas generators' cooling system. Exhaust heat from the generators is not captured. CAE report that the high moisture content of the biogas makes this an inefficient option. There are three heat monitors inside the digester, with a target substrate temperature of 35-38°C. These monitors appear to be faulty at times, with readings from 9 to 46°C recorded during the site visit, and it is not clear that the heating system is working as intended.

Gas mixing takes place at the centre of the digester, where a supporting wall is located. Air is injected to remove H₂S. After a 20-40 day retention time, the gas (with around 60% methane content) is directed via a moisture scrubber to two 250 kVA/200 kW 3rd generation 'Organergy' containerised gas generators from CAE.¹⁵

4.2.2 Power supply and demand

The farm owners estimate that the manure from four cows can produce sufficient biogas to support a 1 kW electrical load. The 1,900 cows at Uilenkraal could therefore support up to **475 kW**.¹⁶ The farm's power records show that the AD plant in fact supplied only 154 MWh_e per month during 2020, translating to an average load of **211 kW**. This means that the plant is supplying as little as 44% of its estimated electricity potential, based on the number of cows stalled and the owner's expectations.

The farm's electricity consumption records show that total average demand during 2020 was **293 kW**. The electricity is used predominantly (60%) for the feed mill as well as the milk plant (20%) and irrigation system (20%). With the AD plant supplying an

¹⁵ CAE's latest (5th generation) units are fitted with turbochargers that increase their rating to 300 kVA.

¹⁶ 400 of the cattle are oxen and have lower manure output than the Friesians, so the assumption of 1 kW per 4 cows may be optimistic across the whole herd.

average of **211 kW**, it therefore met only 72% of the farm's power requirements for the year. The 28% shortfall (715 MWh_e) was drawn from the grid.

Uilenkraal has two 600 kVA diesel standby gen-sets in case both the grid and biogas generators are out of action. These run for up to two hours per day during the worst periods of grid unreliability and produce electricity at three times the cost of grid power. The biogas helps minimise the use of diesel when the grid power cuts out.

The farm's power load drops to around 70 kW at night. One gas generator is usually switched off and the other is throttled back. This reduces the heat available for digester heating, so potentially has a negative impact on gas productivity.

It is clear that the design capacity of the system is not being fully achieved. On the supply side, the gas generators are operating at as little as 44% of their potential, based on the number of cattle feeding the system, while on the demand side, they are meeting only 72% of the farm's total power requirements. This reflects a combination of supply and demand limitations. First, the digester is probably under-performing due to sand ingress, crusting and (possibly) heater faults. Second, the gas generators (with 400 kW combined capacity) cannot meet the peak power load of 700 kW when the feed mill is operational. Third, there is no off-taker for the average surplus of 107 kW, which is mainly available at those times when the feed mill is not active. Being unable to sell excess power to the grid when the farm load dips, CAE is occasionally forced to flare gas. These inefficiencies in both power generation and power consumption illustrate the challenges of optimising such a system, and the complexity of plant sizing and load-matching.

4.2.3 Use of digestate

The fibrous portion of the digestate is extruded through a screw press, dried in the sun and mixed with sawdust to provide cattle bedding. This fibre was previously dried using a biogas burner, but this was decommissioned as it consumed too much gas. The liquid digestate is spread onto crops and pasture with a simple tractor/spreader system (previously used for the spreading of manure). The best results are reportedly seen in the damper winter season, whereas in summer the nutrients can 'burn' dry plants. While a number of advantages of biogas digestate over untreated slurry as fertilizer are mentioned in the literature,¹⁷ the farm owner surprisingly reports no discernible productivity improvement. The nearby Fair Cape Dairy is undertaking trials on the efficacy of fortified biogas digestate as a soil improver.

4.2.4 Operation and maintenance

CAE has one operator permanently on site for routine monitoring and maintenance of the AD plant and generators, and can bring in up to four additional staff at short notice to rectify faults. The system is monitored remotely and triggers alarms if key parameters are abnormal.

Ingress of sand into the digester has been an ongoing problem, especially during dry and windy summer afternoons. As much as 2 m³ of sand was entering every day, blended with the cattle manure, and some 2,000 m³ (3,200 t) of sand had to be mechanically removed from the digester after three years of operation. The problem

¹⁷ Digestate is said to be easier to pump and apply than untreated slurry; flows into soil faster; makes N and P more available; avoids burning of plants; increases soil microorganisms and humus; improves pasture palatability; and reduces odours, pathogens and weeds (Hawkins & Stanway, 2013).

was addressed by constructing two traps that now block 80% of the sand. CAE is developing a system for extracting sand without removing the gas membrane.

Lagoon-type AD plants are technologically straightforward and cheaper than continuous stirred tank reactors, but as a modified plug-flow system they bring a risk of crusting and underperformance due to unequal heat distribution and control. The Uilenkraal digester experienced repeated crusting during the first two years of operation, caused by a combination of straw from animal bedding and the fibrous portion of the feed rations that the cattle tend to selectively reject. This resulted in plant shutdown for almost a year. The digester was eventually opened up and the crust, which was 4 m thick in some places, was removed with a swamp excavator. Six 300 mm propeller mixers were retrofitted to address the issue, though these may be under-sized and are not operated continuously. The site visit revealed that the crusting is again becoming a problem, and may require a second round of remedial measures.

The generators are serviced every 15,000 hours up to a projected lifespan of 60,000 hours, with replacement of pistons, connecting rods, bearings and liners, including new valves, valve seats, valve guides and rockers.

The farmer has some concerns that improvements in the formulation of cattle feed to optimise milk production may result in a reduction in gas production in the digester, because more of the metabolizable energy is taken up by the cows and not left in the manure. This could affect the performance of the AD system.

The farm owner reports that "It is not a turnkey system. Five years down the line we are still learning". Despite the challenges faced, the farm is making significant savings on electricity (see next section) and the venture has been a valuable learning site for CAE to improve its AD and generator technology, which it has been continually upgrading for additional installations in South Africa and Namibia.

4.3 ECONOMIC ASSESSMENT

Table 4-1 summarises the data used in the LCC model for the Uilenkraal dairy, as the Bioenergy Case, comparing it with a Base Case dairy farm drawing all electricity from the grid. The economic assessment is modelled from the perspective of the farm owners, and does not account for the costs and revenues of CAE, as the independent technology provider and operator of the power plant.

Table 4-1: Key project data for economic modelling

Category	Parameter	Value
General parameters	Discount rate	5.75% ¹⁸
	General growth rate	4.10% (Consumer Price Index) ¹⁹
	Electricity retail price	ZAR 1.85/kWh (125.56 USD/MWh) ²⁰
	Currency exchange rate	14.733 ZAR/USD (3-year average)
Base Case	Source of electricity	Eskom grid plus 2 x 600 kW _e gensets
	Electricity consumption	2,593 MWh/year
	No. of livestock	1,900 cattle and oxen stalled indoors

¹⁸ www.photius.com/rankings/2020/economy/central_bank_discount_rate_2020_0.html

¹⁹ www.cia.gov/the-world-factbook/countries/south-africa/#economy

²⁰ Eskom Ruraflex tariff, averaged from Uilenkraal's 2020 invoices including all extra charges. It is assumed that the average cost of grid electricity will remain the same after the reduction in power purchase following the installation of the AD plant, although for various reasons related to tariff bands and ancillary charges for different levels of consumption at different times of day, this may not be the case in practice.

Category	Parameter	Value
Bioenergy Case	Source of electricity	Biogas generators supplying most electricity, supported by the grid. 600 kW _e diesel genset for emergencies, with negligible use
	Gas generator rating	2 x 200 kW _e
	Power supply from AD plant	1,848 MWh _e /yr (72% of total; balance from Eskom)
	CAPEX (for AD+CHP)	ZAR 11 m (~USD 1.143 m) ²¹ plus ZAR 1.4 m (~USD 0.105 m) retrofit, Yr 4 ²²
	OPEX	USD 36,600 per yr ²³
	Electricity price	ZAR 0.74/kWh to CAE ²⁴ (USD 50.36/MWh); Eskom power price as above.

Using these input parameters, the LCC model shows that the Uilenkraal AD plant delivers a significant reduction in the cost of electricity for the farm, as shown in Figure 4.2. It is estimated that it delivers a reduction in LCOE_{electricity} from around USD 194 to USD 172 per MWh, compared with the Base Case scenario.

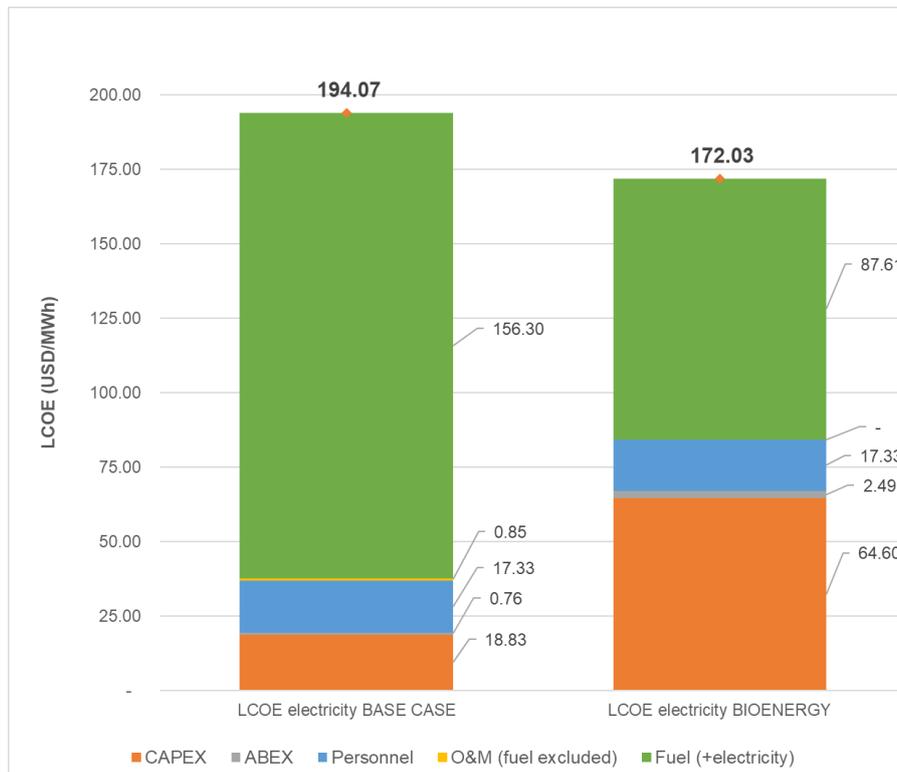


Figure 4.2: LCOE comparison for electricity, Base Case vs. Bioenergy Case

4.4 COMMERCIAL SUCCESS FACTORS

The supply chain for Uilenkraal's AD operation is summarised in Figure 4.3.

²¹ Average exchange rate in 2013: 0.104 USD/ZAR (www.excelrates.com/historical-exchange-rates/ZAR-USD)

²² Average exchange rate in 2017: 0.075 USD/ZAR (www.excelrates.com/historical-exchange-rates/ZAR-USD)

²³ Assumes three full-time equivalent workers for manure scraping and feedstock management. As the analysis is from Uilenkraal's perspective, OPEX does not include CAE's costs of operating and maintaining the gas generators.

²⁴ Tariff charged by CAE to Uilenkraal in Feb 2021, reviewed periodically.

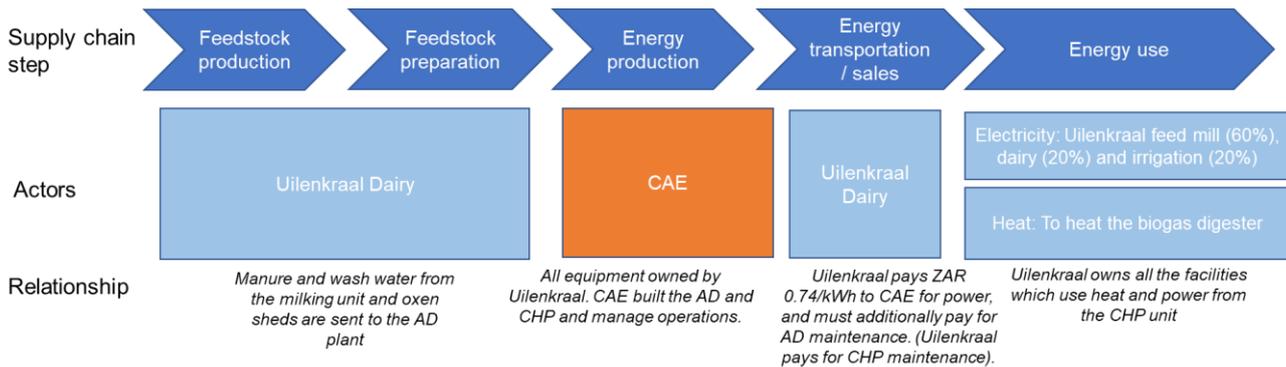


Figure 4.3. Overview of Uilenkraal supply chain

The key factors for commercial success at Uilenkraal have been the project developer's full ownership and control over the supply chain, demand-side factors relating to onsite electricity demand, the business ownership structure and the ability to secure finance. These are discussed in turn below:

- Supply chain control:** Analysis of supply chain archetypes in an earlier stage of the research revealed that having onsite supply of feedstock under the full control of the project owner is an important factor for the success of projects such as this, ensuring ample year-round availability of raw material at no cost.
- Onsite electricity demand:** The presence of a large commercial feed mill, which accounts for around 60% of the farm's total electricity demand, has been an important driver for the commercial case at Uilenkraal. It has provided a reliable load and an opportunity to avoid significant Eskom power purchase. Since the decommissioning of the biogas-fuelled digestate dryer, however, there is no valorisation of heat, beyond the use of engine cooling water to heat the digester.
- Ownership structure:** Uilenkraal purchased the AD and CHP system from CAE, and now owns the fixed assets. CAE provided the technology and manages the system. Under the terms of a 10-year PPA, CAE sells electricity to the farm at a current (Feb 2021) rate of ZAR 0.74 (USD 0.05)/kWh, periodically renegotiated, compared to purchasing from the grid at ZAR 1.85 (USD 0.13)/kWh. This covers CAE's costs of routine operation and generator maintenance and repair, while digester feeding, major equipment replacements and upgrades are the responsibility of the farm. This allows Uilenkraal to focus on its core dairy business, while a specialist AD provider built the plant and now operates it.
- Ability to secure finance:** Uilenkraal contributed a fixed amount towards the CAPEX of around ZAR 11 million (~USD 0.8 m), the majority of it in 2014, plus some later costs for repairs and the addition of mixers in the digester. CAE contributed 'sweat equity' of time, management and expertise, and is recouping this investment, estimated at 33% of the overall project development costs, by selling power to Uilenkraal. It is understood that at least ZAR 8 m (USD 770,000) of Uilenkraal's contribution came from a commercial bank loan, which was part of a larger loan of ZAR 23 m (USD 2.2m) (with an interest rate of 9% p.a.) secured primarily for building new cattle sheds. The bank did not, therefore, lend specifically for the AD plant, but agreed to append this to a larger loan for a more traditional infrastructure upgrade. This reduced the bank's perceived risk and facilitated the credit line for the AD system.

5 POTENTIAL FOR WIDER ADOPTION

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

5.1 BIOMASS RESOURCE ASSESSMENT

5.1.1 Livestock sector in South Africa

Livestock production in South Africa takes place at both subsistence scale and at medium and large commercial scale (Milk SA, 2020a; Oduniyi et al., 2020). While poultry and sheep account for the largest number of animals in the country, cattle are the dominant livestock sub-sector in economic terms (Oduniyi et al., 2020).

The size of the national cattle herd is just below 13 million (FAO, 2020), comprising 80% beef cattle and 20% dairy cattle (Oduniyi et al., 2020). Dairy cattle are kept both on pasture and in feedlots, and, on the large commercial farms, lactating cows are housed in sheds. Daily milk yield averages about 18 litres per cow, though with large variations between management systems and cattle breeds, with some commercial farms achieving daily yields of over 25 litres per cow (Milk SA, 2020a).

A profitable commercial dairy farm requires a herd of at least 100 lactating cows (Milk SA, 2013a). The total herd has to be about twice this size, considering that only about 50% are lactating at any time (Mezzadri & Francescato, n.d.; Milk SA, n.d.) There are about 1,200 commercial scale milk producers in South Africa and average herd size is about 460 lactating cows (Milk SA, 2020a). 57% of farms have 50-400 lactating cows, while about 23% of herds contain between 400-750 lactating cows and 20% are larger than 750 lactating cows (Milk SA, 2013b, 2020a). Based on this, a minimum of 180,000 lactating cows are kept on large commercial farms (see Table 5-1).

Table 5-1 Dairy farm and herd size categorisation in South Africa (Milk SA, 2020a)

Dairy farm size	No. of lactating cows per farm	No. of dairy farms	Total lactating cows	
			Lower estimate	Upper estimate
Small	50 - 400	684 (57%)	34,200	153,900
Medium	400 -750	276 (23%)	110,400	158,700
Large	> 750	240 (20%)	180,000	>180,000
	<i>460 (average)</i>	<i>1,200</i>	<i>552,000</i>	

5.1.2 Bioenergy potential from the dairy sector

Slurry from stalled dairy cattle is a potentially valuable feedstock for energy production using biogas from AD. However, it is only commercially viable to collect these wastes when the cows are kept in modern housing with a waste management system, where the slurry, used bedding and wash water is available as feedstock. This largely rules out cattle kept in feedlots, where their manure is likely to be contaminated with sand or soil. Scale is also important; it has been estimated that commercially feasible biogas production on a dairy farm requires a herd of at least 400 lactating cows (Laks, 2017).

Within the entire dairy sector, it is therefore only the waste from the larger commercial farms with over 800 dairy cows that offers suitable and sufficient feedstock for AD. In

2020, about 20% of the country's herds had more than 750 lactating cows (Milk SA, 2020b). With ~1,200 milk producers (Milk SA, 2020b), this means there will be about 240 farms with suitable herds to generate sufficient feedstock for commercial scale AD, with an estimated 180,000 lactating cows producing collectable manure at any time.

Making conservative assumptions, one housed, mature dairy cow generates about 50 kg/day of slurry (Shine et al., 2020; The Scottish Government, 2016; UK Environmental Information Data Centre, 2020) with a biogas potential of 20-30 Nm³/t fresh matter (Agricultural Research Council, 2016; Bayerisches Staatsministerium für Ernährung, 2020). The slurry from one dairy cow can therefore produce 1.0-1.5 Nm³ of biogas per day. Per housed and milked cow, an additional 35 litres of wash water from cleaning tanks, milking facilities and stalls can be assumed (The Scottish Government, 2016).

On this basis, a dairy herd of 1,900 housed cows (such as on farms like Uilenkraal dairy) is likely to produce around 162 t of slurry and wash water per day, generating 3,240-4,860 Nm³ of biogas. For South Africa as a whole, of the 552,000 lactating cows, at least 180,000 are estimated to be kept on large commercial farms (Milk SA, 2013b, 2020a). If slurry and washwater could be collected from these housed and stall-fed cows, this would result in an estimated 15,300 t of slurry and wash water per day, with total biogas production potential of 306,000-459,000 Nm³.

5.1.3 Mass energy balance of AD in a dairy farm

Table 5-2 shows the mass-energy balance (MEB) parameters for an AD plant using dairy cattle slurry and wash water for CHP. The input data are based on the specifications of the Uilenkraal facility.

Table 5-2: Mass-energy balance, dairy sector CHP

Parameter	Units	Value
Input parameters		
Biomass feedstock		Dairy cow slurry
Solids content	%	10%
Energy installed	MW _e	0.4 MW _e
Capacity factor	%	53%
Annual operational hours	hrs	4,643
Process		AD with CHP (electricity)
Electrical efficiency	%	30%
Output of the MEB model		
Biomass flow	kg/s (wet basis)	1.8
	annual tonnes (wet basis)	30,276
Biogas production	Nm ³ /s	0.08
	annual Nm ³	1,279,046
Biogas yield per tonne of feedstock	Nm ³ /t (wet basis)	42.2
Energy output		
Electricity per t of biomass (slurry)	MWh _e /t (wet basis)	0.06
Electricity	MW	0.4
	annual MWh	1,857
Loss	MW	0.9
	annual MWh	4,333

Figure 5.1 shows the results of the MEB model based on the above-stated specifications for the Uilenkraal AD plant, indicating the biomass flows and energy production, including losses. Based on model results, such a CHP facility requires 30,276 t/yr of slurry (wet basis). Based on the model, an estimated 180,000 stalled and lactating dairy cattle in South Africa producing about 5.6 million tonnes (Mt) of feedstock per year could provide sufficient feedstock for around 184 facilities of this size.

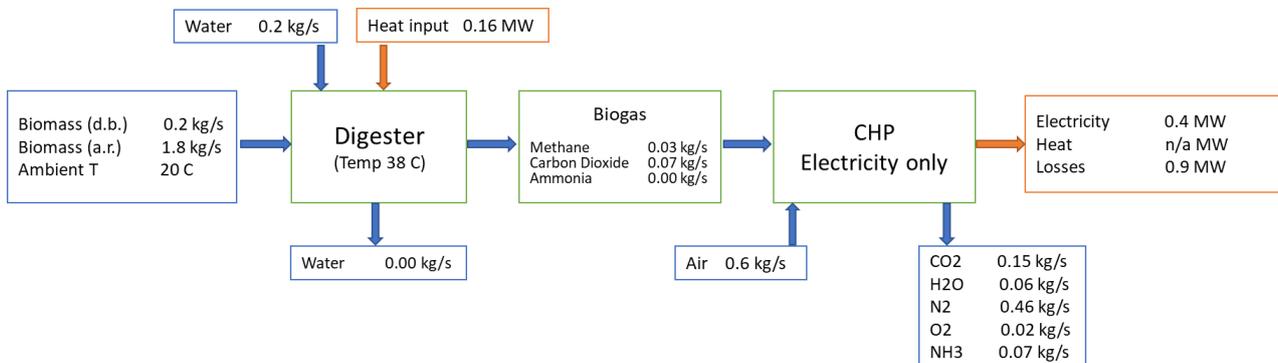


Figure 5.1. Mass-energy balance electricity generation – based on input specifications of Uilenkraal dairy

A large-scale commercial farm with 1,900 lactating cows can produce about 58,948 t of feedstock per year. This can provide an energy potential of about 0.78 MW_e based on the model results. If heat were also to be produced, an additional potential of 1.2 MW_{th} would be available. On a national level, commercial large-scale farms, with 180,000 lactating cows in total, could have an energy potential from AD of 73.8 MW_e and 112.5 MW_{th} (342,549 MWh_e and 519,536 MWh_{th} per annum). The model indicates an optimal biogas yield of 42 Nm³ per tonne of fresh slurry. Achieving such high yields requires contamination of the slurry to be avoided and the addition of water to be minimised. The model assumed solids content of 10%. If this was to decrease (through the use of more washwater, for example), larger volumes of feedstock would be required to produce the same amount of biogas, and with it would come a need for larger storage and handling facilities for the slurry and washwater.

5.2 TECHNOLOGY

5.2.1 Technology supply chain

CAE is one of several South African companies competing for commercial AD opportunities. The market saw encouraging growth from around 2009, when a new Renewable Energy Feed-in Tariff was gazetted. Although the new tariff did not initially include any provision for power from biogas, the industry was optimistic that this would be introduced.

A number of AD installations were commissioned at beef and dairy feedlots, piggeries, poultry farms, abattoirs and food processors. Several companies entered the market with tailor-made AD solution, such as: **CAE** with its Uilenkraal dairy project and others at a piggery (near Bapsfontein) and a wastewater treatment plant (at Mariental, Namibia); **Selectra** (with a 'dairy power in a box' concept); **Bio2Watt** (at a beef cattle feedlot at Bronkhorstspuit); **Veolia** (at a milk processing plant near Port Elizabeth); **Biogas SA** (at an abattoir in Gauteng and a shopping mall in Cape Town); and **Renen** (with an induced blanket reactor at a horticulture farm near Pietermaritzburg).

The most prolific local developer was probably **iBERT**, which disseminated complete-mix 'Biogas Express Reactor Technology' developed by Innsbruck University (Austria) and installed at least six plants, including at Mandeni (KwaZulu-Natal) using sugar cane waste; an abattoir in Cullinan (Gauteng) and Jan Kempdorp (North West Province); a sheep farm at Riversdale (Western Cape); a piggery at Queenstown (Eastern Cape); and the Zandam cheese processing plant near Cape Town. iBERT used proven AD concepts from a European developer, with local manufacture and assembly with very limited success.

Bio2Watt worked more directly with a European partner at Bronkhorstspuit, importing a 4.6 MW complete mix digester from Combigas (Denmark). A second Bio2Watt venture at a dairy farm near Malmesbury (Western Cape) intends to use technology from **Anaergia**. Anaergia is thought to be the only international company with a permanent presence in South Africa, and brings technology from its German subsidiary, UTS Biogastechnik. Anaergia installed an AD system at Cape Town's waste-to-energy plant in 2017, and was involved in technical troubleshooting at Bronkhorstspuit. Using a similar partnership model, **Biogas Nord** supplied equipment from Beckedorf BioEnergy (Germany) to a fruit juice business at Grabouw (Western Cape) fed with apple pomace and abattoir waste; **Tecroveer** installed Dutch AD technology to process alcohol waste at a Distell facility in Gauteng; **The Waste Transformers** also installed a containerised Dutch technology at an AD plant at the N1 City Mall in Cape Town; and **Zorg Biogas** (Germany) supplied two digesters to the Rugani Carrot factory at Tartlon (Gauteng).

Opinions differ on the viability of introducing European technology. While German, Dutch and Austrian AD systems are technically well proven, they were developed in the European commercial environment where subsidies were originally offered for renewable energy. The same financial incentives either do not exist or cannot be readily accessed in South Africa, making transplanted European technology uncompetitive for a majority of local businesses, whose internal electricity demands are insufficient to justify such costly investments, and who cannot access viable tariffs for external power sales. Several of the above-mentioned plants were reportedly motivated by corporate social responsibility concerns or were 'grudge' purchases to comply with environmental controls.

5.2.2 Technical considerations for replication

The South African AD market remains small. Only 23 commercial-scale plants could be identified, of which just seven are believed to be operational. Only iBERT is thought to have installed more than two operational systems. Unfortunately, iBERT reportedly went into business rescue in 2020. According to Mergence Capital, one of iBERT's financiers, small-scale AD plants are not commercially viable and Mergence was encouraging a shift to larger and more profitable opportunities with economies of scale.

To grow the AD market in the dairy sector (and more generally), lower cost, localised versions of proven international technology could facilitate wider uptake in the subsidy-free South African context. CAE is pursuing this approach as its commercial strategy. It is one of very few companies that have developed South African-made biogas generators, another being Sustain Power (although the latter is mainly assembling German units). CAE sources local components where possible and aims to eliminate concrete in future installations to further cut costs (and to reduce its carbon footprint).

While world-leading AD technology is available to potential AD developers in the South African dairy sector, the issue for wider replication is one of cost and its impact on payback time. This is motivating a small number of specialist companies to develop locally manufactured versions of European technology. They are adopting proven technical principles from international suppliers, and combining this with selective import of competitively sourced components, local manufacture of equipment and cost-cutting design modifications. This blended approach cuts costs and can stimulate wider adoption.

5.3 ECONOMIC VIABILITY

The sensitivity of LCOE to a number of relevant variables was assessed. These were total power demand, the average grid power tariff and the 'bioenergy fraction' (the percentage of power derived from the AD plant, rather than Eskom purchase).

Figure 5.2 considers the effect on LCOE of a range of electricity demand values from 850 to 3,100 MWh/year. The modelling reveals that the AD plant continues to provide cheaper power for the farm owner down to a total power demand of around 880 MWh/year, which is about one third of the current power demand of 2,600 MWh/yr.

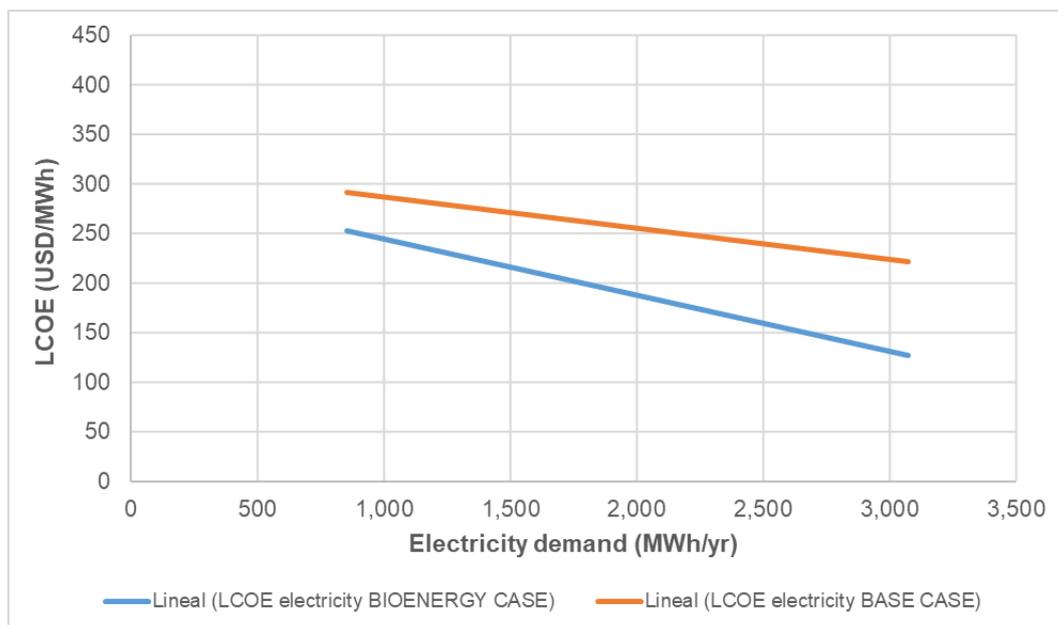


Figure 5.2. LCOE sensitivity to electricity demand

Uilenkraal pays a yearly effective averaged electricity tariff to Eskom of about USD 125.6/MWh (1.85 ZAR/kWh), while the cost of self-generated power billed by CAE is USD 50.4/MWh (0.74 ZAR/kWh). Figure 5.3 below provides an average LCOE comparison of the Base Case to the Bioenergy Case for a range of possible Eskom tariffs from USD 70 to 200/MWh). The model tool shows that the minimum effective tariff for grid power at which the Bioenergy Case becomes less attractive than the Base Case is USD 77/MWh (1.134 ZAR/kWh). Any average Eskom tariff above this favours this Bioenergy Case and supports investment in an AD plant.

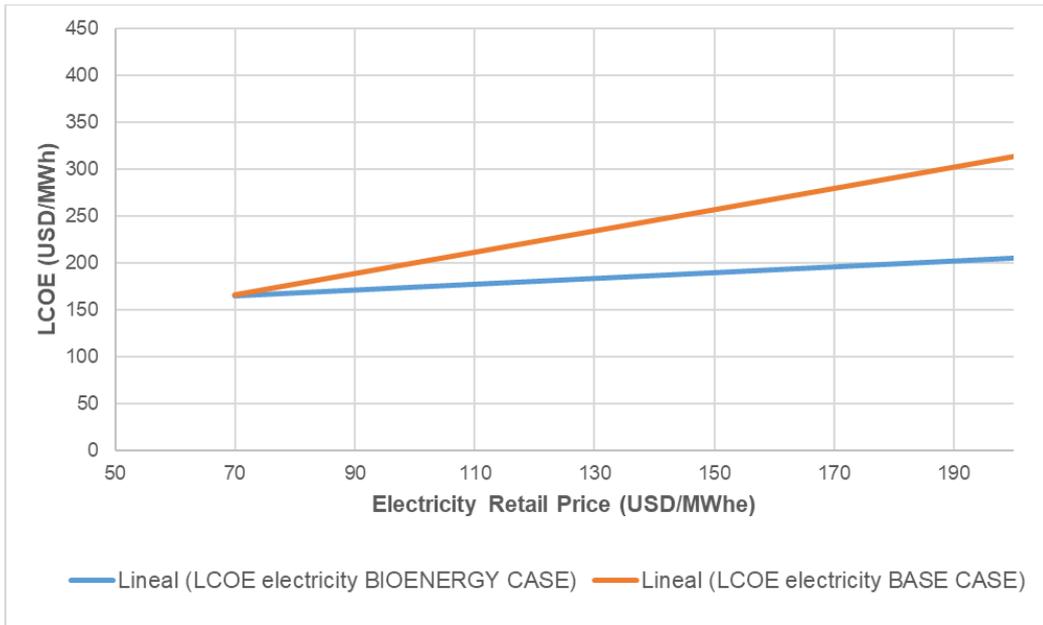


Figure 5.3. LCOE sensitivity to grid power cost

The influence of the 'bioenergy fraction' on electricity cost was investigated. The results in Figure 5.4 show that the $LCOE_{\text{electricity}}$ for the Bioenergy Case remains lower than the Base Case cost of electricity right down to 20%, meaning that the project owner will still save on electricity costs up to the point where more than 80% of all power has to be purchased from the grid. 28% of the farm's power is currently purchased from the grid.

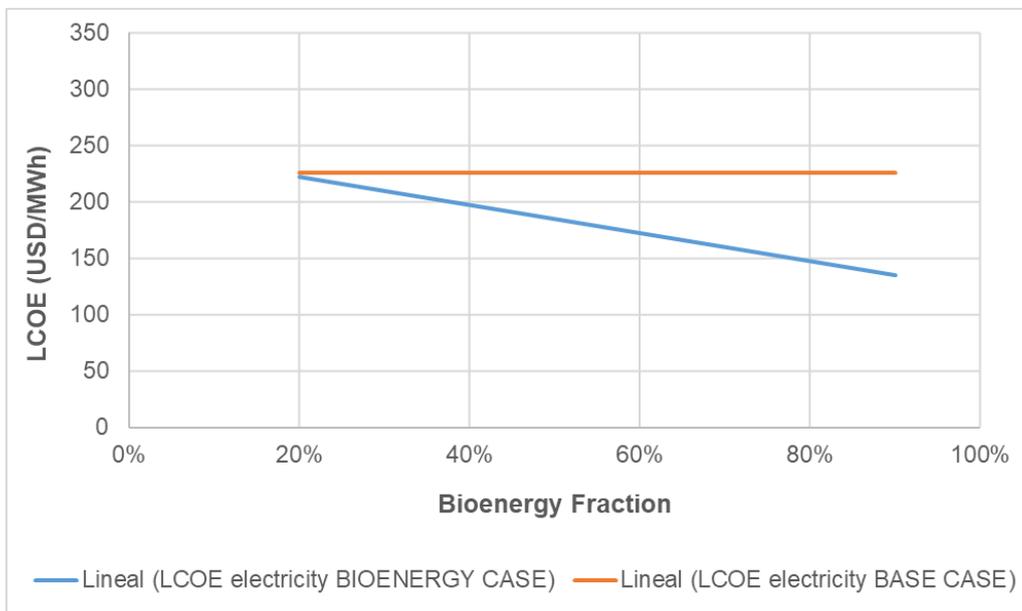


Figure 5.4. LCOE sensitivity to bioenergy fraction of total power supply

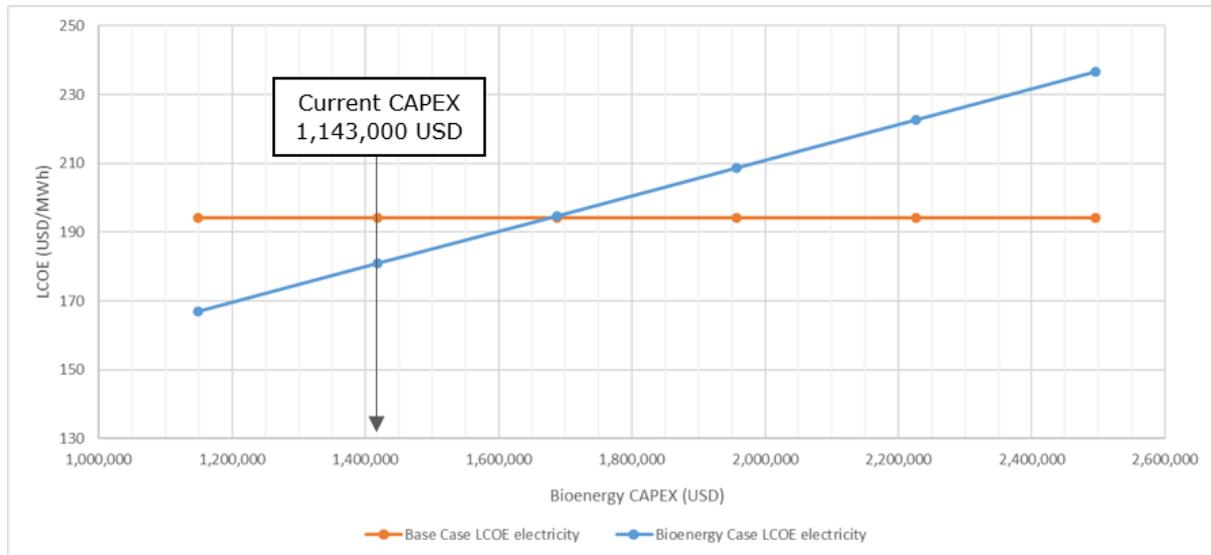


Figure 5.5 illustrates the effect of CAPEX on the LCOE comparison. The results show that the tipping-point for the viability of the Bioenergy Case is at about 1.5 times the actual CAPEX value of the Uilenkraal plant, indicating that a CAPEX of around USD 1.7 million could be incurred in the Bioenergy Case before the LCOE electricity reaches the Base Case LCOE reference.

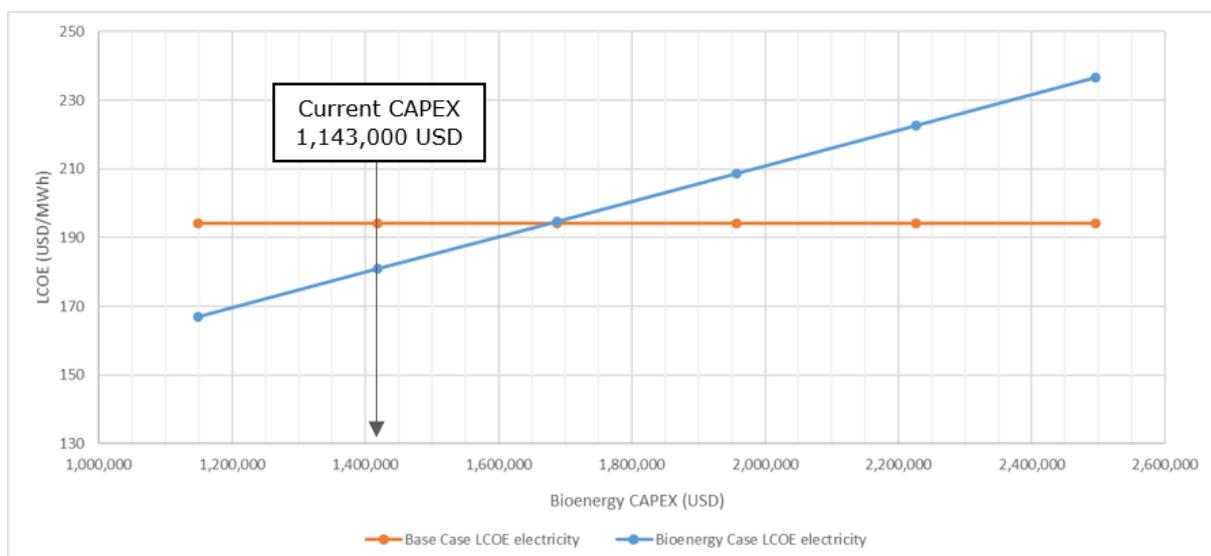


Figure 5.5: Sensitivity of LCOE to CAPEX increase

5.4 COMMERCIAL PROSPECTS FOR REPLICATION

This section explores the prospects for replication of the Bioenergy Case, considering market potential (based on demand for electricity within South Africa's dairy sector), demand for heat and power, ownership structure and financing approach.

5.4.1 Market potential

Provincial data on dairy production (Milk SA, 2020a) and typical dairy energy consumption values (Shine et al., 2020) were used to determine electricity consumption in the dairy sector by Province, while estimates from a Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) study were used for potential electricity supply, based upon manure production and biogas potential (Agricultural Research Council,

2016). Figure 5.6 illustrates the resulting estimates of dairy farm power requirements and the potential electricity supply from manure-based AD, by province.

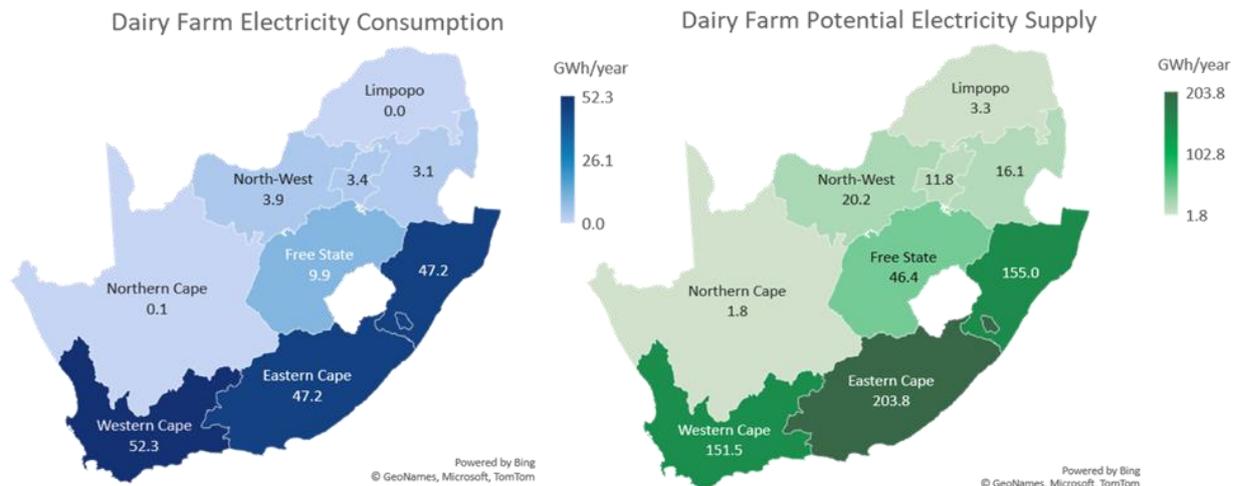


Figure 5.6. Estimated dairy farm electricity consumption and estimated potential dairy farm electricity supply from biogas, by Province

Estimates for total electricity demand in the dairy sector range from 137 to 200 GWh_e/year, representing open grazing scenarios at the lower end and confinement-based scenarios at the upper end (Milk SA, 2020b; Shine et al., 2020). This compares to a potential supply of ~609 GWh/year from manure-based AD (Agricultural Research Council, 2016). This suggests that the dairy sector could be self-sufficient in electricity if all manure was collected and fed to AD units for production of biogas for electricity generation. Electricity demand and power generation potential from manure are both highest in the country's southern Provinces, naturally in the areas where milk production is concentrated.

The estimate of total electricity demand in the sector up to 200 GWh_e/year does not translate into an equivalent commercial opportunity for the replication of AD, as the majority of the cattle are on small farms where feedstock is insufficient, contaminated or uncollectable (see 5.1), and where the commercial case for AD is weak. The maximum opportunity is on the 240 large-scale dairy farms with more than 750 lactating cattle. But even here, there are very few dairies that have the same on-site electricity demands as Uilenkraal, with its exceptional power demands linked to on-site feed mill. The commercial opportunity will, in reality, be limited to those milk producer/processors who (as section 3.2 explained) have fallen in number to just 68. It is these integrated operations, that combine milk production with processing, where on-site power demands are sufficient to make AD worth considering.

5.4.2 Demand for heat and power

Barriers and enablers to commercial adoption of AD in the dairy sector are classified according to whether the demand for heat and power comes from self-consumption, local clusters or (for electricity) grid export (Table 5-3).

Table 5-3: Barriers and enablers to the use of processing residues for AD in Kenya's horticulture sector

Demand	Barrier to business model	Enabling conditions
Heat for self-consumption	Absence of on-site heat demand: The heat from the CHP	More energy intensive processes onsite: If dairy

Demand	Barrier to business model	Enabling conditions
	unit at Uilenkraal is only used to heat the biogas digester. Other dairy farms also lack onsite demands for heat. They mostly raise Holstein Friesian cattle, which prefer cool weather, so no heating is required for milking sheds.	farms were to process milk on-site, then heat would be needed for milk pasteurisation, bottling and production of added-value dairy products. This could boost the commercial case for AD and increase replication potential.
Electricity for self-consumption	<p>Limited onsite electricity demand: Few dairy farms have large on-site requirements for electricity. Even those with milk processing plants, such as Fair Cape Dairy, tend to locate their processing facilities in urban areas closer to their markets, and away from their (largely rural) milking operations.</p> <p>Variable on on-site power load: A dairy farm's energy requirements are variable through the day and year, ranging from 80 to 700 kW at Uilenkraal. Its gas generators are too small to meet the peak demand and throttled back when demand drops, resulting in sub-optimal utilization of the technology.</p>	<p>Significant on-site power demand, in addition to standard dairy operations: 60% of Uilenkraal's peak demand of 700 kW_e is used for its feed mill, providing an important demand centre for the power from the AD plant. If other dairy farms had facilities with similarly large electricity demands, this would significantly improve the investment case. 68 dairy farms are known to process their raw milk (Milk SA, 2020a) and this will increase their electricity load and make them more likely adopters. This number is down from 114 farms in 2014, however, indicating declining trend in such vertically integrated facilities.</p>
Electricity for grid export	<p>Wheeling charges and administrative requirements diminish the attractiveness of grid export: Whilst it might be possible for smaller scale electricity producers (100 kW to 1 MW) to sell electricity to municipalities via the grid ('wheeling'), barriers exist that hinder the likelihood of this happening in practice. The costs and administrative requirements of wheeling are considerable and would likely not warrant a rural dairy seeking to qualify as a SSEG under the new legislation (which is still not passed at the time of writing).</p>	<p>Regulatory reform: The recent (June 2021) announcement by the DMRE Minister that more support would be given to sub-1 MW projects is promising, but yet to be implemented.</p> <p>The Electricity Regulations on New Generation Capacity (DMRE, 2020a) announced in October 2020 mandate Eskom to work with municipalities to obtain electricity from small-scale producers of renewable electricity (DMRE, 2020b). While this requires the municipality concerned to be in good financial standing, it opens up interesting new opportunities for independent small-scale power producers.</p>

In addition to the self-consumption of heat and electricity, the export of heat and/or electricity to local clusters was investigated as a possible enabler for replication. However, given the lack of clustering of commercial and industrial businesses close to dairy farms (as evidenced through extensive interviews with local stakeholders and literature) and lack of government policies to promote such industrial clustering, demand from local clusters is not likely to enable replication of this pathway.

Based on this analysis, opportunities for AD to supply heat for on-site use at dairy farms are very limited, and heat demand will not be a significant driver of replication. The main driver of demand for AD in the dairy industry will be electricity. The Uilenkraal venture is exceptional because of the power demands of the associated feed mill. As most dairy farms have lower onsite power requirements and because these requirements fluctuate considerably, potential investors will need to sell their surplus power to the grid (or third party via wheeling agreements) in order to make similar investments worthwhile. Recent regulatory developments have made wheeling agreements easier in principle, but they are not without their cost and administrative hurdles.

5.4.3 Ownership structure

Under the partnership agreement between CAE and Uilenkraal, Uilenkraal runs the dairy farm and the specialist technology provider has built and operates the AD plant, generating its revenues from selling electricity. CAE sees no other viable operating structure in fact, given the specialist skills required to run AD systems. "If the builder doesn't operate it, it isn't going to work", according to the company's owner.

5.4.4 Financing approach

There has been a lack of interest in AD in the dairy sector, making it hard to gauge potential investor interest. The most appropriate sources of finance will depend on the particular project conditions (feedstock supply, technology and offtake agreements).

A key consideration is capital cost. Based on the experiences gained at Uilenkraal and its other AD installations, CAE has determined that any new AD plants must cost less than ZAR 30 m (USD 1.8 m) per installed MW, if they are to prove competitive with Eskom and achieve a commercially attractive payback period for investors.

Models such as Uilenkraal, where ownership and management responsibilities are split, could make it easier to raise finance, as this model is likely to be more commercially viable than one where the project developer owns and operates the system themselves. Adopting a similar arrangement, Fair Cape has a PPA with a solar PV developer (located at their milk processing plant), which puts the management of renewable energy the system at arm's length from the core operations of the dairy processor.

Access to credit could also be facilitated by bundling an AD plant with a more traditional loan for an infrastructure upgrade, which will be more familiar to banks that lend in the South African agricultural sector.

5.4.5 Conclusion

Uilenkraal is a large farm generating significant residues suitable for AD, with owners who are innovators, risk-takers and early adopters of renewable energy. While there is potential in the South African dairy industry for other farms to adopt AD as a source of electricity, there are a number of barriers including inadequate farm scale, high upfront

cost, technology unfamiliarity, poor access to credit and an inability to sell power reliably into the grid. Dairy farms with exceptional power demand will be the most viable sites, notably those that process their own milk. Should a business case be viable, accessing finance (e.g. a commercial loan) for the AD plant as part of a larger financing package for general infrastructure upgrades at a dairy farm may help to reduce the perceived risk in the eyes of the financier.

5.5 GENDER AND INCLUSION

South Africa faces historical issues of both gender and racial discrimination. The majority of women in South Africa have had limited opportunity for socio-economic development, aspects of which still disadvantage them today (Ozoemena, 2018). We have made attempts to highlight key areas of concern and structure recommendations around these, which would be pertinent to investments similar to the Bioenergy Case in this study.

Despite barriers that block women from reaping the full economic benefits of dairy and cattle farming (such as barriers to lands rights), women play a significant role in the dairy sector as a proportion of the engaged workforce. They have roles in decision-making in the running of cattle farming and animal care, as well as key roles as decision-makers at the household level (Reddy & Goga, 2015). High engagement of women does not mean there are not gender discrimination issues, however, such as safety in the workplace, fair labour rights and wage parity. And despite having decision-making roles in smallholder livestock farming, there is little evidence that these roles and rights have filtered through to larger commercial dairy farms.

There are various policies that aim to increase gender inclusion, such as the Protocol on the Rights of Women in Africa. The Protocol is intended to ensure the protection of rights that are crucial for the socio-economic development of women, such as the right to inheritance and the rights of widows and girls. However, the reliance on, and likelihood of, high-level protocols having an impact on the ground is still an ongoing challenge (Reddy & Goga, 2015). It is therefore encouraged that any investments for expansion in the bioenergy base case adhere to existing frameworks and protocols which are established in South Africa, designed to reverse inequalities. One such initiative is through South Africa's Broad-Based Black Economic Empowerment (BBBEE) initiative. This sets out a framework for code of good practice around: ownership, management control; equity in employment; procurement and socio-economic development. From our research, it seems that the larger commercial dairy farms have gender and social inclusion awareness, with dairy processors such as FairCape being BBBEE-registered. Future investments should capitalise on existent frameworks, with any donors to the sector insisting on transparency in gender, ethnicity and working conditions.

5.6 INSTITUTIONAL, MARKET AND REGULATORY FRAMEWORK

As previously explained (section 5.4), further adoption of AD in South Africa's dairy sector is likely to be limited to those few farms that have significant on-site electricity demands, either for their own milk processing plants or for an ancillary enterprise such as a feed mill. For most potential adopters, commercial viability will rely on being able to sell surplus power at an attractive tariff and with minimal bureaucracy. However, the opportunities for power sales into the Eskom grid from small-scale bioenergy producers have been very limited, despite the huge success of the REIPPPP in bringing massive

additional renewable power capacity online at >5MW scale. Eskom has had almost monopoly control over distribution infrastructure and has made grid feed-in, net metering and wheeling arrangements for small-scale independent power producers cumbersome and unattractive.

It is encouraging that the Minister of DMRE gazetted amendments to the Electricity Regulations on New Generation Capacity (DMRE, 2020a) in October 2020 that facilitate municipal power generation and expanded purchase from SSEGs, as opposed to Eskom, and which mandate Eskom to work with municipalities to obtain electricity from small-scale producers of renewable electricity (DMRE, 2020b). While this requires the municipality concerned to be in good financial standing, it opens up interesting new opportunities for independent small-scale power producers.

South Africa has 257 municipalities and local authorities with their own electricity distribution companies who mostly use their grids, for a small fee, to get electricity from Eskom to their customers. A number of municipalities (e.g. City of Tshwane/Pretoria, City of Cape Town²⁵) have their own power stations, generating some or all of their own electricity. Municipalities such as Johannesburg, Pretoria and Cape Town can now apply to generate their own electricity, provided they have met certain conditions such as having an Independent Development Plan and having no debts to Eskom (Republic of South Africa, 2020).

There are also hundreds of mines, other industries and residential areas with their own electricity distribution systems, who are free to purchase from SSEGs (Baker & Phillips, 2019). Over 40% of Eskom's electricity is now distributed through grids owned and operated by municipalities, industrial parks and other commercial and residential entities. NERSA allows SSEGs, such as Uilenkraal, to sell directly to these municipalities and industries.

But as dairy farms are located in rural areas and unlikely to be connected to a municipal grid, they would still have to wheel using Eskom's grid to transport the electricity to the municipality, and pay the charges associated with doing so (known as 'gen-wheeling tariff rates').²⁶ The costs and administrative requirements are considerable and would likely not warrant a rural dairy seeking to qualify as a SSEG under the new legislation (which is still not passed at the time of writing). An extensive amount of information is required for an SSEG to obtain a licence to generate electricity for export to the grid (NERSA, 2020), to net-meter electricity, to wheel electricity to another party (Eberhard & Naude, 2017; Eskom, 2020a, 2021) or to 'bank' electricity with Eskom (Eskom, 2020b).

It is therefore likely that most dairy farms will remain uninterested in selling power to the Eskom grid. And unless Eskom significantly reduces its wheeling charges and administrative requirements, they will also not benefit from the recent changes facilitating sales by SSEGs to other customers (e.g. municipalities and large industries). This will only happen if the Government forces Eskom to significantly reduce its transaction requirements and charges (particularly the connection costs and meter charges to both the electricity supplier and the buyer).

²⁵ Steenbras Power Station (pumped storage) generates 180 MW_e,

²⁶ See www.eskom.co.za/CustomerCare/TariffsAndCharges/Pages/Schedule_Of_Standard_Prices.aspx

5.7 REPLICATION POTENTIAL IN OTHER TARGET COUNTRIES

5.7.1 Introduction

This section explores the potential for wider adoption of the Bioenergy Case in the other BSEAA2 target countries. The intention is to summarise the prospects for replication of the model, based on the commercial environment in each of those countries and their respective dairy 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 dairy sector is of growing commercial importance in the ten BSEAA2 target countries, driven, in the first instance, by rapid urbanisation and middle-class demand for milk products. After South Africa, the largest dairy production in the target countries is found in Kenya, followed by Zambia, Uganda, Nigeria, Tanzania, Rwanda, Ethiopia and Ghana.

Ethiopia: With a population of 100 million, Ethiopia has a huge potential market for milk and milk products. The country produces about 4 billion litres of milk per year, which is low given that it has around 60 million cattle, more than any other country on the continent. While ~90% of its milk comes from cows, camels, goats and sheep also produce a significant share. Almost all of Ethiopia's dairy animals range freely in rural areas under small-scale family management, using local breeds with low milk productivity. Most milk is consumed at household level, with any surplus usually converted into traditional butter and white cheese for own consumption and local sale (Tegegne et al., 2013). Close to urban markets, farmers have access to artificial insemination and use crossbred and high-grade dairy animals in more intensive systems with concentrated feeds (Mayberry et al., 2017). But only 1% of Ethiopia's dairy cattle are raised in this way, and even with modern husbandry practices, most of their milk is still sold informally into local markets. A very small amount is sold to dairies who sell into supermarkets and upper income urban shops (Tegegne, 2018). Ethiopia does not have any operational dairy waste-based AD plants.

Ghana: Ghana's demand for dairy products is gradually increasing because of dietary changes and increasing urbanization (Gidiglo, 2014). Ghana has very few dairy cattle - most cattle are kept in the arid and semi-arid north, and are not raised for milk. The cattle are not close to any milk collection centres. The far south is not suitable for dairy cattle, primarily for climatic reasons. The same applies to Nigeria, Cote d'Ivoire, Liberia, Sierra Leone, Togo, Benin and Cameroon. With limited local production, the country's dairy processors (producing ice cream, baby foods, chocolate milk, yoghurt and long-life milk products) increasingly rely on milk imports, mostly from Europe (New Food, 2016). Imports of dairy products were worth around USD 70 million in 2019 (TrendEconomy, 2021). Ghana does not have any operational dairy waste-based AD plants.

Kenya: Kenya's dairy industry was started by settlers in the 1920s, with indigenous smallholder farmers setting up over 1,000 dairy cooperatives at independence under the Kenya Co-operative Creameries²⁷ (Renewable Energy Department, 2020). Rapid growth of the tourism sector during the 1970s stimulated a modern dairy industry and,

²⁷ KCC was founded by colonial settlers in 1926 and transformed into Kenya's largest dairy company in 1964.

by the late-1970s, Kenya was a major exporter of dairy products to neighbouring countries, North Africa and the Gulf states.

The dairy industry is one of the most economically active sectors in Kenya, overseen by the Kenya Dairy Board²⁸, with over 300 licensed producer/processing entities (Kenya Dairy Board, 2021). It contributes over 4% of GDP (ibid., p.7), is growing at over 5% per year, with milk processing capacity growing at over 7% p.a.. Over 1.3 million smallholder dairy farmers with over 4.5 million dairy cows produce about 3 billion litres of milk per year, most of which is not marketed. The dairy industry contributes to 3.5% of national GDP and 14% of agricultural GDP (State Department of Livestock, 2017).

Bioenergy demand stems from the need to refrigerate milk before it is taken to collection centres. Several micro-AD pilot projects involving over 100 smallholder dairy farmers are underway (Simgas, 2021; SNV, 2020), and one commercial-scale AD project (at Kilifi Plantations) involves the mixing of dairy cattle manure with sisal wastes. Kenya's Bioenergy Strategy foresees 20,000 dairy biogas refrigerating units for dairy farmers by 2030 (Renewable Energy Department, 2020). Kenya has set out an ambitious dairy sector strategy to improve and modernise dairy production for over one million farmers, where AD from dairy livestock waste plays a major role in "reducing high-emission energy in the dairy sector" with finance and technical assistance to biogas companies (State Department of Livestock, 2017).

Nigeria: Nigeria, with a population approaching 190 million, the highest in Africa, has a cattle population of 20.5 million, of which only 11.5% (2.3 million) are dairy cattle (PWC Nigeria, 2017). Nigerian cattle are reared primarily under pastoral grazing systems, with over 70% of Nigeria's dairy cattle stock being herded from the country's northern states into the so-call 'Middle Belt' in search of pasture and water (CSIRO, 2020)²⁹. Dairy cattle in the north of Nigeria have lower milk yields than cattle managed on farms, which tend to prevail in the Middle Belt, where Nigeria's capital, Abuja, and several of Nigeria's largest urban areas are found. The Middle Belt produces nearly 80% of Nigeria's commercial dairy (CSIRO, 2019a) with 80% percent of the commercial dairy farms located in the north central region (FAO, 2018).

There are three major production systems in Nigeria, namely the pastoral, the semi-intensive and the intensive commercial (Sahel Consulting, 2019). On average, dairy cows in Nigeria produce 1.5-2 litres of milk daily, one of the lowest in the world (PWC Nigeria, 2017). Imported milk (primarily powdered milk) accounts for 75% of milk processing inputs. Urbanisation, improving household incomes and general population growth is pushing demand for dairy products with growth estimated at 3.2% to 3.5% per annum (Sahel Consulting, 2019). Cattle milk production amounts to 585,000 tonnes of milk per year, that only covers 40 percent of the demand (FAO, 2018).

Nigeria's dependence on imported dairy production (particularly powdered milk which is reconstituted into milk and dairy products) and its very low level of dairy cow productivity, combined with a very slow growth in the intensive commercial sector do not bode well, in the short term, for utilising dairy cattle wastes for anaerobic digestion for energy generation within the BSEAA2 range. That, coupled with no AD project

²⁸ www.kdb.go.ke/

²⁹ See also ILRI (International Livestock Research Institute - Addis Ababa)/CSIRO on northern Nigeria dairy cattle (CSIRO, 2019b) and central Nigeria dairy cattle (CSIRO, 2019a).

development history, does not give an encouraging outlook for investment in bioenergy from Nigeria's dairy cattle waste sector. (CSIRO, 2020).

Rwanda: The Government of Rwanda has made significant investments in developing its dairy sector to meet sustainable development goals and to improve livelihoods of rural farmers. Dairy cattle account for over half of Rwanda's livestock. The current 'farm gate' value of annual milk production is approximately USD 162 million (TRAIDE Rwanda, 2019).

Milk consumption has increased in Rwanda from 20 litres per capita per year in 1991 to 68 litres in 2019 through dedicated efforts by the Government of Rwanda, engaging a number of development partners and the formation of farmers' dairy associations over the past 15 years (ibid). However, in 2019 only 3% of the dairy production in Rwanda was commercialised with the remainder either consumed by the farm families themselves, or traded or sold informally (ibid). In 2016, approximately 10% of all dairy production was processed by one means or another (Ministry of Foreign Affairs, Netherlands, 2016). Only a small amount of dairy, primarily milk and homemade butter (ghee) is exported primarily to the Democratic Republic of the Congo and Burundi. While considerable attention is being paid to dairy in Rwanda by both the Government and development partners, the sector is still in its early stages of growth with little commercial, formal sector activity at present.

Tanzania: Tanzania has a long history of dairy farming, but the industry has never flourished, despite steadily rising demand for dairy products. The demand for packaged milk is significantly higher than supply. The traditional sector contributes about 70% of total production, with 25% coming from the smallholder dairy sector and the remaining 5% from large-scale dairy farms. Dairy sector AD biogas plants are currently limited to small-scale farm operations (SNV, 2020). However, expansion of several programmes, including the SNV programme, with several commercial entities (e.g. Simgas) look to increase the number of AD systems, including larger ones to utilise yields from Tanzania's growing dairy stock for milk chilling in rural areas (Camco Clean Energy (Tanzania), 2013).

Uganda: Dairy is an important sector of Uganda's economy, contributing about 9% of GDP. The country produces about 2.4 billion litres of milk every year, about a third of which is processed and the rest is sold as raw milk. Over the past 20 years, Ugandan smallholder dairy farmers have formed cooperatives and set up national distribution networks. Recently, smallholder AD projects for chilling milk have been set up with international support. As in Kenya, and the dairy sector is growing rapidly (Mbowa, 2019).

Zambia: Zambia has a large livestock sector with approximately 3 million head of cattle, around 80% of which are owned by some 300,000 traditional smallholder farmers. They rear mostly traditional Zebu cows and use the milk for their own consumption, with little milk sold commercially. Zambia nevertheless has about 3,500 small and medium dairy farms, with daily milk production that varies widely from 20 to 250 litres per farm. Most of this milk is sold locally on an informal basis.

However, there is an active and growing smallholder dairy co-operative movement under the Dairy Association of Zambia (DAZ) with some 40 co-ops with 1,700, mainly smallholder dairy farmer members (Table 5-4).

Table 5-4: Zambia Dairy Co-operatives, 2020 Source: (DAZ, 2021)

Province	No. of cooperatives	No. of members
Central	14	365
Copperbelt	24	1,165
Lusaka	2	170
Total	40	1,700

Another 70 dairy farms produce over 45% of the commercially sold milk (Dutilly et al., 2020). These large-scale commercial dairy farms which use only specialised cattle breeds and produce an average of 2,000 litres of milk per day (Mumba & Pandey, 2013). They account for almost all commercial dairy production and processing and export a significant amount of milk and dairy products to South Africa, Namibia, Tanzania and Zimbabwe. Zambia does not have any operational AD plants, other than household plants, based on dairy waste supported by SNV and SimGas for small-scale (<10 kW) biogas-fuelled milk refrigeration (SNV, 2020). However, there are plans for larger livestock AD units, as set out in Zambia's Bureau of Standards specifications for livestock biogas plants (Zambia Bureau of Standards, 2014)

5.7.3 Summary of replication potential other target SSA countries

None of the other SSA countries targeted under BSEAA2 have a commercial dairy sector as large and modern as South Africa's, but several have dairy sectors that are growing, both in terms of rising demand (including export demand in Kenya, Uganda and Zambia) and increasing numbers of producers. There is clearly technical potential for manure-based AD in these countries. But whether that potential can be developed on a large commercial scale remains to be seen.

Kenya, for example, has some 180,000 small-scale commercial milk producers selling over 70% of the country's marketed milk through cooperatives (Ministry of Agriculture, Livestock & Fisheries, 2017). There are more than 1.3 million additional small dairy producers who are targeted by government and international agencies to improve their stock and skills to enter the formal dairy market (ibid., p 13). Ugandan dairy farmers are following the Kenyan trend and, as noted, Zambia has a growing export market. Zambia has an increasing number of small-scale dairy farms with increased interest being cited for piloting AD systems (SNV, 2020). The target countries have some of the fastest growing urban populations in Africa, with dramatically rising demand for dairy products. Much of this demand is being met through imports but increasing numbers of national producers are entering the market.

What seems increasingly likely, certainly in the Kenya and Uganda cases, is that cooperatives and commercial dairies will set up chilling centres for smallholder dairy farms located within a short radius of these centres to supply their milk. This is already occurring on a small-scale in Kenya. If this 'cooling infrastructure' can be expanded, then, the dynamics of small dairy farmers will transform significantly. Early tests with small-scale AD-based milk chillers show promise, and if they can be increased in size on a commercially viable basis, this could be the catalyst to transforming small dairy production in rural SSA. This observation is reinforced by the newly-released Finance Act 2021 with its removal of VAT from 'pre-fabricated biogas digesters [no size specifications] and biogas (Republic of Kenya, 2021). This is an area in dairy AD to watch over the next few years, as it will reduce the cost of all milk biogas coolers of all sizes.

6 SUMMARY AND CONCLUSIONS FOR REPLICATION

Based on the analysis of the experiences at Uilenkraal, 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 manure-based AD in the dairy sector in South Africa. 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).

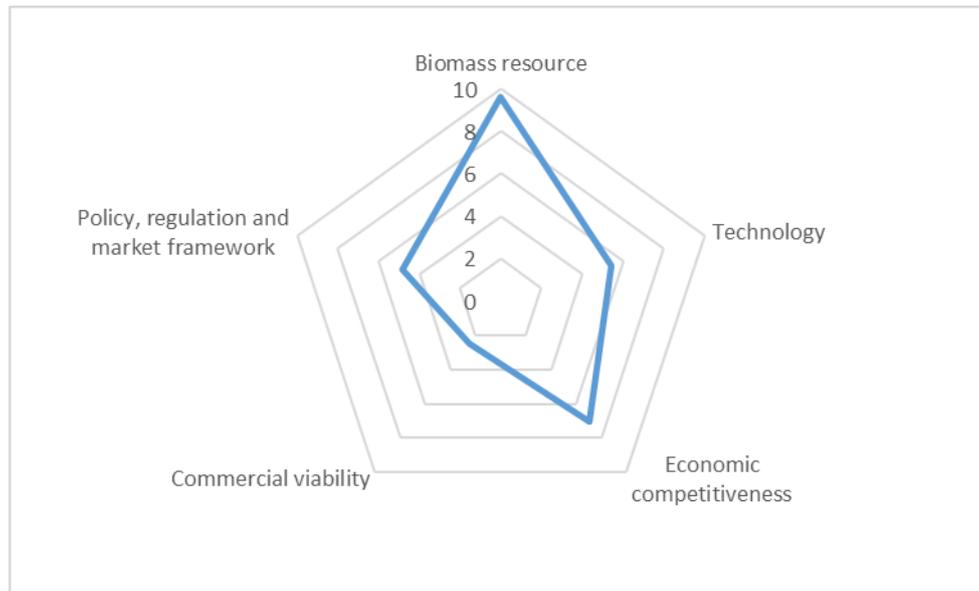


Figure 6.1 Impact of key factors on wider adoption of bioenergy case

South Africa is SSA's leading milk producer and has the largest and most commercialised dairy processing industry on the continent. The industry has seen considerable consolidation over the past two decades, with the number of commercial farms decreasing from 50,000 to 1,200, at the same time as average herd size has increased from 170 to 1,000.

This consolidation presents a potential opportunity for producing energy from manure and slurry from dairy cattle in farms where cows are kept in modern housing with a manure management system, and where the slurry, used bedding and wash water is available as feedstock. This opportunity is particularly commercially feasible on dairy farms with a herd of at least 400 stalled lactating cows (800 in total given that only 50% of cows are lactating at any point). According to our biomass resource assessment, about 240 dairy herds in SA exceed 750 cows and will meet these enabling criteria. The power generation potential from manure-based AD and the electricity demand from the dairy sector are both highest in the Western Cape, Eastern Cape, KwaZulu-Natal and Free State Provinces, where milk production is concentrated, making these the most promising regions for further biogas-based electricity production. The availability and access to suitable biomass within large scale dairy farms in South Africa is therefore not a bottleneck to wider adoption.

The economic analysis reveals a favourable reduction in the net cost of electricity after installing a 400 kW biogas-powered CHP plant at the Uilenkraal dairy, with an estimated reduction in LCOE for electricity of about 11% over a 10-year modelling period.

Sensitivity analysis reveals that the AD plant can provide cheaper power than full grid reliance down to a total power demand that is about one third of the current demand, and down to a bioenergy fraction (the percentage of power derived from the AD plant) of about 20% (compared with 72% at present). For plants of a similar size, an average grid power cost above USD 77/MWh favours such an investment, significantly lower than the farm owners' current grid power cost of around USD 126/MWh. From a capital cost perspective, such an AD plant is viable for a cost that is up to 1.5 times the cost of the flagship project. The investment is, therefore, economically competitive, not only under current parameters, but also at significantly lower power output levels, and with significantly cheaper grid power.

While the assessments of the biomass resource and economic competitiveness indicate a promising opportunity for AD-based energy generation in the dairy sector, wider adoption has been hampered by a number of barriers and challenges.

From a technology perspective, while access to suitable AD technology is not a barrier to adoption within the dairy industry, much of that technology was developed in subsidised European environments and replication in SSA is hampered by high cost and impact on payback time. This realisation is driving a small number of specialist South African companies to develop locally-manufactured versions of European technology. They are adopting proven technical principles from international suppliers and combining these with selective importation of competitively sourced components, local manufacture of equipment and cost-cutting design modifications. This blended approach cuts costs and can stimulate wider adoption. They are also offering outsourced installation and management services that permit the investor to focus on their core commercial business (i.e. milk production), while leaving the technically complex aspects of managing digester performance and the CHP plant to the technology provider, who sells power back to the project owner.

From a commercial perspective, further adoption of AD in South Africa's dairy sector is likely to be limited to those few large farms that have significant on-site power demands, either for their own milk processing plants or an ancillary enterprise such as a feed mill. But the number of combined producer/processors has been falling, with milk production being predominantly rural and dairy processors located primarily in large towns and cities, so the opportunity is limited. Potential adopters also need access to finance, for which the separation of the AD operation from the farm's core business helps de-risk the investment by the farm owner.

Beyond practical constraints for self-use, the other key barrier restricting wider adoption of AD by dairy farms relates to electricity policy. For most potential adopters, commercial viability relies on the ability to sell surplus power at an attractive tariff and with minimal bureaucracy, which is currently a constraining factor. South Africa's progressive policies to support renewable energy development, including its very successful Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), have provided a strong impetus for renewable electricity growth over the past decade. There have also been encouraging recent amendments to the Electricity Regulations, given the increasing unreliability of the national grid. These changes mandate Eskom, the state-owned national utility, to work with municipalities and large industries to procure electricity directly from small-scale producers (known as small-scale embedded generators/SSEGs) of renewable electricity. While this opens

interesting new opportunities for small-scale power producers, uptake has been limited owing to the high costs and administrative requirements for 'wheeling' electricity using Eskom's grid, especially for rural generators such as dairy farms. For more dairy farms to become interested in generating power from AD and selling that power, Eskom will need to significantly reduce its wheeling charges and administrative requirements (e.g. reporting, onerous application procedures, etc.) and improve its rural network infrastructure (e.g. upgrading grid connections) to accommodate smaller scale embedded generators.

With respect to replication potential in other target SSA countries, none of the other SSA countries has a dairy sector as large and modern as South Africa's, but several (including Kenya, Uganda, Tanzania and Zambia) are growing and becoming more formalised, under the framework of cooperatives and large commercial dairies. Pilots to set up AD-based milk chillers that enable small dairy farmers using small (e.g., 20 litre milk storage capacity) AD units to chill their milk is taking place on a small scale in these four countries. While commercial viability is yet to be demonstrated, this has the potential to increase the number of small-scale dairy producers to provide significant amounts of milk in currently remote locations to larger processors and markets.

In sum, there is a strong underlying technical potential for bioenergy use in large commercial dairy farms in South Africa, and more widely in SSA. Wider uptake will largely depend on innovation in localisation and cost reduction of AD technologies, sufficiency of internal demand for heat and /or power at milk production sites, and a conducive policy framework for small-scale power producers to sell surplus electricity to the grid or to wheel power to willing off-takers.

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Appendix 2: People consulted

Organisation	Name	Position	Mode of contact
Camco Clean Energy	Laura Lahti	Impact Manager	Call
Cape Advanced Engineering	Andrew Taylor	CEO	Call
	Vianca Nigrini	Project Execution Engineer	
Dept. of Mineral Resources & Energy	Yaw Afrane-Okese	Senior Energy Advisor	Call
Eskom	Danny Petersen	DSM Advisor (Western Cape Operating Units)	Call
Fair Cape	Colin Ohloff	Environmental Officer	Call
GiZ South Africa	Jonathan Curren	Technical Advisor - Flagship Programme and Climate Change	Call
Green Cape	Yaseen Salie	Bioenergy Analyst	Call
IPP Office	Elmarie Oosthuizen	Programme Manager	Call
	Pervelan Govender	Head of Technical	
Lereko Metier Sustainable Capital fund	Michael Goldblatt	Associate	Call
Limpopo Dairies	Carrol Munyai	Accountant	Call
Mergence Capital	Mark Van Wyk	Head: Infrastructure & Development (SA)	Call
NERSA	Letsatsi Melato	Head of Gas Department	Call
	Evah Mathabele	Director, Regulations Department	Call
	Sindiswa Mkhwanazi	Regulations Department	Call
	Siphiwe Khumalo	Licensing Department	Call
	Chisilo Mwanza	Licensing Department	Call
Southern African Biogas Industry Association	Jason Gifford	Chairman	Call
South Africa National Energy Development Institute	Dr Karen Surr ridge	Centre Manager, Renewable Energy Centre of Research & Development	Call
Sunshine Seedlings	Ken Liesegang	Managing Director	Call
Uilenkraal Dairy Farm	William Basson	Co-owner	In person
	Coenraad Basson	Son	
UNIDO	Nokwazi Moyo	Project Manager	Call
Veolia	Ivan Kriel	Eastern Cape Solutions Sales Manager	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:

$$BMP = C_p * RPR * RF$$

Where: BMP = available residual biomass in tonnes per year
C_p = 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

Livestock	Feedstock	Animals large farms (heads) ¹	Total biomass (Mt/yr)	Recoverable fraction	Biomass potential (Mt wet basis)	Biogas potential (Nm ³ /t fresh matter) ^{2,3}	Biogas potential (Nm ³)	Moisture content as received (wt%) ²	Volatile matter (wt%) ²
Dairy herd	Slurry (dairy cows housed)	180,000	3.3	1	3.3	20	65,700,000	90	85
Dairy herd	Wash water (dairy cows housed)	180,000	2.3	1	2.3	5	11,497,500	99	85

Crop	Feedstock	Production scale	Current use	Existing supply chain	Mobilisation
Dairy herd	Slurry (dairy cows housed)	Small and large scale	Applied to fields if slurry collected and where linked to farming	yes	Utilisation as part of manure management
Dairy herd	Wash water (dairy cows housed)	Small and large scale	Applied to fields if slurry collected and where linked to farming	yes	Utilisation as part of manure management

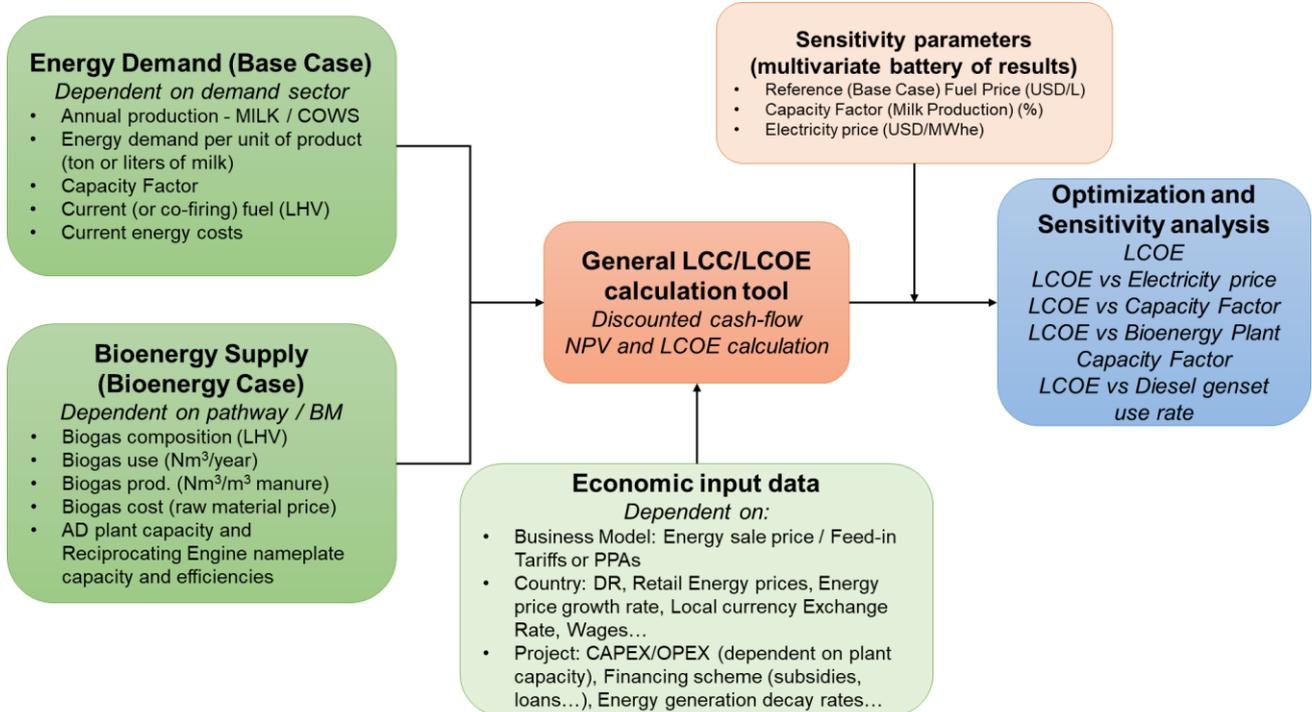
Residue-to-product ratios (RPR)

Feedstock	Residues type	RPR	Note
Dairy cow	Slurry	18.3 t p.a.	50 kg slurry per cow per day ⁴
Dairy cow	Wash water	12.8 m3 p.a.	35 l wash water per cow per day ⁵

Sources:¹ (FAO, 2020); ² (LfL, 2021); ³ (Agricultural Research Council, 2016); ⁴ (Environmental Information Data Centre, 2020); ⁵ (The Scottish Government, 2016)

Appendix 4: Life-Cycle Cost toolkit functions

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



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

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

Where:

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

Appendix 5: Multi-Criteria Analysis input data

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

Appendix 6: Photos of Uilenkraal dairy farm and AD plant



Uilenkraal dairy farm
(Coenraad Basson)



Cattle shed
(Darius Boshoff)



Manure scraper (now defunct)
(Dairy Global³⁰)



Manure & slurry collection channel
(Darius Boshoff)



Digester and membrane
(Darius Boshoff)



Mixer entry point
(Darius Boshoff)

³⁰ www.dairyglobal.net/Articles/General/2015/3/South-African-milk-farm-invests-millions-1723328W



Gas generators
(Darius Boshoff)



Main farm transformer
(Darius Boshoff)



Feed mill
(Darius Boshoff)



Milling equipment
(Darius Boshoff)



Digestate
(Darius Boshoff)



Back-up diesel generator
(Darius Boshoff)