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Technical Paper On Climate Adaptation In Agro-Processing Industries In South Africa



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Trade, Industry and Competition
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List of Acronyms

BECCS : Bioenergy with Carbon Capture and Storage

CCS : Carbon Capture and Storage

CDD : Consecutive Dry Days

CIP : Cleaning-in-Place

CL : Closed-loop cooling

DAFF : Department of Agriculture, Forestry, and Fisheries

DC : Dry cooling

DTIC : Department of Trade, Industry, and Competition

EBITDA: Earnings Before Interest, Taxes, Depreciation and Amortization

ECM : Energy Corrected Milk

GHG : Greenhouse Gas

HC : Hybrid cooling (combining wet and dry cooling)

IoT : Internet of Things

IPCC : Intergovernmental Panel on Climate Change

IRP : Integrated Resource Plan

IVRS : Integrated Vaal River System

LCA : Life Cycle Assessment

LPG : Liquefied Petroleum Gas

OCARA : Operational Climate Adaptation and Resilience Assessment

OT : Once-through cooling

REEs : Rare Earth Elements

RWH : Rainwater Harvesting

RTDs : Ready-to-drink

SAB : South African Breweries

SAPA : South African Poultry Association

SASA : South African Sugar Association

SSP : Shared Socioeconomic Pathways

Toe : Tonne of Oil Equivalent

UCG : Underground Coal Gasification

VRESAP : Vaal River Eastern Sub-System Augmentation Project.

VRESS : Vaal River Eastern Sub-System

WEAP : Water Evaluation and Planning

WMP : Whole Milk Powder

WSAs : Water Services Authorities

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Executive Summary

South Africa's agro-processing industry plays a vital role in the economy, contributing 2.8% to GDP, but is highly vulnerable to climate change impacts, particularly in water and energy. **With the country facing a projected water deficit of up to 3.8 billion m³ by 2030, coupled with an energy crisis, the sector's stability is at risk.** Key sub-sectors, such as food and beverages, rely heavily on these resources and are increasingly exposed to extreme weather events. Adaptation strategies, including improved water management and energy efficiency, are essential. **Timely investment in resilience could generate returns of up to \$19 for every dollar spent, safeguarding both the industry and the broader economy.**

Assessing Climate Risks and Resilience in South Africa's Agro-Processing Sector

This report explores the impact of climate change on South Africa's agro-processing industry, focusing on the dairy, fruit and vegetable, beverage, red meat, poultry, and sugar sectors, with particular emphasis on their water and energy supply systems. A comprehensive literature review of over 120 sources was conducted, and case studies were used to examine energy-related issues, while water-related insights were gathered through three semi-structured interviews. Climate hazard analysis was performed using the Climate Viz digital platform, which integrates key climate indicators into organizational assessments by drawing on various databases and reference scenarios, including Shared Socio-economic Pathways (SSPs). The tool analyses historical data from 1950 to the present and generates projections beyond 2100, with mapping capabilities at a 20 km x 20 km resolution. Climate risk analysis was conducted using the OCARA methodology, considering SSP2 and SSP8 scenarios to assess and prioritise climate risks across the agro-processing value chain. This methodology provides valuable insights for resilience building and adaptation strategies.

Market Overview of the Agro-Processing Industry in South Africa

South Africa's agro-processing industry is a key economic driver, **contributing 30.5% to the manufacturing GDP and generating more than 2 million jobs.** The industry includes five key sectors: dairy, meat, sugar, beverages, and fruit and vegetable processing. **Of these, dairy, beverages, and fruit and vegetable processing together represent over 80% of the market value, with fruit and vegetable processing alone accounting for 46%.** The geographic distribution of these sectors differs across the country, with dairy production concentrated in the Western Cape, KwaZulu-Natal, and Gauteng; sugar in KwaZulu-Natal and Mpumalanga; beverages in Gauteng and the Western Cape; poultry in Mpumalanga, Western Cape, Northern Cape, and Northwest; and red meat in Mpumalanga, Free State, and Gauteng. As a result of this geographical diversity, these sectors are exposed to different climate change patterns, with each region facing its own unique set of challenges related to water and energy availability, temperature fluctuations, and extreme weather events. **Among these sectors, sugar, dairy processing, and beverage manufacturing are identified as the most energy-intensive, while the fruit and vegetable processing sector, along with dairy and poultry/meat, are the highest water consumers.** These sectors are particularly vulnerable to the impacts of climate change, making efficient water and energy management critical for their long-term sustainability.

Climate Trends and their Implications for South Africa's Agro-Processing Industry

South Africa's climate is diverse, with arid regions in the west and subtropical areas in the east. Average temperatures have risen twice the global rate since pre-industrial times, **with projections of up to 4°C increase by 2100 under +2°C of global warming.** If global warming reaches +3.3°C, which is the current trajectory, it would lead to severe climate disruptions.

The agro-processing value chain is heavily impacted by key climate hazards such as thermal stress, drought, and water scarcity, as well as severe storms/flooding. These hazards disrupt food production, processing, and supply chains, as well as energy and water management systems.

The climate analysis for South Africa's nine provincial capitals was conducted for two key time horizons—2050 and 2090—using 21-year windows. The study focused on two climate scenarios: Business as Usual (SSP 2-4.5), which assumes governments will meet climate commitments, leading to global warming of +2.7°C by 2100, and the Pessimistic Scenario (SSP 5-8.5), based on continued fossil fuel use, resulting in global warming of +4.4°C by the end of the century. Climate data was sourced from the Copernicus Interactive Climate Atlas, which integrates 20 climate models with a spatial resolution of 1°x1°. The results paint a concerning picture for South Africa's future climate, with significant variations across provinces and timeframes.

Temperature Trends: Under the SSP2-4.5 scenario, temperatures are projected to rise by 1-2°C, with the highest increases occurring in Limpopo and Northern Cape. However, in the Pessimistic SSP5-8.5 Scenario, the temperature rise becomes much more dramatic, climbing by 3-5°C. Limpopo could potentially reach 45°C by 2081-2100, while several other provinces may experience temperatures exceeding 40°C.

Consecutive Dry Days (CDD): Looking at the number of consecutive dry days, provinces such as Northwest and Limpopo are expected to face the highest increases. Under SSP2-4.5, CDDs will rise to 74 and 60 days, respectively, by 2081-2100. Under the SSP5-8.5 scenario, this increase becomes even more pronounced, with Northwest reaching 87 days and Limpopo 72 days of consecutive dry weather.

Precipitation Patterns: Precipitation patterns show a mixed outlook. In the SSP2-4.5 scenario, KwaZulu-Natal will see the highest increase in rainfall, rising from 130.1 mm (2021-2040) to 134.0 mm (2081-2100). On the other hand, Western Cape will experience a decline from 24.6 mm to 22.5 mm over the same period. Under the SSP5-8.5 scenario, KwaZulu-Natal will see further increases in rainfall, reaching 135.9 mm, while Western Cape faces even drier conditions, with rainfall dropping to 19.8 mm. Extreme precipitation events, particularly in the eastern and northeastern regions, are expected to intensify, potentially causing localized flooding.

Wind Speed: Wind speeds are projected to increase across the country. In the SSP2-4.5 scenario, Western Cape will experience the highest winds, increasing from 127.5 to 127.7 km/h, with Northwest and Northern Cape reaching 82.6 and 84.6 km/h, respectively. Under the SSP5-8.5 scenario, wind speeds increase further, with Western Cape reaching 127.9 km/h, and Northwest and Northern Cape climbing to 85.0 and 86.3 km/h.

These climate changes present a series of critical hazards for South Africa's food processing sector. **Thermal stress is a significant concern, particularly for fruit and vegetable production in Limpopo and poultry farming in Northern Cape and Northwest**, all of which will be increasingly impacted by higher temperatures. **The risk of rainfall and flooding is particularly worrying for the sugar, dairy, and meat sectors in KwaZulu-Natal**, where extreme precipitation events are expected to become more frequent and intense. Lastly, **water scarcity is a growing challenge, especially for**

dairy and fruit and vegetable production in the Western Cape, which could face even more severe water shortages in the coming decades. These climate trends highlight the urgent need for the agro-processing industry to adapt to the changing environment, with a focus on resilience and sustainable practices to mitigate these escalating risks.

Assessing the Agro-Processing Industry's Vulnerability to Climate Change

South Africa's agro-processing industry value chain is highly susceptible to climate change, given its dependence on specific agricultural regions, intricate value chains, weather-sensitive production processes, and infrastructure weaknesses. Climate impacts such as droughts, heatwaves, and extreme weather events jeopardize supply sources, production, and infrastructure. Using the OCARA methodology, key climate risks identified include thermal stress, water scarcity, and extreme weather events like flooding, which disrupt agricultural productivity, operational conditions, and increase costs, while also damaging infrastructure. **Thermal stress compromises product quality and production conditions, while water scarcity threatens both agricultural output and processing operations. Additionally, the rising demand for refrigeration due to increasing temperatures further burdens energy systems and escalates operational costs.** Flooding presents risks to buildings, warehouses, and supply chains.

Energy Consumption in the Agro-Processing Industry

The food processing sector is a major global energy consumer, with an annual usage of 200 EJ. South Africa's food processing industry mirrors this trend, particularly in energy-intensive sectors like dairy, sugar, and beverages. **Energy consumption varies by product, with refrigeration accounting for 30% of electrical energy use and heat contributing to over 70% of total energy demand.**

Dairy processing is one of the most energy-intensive sectors, with an average energy consumption of 8 MJ/kg. Both electricity and thermal energy are heavily utilised, with key processes like pasteurisation, drying, and refrigeration driving significant energy demand.

In sugar processing, the average energy demand is 7 MJ/kg, with refrigeration making up 25% of total energy consumption. Thermal energy is primarily used by evaporative crystallizers.

Potato-based products, such as crisps and french fries, are among the most energy-demanding in the fruit and vegetable processing sector, requiring an average of 17.3 MJ/kg.

Poultry processing, at an average of 5.5 MJ/kg, is highly energy-intensive due to significant refrigeration needs, while red meat processing is less demanding, requiring an average of 2.87 MJ/kg.

Water Consumption in the Agro-Processing Industry

In 2021, the national average water consumption was 237 liters per capita per day. If current trends continue, South Africa could face a water supply-demand deficit of 2.7 to 3.8 billion m³ annually by 2030, or 17% of its available water resources. **The country is already using 98.6% of its total water supply, with 77% coming from surface water, which is highly vulnerable to climate change.**

The agro-processing sector consumes around 130 million m³ of water annually, with food and beverages making up 55% in 2019. This does not include the water used for raw material production. Water consumption is broken down as

follows: Fruits and Vegetables (34.1%), Brewing and Wineries (20%), Animal Slaughtering (19.3%), Dairy (13.3%), and Sugar (7.4%). Cleaning processes account for the largest share.

Climate Risks and Energy Supply



Coal-Fired Power Stations:

Climate change poses major risks to coal-fired power generation, particularly in South Africa, where coal-fired plants supply more than 95% of electricity. **Rising temperatures can reduce thermal efficiency by 0.1–0.5%, with capacity losses of 1–2% per °C increase.** Reduced precipitation limits cooling water availability, potentially causing shutdowns or reduced output. **Wet-recirculating cooling systems are more resilient than once-through systems, which are highly vulnerable to water scarcity and higher water temperatures, leading to potential reductions in power generation.** Extreme weather events like heatwaves and storms further strain plants, with risks such as coal stockpile self-ignition and damage to infrastructure. **Increased rainfall and flooding lead to “wet coal,” where excess moisture reduces coal’s energy content and raises operational costs.** Boilers must evaporate this moisture before efficient combustion, sometimes forcing reduced capacity or temporary production suspensions. **Heavy precipitation can reduce boiler efficiency by about 1% for every 10% increase in moisture.** Additionally, higher air temperatures lower combustion air density, which in turn reduces boiler efficiency.



Grid:

The major risks to South Africa’s electricity grid are **wildfires, heatwaves, and tropical cyclones.** Eskom’s transmission network, which spans over 300,000 km, is particularly vulnerable to these extreme weather events. Wildfires, worsened by rising temperatures, can damage infrastructure, while cyclones and storms have the potential to topple trees and disrupt power lines.



Substations:

Substations face substantial risks from flooding, including structural and material damage, power outages, fires, and system failures.



Oil & Gas:

The oil and gas industry in South Africa, heavily reliant on imports, **faces climate risks including tropical cyclones disrupting production and supply chains, particularly in coastal areas like Mozambique’s gas fields.** Rising temperatures also threaten transport infrastructure, increasing pipeline rupture risks and reducing efficiency in heat recovery systems.



Solar PV:

Solar PV systems face challenges from climate change. High temperatures during heatwaves reduce solar panel efficiency by 0.3% to 0.5% for each degree above 25°C, **with extreme heat events causing a generation decline of 13.5–22.5%.**



Bioenergy:

Thermal stress from rising temperatures can affect the growth and quality of biomass sources like sugarcane, maize, and energy crops, potentially reducing availability and efficiency. Water instability, including droughts and changing rainfall patterns, also threatens biomass production, as water is essential for crop growth and processing.

Water Use in Energy Production: Challenges for the Clean Energy Transition

This report examines the relationship between water consumption and energy production, focusing on fossil fuels and critical minerals essential for the clean energy transition.

Unconventional fuels like oil sands (~2.8 m³/toe) and tight oil (~2.2 m³/toe) are significantly more water-intensive than conventional crude oil (~1.8 m³/toe) and natural gas (<0.2 m³/toe). Coal (~2.7 m³/toe) ranks highest among conventional fuels in water consumption.

The water demand of critical minerals is also substantial, with lithium (~0.75 m³/kg) and rare earth elements (~0.6 m³/kg) being the most intensive, followed by copper (~0.4 m³/kg), nickel (~0.3 m³/kg), and cobalt (~0.25 m³/kg). The transition to clean energy depends on these water-intensive minerals, particularly for battery storage, wind, solar, and electricity networks. More than 50% of global lithium production occurs in water-stressed areas, increasing vulnerability to supply constraints.

By 2080-2100 (SSP5-8.5 scenario), approximately 20% of mining operations will face extreme drought conditions, amplifying competition for water resources.

The clean energy sector must integrate water-efficient extraction and processing methods to mitigate risks associated with growing water scarcity.

This analysis highlights the urgent need for sustainable resource management to balance energy security and environmental protection.

Water Footprint of Energy: Biomass, Coal, and CCS Challenges

Biomass has the highest median life cycle water consumption at 8.5×10^4 L/MWh, significantly higher than other energy types. Coal power plants show relatively high but consistent water consumption. Carbon Capture and Storage (CCS) increases significantly water use and reduces efficiency in thermal power plants, especially those using natural gas and biomass with combined cycle cooling.

Water Stress and Climate Impact on Eskom: Navigating Future Water Scarcity Risks

Eskom, responsible for 2% of South Africa's annual freshwater consumption, uses approximately 320,000 million liters of water per year, primarily for cooling, steam generation, ash handling, and emissions control. **Its power stations, particularly in water-stressed regions like Mpumalanga, Free State, and Limpopo, are highly dependent on water. The Vaal River Eastern Sub-System supplies water to 11 Eskom stations.** Climate change exacerbates water stress in the Vaal catchment, projected to face water shortages by 2040 due to reduced precipitation and increased temperatures. This puts pressure on sectors like agriculture and electricity generation. **A study highlights that none of the future scenarios for the Vaal catchment fully meet demand, suggesting the need for inter-basin transfers, wastewater reuse, and better conservation.**

Mitigation and Adaptation through Industrial Energy Efficiency

Improving industrial energy efficiency offers both significant climate and economic benefits. A continuous increase in both thermal and electrical energy efficiency across industrial sectors can help reduce global temperature rise, lower energy intensity, and significantly decrease CO₂ emissions and reduce cost.

In the agro-processing industry, there are several high-potential thermal energy efficiency solutions. Waste heat recovery systems provide a cost-effective alternative to renewable heat production. These systems deliver substantial savings and require lower capital expenditure compared to renewable energy systems.

Electrical efficiency is particularly crucial for electricity-intensive sectors like meat processing, as well as for applications in refrigeration and air conditioning.

Thermal solar is a highly suitable option for medium-temperature heat processes, which are commonly found in sectors like milling and brewing, and it is easier to install than biogas or biomass solutions.

Solar PV is a versatile energy solution applicable across all sectors.

Finally, biomass and biogas solutions are most effective for processes that demand large, constant amounts of heat or produce methane-rich waste.

Climate Change: An Adaptation Challenge for Industries and their Water Use

The vulnerability of water resources to climate change is a greater challenge than its direct impact on hydraulic systems. In South Africa, climate hazards threaten water availability and quality, making industrial operations dependent on diversifying supply sources. **Groundwater, less vulnerable to climate change and often of superior quality compared to surface water, and rainwater harvesting—a low-cost, effective method—are key alternatives.**

The 5 Rs of water efficiency—Reduce, Reuse, Recycle, Recover, and Rethink—are essential for sustainable water management:

Reduce: Real-time monitoring and leak detection can cut water use by 30% with low investment.

Reuse: Closed-loop systems can reduce consumption by 5-10%.

Recycle: Wastewater and effluent recycling support zero liquid discharge goals.

Recover: Steam recovery improves efficiency.

Rethink: Optimising processes with AI, dry cleaning, and better scheduling.

Adoption remains limited due to high costs, but as climate adaptation becomes urgent, industries are increasingly embracing water-saving strategies.



*In the agro-processing industry, there are several high-potential thermal energy efficiency solutions. **Waste heat recovery systems provide a cost-effective alternative to renewable heat production.** These systems deliver substantial savings and require lower capital expenditure compared to renewable energy systems.*

Building Climate Resilience in Food Processing

Conducting a climate risk analysis and developing tailored adaptation strategies for food processing clusters is crucial, with a particular focus on regional risks such as flooding, thermal stress, and water scarcity. **In KwaZulu-Natal, the Sugar and Dairy sectors are vulnerable to storm and flooding risks. The Poultry sector in the Northern Cape and Northwest faces significant exposure to thermal stress. In Limpopo, the Fruit & Vegetable sector needs to assess the impact of thermal stress, while in the Western Cape, the focus should be on addressing the risks posed by water scarcity.**

Cooling is a critical aspect of climate resilience, particularly in industries and sectors that rely on refrigeration, air conditioning, and temperature-sensitive processes. Given the increasing frequency of extreme heat events and the impact of thermal stress on both equipment and human productivity, strategies to optimise cooling systems are essential.

Strategic Business Opportunities for Climate Resilience

To build climate resilience, businesses should focus on four key areas: **Readiness, Robustness, Resourcefulness, and Recovery.**

- Readiness involves **conducting comprehensive climate risk assessments**, designing climate-proof solutions, improving risk awareness, and integrating resilience into regulatory frameworks.
- Robustness emphasises **adapting production processes to better cope with water and heat challenges**, enhancing energy efficiency, and utilising smart technologies to optimise resource management.
- Resourcefulness focuses on **diversifying energy and water sources**, adopting climate-resilient materials, and securing investments that prioritise climate resilience.
- Recovery centers on establishing **early warning systems**, promoting climate insurance, and preparing businesses for emergency situations.



The agro-processing industry in South Africa, like many other industrial sectors, relies heavily on energy-intensive and water-intensive processes for both electricity and heat generation. Currently, its energy mix is dominated by coal-fired power from ESKOM (electricity) and on-site coal-fired boilers (heat). This dependence on coal not only results in high carbon emissions but also exposes the industry to climate-related risks such as thermal stress, water scarcity, and extreme weather events (storms, flooding).

To strengthen energy security and reduce carbon emissions, agro-processing players are exploring alternative power and heat generation technologies, including solar PV, bioenergy, and gas. However, while these technologies are often assessed for their impact on energy security and emissions reduction, their vulnerability to climate change—and the potential of energy efficiency measures—are often overlooked.

The energy-water-climate nexus underscores the interdependencies between energy systems, water resources, and climate change. Addressing this nexus is critical, especially as the industry faces multiple crises simultaneously:

- **Energy security risks** – ESKOM's supply vulnerabilities and rising electricity costs.
- **Water security risks** – Municipal water supply and water scarcity due to climate change.
- **Decarbonization pressure** – The need for fuel switching to reduce emissions.
- **Industrial resilience** – Ensuring long-term sustainability by integrating climate adaptation.

To optimise investments and avoid unnecessary CAPEX, energy (thermal and electrical) and water efficiency must be prioritised before fuel switching. A strategic approach that integrates efficiency, low-carbon technologies, and climate resilience will be key to ensuring a sustainable agro-processing industry in South Africa.



Targeted Climate Action for the Agro-Processing Sector: Prioritising Resilience and Adaptation

High-Priority Sectors for Climate Action:

The fruit and vegetable, beverage, and dairy sectors are critical for resilience-building. With their high market importance and substantial resource consumption, they require immediate attention to reduce vulnerabilities and improve resource management. Both beverage and dairy are energy- and water-intensive, which makes their adaptation to climate risks particularly urgent.

Localized Risk Sectors:

Poultry and sugar face significant localised climate risks, particularly related to thermal stress and water instability. While these sectors are less critical in terms of market importance, their regional dependencies mean that localised climate adaptation strategies are vital.

SMME Risk Considerations:

The fruit and vegetable and beverage sectors, as well as SMMEs, face an exacerbated climate vulnerability. These smaller enterprises are less likely to have the financial or technical resources to respond to climate-related challenges, making it necessary to include targeted support programs in climate resilience strategies.

Introduction

The agro-processing industry in South Africa is a cornerstone of the national economy, contributing 2.8% to GDP growth in 2021 while playing a critical role in employment and food security. By transforming raw agricultural materials, this sector supports urban and rural livelihoods, strengthens economic resilience, and opens valuable export opportunities. However, its heavy reliance on water and energy resources makes it particularly vulnerable to the impacts of climate change.

At the same time, South Africa's water and energy sectors are already under strain due to aging infrastructure, skills shortages, and increasing demand. Climate change exacerbates these challenges, intensifying shortages, and risks for key industries such as agro-processing.

The effects of climate change are already notable: more frequent heatwaves, prolonged droughts, and shifting rainfall patterns are disrupting agricultural and agro-industrial systems. These disruptions are expected to worsen, with temperature increases of up to 4°C projected by the end of the century, in South Africa, if global warming exceeds +2°C. According to the IPCC, the world is currently on track for a 3.3°C increase, making immediate action critical.

Failing to address climate change will have severe economic repercussions. Since 2000, climate-related disasters have resulted in over \$3.6 trillion in global damage. Without prompt action, global GDP could decrease by up to 22% by 2100. However, investing just 3% of cumulative global GDP—2% in mitigation and 1% in adaptation—could prevent these losses and generate returns up to five times higher¹.

Tackling climate change in Africa will require \$140–300 billion annually by 2030. Currently, financing ranges from \$56–73 billion, with 30% of this directed to the continent. Of this, 46% are allocated to adaptation and 39% to mitigation. The ADB has committed to doubling its climate financing to \$25 billion by 2027. Investments are increasing in adaptation and resilience solutions, emphasising precision farming, sustainable practices, and energy efficiency. Energy resilience receives 30% of the funds, focusing on storage, backup systems, and on-site generation to ensure continuity and enhance long-term energy security.

Critical sectors like food and beverages are particularly exposed to physical climate risks, 47% of global companies review their business continuity plans every six months, with 31% doing so quarterly. These companies recognise climate change as a major risk, with 71% identifying climate-related weather events—such as floods and droughts—as significant concerns.

For instance, Nestlé incurred estimated losses of \$925 million to \$1.15 billion due to droughts in Brazil's coffee regions. Such risks could put up to 25% of corporate Earnings Before Interest, Taxes, Depreciation and Amortization at stake within two decades¹. Despite these escalating threats, many companies continue to treat climate risks as compliance issues rather than strategic priorities.

Few companies thoroughly evaluate their risk exposure and invest sufficiently in adaptation. However, those that do and report their returns to CDP anticipate a highly positive payback, with returns ranging from \$2 to \$19 for every dollar invested. This is particularly true within the food and beverage sector.

To gain deeper insight into the challenges faced by South Africa's agro-processing industry, it is crucial to examine the impact of climate risks on the value chain, particularly in relation to water and energy supply.

South Africa's agro-processing industry faces mounting challenges from climate-related risks, with water scarcity being a critical concern. As the 31st most water-scarce country globally, South Africa's water crisis has been worsened by climate change. If current trends persist, the country could

experience a water supply-demand deficit of 2.7 to 3.8 billion m³ annually by 2030, representing 17% of its available water resources. Prolonged droughts, unpredictable rainfall, and rising temperatures are further straining water availability, disrupting agricultural production, and processing. These conditions create bottlenecks in the supply of raw materials and diminish the efficiency of water-intensive processes.

Energy disruptions are another significant issue, as the agro-processing sector heavily depends on energy for activities such as drying, milling, refrigeration, and packaging. Climate-driven damage to energy infrastructure is compounded by South Africa's ongoing energy crisis.

Additionally, the frequency and severity of extreme weather events, including floods, storms, and heatwaves, are on the rise. These events damage infrastructure, disrupt logistics, and delay transport, leading to significant post-harvest losses from storage failures. Together, these factors underscore the urgent need for adaptive strategies to build resilience within the agro-processing value chain.

The agro-processing industry faces mounting risks from climate change and because of its critical economic role it's vital for them to adapt. While South Africa is taking steps to address these challenges through initiatives, like the Integrated Resource Plan (IRP), which outlines the strategy to transition to a more sustainable and resilient energy system, gaps remain in implementation, particularly for smaller industries. These challenges raise a central question:

How can South Africa's agro-processing industry strengthen its resilience to the escalating impacts of climate change, in particular related to water and energy infrastructure?

To address this overarching question, the study delves into several key research inquiries:

- Which sectors within the agro-processing industry are the most intensive users of water and energy?
- Where are these industries located, and what are the climate risk profiles of these regions?
- How does climate change affect the water and energy systems utilised by the sector?
- What feasible and effective adaptation measures can mitigate these impacts?

To address these questions, we propose the following approach:

First, we will examine the agro-processing industry in South Africa with an in-depth analysis of five key sub-sectors. Second, we will assess the impact of climate change on South Africa, focusing on four primary hazards. Next, we will conduct a risk analysis and evaluate the vulnerability of the agro-processing sector and its value chain. This will be followed by a detailed study of energy and water consumption, their vulnerabilities, and efficiency measures. Additionally, we will propose adaptation strategies to mitigate these challenges. Finally, we will explore the business opportunities that climate change presents.

Methodology

This report examines the impact of climate change on the agro-processing industry in South Africa, with a particular focus on the dairy, fruit and vegetable, beverage, red meat, poultry, and sugar sectors, along with their energy and water supply systems, which are crucial for their sustainability and resilience.

A comprehensive literature review was conducted, **incorporating over 120 references**. These references were compiled into a document and categorised by theme (e.g. climate change in South Africa, climate change and energy supply, or agro-processing and climate change in South Africa), year of publication, type of publication (report, article, website), and source.

In addition to the literature review, **the energy focus was developed through case studies, while the water focus was primarily shaped by three interviews** offering different perspectives: a startup (Takats'eau), a scientist (Water Geothermal Sustainability), and a leader in water management (Veolia).

The focus on water was informed by three interviews, which were conducted using a semi-structured questionnaire. Each interview lasted between 45 and 60 minutes and aimed to gather diverse perspectives on existing technologies and innovations, as well as to validate information from the literature review. We chose to interview stakeholders from different sectors to obtain a broad range of perspectives. These included a startup specialising in water management with innovative

technologies, a large-scale company in water utility, and a hydrogeologist. The details of the interviews can be found in Appendices 2 to 5.

The climate hazard analysis was conducted using the **Climate Viz tool, which employs generative AI to integrate key climate indicators into organizational assessments**. To ensure precision, the platform utilises multiple databases and various reference scenarios, including Shared Socio-economic Pathways (SSPs), while accounting for different time horizons.

This approach provides climate data even for regions with limited information or hard-to-reach areas. Climate Viz processes historical data from 1950 to the present and generates projections extending beyond 2100, with mapping capabilities at a resolution of 20 km x 20 km.

For the climate risk analysis, we used OCARA **methodology. This tool is designed to help organizations build resilience to both current and future climate impacts**. OCARA enables the identification and prioritisation of climate change signals—whether weak or strong—across the entire value chain.



A recent global study on climate change and the food processing industry value chain shows that about 60% of research focuses on agricultural production, 17% on distribution, and just 1% on processing. Furthermore, there is a significant gap in research from Africa.

01

Overview of South Africa's Agro-Processing Industry

The agro-processing industry adds value by transforming raw agricultural, forestry, and fisheries products into forms suitable for storage and consumption. In South Africa, the Department of Agriculture identifies **11 key subsectors: food products, paper, wood, tobacco, leather, textiles, furniture, footwear, beverages, rubber, and wearing apparel.**

South Africa's agro-processing sector is estimated to contribute about 30.5% of the real value-added GDP to the manufacturing sector. This industry is considered as one of the crucial economic sectors to transform the South African

economy through sustainable creation of employment, business opportunity, investment attraction, and growing the export base.

In their 2022 economic review of the agro-processing industry in South Africa, the Department of Trade, Industry, and Competition (DTIC) presented the seasonally adjusted sales performance of all 11 subsectors of the industry, as illustrated in **Figure 1**.

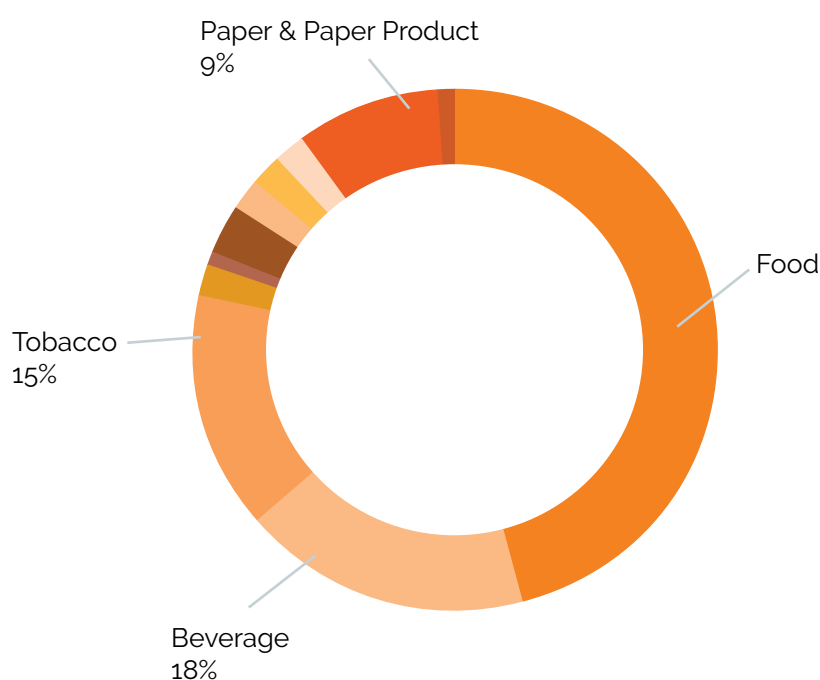


Figure 1: Seasonally Adjusted Value of Sales in Agro-processing Industry in 2022, by Iroko Africa

As illustrated above, **the food processing cluster is the largest within agro-processing. The food processing industry is typically categorized into five distinct clusters** based on the activities involved:

- Processing and preservation of meat, fish, fruits, vegetables, oils, and fats.
- Dairy processing including products like yogurt, cheese, milk, butter, and cream.
- Production of grain mill products, starches, and animal feed.
- Manufacturing of confectionery and baked goods, including sugar, chocolate, pasta, syrups, custards, and related items.
- Beverage production, encompassing both alcoholic and non-alcoholic drinks, as well as bottled water,

typically considered part of the broader food processing sector.

As a high-performing manufacturing sector with significant growth potential, the food processing industry, the largest economic contributor, is energy-intensive, water-dependent, and highly vulnerable to the impacts of climate change. These vulnerabilities affect agricultural inputs, essential infrastructure (roads, building integrity, water, and energy supply) as well as operational conditions (heating and cooling production systems).

02

Food Processing Market Analysis

The food processing sector is South Africa's third-largest manufacturing industry, contributing 27% to the manufacturing GDP and over 3% to the national GDP in 2018.

This sector is a major employer, providing jobs for 2 million people. It encompasses key industries such as meat, fish, fruit, vegetables, dairy, grains, animal feeds, and bakery products. This report focuses on five main clusters that are

vital to manufacturing development and are particularly vulnerable to the impacts of climate change: Dairy, Meat, Sugar, Beverages, and Fruits and Vegetables.

These five clusters collectively represent about 55% of the agro-processing industry's water consumption, with sugar production, dairy processing, and beverage manufacturing identified as the three most energy-intensive sectors.

2.1 Dairy Processing Cluster

In 2021, the South African dairy sector generated **ZAR 185 billion in revenue and employed over 1 million people.**

Milk production in South Africa has grown significantly, increasing by 31% from 2.59 million tonnes in 2009 to 3.4 million tonnes in 2018. Production is seasonal, with peaks in October and November and lower levels between April and June due to climatic conditions and feed costs.

In the South African dairy market, 62% of milk is used for liquid products, and 38% for concentrated products. The liquid product composition includes 43% UHT milk, 34% pasteurized milk, 12% yogurt, 8% other liquid dairy products, 2% flavoured milk, and 1% cream. On the concentrated product side, 16% for butter, 7% for skimmed milk powder (SMP), and 12% for whole milk powder (WMP). The demand for fluid dairy products is expected to grow by 1.4% annually, while concentrated products will grow by 2.4% annually.

The South African dairy market is made up of a combination of vertically integrated operations (especially among larger players) and separate dairy farms and processors.

Key players in South Africa's dairy industry include **large companies** like Parmalat, Nestlé, Danone, Clover, Woodlands, and Coega, along with medium-sized processors expanding regionally and nationally.

In 2020, the **Western Cape led milk production with 31% of the national total, followed by KwaZulu-Natal at 27% and Eastern Cape at 26%. These coastal provinces contributed around 84% of total milk production.** Other provinces, such as the Free State (6%), Gauteng (4%), Mpumalanga (3%), North West (2%), and the Northern Cape and Limpopo (less than 1% each), made much smaller contributions. The dominant coastal regions, while benefiting from better pastures that contribute to higher production levels, are **also highly vulnerable to climate risks, particularly heavy rainfall, and flooding.**

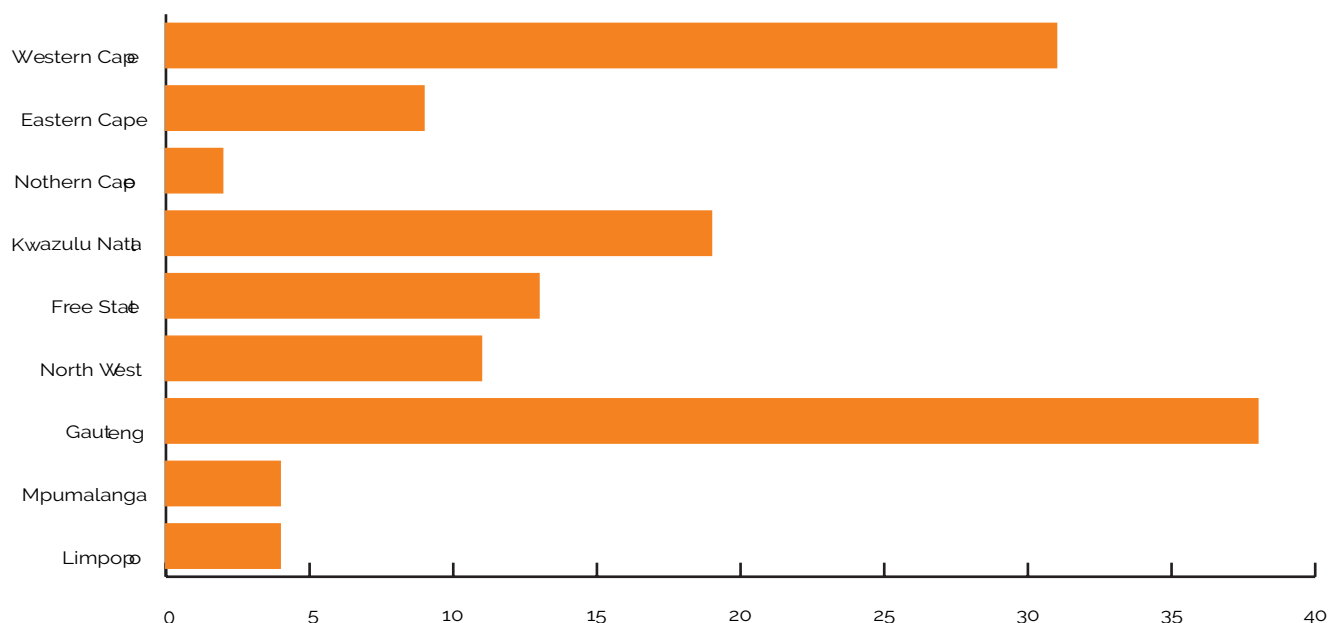


Figure 2 Number of Milk Processors per Province in 2019, by Iroko Africa



In 2016, drought caused a significant drop in the milk to maize price ratio, impacting dairy profitability. While a record maize harvest in 2017 improved feed grain prices, drought-related feed cost increases in 2019 led to expected reductions in milk production.

2.2 Beverage Processing Cluster

The beverage sector in South Africa encompasses both non-alcoholic beverages, such as soft drinks, fruit juices, and bottled water, as well as alcoholic beverages, including beer, wine, and spirits. This sector plays a significant role in exports, with wine being one of the country's top agricultural exports. The South African beverage market is projected **to grow from ZAR 356 billion in 2023 to ZAR 458 billion by 2028, with over 500,000 people employed in the sector.**

Alcoholic Beverage

In 2022, the alcoholic beverage market in South Africa was valued at **ZAR 215 billion**, with 48% of this value coming directly from liquor manufacturers and their immediate suppliers. Production is expected to reach **2,921 billion liters by 2025.**

The alcoholic beverages market is broadly segmented into four sub-categories: beer, wine, spirits, and ready-to-drink alcoholic beverages (RTDs). **The liquor industry drives significant economic activity through an extensive value chain** that links upstream producers, such as agriculture, machinery, and packaging, to downstream sectors, including distributors, wholesalers, retailers, tourism, and hospitality.

In terms of market share and volume, beer accounts for 71% of the alcoholic beverage market by volume. SAB (South African Breweries) produces more than 70% of the beer in South Africa, with an annual production capacity distributed across **7 breweries and 42 beer depots.**

Leading industry players in the alcoholic beverage sector include Distell Group Limited, known for its diverse portfolio of wines, spirits, and ciders; Anheuser-Busch InBev SA/NV, a global brewing giant; and Diageo plc, renowned for its premium spirits such as whisky, vodka, and gin.

South Africa is also renowned for its wine production, particularly in the Western Cape, which is known for its favourable climate and soil conditions. This region is home to most of South Africa's vineyards and wine estates, with key players including Distell Group Limited, Anheuser-Busch InBev SA/NV, and Diageo plc. Moreover, in 2021, there were approximately 2,800 wine producers cultivating over 92,000 hectares of vineyards.



*In South Africa's winelands, a two-year-long drought has begun diminishing recent vintage production volume. Just as South African wines were gaining renown and respect from wine critics and sommeliers around the globe, the **El Niño-Southern Oscillation (ENSO)** occurred and brought excessive heat and drought to the country.*

Non-Alcoholic Beverage

The South African non-alcoholic beverage sector was valued at **ZAR 107 billion in 2022** and includes a variety of products such as soft drinks, bottled water, fruit juices, and energy drinks. Production is expected to reach **5,3 billion liters by 2025.** Key industry players include Coca-Cola Beverages South Africa, PepsiCo, Ceres Fruit Juices, and Nestlé. Non-alcoholic beverages, particularly fruit juices and soft drinks, are significant export products for the country.

Gauteng is a central hub for non-alcoholic beverage processing due to its robust infrastructure and strategic location, which facilitates efficient manufacturing and distribution.

2.3 Fruit and Vegetable Processing Cluster

The fruit and vegetable processing sector is a vital component of South Africa's economy. In 2019, the fruit and vegetable manufacturing sector generated **ZAR 566.7 billion**, with ZAR 155.7 billion coming from the processing of fruits, vegetables, meat, and fish.

This industry is closely connected with the agricultural sector, playing a key role in the value chain. The main activities include producing fruits and vegetables, primarily for the fresh market, packaging and storing produce in **cold storage to maintain quality, and processing through drying, freezing, preserving, juicing, and making pulps.**

In 2020, the industry produced an average of **15 million tons of fruits and vegetables.** Reject fruits and vegetables are processed into products like juice concentrates, purees, pulps, and preserves, which account for 29% of total fruit production. Only 40% of the fruit produced is sold locally, while the remaining 60% being exported.

Major players in this sector include Ceres Fruit Juices, Dole South Africa, TWK Agriculture, Zeder Investments, Tiger Brands, which dominates both the fruit and vegetable processing markets, and Rhodes Food Group, a significant player in fruit processing.

Geographically, the main provinces for fruit and vegetable processing are the **Western Cape, known for its favorable climate and agricultural output, KwaZulu-Natal, which plays a significant role in processing, and Mpumalanga, Limpopo, and Eastern Cape,** which contribute to processing specific fruits and vegetables for both local consumption and export.

2.4 Meat and Poultry

The South African meat and poultry processing market was valued at **ZAR 96 billion in 2020**. The market is divided into three primary submarkets: the fresh meat market, which includes fresh, chilled, or frozen meats from domestic and wild animals such as red meat, pork, mutton, and poultry; the processed meat market, which covers dried, salted, brined, or smoked meats, including cold and roast products, ham, bacon, and sausages; and the meat substitutes market, which features plant-based alternatives to meat.

Annual production in 2022 was **1.9 million tons for poultry and 0.98 million tons for red meat**, which has been the average over the last decade. The South African poultry market consists of about 265 formal abattoirs, while the red meat market has approximately **430 abattoirs processing cattle**, pigs, and sheep. Major players in the red meat sector include Karan Red Meat, Red Meatmaster Group, and Cavalier Group, which operate large-scale processing facilities.

Geographically, **the poultry market is dominated by the Northwest, Western & Northern Cape, and Mpumalanga provinces**, which together hold more than 50% of the market share. **For red meat, Mpumalanga led production in 2019/20** with 21% of the total red meat produced, followed by the Free State with 19%, and **Gauteng** at 17%. Limpopo and the Western Cape each contributed 5%.

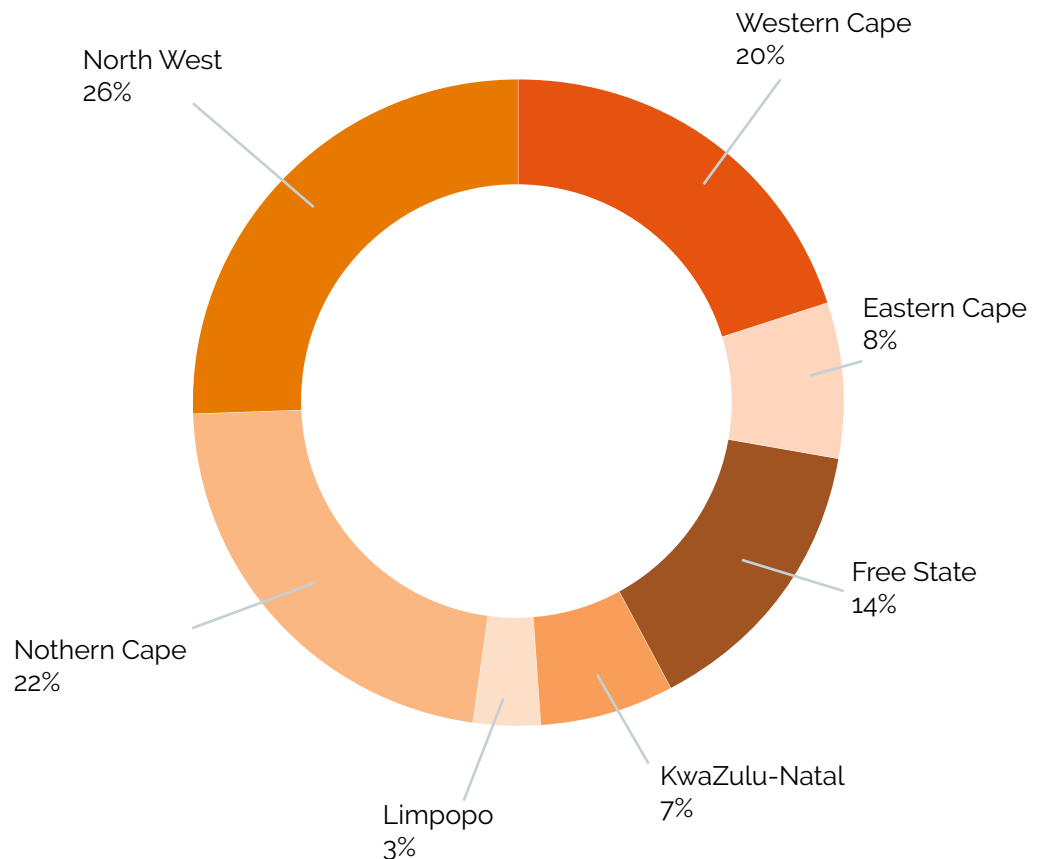


Figure 3: Geographic Distribution of Broilers (Poultry) in SA in 2020, adapted by Iroko Africa

Red Meat production and slaughtering reached their peak in 2015/16, largely due to a drought that forced many farmers to liquidate their herds. A survey conducted in 2022 by SAPA indicates that weather-related challenges, such as excessive rainfall, extreme heat, or cold, contribute to poor growth rates and high mortality rates.

In 2023, the impacts of Cyclone Freddy led to the closure of Illovo's Maragra sugar operation in Mozambique and caused severe damage to operations in Malawi.

2.5 Sugar Processing Cluster

The South African sugar industry generates over **ZAR 20 billion in direct income annually** and supports 69,790 direct jobs and 350,000 indirect jobs. The country produces an average of **2.2 million tons of sugar per season**, with 70% sold within the Southern African Customs Union (SACU) and the remainder exported to Africa, Asia, and the Middle East.

Sugarcane accounts for 80% of global sugar production, and this is mirrored in South Africa, where 80% of sugar is derived from sugarcane and the remaining 20% from sugar beet.

Key stakeholders in the industry include growers, millers, refiners, retailers, and industrial users, all coordinated by the South African Sugar Association (SASA).

The sugar industry is supported by **six milling companies and operates 12 sugar mills** in cane-growing regions across South Africa. Key industry players include Illovo Sugar, Tsb Sugar, and Tongaat Hulett.

The primary sugarcane-growing regions are KwaZulu-Natal and Mpumalanga, which together contribute nearly 50% of the field crop farming income in these provinces.

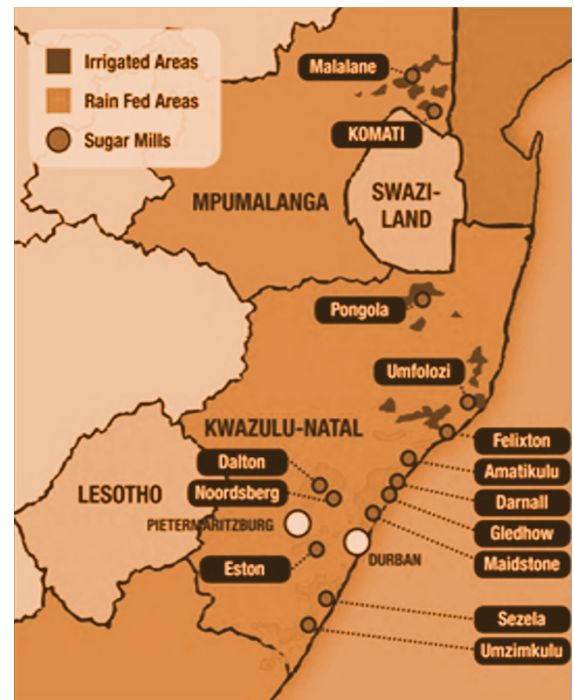


Figure 4 : Sugar Processing Geographic Distribution in SA, adapted by Iroko Africa

Table 1 below presents a summary of the market value, annual production volume, and corresponding provinces for each sector.

Cluster	Market Value (Billion ZAR)	Estimated Annual Production Volume	South Africa Provinces
Dairy	185	3,4 million tons	Western Cape KwaZulu-Natal Gauteng
Sugar	20	2,2 million tons	KwaZulu-Natal Mpumalanga
Beverage	356	8,2 billion liters	Western Cape Gauteng
Poultry	49	2,1 million tons	Mpumalanga Western Cape Northern Cape North West
Red Meat	37	0,9 million tons	Mpumalanga Free State Gauteng
Fruit & Vegetable	566	15 million tons	Western Cape KwaZulu-Natal Eastern Cape Mpumalanga Limpopo

Table 1: Food Processing Market Value, Production Volume and Geographic Distribution in SA, by Iroko Africa

South Africa's agro-processing sector, representing a major contributor to the economy, is **dominated by the fruit and vegetable, beverage, and dairy industries which together account for over 80% of the market value**. While fruit and vegetable production is geographically diverse, beverage and dairy production are primarily concentrated in Gauteng and the Western Cape. Other provinces like Mpumalanga,

Northern Cape, and Free State are key for poultry, red meat, and sugar production, with KwaZulu-Natal playing a significant role in sugar and dairy. These regional specialisations are essential for understanding the sector's economic impact and its vulnerability to climate change.

03

South African Climate Profile and Hazards

3.1 On Our Way to a +3.3°C Global Warming: Insights from the IPCC

Today, all scientific models, including the IPCC, **indicate that we are on a trajectory toward a global temperature rise of +3.3°C**. This level of warming would significantly surpass the targets set by international agreements, such as the Paris Accord. The consequences of such a rise would include severe

climate disruptions, increased extreme weather events, and profound impacts on ecosystems and human societies. **Table 2** below describes the emissions scenarios considered in the IPCC's sixth assessment report.

Scenario	Description	Global Warming by 2100
SSP1-1.9	A very low – emission reference scenario; implies net zero emissions by mid century	Below 1.5°C
SSP2-2.6	A low-emission reference scenario; implies net zero emission in the second half of the century	Below 2°C
SSP3-4.5	An intermediate scenario, in line with the upper end of aggregate NDC emission levels by 2030	Below 3°C
SSP4-7.0	A medium to high reference scenario with no additional climate policy. Emissions almost double by 2100, compared to today's levels	Above 3°C
SSP5-8.5	A high reference scenario with no additional climate policy. Emission triple by 2100, compared to today's levels	Above 4°C

Table 2: Emission Scenarios in IPCC's Sixth Assessment Report

When conducting climate risk analysis, it is **essential to evaluate two extreme scenarios**, typically the SSP2 and SSP5 scenarios. These two scenarios were applied in this research paper to assess the potential impacts of four major climate hazards—**Thermal Stress, Drought and Water Scarcity, Wind Speed Variability, and Severe Storms and Flooding**—across South Africa's nine provinces. These four hazards are the most critical to sectors such as food processing, energy infrastructure, and water management.

1. Thermal Stress: Elevated temperatures can disrupt production processes, increase energy demand, and strain water availability, thus reducing the efficiency across food processing, energy, and water sectors.

2. Drought and Water Scarcity: Prolonged droughts and reduced rainfall can severely affect water supply, particularly for water-intensive industries like food processing and energy generation.

3. Wind Speed Variability: Higher wind speeds can damage agricultural production, livestock, and infrastructure, causing operational interruptions across food processing, energy distribution, and water management systems.

4. Severe Storms and Flooding: Extreme weather events like storms and flooding can damage infrastructure, disrupt supply chains, and cause operational challenges in the food, energy, and water sectors.

The data discussed below have been provided by the Platform Climate Viz, which utilises generative AI to incorporate key climate indicators into organizational analysis. To ensure precision, the platform relies on a variety of databases and reference scenarios, including Shared Socio-economic Pathways (SSPs), while considering different time horizons.

This tool provides climate data for regions with limited information or hard-to-reach areas. Climate Viz processes historical data from 1950 to the present and generates projections extending beyond 2100. Additionally, the tool supports mapping with a resolution of 20 km x 20 km.

3.2. Mapping South Africa's Climate Profile

South Africa's climate profile, as shown in **Figure 5**, is characterised by its diverse geographic and climatic zones, ranging from arid regions in the west to subtropical areas in the east. The country's complex topography, featuring high plateaus and coastal plains, **contributes to its varied climate**

patterns. The western interior experiences arid to hyper-arid conditions, while the southeastern and eastern parts are more humid. This diversity creates distinct ecological zones, including eight biomes such as grassland, savanna, and fynbos.

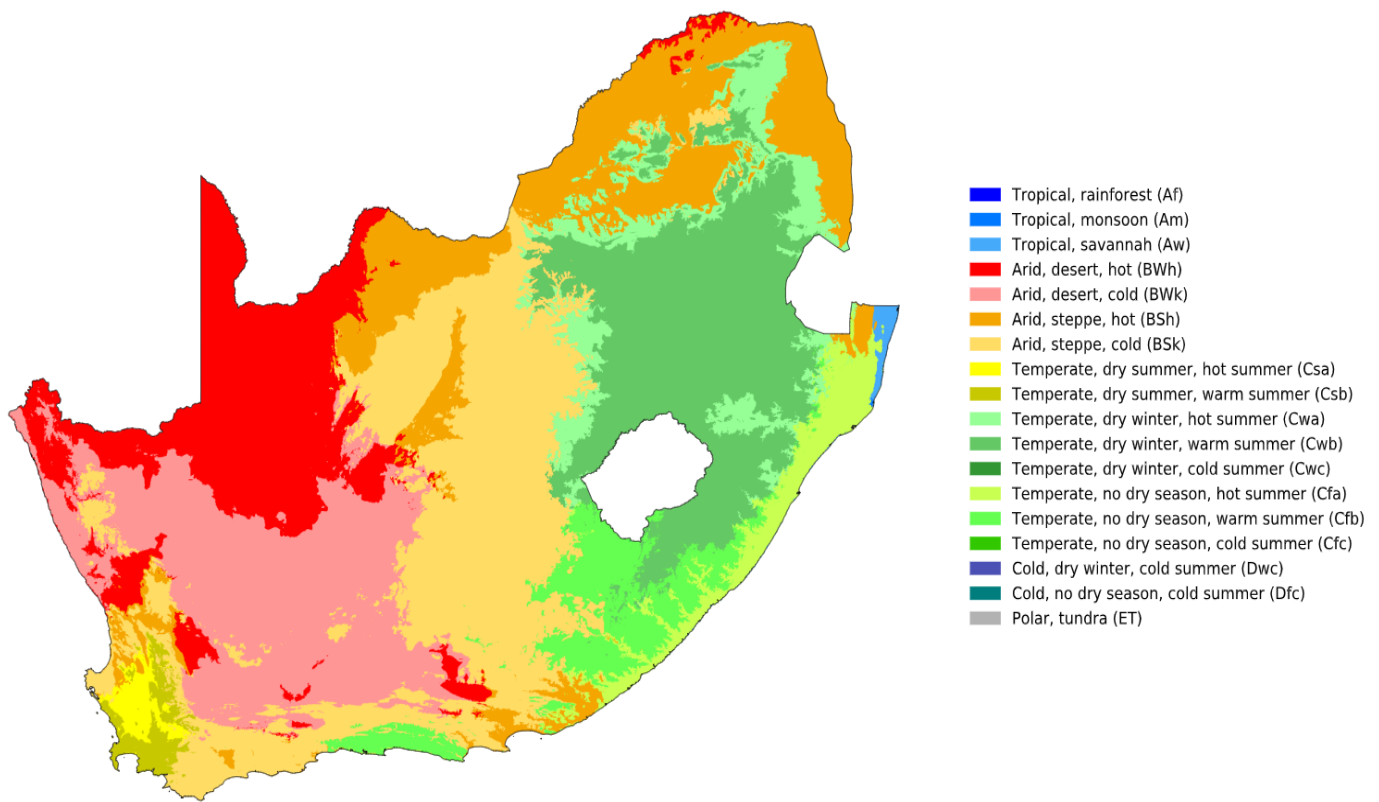


Figure 5: South Africa's Geographic and Climatic Zones;
Source: Köppen-Geiger Climate Classification Maps at 1-km Resolution

Climate change is having a profound impact on South Africa. **Mean annual temperatures have increased by twice the global average** compared to pre-industrial levels. Observed effects include **more frequent heat waves, longer dry spells, and changes in rainfall patterns.**

These changes are projected to intensify, **with potential temperature increases of up to 4°C by the end of the century if global warming reaches +2°C** which can have serious consequences for the food processing industries.

04

Food Processing Industry: Main Climatic Risks

The remainder of the report will focus on the four key climate related hazards and their impacts on South Africa's food processing industry value chain.

4.1. Four Key hazards



Thermal Stress

The escalating climatic conditions in South Africa are precipitating significant thermal stress especially across agricultural ecosystems, manifesting through these primary mechanisms:

Crop Yield Degradation

- Increasing average temperatures are systematically undermining crop productivity
- Heightened frequency of extreme heat events is disrupting critical plant physiological processes
- Projected temperature increases are expected to exponentially reduce agricultural output

Livestock Productivity Impairment

- Unprecedented heat stress is compromising livestock health and reproductive capabilities
- Rising thermal indices correlate directly with:
 - Reduced animal weight gain
 - Diminished reproductive efficiency
 - Increased mortality rates in vulnerable livestock populations



Water Resource Scarcity and Instability

South Africa's hydrological profile presents a complex and precarious landscape:

Quantitative Water Constraints

- Ranked globally as the 31st most water-scarce nation
- Chronic water deficiency threatens agricultural sustainability
- Limited water resources necessitate urgent adaptive strategies

Precipitation Pattern Disruptions

- Increasingly erratic rainfall regimes characterised by:
 - Prolonged drought periods
 - Intermittent, high-intensity flood events
 - "Green drought" phenomena, where precipitation supports only rudimentary vegetation growth

Agricultural Irrigation Challenges

- Reduced water availability compromising irrigation infrastructure
- Increased variability in water supply undermining crop planning and management
- Potential long-term shifts in cultivable land and crop selection



Wind-Related Disruptions

Soil Degradation and Erosion

- Over 70% of productive land in Southern Africa is affected by various forms of erosion
- Wind erosion is prevalent in drier western parts of South Africa, affecting more than 25% of the country
- Susceptible areas include the Northern Cape, western Free State, and North-West Provinces

Agricultural Productivity Impact

- Wind speed trends affect crop yields and livestock production
- Coastal zones experience larger decreases compared to inland regions

Infrastructure damage

- An increase in wind power can compromise building structures, disrupt production infrastructure, and affect electricity and water supplies



Flood-Related Agricultural Disruptions

Crop Production Losses

- Extensive Damage to Cultivated Land
 - Floods in KwaZulu-Natal and the Eastern Cape since June 1, 2024, have caused widespread destruction to agricultural areas
- Significant Yield Reduction
 - Floods cause more damage than other shocks, reducing crop production per plot by an average of 62%

Infrastructure Damage

- Agricultural Facilities
 - Severe flooding has led to extensive damage to agricultural infrastructure in regions like the Western Cape
 - Essential facilities such as irrigation systems, storage units, and processing plants are often compromised

The evolution of these indicators has been analysed at a provincial level **from the present until the 2050- and 2090-time horizons**. Each horizon is represented by a 21-year window (for instance, the data corresponding to the 2050 horizon is the average from 2041 to 2060).

The climate data on the 9 capitals areas of South Africa Provinces has been studied.

The focus is on two climate scenarios:

- **Business as usual - SSP 2 4.5** - corresponding to the scenario where governments meet their climate commitments. This scenario leads to global warming of +2.7°C by 2100.
- **Pessimistic - SSP 5 8.5** - corresponding to a pessimistic scenario based on fossil fuels. This scenario leads to global warming of +4.4°C by 2100.

The Copernicus Interactive Climate Atlas is the source of the data used in this study. We considered **20 climate models with a spatial resolution of 1°x1°**.



4.2. Assessment of Key Hazards Under SSP2-4.5 and SSP5-8.5 Scenarios

1. Thermal Stress

To evaluate this hazard, we selected two indicators: the annual count of days with maximum temperature above 35°C and the annual maximum temperature.

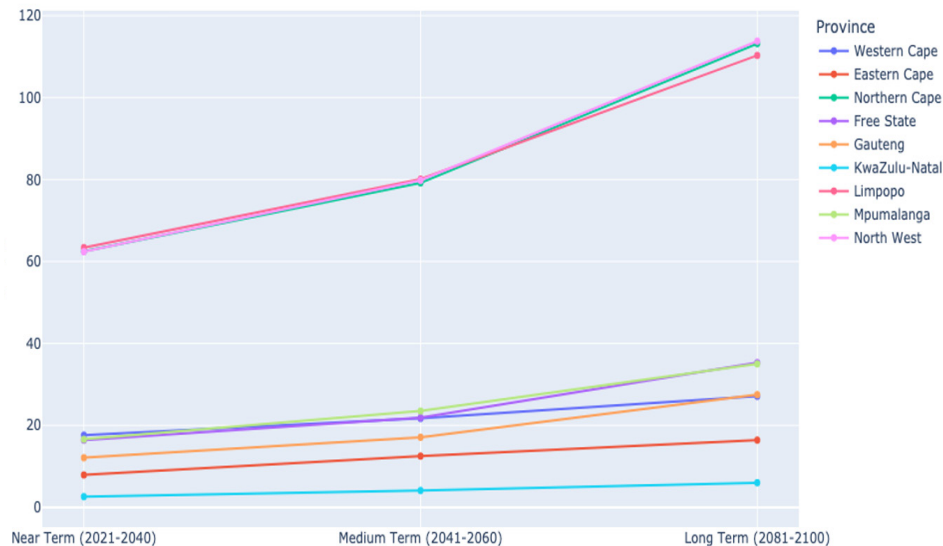


Figure 6: Scenario SSP2-4.5 – Number of Days Exceeding 35°C for Thermal Stress

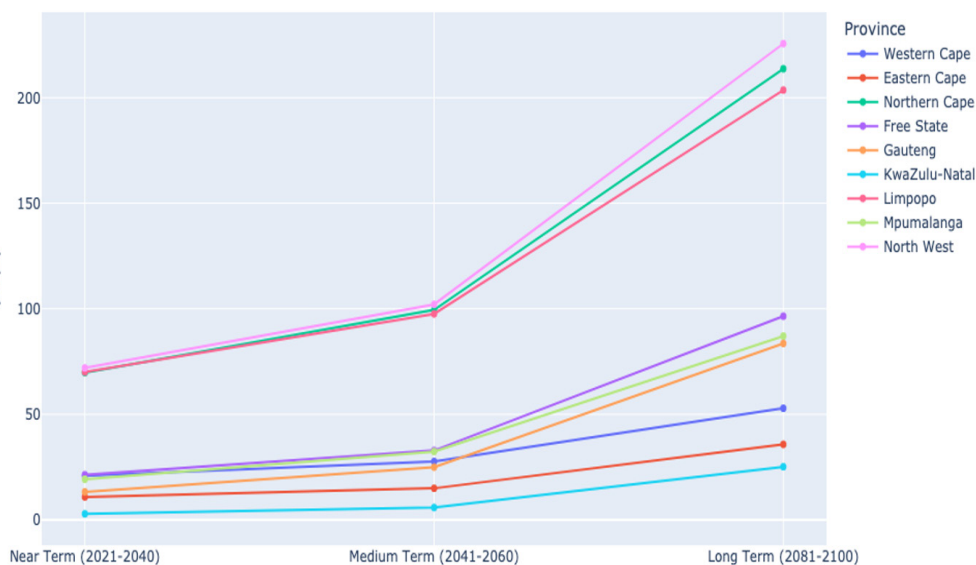


Figure 7: Scenario SSP5-8.5 – Number of Days Exceeding 35°C for Thermal Stress

Analysis:

- **Western Cape:** Moderate increase in both scenarios, with SSP585 showing a more dramatic rise (16 to 48 days) compared to SSP245 (10 to 22 days)
- **Eastern Cape:** Minimal change in SSP245 (0 to 4 days), but substantial increase in SSP585 (0 to 22 days)
- **Northern Cape:** Highest overall values, with dramatic increases in both scenarios. SSP585 shows an extreme rise from 48 to 208 days
- **Free State:** Moderate increase in SSP245 (2 to 12 days), but significant jump in SSP585 (2 to 75 days)
- **Gauteng:** Similar pattern to Etat libre, with a more pronounced increase in SSP585 (0 to 62 days)
- **KwaZulu-Natal:** Minimal change in both scenarios, suggesting a more temperate climate
- **Limpopo:** Second highest values after Nothern Cape with substantial increases in both scenarios
- **Mpumalanga:** Moderate increases, more pronounced in SSP585 (6 to 64 days)
- **North West:** Similar pattern to Nothern Cape, with extreme increases, especially in SSP585 (44 to 210 days)

The analysis of the number of days exceeding data across South African provinces **reveals a clear trend of increasing extreme heat days, with significant variations between coastal and inland regions.**

The SSP5-8.5 scenario consistently shows more dramatic increases compared to SSP2-4.5, highlighting the potential impact of different climate change trajectories.

Inland provinces, notably Northern Cape, Limpopo, and Northwest, are projected to experience the most severe climate impacts, particularly affecting agro-processing sectors such as **sugar, poultry, fruit and vegetable**, which are prominent in these regions.

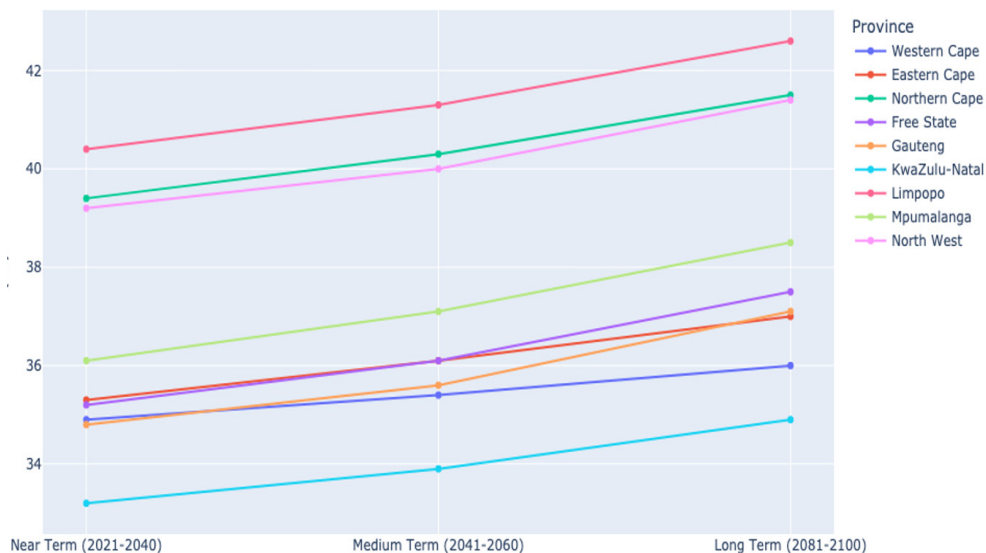


Figure 8: Scenario SSP2-4.5 – Mean Month Maximum Temperature (°C) for Thermal stress

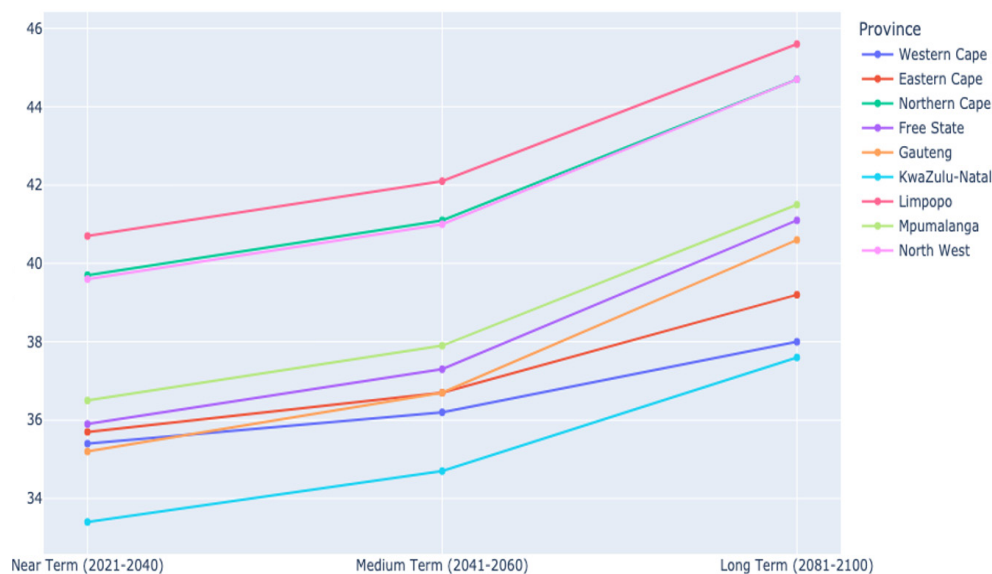


Figure 9: Scenario SSP5-8.5 – Mean Month Maximum Temperature (°C) for Thermal stress

The analysis of maximum temperature data across South African provinces reveals a **consistent warming trend in both SSP2-4.5 and SSP5-8.5 scenarios**, with more pronounced increases in the latter.

Limpopo consistently shows the highest temperatures, while KwaZulu-Natal remains the coolest across all periods.

In the SSP2-4.5 scenario, temperature increases are moderate, with most provinces experiencing a 1-2°C rise from near to long term. The SSP5-8.5 scenario, however, shows a more dramatic warming pattern, with increases of 3-5°C for the same period.

Inland provinces like **Limpopo, Northern Cape, and North West** exhibit the highest temperatures and most significant increases.

Coastal provinces such as Western Cape and KwaZulu-Natal show more moderate warming, likely due to oceanic influence.

The long-term projections (2081-2100) in SSP5-8.5 are particularly concerning, **with Limpopo reaching 45°C, and several other provinces exceeding 40°C with a significant impact to be expected for the Fruit and Vegetable sector.**

2. Water Resource Scarcity and Instability

To evaluate this hazard, we select two indicators: the annual consecutive dry days and the annual mean of daily accumulated precipitation.

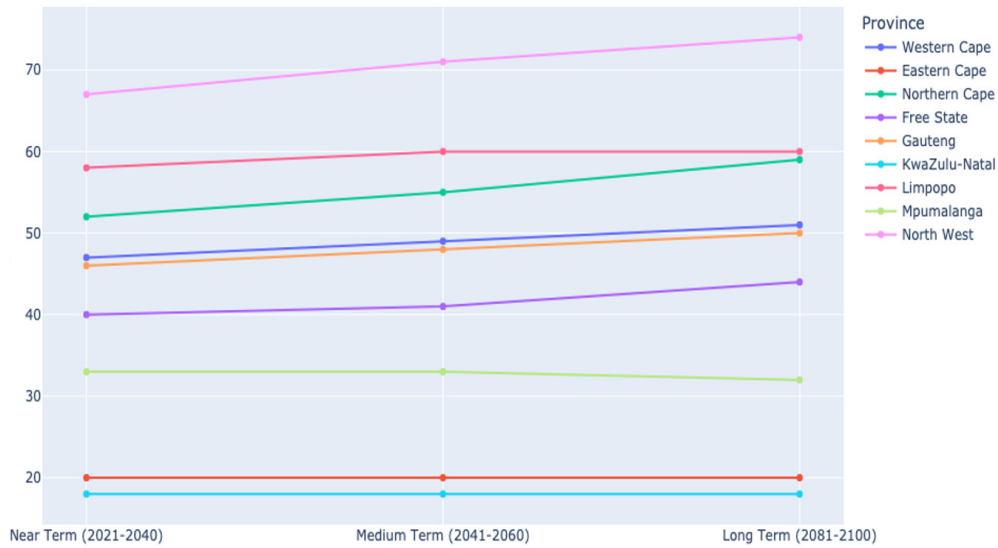


Figure 10: Scenario SSP2-4.5 Maximum Consecutive Dry Days for Water Resource Scarcity and Instability

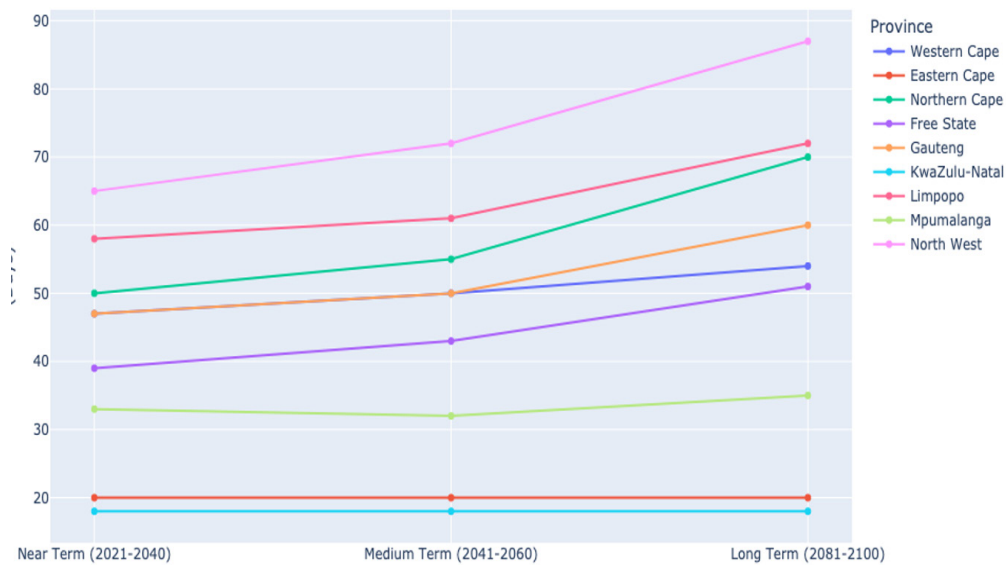


Figure 11: Scenario SSP5-8.5 Maximum Consecutive Dry Days for Water Resource Scarcity and Instability

The analysis of precipitation across South African provinces under SSP2-4.5 and SSP5-8.5 scenarios **reveals significant trends and variations.**

Under SSP2-4.5, provinces like North West and Limpopo show the highest CDDs, increasing to 74 and 60 days by 2081-2100, respectively. In contrast, KwaZulu-Natal remains stable for 18 days throughout. Under SSP5-8.5, CDDs rise more

sharply, with North West reaching 87 days and Limpopo 72 days in the long term.

Geographic factors such as arid climates in the north and coastal influences in KwaZulu-Natal explain these variations.

Limitations include potential uncertainties in climate models and regional variability.

Province	Near Term (2021-2040)	Medium Term (2041-2060)	Long Term (2081-2100)
Western Cape	24.6	23.2	22.5
Eastern Cape	89.3	88.8	89.5
Northern Cape	47.5	47.5	46.0
Free State	64.9	65.7	64.6
Gauteng	69.4	69.0	69.2
KwaZulu-Natal	130.1	131.1	134.0
Limpopo	51.6	50.4	50.1
Mpumalanga	83.3	81.7	82.4
North West	49.6	48.6	47.6

Table 3: Scenario SSP2-4.5 - Annual Means of Daily Precipitation Cumulus (mm) for Water Resource Scarcity and Instability

Province	Near Term (2021-2040)	Medium Term (2041-2060)	Long Term (2081-2100)
Western Cape	25.3	23.5	19.8
Eastern Cape	89.6	89.4	88.5
Northern Cape	47.5	46.3	43.6
Free State	66.3	66.3	64.1
Gauteng	70.0	69.9	68.6
KwaZulu-Natal	132.4	132.9	135.9
Limpopo	51.6	51.5	49.7
Mpumalanga	83.7	83.4	81.6
North West	49.6	48.0	45.7

Table 4: Scenario SSP5-8.5 - Annual Means of Daily Precipitation Cumulus (mm) for Water Resource Scarcity and Instability

The analysis of precipitation across South African provinces under SSP2-4.5 and SSP5-8.5 scenarios reveals significant trends and variations.

Under SSP2-4.5, **KwaZulu-Natal consistently exhibits the highest precipitation levels, increasing from 130.1 mm in the near term (2021-2040) to 134.0 mm by the long term (2081-2100).** In contrast, the Western Cape shows a declining trend, dropping from 24.6 mm to 22.5 mm over the same period.

Under SSP5-8.5, KwaZulu-Natal continues to lead with precipitation rising to 135.9 mm, while the Western Cape experiences a more pronounced decrease, falling to 19.8 mm by the end of the century.

Most other provinces display relatively stable or slightly declining precipitation levels, **with Northern Cape and North West remaining at the lower end of the spectrum.**

- **Western Cape:** Consistently shows the lowest extreme precipitation values, with slight decreasing trends in both scenarios, dropping to 23.7mm in SSP5-8.5 by 2081-2100
- **Eastern Cape:** Maintains relatively high precipitation extremes, with stable values around 57mm in SSP2-4.5, but showing notable increase to 61.8mm in SSP5-8.5 by the long term
- **Northern Cape:** Maintains relatively stable values in SSP2-4.5 (~39mm) but shows notable increase to 43.9mm in SSP5-8.5 by 2081-2100
- **Free State:** Demonstrates steady increases across both scenarios, with more dramatic changes in SSP5-8.5, rising from 45.5mm to 54.2mm
- **Gauteng:** Shows moderate increases in SSP2-4.5 (49.4mm to 52.5mm), but substantial growth in SSP5-8.5, reaching 60.7mm by 2081-2100
- **KwaZulu-Natal:** Consistently shows the highest precipitation

extremes, starting at ~76mm in both scenarios and reaching 79.2mm in SSP2-4.5 and significantly higher at 88.3mm in SSP5-8.5 by 2081-2100, indicating substantial intensification of extreme rainfall events

- **Limpopo:** Exhibits clear upward trends in both scenarios, with more pronounced changes in SSP5-8.5, rising from 54.3mm to 65.8mm by 2081-2100
- **Mpumalanga:** Demonstrates the second-highest extreme precipitation values, showing moderate increase from 64.8mm to 67.1mm in SSP2-4.5, but a dramatic rise to 78.8mm in SSP5-8.5 by 2081-2100
- **North West:** Shows fluctuating patterns in SSP2-4.5, but consistent increase in SSP5-8.5, reaching 47.6mm by 2081-2100

3. Instability Flood-Related Trends

To evaluate this hazard, we select 2 indicators: the annual maximum 1-day precipitation and the annual average humidity.

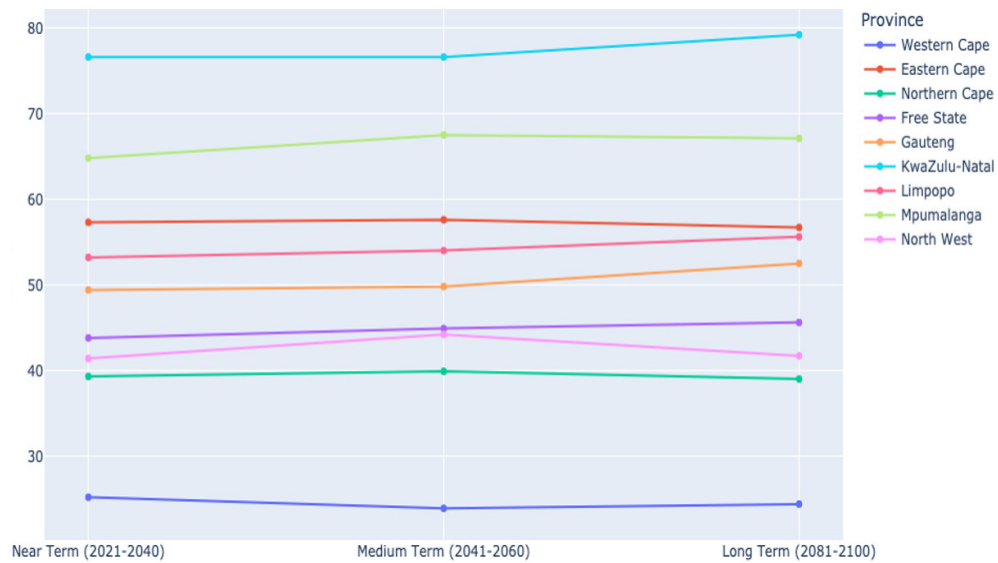


Figure 12: Scenario SSP2-4.5 - Maximum 1-day Accumulated Precipitation (mm) for Instability Flood

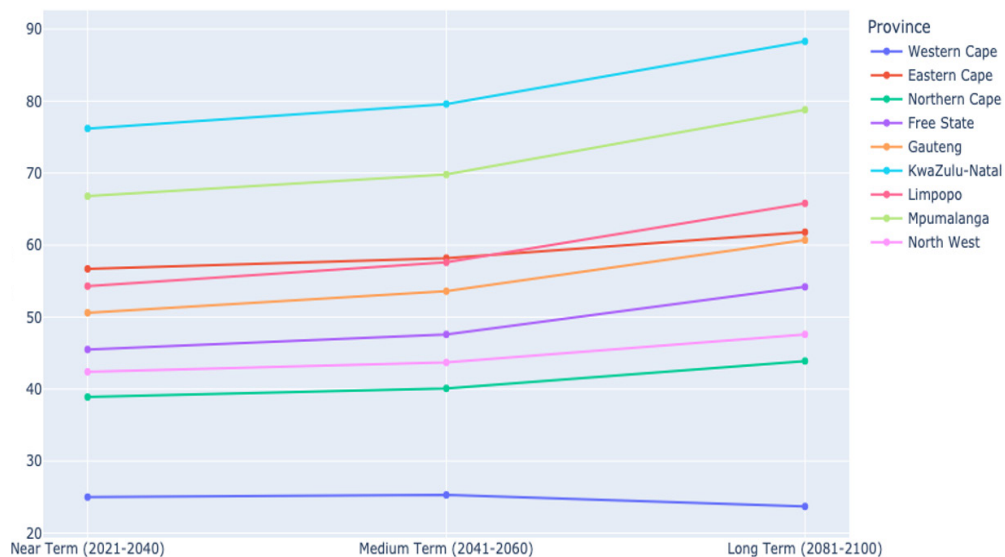


Figure 13: Scenario SSP5-8.5 - Maximum of 1-day Accumulated Precipitation (mm) for Instability Flood

The analysis of maximum 1-day accumulated precipitation across South African provinces reveals distinct regional patterns and varying intensities of change under both SSP2-4.5 and SSP5-8.5 scenarios, with more pronounced increases in the latter.

- **Western Cape:** Consistently shows the lowest extreme precipitation values, with slight decreasing trends in both scenarios, dropping to 23.7mm in SSP5-8.5 by 2081-2100
- **Eastern Cape:** Maintains relatively high precipitation extremes, with stable values around 57mm in SSP2-4.5, but showing a notable increase to 61.8mm in SSP5-8.5 by the long term
- **Northern Cape:** Maintains relatively stable values in SSP2-4.5 (~39mm) but shows a notable increase to 43.9mm in SSP5-8.5 by 2081-2100
- **Free State:** Demonstrates steady increases across both scenarios, with more dramatic changes in SSP5-8.5, rising from 45.5mm to 54.2mm
- **Gauteng:** Shows moderate increases in SSP2-4.5 (49.4mm to 52.5mm), but substantial growth in SSP5-8.5, reaching

The analysis reveals that SSP2-4.5 generally shows moderate changes in extreme precipitation patterns, while SSP5-8.5 projects **more substantial increases, particularly in the eastern and northeastern provinces.**

- 60.7mm by 2081-2100
- **KwaZulu-Natal:** Consistently shows the highest precipitation extremes, starting at ~76mm in both scenarios and reaching 79.2mm in SSP2-4.5 and significantly higher at 88.3mm in SSP5-8.5 by 2081-2100, indicating substantial intensification of extreme rainfall events
- **Limpopo:** Exhibits clear upward trends in both scenarios, with more pronounced changes in SSP5-8.5, rising from 54.3mm to 65.8mm by 2081-2100
- **Mpumalanga:** Demonstrates the second-highest extreme precipitation values, showing moderate increase from 64.8mm to 67.1mm in SSP2-4.5, but a dramatic rise to 78.8mm in SSP5-8.5 by 2081-2100
- **North West:** Shows fluctuating patterns in SSP2-4.5, but consistent increase in SSP5-8.5, reaching 47.6mm by 2081-

Extreme precipitation across South Africa is expected to intensify, particularly under the SSP5-8.5 scenario. The eastern and northeastern regions are projected to face the most significant increases, **which will impact Dairy, Sugar**, as well as **Fruit and Vegetable production in KwaZulu-Natal**. Western

and northern areas show lower values and more stability, while southern regions face moderate changes. These trends highlight varying regional vulnerabilities to extreme rainfall events under future climate scenarios.

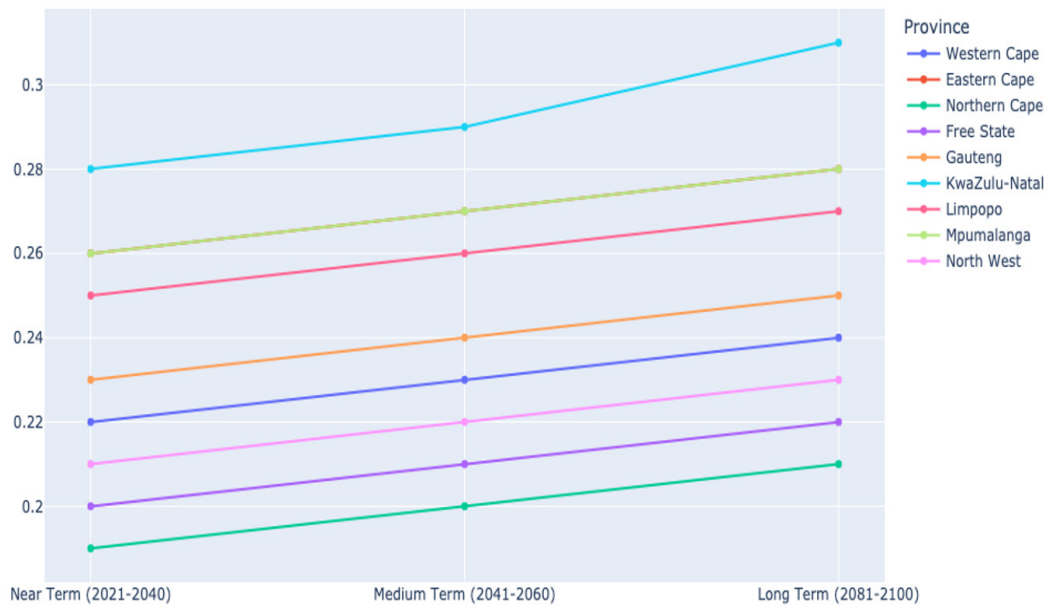


Figure 14: Scenario SSP2-4.5 - Average Humidity (%) for Instability Flood

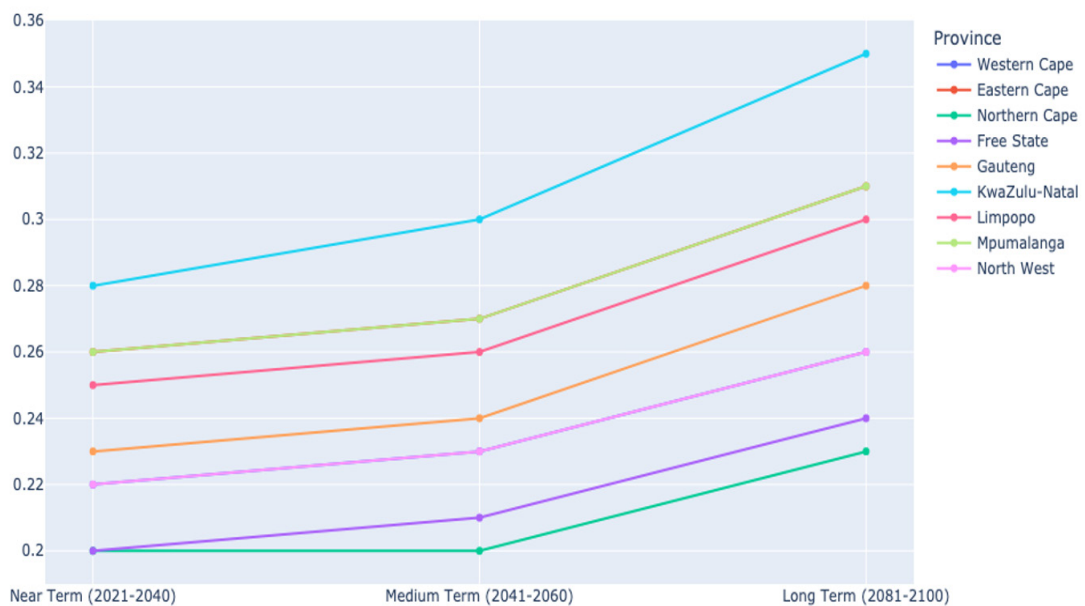


Figure 15: Scenario SSP5-8.5 - Average Humidity (%) for Instability Flood

The analysis of average humidity across South African provinces shows a general increasing trend in both SSP2-4.5 and SSP5-8.5 scenarios, with more pronounced increases in the latter scenario.

- **Western Cape:** Shows a gradual increase from 0.22 to 0.24 in SSP2-4.5, with a slightly stronger rise to 0.26 in SSP5-8.5 by 2081-2100.
- **Eastern Cape:** Demonstrates consistent humidity levels, increasing from 0.26 to 0.28 in SSP2-4.5, but showing a more substantial rise to 0.31 in SSP5-8.5 in the long term.
- **Northern Cape:** Maintains the lowest humidity levels among all provinces, with modest increases from 0.19 to 0.21 in SSP2-4.5 and 0.20 to 0.23 in SSP5-8.5.
- **Free State:** Shows steady increases across both scenarios, rising from 0.20 to 0.22 in SSP2-4.5 and reaching 0.24 in SSP5-8.5 by 2081-2100.
- **Gauteng:** Exhibits gradual increases from 0.23 to 0.25 in SSP2-4.5, with a more pronounced rise to 0.28 in SSP5-8.5 over the long term.
- **KwaZulu-Natal:** Consistently shows the highest humidity levels, increasing from 0.28 to 0.31 in SSP2-4.5, and reaching 0.35 in SSP5-8.5 by 2081-2100.

- **Limpopo:** Demonstrates steady increases from 0.25 to 0.27 in SSP2-4.5, with a more substantial rise to 0.30 in SSP5-8.5.
- **Mpumalanga:** Shows similar patterns to the Eastern Cape, rising from 0.26 to 0.28 in SSP2-4.5 and reaching 0.31 in SSP5-8.5 by 2081-2100.
- **North West:** Exhibits moderate increases from 0.21 to 0.23 in SSP2-4.5, with a more notable rise to 0.26 in SSP5-8.5.

In summary, humidity levels are projected to increase across South Africa under both SSP2-4.5 and SSP5-8.5 scenarios, with more significant changes in SSP5-8.5. **Northern regions maintain lower humidity levels despite modest rises, while southern and eastern areas show substantial increases, highlighting varying regional vulnerabilities to climate change.**

4. Wind Speed Trends

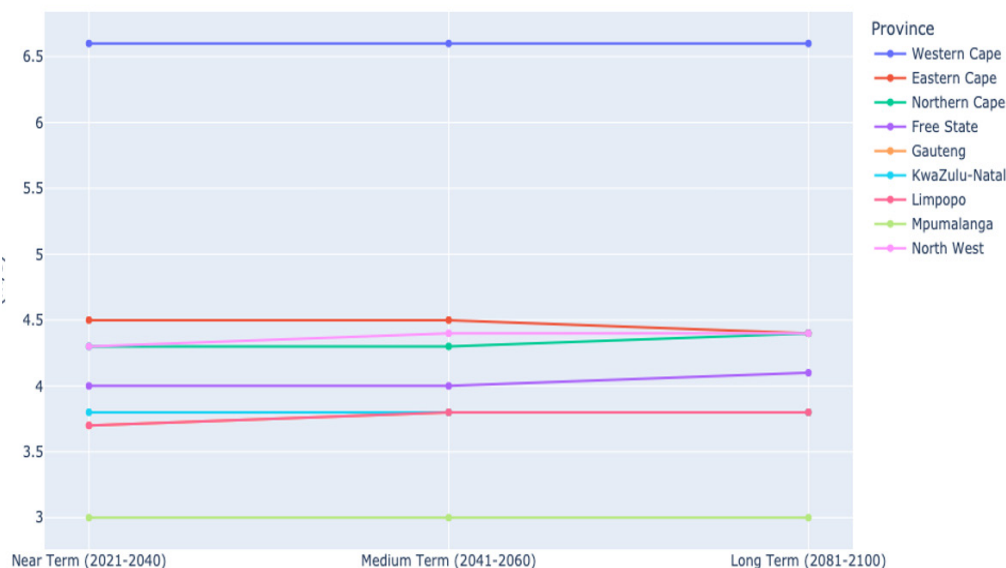


Figure 16: Scenario SSP2-4.5 - Mean Wind Speed (m/s) for Wind speed

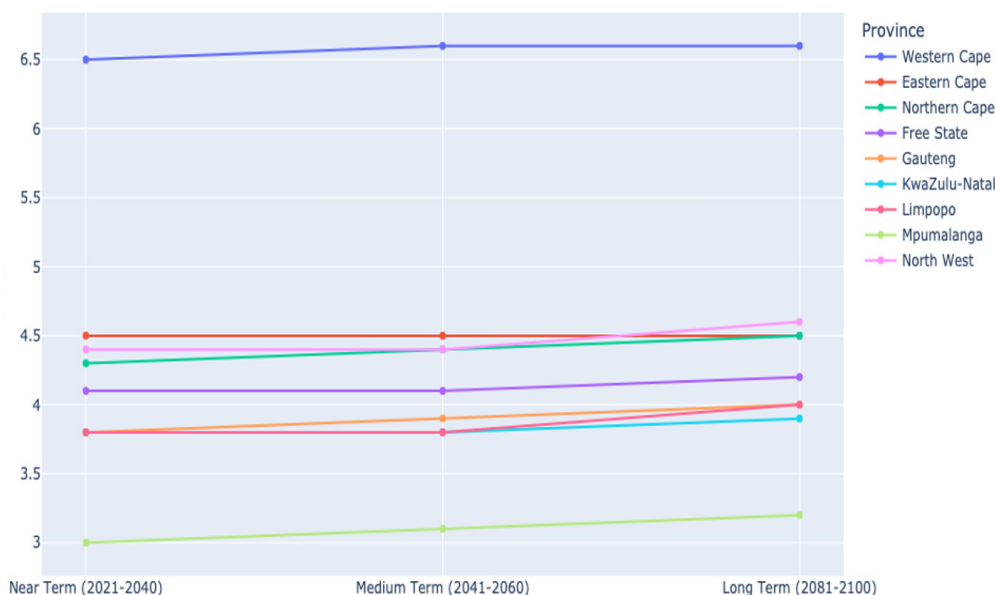


Figure 17: Scenario SSP5-8.5 - Mean Wind Speed (m/s) for Wind speed

The analysis of mean wind speed projections across South African provinces under SSP2-4.5 and SSP5-8.5 scenarios **reveals distinct patterns and regional variations.**

Under SSP2-4.5, most provinces show a slight increase in mean wind speed over time.

Western Cape maintains the highest wind speeds, increasing marginally from 127.5 to 127.7 by 2081-2100. Northwest and Northern Cape exhibit more noticeable increases, reaching 82.6 and 84.6 respectively in the long term. Mpumalanga consistently shows the lowest wind speeds, with a modest increase from 56.0 to 56.6.

The SSP5-8.5 scenario presents a more pronounced upward trend in wind speeds across all provinces. Western Cape still leads with the highest wind speeds, reaching 127.9 by 2081-2100. Northwest and Northern Cape show substantial increases, climbing to 85.0 and 86.3 respectively. Even Mpumalanga, despite having the lowest wind speeds, sees a more significant rise to 58.6 in the long term.

Notably, coastal provinces like Western Cape and Eastern Cape demonstrate more stable wind speeds across both scenarios, likely due to maritime influences. Inland provinces such as Gauteng and North West show more substantial increases, particularly under SSP5-8.5.

These projections suggest that while all provinces may experience some increase in mean wind speeds, the changes are more pronounced under the high-emission SSP5-8.5 scenario.

This trend could have implications for wind energy potential and climate-related planning across South Africa.

Based on the data gathered in the previous section, the following climate hazards by sector and province, warrant close attention:

- **Fruit and Vegetable in Limpopo – Thermal Stress**
- **Poultry in Northern Cape and Northwest – Thermal Stress**
- **Sugar, Dairy, and Meat in KwaZulu-Natal – Rainfall and Flooding**
- **Dairy and Fruit and Vegetable in Western Cape – Water Scarcity**



05

Food Processing Value Chain in the lens of the OCARA Methodology

The food processing value chain refers to the entire process of turning raw agricultural products into value-added goods for domestic consumption and export. **It involves various stages, from raw material production to final product manufacturing and distribution.**

The food processing value chain consists of several stages:

1. Agricultural Raw Material Production involves cultivating crops and raising livestock, which are essential inputs for agro-processing.

2. Primary & Secondary Processing includes transforming raw materials into intermediate or semi-processed goods, followed by more refined products with added value, often packaged and branded.

3. Tertiary Processing focuses on further refinement, packaging, and branding, adding ingredients like preservatives and spices before preparing products for market.

4. Distribution and Retail is the final stage where finished goods are distributed to wholesalers, retailers, and

consumers.

Each stage in the agro-processing value chain is highly exposed to climate change due to its inherent nature.

To assess this exposure, we use the **OCARA** ("Operational Climate Adaptation and Resilience Assessment") tool. **Designed to help economic actors build resilience to current and future climate impacts, OCARA methodology allows for the identification and prioritization of climate change signals—both weak and strong—across the entire value chain.**



The food processing industry is particularly exposed to heatwaves due to the perishable nature of their stocks, the need for refrigeration in their production chain, and the electronics embedded in their equipment.

The OCARA methodology identifies **19 macro-processes and over 100 processes relevant to the food processing value chain**. From this, we selected the most pertinent macro-processes and processes, which were assessed with a priority level above 4 on a scale of 1 to 5, as shown in **Table 5**.

Type	Macro-Processes	Processes
A	Integrity of Buildings	Integrity of Buildings Integrity of Warehouses
A	Maintaining Storage Conditions of Raw Materials, Products, and Waste	Integrity of the Stock of Dry Product. Integrity of the Stock of Fresh Product, Integrity of the Stock of Frozen Product
A	Maintaining Production Conditions	Maintaining Production Conditions Indoor, Maintaining Production Conditions Outdoor, Maintaining Working Conditions
A	Integrity and Proper Functioning of Equipment	Electricity Supply Equipment Mechanical Production Equipment Electronic Production Equipment, Refrigeration Equipment, Water Supply Equipment, Water Treatment Equipment
A	Services Rendered by Natural Assets exploited by the Company	Exploitation of Agriculture Resources
B	Availability and Quality of Supplies – Direct Perimeter of Rank 1 Suppliers	Suppliers of Agriculture Products, Suppliers of Packaging Products
B	Goods Supplies and Distribution – Availability and Quality of Transport Networks	Transport Upstream, Transport Downstream (Road, Rail)
B	Availability and Quality of Electricity Supplies to Sites	Electricity Supply from the Grid, Self-Consumed Solar Electricity
B	Availability and Quality of Supplies of Gas, Steam, Heating, and Cooling	Gas Supply
B	Availability and Quality of Water Supplies to Sites	Surface Water, Water Network
B	Availability and Quality of Telecom and Internet Networks	Telecom Network
B	Removal of Waste and Effluents	Removal of Industrial Waste
C	Value Chain of Suppliers of Rank 1	Local Suppliers, International Suppliers

Table 5: Macro Processes and Processes Exposed to Climate Change, by Iroko Africa

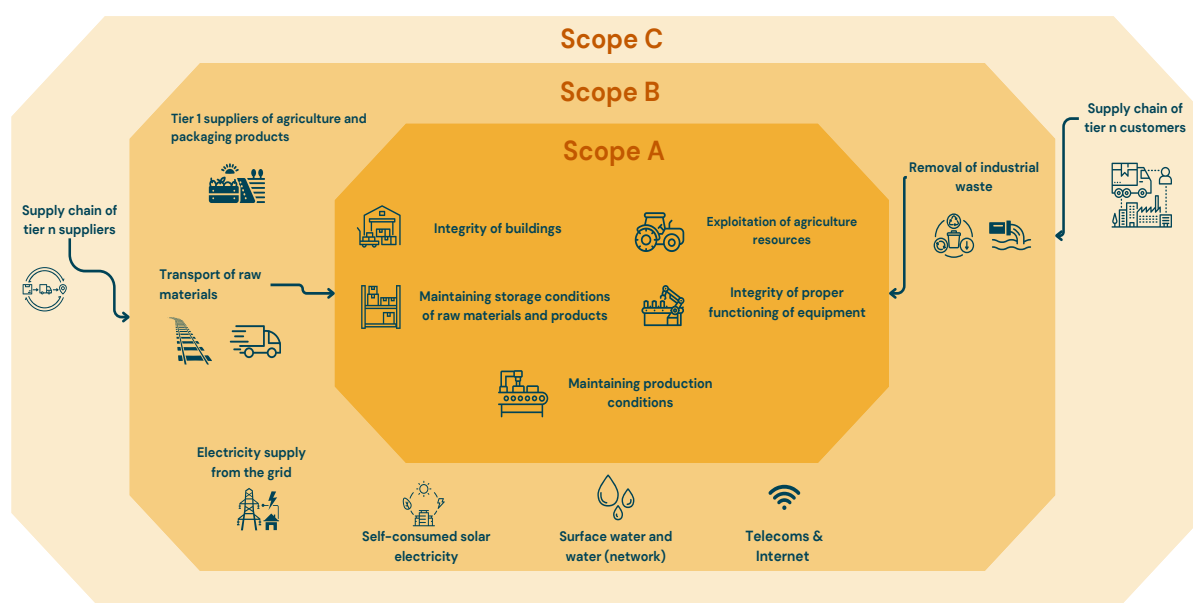


Figure 18: Vulnerable Activities in the Agro-Processing Industry Value Chain

Key:

Tier 1 customers are direct customers of a company.
Tier 2 customers are the customers of tier 1 customers.
Tier n customers follow this pattern, representing customers further down the chain.

06

Assessing the Agro-Processing Industry Vulnerability to Climate

The analysis in this chapter identifies four key climate hazards: Thermal Stress, Water Resource Scarcity and Instability, Wind and Flood Instability. Wind events, when not associated with cyclones, were deemed non-critical

to the sector and are therefore excluded from the study. **Figure 19** highlights the primary climate hazards with the highest likelihood of occurrence and their potential impact on the food processing industry value chain.

	Thermal Stress	Water Scarcity	Flood
Integrity of Buildings, Integrity of Warehouses	●	●	●
Integrity of the Stock of Dry Product, Integrity of the Stock of Fresh Product, Integrity of the Stock of Frozen Product	●	●	●
Maintaining Production Conditions Indoor, Maintaining Production Conditions Outdoor, Maintain Working Conditions	●	●	●
Electricity Supply Equipment, Mechanical Production Equipment, Electronic Production Equipment, Refrigerated Production Equipment, Water Supply Equipment, Water Treatment Equipment	●	●	●
Exploitation of Agriculture Resources	●	●	●
Suppliers of Agriculture Products, Suppliers of Packaging Products	●	●	●
Transport Upstream, Transport Downstream (Road, Rail)	●	●	●
Electricity Supply from the Grid, Self-Consumed Solar Electricity	●	●	●
Gas Supply	●	●	●
Surface Water, Water Network	●	●	●
Telecom Network	●	●	●
Removal of Industrial Waste	●	●	●
Local Suppliers, International Suppliers	●	●	●
	High Stake	Medium Stake	Low Stake
	●	●	●

Figure 19: Agro Processing Supply Chain Vulnerabilities, adapted by Iroko Africa²

The most vulnerable components of the value chain are the exploitation of agricultural resources, stock integrity, and the availability and quality of the water supply. These are followed by electricity supply, maintaining production conditions, and equipment integrity.

This evaluation is supported by findings from the literature review, which are summarised in **Table 6** below.

Dairy Danone	Four Climate Physical Risks mentioned: • Water stress and thermal stress on milk supply chain • Water stress and thermal stress on agriculture resources • Water stress on direct operation • Extreme weather affecting operation
Poultry The Poultry Association	The following Climate Risks are mentioned: • Impact of heat, drought, and floods on feed quality. • Effect of heat on animal genetics. • Thermal discomfort affecting animal performance.
Meat World Economic Forum	Climate change makes it more difficult to grow feedstock for cattle, pigs, and chickens with a recent study showing that for every 1°C increase in temperature, growth is slowed by 7%.
Food Processing Industry Carbone 4	Increase in Temperature and Heat Waves: • Thermal stress for animals. • Accelerated maturation of crops, with reduced growth and nutritional quality. • Possible promotion of pest and nuisance development. • Loss of agricultural land. • Devastating wildfires of crops. • Increased demand for air conditioning and the sizing of cold storage rooms. • Decrease in equipment efficiency. • Loss of equipment efficiency.
Food Processing Industry Carbone 4	Variation in Precipitation and Storm • Flooding and damage to agricultural infrastructure. • Disruption of supply chains. • Lack of water for processing in food manufacturing plants. • Direct destruction of production.

Table 6: Agro-Processing Industry's Vulnerabilities Evaluation, by Iroko Africa



The four major factors contributing to climate change sensitivity include:

- 1. Concentrated supply sources**
- 2. Complex value chains**
- 3. Weather-sensitive production chains**
- 4. Activities dependent on infrastructure**

South Africa ranks as highly sensitive due to its reliance on specific agricultural regions for key inputs, making its supply sources particularly vulnerable to climate impacts like droughts and heatwaves. The country's food processing sector is also characterized by complex value chains that are susceptible to disruptions caused by weather variations. Additionally, South Africa's production chains are highly weather-sensitive, with key crops and livestock being directly impacted by changing temperature and rainfall patterns. **Furthermore, the country's infrastructure, including water supply, electricity, and transportation, is often inadequate and vulnerable to climate-induced disruptions, exacerbating its overall sensitivity to climate change.**

07

Food Processing Industry : Energy Consumption

The global food sector consumes approximately 200 EJ annually, with 30% to 45% of this energy dedicated to processing and distribution activities. Among the most energy-intensive sectors are the production of sugar, dairy products, and beverages. On average, heat accounts for more than 70% of the total energy requirements, as shown in **Figure 21**, while refrigeration represents 30% of electrical consumption. However, energy intensity in food processing varies significantly between finished products,

as mentioned in **Table 7**, underscoring the importance of sector- or product-specific analysis^{3,4}.

Figure 20 below illustrates energy consumption across the value chain.

All data provided within this section comes from research made between 1980 and 2020 in various countries in the world.

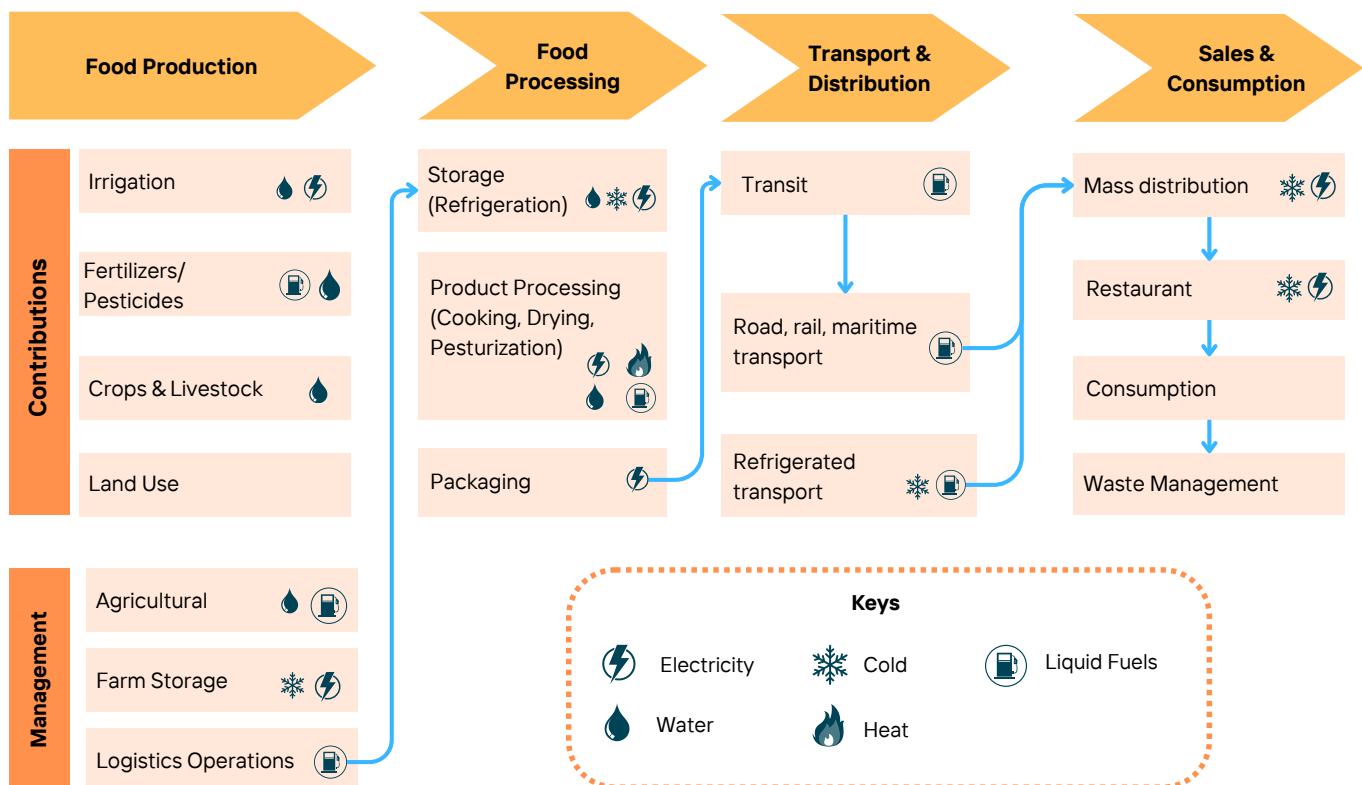


Figure 20 : Food Processing Industry Value Chain and Energy, adapted by Iroko Africa

Cluster	Energy Consumption Range
Dairy	1-15 MJ/kg
Sugar	6-8 MJ/kg
Poultry	5-6 MJ/kg
Red Meat	2-3 MJ/kg
Fruit and Vegetable	1-17 MJ/kg
Alcoholic Beverage	205-240 MJ/hl

Table 7: Energy Consumption Range per Sector, by Iroko Africa

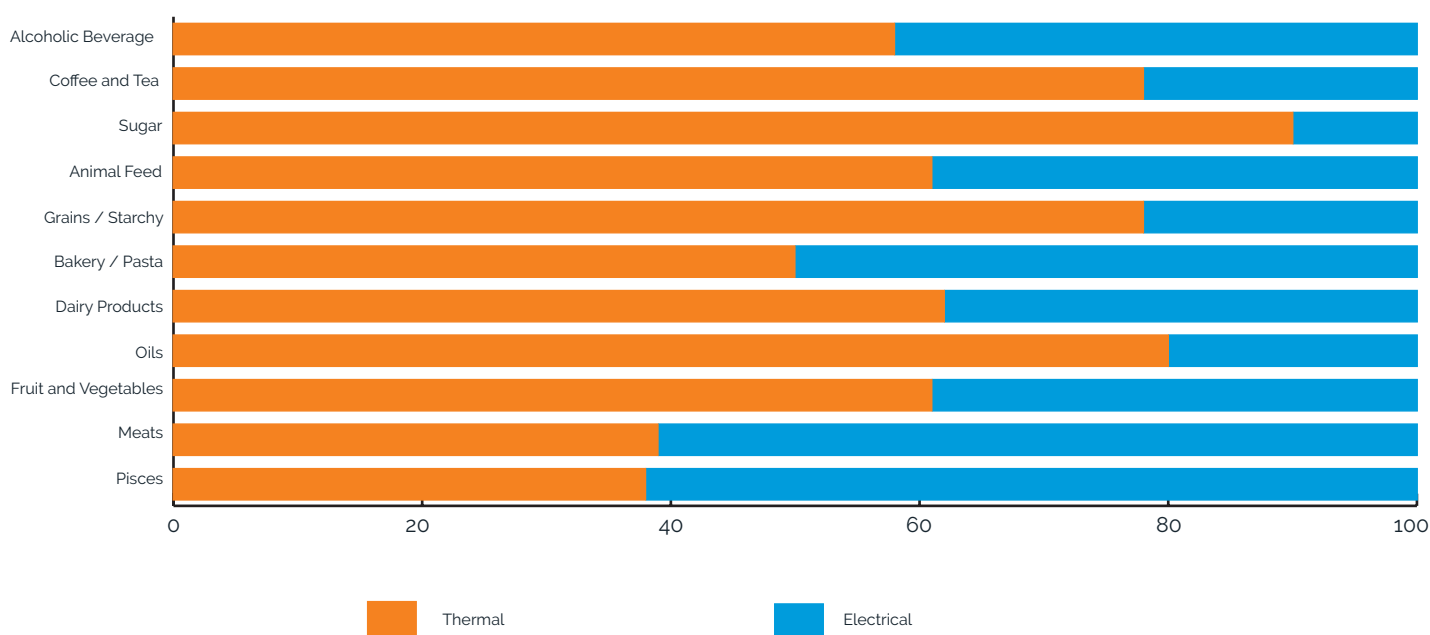


Figure 21: Average Energy Needs per Sector, adapted by Iroko Africa

7.1 Snapshot of Dairy Processing

Dairy processing is recognized as one of the most energy-intensive sectors in the food industry, with energy use spanning electricity and thermal energy for various production processes.

Electricity is used for pumps, refrigeration, control systems, and separation, while thermal energy is required for cleaning, evaporation, and pasteurization. Cleaning-in-Place (CIP) operations, essential for maintaining strict hygiene standards for raw milk, consume significant energy daily.

Energy consumption in dairy products varies by type as illustrated in **Figure 22** below. Cheese is the most energy-

intensive product, requiring 13.85 MJ/kg, while milk powder is less energy-intensive, needing 10.30 MJ/kg for drying and evaporation. Milk pasteurization accounts for 17%-26% of total energy consumption, with potential to recover 90%-94% of heat input.

Ultra-High Temperature (UHT) processing and sterilization require higher temperatures, making these steps particularly energy-demanding. In milk powder production, concentration and drying are the most energy-intensive stages, accounting for 45% and 51% of primary energy use, respectively.

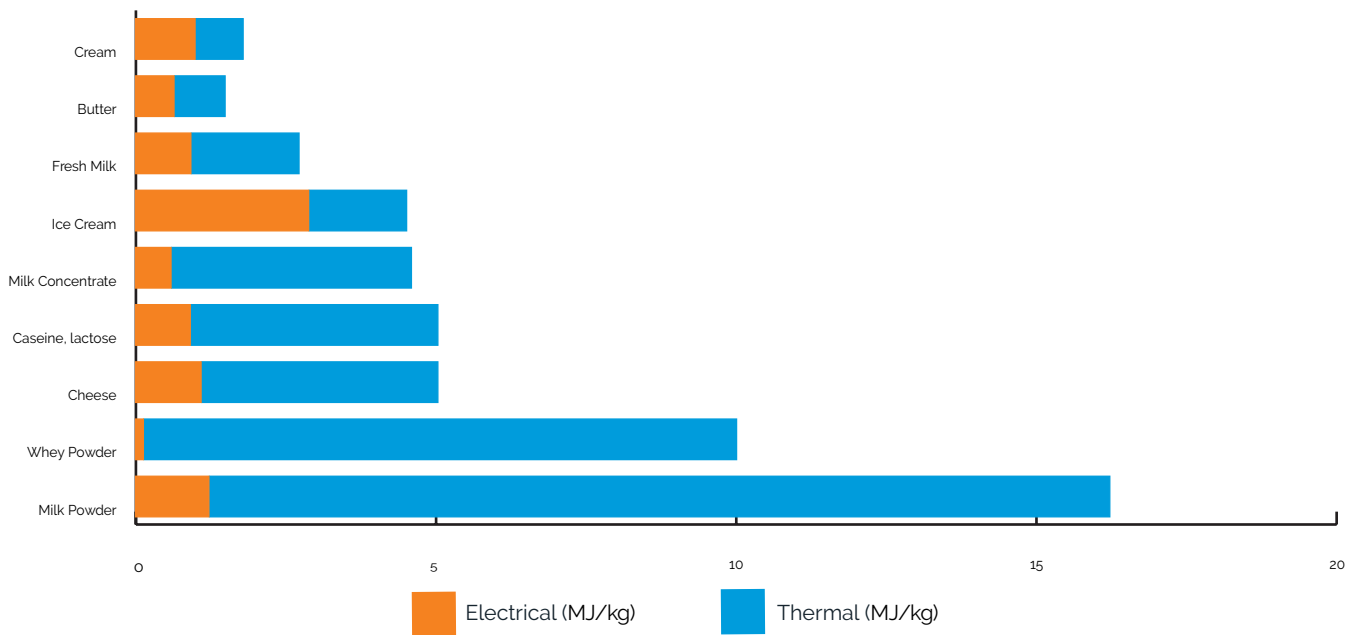


Figure 22: Energy Consumption per Product in Dairy Sector, adapted by Iroko Africa

7.2. Snapshot of Sugar Processing

The average energy required for sugar production is 6.90 MJ/kg. Electricity constitutes approximately 25% of this total energy consumption, with refrigeration accounting for about 50% of the electrical usage. On the thermal side, 65% of the thermal energy is consumed by the evaporative crystallizer. **Figure 23** below provides a breakdown of the energy consumption in sugar transformation per activity. **Figure 24** highlights electrical consumption per activity.

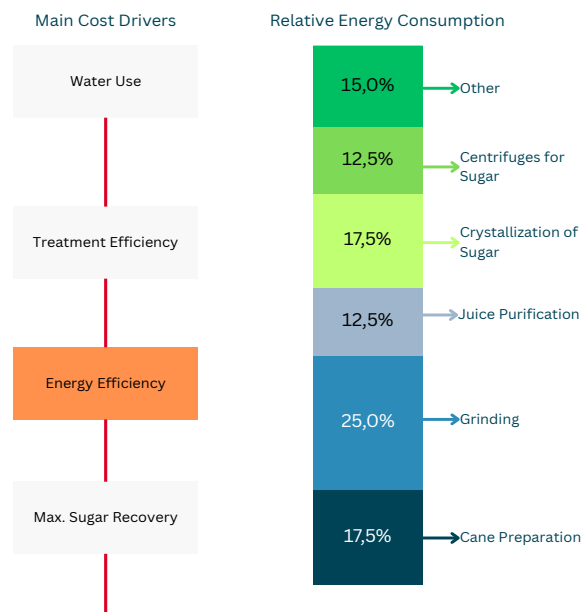


Figure 23: Energy Consumption in Sugar Transformation, adapted by Iroko Africa

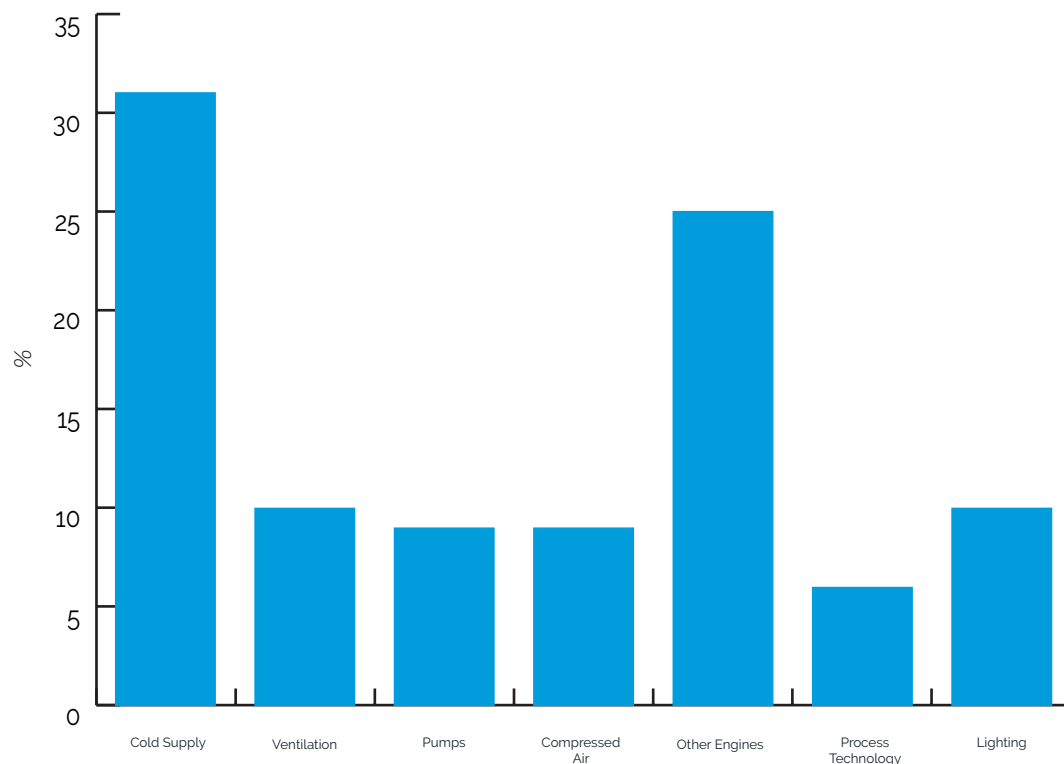


Figure 24⁶: Electrical Consumption per Activity in Sugar Industry, adapted by Iroko Africa

7.3. Snapshot of Fruit and Vegetable Processing

The data within **Figure 25** shows that potato-based products are the most energy-intensive, with crisps and French fries consuming significant amounts of energy, particularly during the drying processes, requiring 17.30 MJ/kg and 14.02 MJ/kg, respectively.

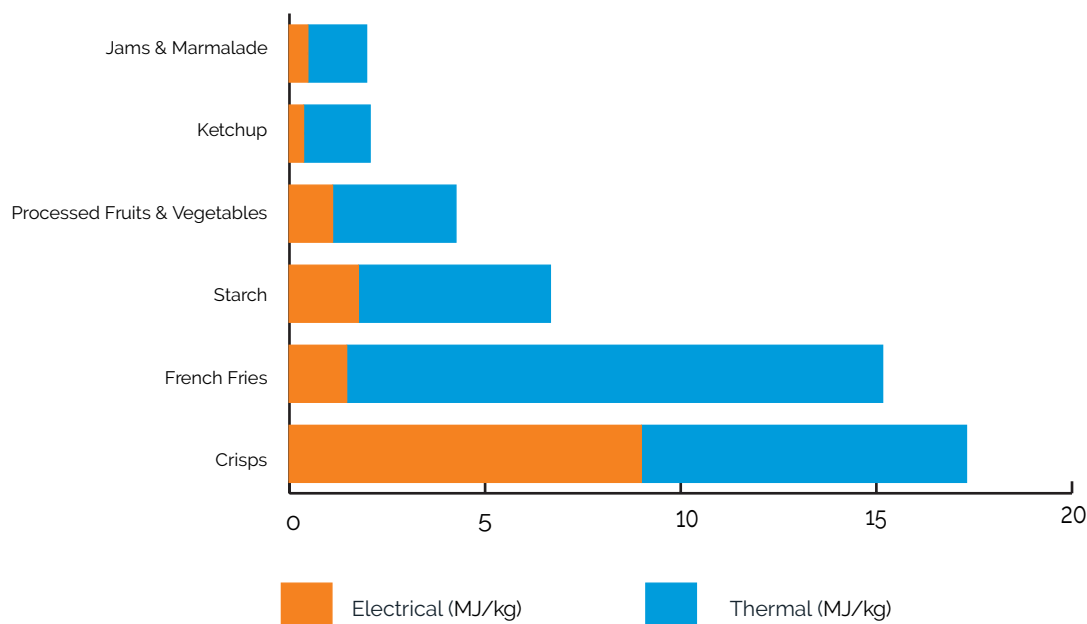


Figure 25: Energy Consumption per Product in Fruit & Vegetable Sector, by Iroko Africa

7.4. Snapshot of Meat Processing

Poultry processing consumes 5.54 MJ/kg of energy, while Red Meat processing requires 2.87 MJ/kg. Frozen meat products generally require more energy than chilled ones.

Poultry products are the most energy-intensive due to higher refrigeration needs and elevated temperatures during the hard scalding process. Additionally, poultry slaughtering consumes more energy than other meats due to operations like hair and

feather removal, singeing, and the increased use of automated equipment, temperature control, and hot cleaning water. In contrast, red meat, veal, and sheep require less energy overall⁷.

Table 7 summarises the range of energy consumption and the average energy requirements for both electricity and thermal energy across different sectors.

Cluster	Energy Consumption Range
Dairy	1-15 MJ/kg
Sugar	6-8 MJ/kg
Poultry	5-6 MJ/kg
Red Meat	2-3 MJ/kg
Fruit and Vegetable	1-17 MJ/kg
Alcoholic Beverage	205-240 MJ/hl

Table 7: Energy Consumption Range per Sector, by Iroko Africa



The South African dairy industry processes approximately 3.5 billion liters of unpasteurised milk annually. Based on local benchmark data and product distribution, this amounts to 8,700,000 kiloliters (kl) of water, 3,875,000 MWh of electrical energy, and 1,000,000 MWh of thermal energy per year. **In terms of electrical energy, refrigeration and compressed air plants typically account for more than 50% of the total demand. For thermal energy, larger plants often rely on coal-powered steam systems, while smaller plants use liquid fuel-driven steam or hot water systems.**

Energy and Climate Resilience in Milk-Dairy Farms and Processing

• Energy Mapping on Dairy Farms⁸

Energy mapping derived from a recent review analysing energy consumption in dairy farms, reveals that total energy use ranges from 2.7 MJ/kg of Energy Corrected Milk (ECM) in organic dairy farms to 4.1 MJ/kg of ECM in conventional farms. ECM standardises milk to the caloric equivalent of milk with 3.5% fat and 3.2% protein content, regardless of fat and protein variations. The difference in energy use between conventional and organic farming is attributed to the higher indirect energy requirements in conventional farming, particularly for feed and fertilizer production. In conventional farming, energy use for fertilizer and feed production accounts for 13% and 43% of total energy consumption. Conversely, in organic farming, energy use for feed production is mainly direct, due to

free-range grazing, and contributes to 34% of total primary energy use, while energy for organic fertiliser production is minimal, under 1%. Overall, across both conventional and organic dairy farms, **32% of total energy use is from direct on-farm activities, while 68% stems from indirect energy use, primarily related to feed and fertiliser production.** In terms of direct energy use, the energy mix consists of 48% electricity and 52% liquid fuels. **Electricity is primarily used for refrigeration, pumping for milk harvesting, water heating, water pumping, and lighting, while liquid fuels such as diesel, kerosene, natural gas, LPG, and lubricants are used for on-farm activities like water heating and powering mechanical machinery.**

• Manufacturing Energy Mapping

After milk production on the farm, it is transported to a dairy manufacturing plant where various processes occur to create the end-products. **Dairy manufacturing requires substantial energy due to heating and cooling processes.** The energy demand per kg of raw milk processed in dairy plants varies from 0.8 to 1.9 MJ, depending on the products and production scale. **Energy consumption in dairy processing is mainly from electricity and fuel use.**

Processes like refrigeration, packaging, homogenisation, standardisation, milk pumps, and plant automation require electricity, while heat treatment processes use steam produced from fossil fuel combustion. Different dairy products exhibit variations in energy mix. Fresh dairy products (cheese, fresh milk, butter, cream, and ice cream) have an energy mix consisting of 43.9% electricity, primarily used for refrigeration, and 56.1% fuel, which is utilised for generating heat during the manufacturing process. Long shelf-life products like casein, lactose, milk powder, and whey powder, on the other hand, have an energy mix of 8.1% electricity and 91.9% fuel on average, **due to their extensive processing requirements. Clean-In-Place (CIP) processes for maintaining hygiene in dairy processing equipment consume a significant portion of the energy, especially for pasteurisation.**

• Cold Chain Energy Mapping

Fresh dairy products require controlled environmental conditions for optimal storage and transportation. **The cold chain is critical for maintaining food quality and safety, contributing significantly to energy use in the dairy sector.** Various truck types used for distribution of dairy products consume varying amounts of energy per ton of products transported and per kilometer: medium rigid trucks consume 2.97 MJ, large rigid trucks 1.31 MJ, and 32-ton articulated trucks 0.94 MJ. Cold storage in retail outlets also contributes to energy usage, with up to 0.2 MJ/kg of milk used for storing pasteurised milk over a 10-day period.

• Waste

Waste significantly impacts sustainability in the dairy supply chain, increasing indirect energy use. Dairy product loss represents 20% of total production, distributed as 17–30% during manufacturing, 9–12% in transportation, 2–9% at retail, and 53–71% at the consumer level, where waste is highest.

• Carbon Footprint

The carbon footprint of the dairy sector is predominantly influenced by energy use across various stages of the supply chain. Key findings from several studies include:

1. Life Cycle Assessment (LCA) Studies

The farm stage is the largest contributor to GHG emissions, accounting for 86.9% of emissions for milk and 72.2% for yogurt, primarily due to bovine enteric fermentation. In the manufacturing stage, emissions stem from fossil fuel and electricity use, contributing 95% for milk and 98.3% for yogurt, while water, wastewater, chemicals, and refrigerants

play a smaller role, representing 5% of emissions for milk and 1.7% for yogurt.

2. Full Milk Supply Chain (Farm-to-Fork)

Total GHG emissions for milk are estimated at 2.05 kg CO₂e per kilogram. Of this, 0.76 kg CO₂e is derived from energy usage, with 51.4% originating from fuel and 48.6% from electricity. The farm and cold chain stages contribute the most to energy-related emissions, with refrigeration in the cold chain being the largest contributor.

• Climate Change and Adaptation:

Climate change impacts all stages of the dairy supply chain, leading to increased energy demand across the sector. At the farm level, changes in climatic conditions such as reduced crop yields and increased ambient temperatures can lead to heat stress in cows, necessitating cooling systems. At the manufacturing stage, the development of **heat-resistant pathogens in raw milk could require more intensive heat treatments, thus increasing energy demand. In the cold chain, higher ambient temperatures will necessitate more energy for refrigeration.** Adaptation strategies include the development of energy-efficient refrigeration technologies as well as the implementation of IoT for better monitoring.

• Mitigation Strategies:

To improve sustainability in dairy manufacturing, dairy plants are encouraged to shift from conventional energy use to cleaner forms, such as biofuels, and to derive electricity from renewable sources. **Practices such as installing energy-efficient equipment, improving the insulation of heating and cooling systems, and fixing steam leakages can significantly reduce energy consumption.** Emerging technologies like microwave (MW) and radio frequency (RF) are being explored for non-conventional heat treatment processes in dairy production, offering improved product quality and energy efficiency. Non-thermal techniques, including ultrasound (US), high-pressure processing (HPP), and Pulsed Electric Field (PEF), are also promising alternatives for reducing energy use in dairy processing.

08

Climate Change and Energy Systems Vulnerabilities

Accelerating climate change poses a significant risk to global energy security, impacting the entire energy system, **from fuel extraction to power generation and infrastructure resilience**. It also alters energy demand patterns^{9,10,11}.

Building on the literature review and case studies as well as extending the climate hazards modeled in the previous

analysis, this chapter explores the effects of Thermal Stress, Water Resource Scarcity and Instability, Wind Speed and Flood Instability on the vulnerability and resilience of existing and alternative energy infrastructure within South Africa's food processing industry.

8.1. Impact of Climate Change on Thermal Power Generation

Climate change presents significant challenges for power generation, especially for thermal plants. These plants, which accounted for nearly 65% of global electricity production in 2016, are expected to contribute to 52% of global generation by 2040. In South Africa, fossil-fired plants are responsible for 95% of the country's electricity.

The risks climate change poses to thermal power plants are varied and complex, ranging from diminished cooling efficiency to structural damage caused by floods, storms, and lightning.

As temperatures rise, thermal efficiency can decrease by 0.1–0.5%, potentially leading to capacity losses of 1–2% for every degree Celsius increase.

Additionally, reduced precipitation may limit the availability of cooling water, potentially forcing plants to reduce capacity or shut down entirely.

Extreme weather events like heatwaves, storms, flooding, and lightning further amplify the impact of gradual climate change on thermal plants. For example, in 2006, 11 thermal power plants in Germany had to reduce their output by 1,741 MW due to high water temperatures. These extreme conditions also risk overheating critical control equipment, making plant operations even more vulnerable.



Climate change is increasingly recognised as a key environmental and business issue, impacting the entire electricity grid value chain—from generation and transmission to distribution and consumer demand. These changes expose the sector to financial risks linked to climate-related impacts that vary by region

Risks Posed by Extreme Weather Events and Climate Trends on Coal-Fired Power Plants

Extreme weather events combined with climate trends introduce significant risks for coal-fired power plants. Heavy precipitation can drench coal stockpiles, reducing boiler efficiency by 1% for every 10% increase in moisture. In hot spells or dry periods, coal stockpiles may self-ignite, requiring more cooling and posing additional risks. The risk of dust and drying from coal stockpiles also increases.

Lightning, extreme winds, and storms can disrupt power systems, damage buildings, and lead to plant shutdowns. The combination of high temperatures, droughts, and high winds exacerbates dust release from storage areas, and the operation of CO₂ capture technologies significantly increases water consumption, doubling it.

Adaptation Strategies for Thermal Power Plants Under Extreme Weather Conditions

To address the challenges posed by climate change, thermal power plants must adopt a range of adaptation strategies, from cost-effective solutions to more substantial upgrades. Low-cost measures like recycling process water can meet 25–37% of a plant's water needs, while more expensive upgrades, such as dry cooling towers, may be necessary. For example, retrofitting cooling systems in the U.S. alone could cost over US \$95 billion. Transitioning from once-through cooling systems to recirculating systems or adopting dry cooling technologies are crucial strategies to mitigate the impacts of extreme heat.

To further mitigate risks from extreme weather events and climate change, thermal plants must implement

These include addressing challenges like reduced thermal efficiency from warmer average temperatures and limited cooling water availability. **Using alternative cooling methods such as non-traditional water sources, reusing process water, and transitioning to dry cooling systems can help maintain performance in hotter conditions.**

For risks associated with severe weather events like flooding, strong winds, and lightning, additional strategies are required. These include building flood defenses, enhancing drainage systems, and reinforcing plant structures to withstand extreme weather.

Ensuring multiple connections to the grid is also essential for continued operation. To protect critical infrastructure from lightning, improvements such as enhanced lightning protection, grounding of sensitive components, and housing critical systems in protected or underground locations are vital.

By adopting these diverse adaptation measures, summarised in **Table 8**, thermal power plants can improve their resilience and ensure continued, reliable power generation in the face of a changing climate.

Impact	Potential Vulnerabilities	Examples of Adaptation Options
Higher air temperatures	Reduction in the efficiency of thermal conversion, accounting for decreased cooling efficiency and reduce operation level and shutdown. Capacity loss: • 0.1-0.2% in USA • 0.1-0.5% in Europe • It can reach 1-2%/°C temperature increase Increased temperature and reduced availability of water for cooling, causing less power generation and annual average load reduction of 0.1-5.6%	• Site in cooler areas • Use non-traditional water sources • Reuse process water from flue gases (can cover 25-37% of cooling needs) • Apply coal drying or condensers • Use ice to cool air before entering the gas turbine (increase efficiency and output) • Use condenser at the outlet of cooling tower to reduce evaporation losses by up to 20%
Precipitation	Variations in precipitation mean less and warmer water for cooling, which reduces cooling efficiency and may reduce power generation	Consider alternative cooling technologies: dry cooling towers, regenerative cooling, heat pipe exchangers
More frequent and intense hot temperatures	• Hot spells aggravate the impacts of the average warmer conditions • Less conversion and cooling efficiency • Overheated buildings • Self-ignition of coal stockpiles	• Locate new plants at cooler sites • Install air-conditioning in building • Cool coal stockpiles by water spraying
More frequent and longer periods of low precipitation or drought conditions	• Low precipitation leads to reduced water availability and more competition for water • Less and warmer cooling water leads to potential reductions in output or even shutdown	• Consider alternative cooling options (reuse wastewater and recover evaporated water in recirculating systems) • Consider dry cooling

Table 8: Extreme Weather Impact on Thermal Power Plants and Adaptation Measures, adapted by Iroko Africa

Impact of Climate Change on Thermal Power Plant Cooling Systems

Rising temperatures are projected to significantly reduce the efficiency of power plant cooling systems, with plant efficiencies declining by up to 1.3% per 1°C increase in temperature. The impact is particularly severe for once-through cooling systems, which are highly vulnerable to rising water temperatures and changing river flows. Studies suggest that a water temperature increase of 1.5°C to 3°C could reduce thermoelectric power plant capacity by 5% to 15%. Furthermore, once-through cooling systems are more susceptible to water scarcity, with potential reductions in power generation of up to 52%, compared to just 17% for wet-recirculating systems. This puts South Africa's coal-fired power plants at significant risk, as most of them rely on once-through cooling

At the same time, the country's food and beverage industry, which continues to depend on coal-fired boilers for heat production, is also facing challenges. **Climate change is disrupting the quality of coal used in industrial boilers, as increased rainfall and floods lead to "wet coal," where excess moisture reduces energy content.** This forces boilers to operate at reduced capacity or suspend production

temporarily. **The combination of higher air temperatures and increased water temperatures used in steam generation further exacerbates the problem,** lowering combustion efficiency and requiring more fuel to maintain desired thermal output. These compounding climate impacts, from the cooling system inefficiencies of power plants to the degraded coal quality affecting industrial boilers, **underline the urgent need for adaptation strategies to mitigate these risks across South Africa's energy and industrial sectors.**



In coal fired thermal plants, heavy precipitation events can lead to coal drenching and reduce boiler efficiency by about 1% per 10% increase in moisture. More frequent hot spells or longer dry periods may lead to self-ignition of coal stockpiles (more cooling is needed to prevent it) and to drying and dust blown away from storage of incoming coal stocks and from waste products stored after combustion.

Criteria	Once-Through Cooling System	Wet-Recirculating Cooling System
Water Usage	Withdraws large volumes of water from nearby sources, consuming less in the plant process but requiring significant cooling water.	Recirculates water within a closed-loop system, using less water but still requiring substantial amounts for cooling.
Water Resources Impact	Puts pressure on local water resources, especially in water-scarce regions. High withdrawals can harm ecosystems.	Reduces water withdrawals but can impact water quality and still requires significant water, especially in hot weather.
Efficiency & Capacity	Higher immediate efficiency, but cooling effectiveness drops with high temperatures and limited water availability.	More efficient in water conservation but faces reduced capacity during extreme heat as water warms in the system.
Environmental Impact	Can cause thermal pollution and deplete water sources, disrupting ecosystems.	Lesser impact on water sources but can heat surrounding bodies of water, affecting ecosystems.
Climate Sensitivity	Vulnerable to climate change, especially with rising temperatures and shifting water flows, reducing cooling efficiency.	Sensitive to heat, reducing cooling effectiveness, though more resilient to climate impacts than once-through systems.

Table 9: Comparative Analysis of Two Thermal Power Plant Cooling Systems, by Iroko Africa

Climate Resilience Assessment for the 1,2GW Thabametsi Coal-Fired Power Station in Limpopo, South Africa¹²

The Climate Risk Assessment (CRA) for the 1,200 MW Thabametsi power plant highlights key climate-related risks due to its location in a water-scarce area prone to extreme weather events. Projected climate impacts include rising temperatures, increased droughts, and potential flood and wildfire risks. Water availability remains a critical concern, particularly given reliance on the Mokolo-Crocodile Water Augmentation Project (MCWAP-1 and -2), with uncertainties around future water supply and quality. Flood risks could threaten infrastructure and water contamination, while social concerns over water allocation may impact the project's social license to operate.

Climate Baseline

- **Geographic and Climatic Context:** The site is in a semi-arid region with summer precipitation.
- **Temperature:** Winters average 15.7°C, summers 26.0°C, with extreme highs reaching 43.6°C.
- **Precipitation:** Annual rainfall is 401mm, mostly in summer (Oct-May), with little from April-Sept.
- **Extreme Weather Events:**
 - **Flooding:** Past events have impacted infrastructure and required evacuations.
 - **Tropical Cyclones:** Have affected nearby areas but not Lephalale directly.
 - **Droughts:** Frequent, leading to agricultural losses and water shortages.
 - **Wildfires:** Common, causing damage to property and natural reserves.

Climate Change Projections (2040-2060)

- **Temperature:** Increase of 2-3°C, with more frequent hot ($\geq 30^{\circ}\text{C}$) and very hot ($\geq 35^{\circ}\text{C}$) days, and heatwaves.
- **Drought:** Longer dry spells (March-August), increasing drought risk.
- **Precipitation:** Model projections are uncertain—some indicate increases, others decrease.
- **Wind Speeds:** Projections unavailable; both increases and decreases are considered.

Four high-rated risks for the project

- 1. Water Availability** – The project relies on the Mokolo Crocodile (West) Water Augmentation Project (MCWAP), but MCWAP-1 is already at high risk, and MCWAP-2 depends on uncertain runoff from industrial users.
- 2. Water Quality** – Increased industrial use and climate change impacts (erosion, sedimentation) may degrade water quality, particularly in the Crocodile (West) catchment, already facing pollution risks.
- 3. Flooding** – The Mokolo River's flood risks could lead to infrastructure damage and contamination from ash dump ponds, with flood design standards potentially exceeded over time.
- 4. Social License to Operate** – Water scarcity concerns among residents and farmers may lead to opposition against industrial users, despite the project's limited water demand (1.8% of Mokolo Dam's yield).

Risk	Risk (Present Day)	Risk (2050s)	Residual Risk 2050s, after adaptation)
High temperatures result in reduced thermal efficiency	Low	Medium	Medium
High temperatures and heatwave conditions pose a health risk to the workforce	Medium	Medium	Low
High temperatures and heatwave events result in spontaneous combustion at the coal stockpiles	Low	Low	Low
Wildfires in the wider area disrupt access to the site and damage utilities infrastructure	Low	Medium	Low
Lower than normal precipitation levels and increased drought result in water shortages	High	High	High
Lower than normal precipitation levels and increased drought create water quality issues	Medium	High	High
High wind speeds / wind gust damage infrastructure	Low	Medium	Low
Flood events affect the site causing equipment damage / Operational disruption	Medium	Medium	Low
Flood events affect the site causing polluted water overflows	Medium	High	Low
Flood events affect the wider area resulting in reduced / lack of accessibility to the site	Medium	Medium	Medium
Dry spells / drought events result in increased dust generation	Low	Medium	Low
Dry spell / drought events affect communities and threatens social license to operate	Medium	High	Medium

Table 10: Risks Assessment through Different Scenarios, adapted by Iroko Africa



Water Instability Risks at Thabametsi Power Plant: A Comprehensive Assessment

The Thabametsi Power Plant is situated in a water-scarce region with annual rainfall of just 401mm, placing significant pressure on its water resources. Water is critical to the plant's operations, supporting steam cycles, fire protection, and potable use. However, the primary water source, Mokolo Dam, is nearing capacity amid rising demands from power plants, mining operations, and urban areas. To address these concerns, the Mokolo and Crocodile (West) Water Augmentation Project (MCWAP) was initiated, with MCWAP-1 (completed in 2015) allocating 39.7 Mm³/year, and MCWAP-2 (planned for 2021) aimed to transfer 75-100 Mm³/year from the Crocodile River.

Water Shortages Due to Lower Precipitation and Drought

The Thabametsi Power Plant relies on the MCWAP-1 allocation from Exxaro to meet its water needs, requiring 720,000 m³/year. However, climate projections for the Lephalale region are uncertain, with potential decreases in rainfall expected to impact water availability. Increased evaporation and irrigation demand exacerbate this issue. Additionally, while heavy rainfall may increase runoff, it also brings the risk of sedimentation, which could disrupt water supply quality. As noted in the 2013 National Water Resource Strategy (NWRS), climate risks are significant, but there are gaps in institutional capacity and hydrological modeling that contribute to uncertainty around future water allocations. To ensure long-term water security, integrated planning and climate risk considerations are crucial.

Water Quality Degradation from Decreased Precipitation and Drought

Decreased precipitation and drought in the Mokolo, Crocodile (West), and Vaal catchments pose a serious threat to water quality. The Crocodile River, a critical water source for Thabametsi Phase 2, is already contaminated by industrial effluent, organic pollutants, and sewage. Climate change could exacerbate water quality issues, leading to increased erosion, sedimentation, and higher temperatures, which may promote harmful algal blooms. Summer storms are expected to intensify these impacts, further compromising water quality. Industrial growth, land-use changes, and the potential expansion of mines and petrochemical industries may further degrade water quality in the future. Regular water quality monitoring is essential to detect and manage these risks early on.

Flooding Risks to Assets and Operations

Flooding presents a significant risk to the Thabametsi Power Plant, as water accumulation on-site or blocked access roads could damage assets or disrupt operations. The Mokolo River and its tributaries present flood risks, although the plant site is located on a shallow slope, and surface water is expected to drain away. To mitigate this risk, the site will be raised by 200mm above the surrounding area. However, a detailed site-specific flood risk assessment, considering future climate change scenarios, is necessary to ensure that the plant can withstand more severe flood events in the future.

Increased Rainfall Intensity and Flooding Risks to Drainage Systems

As rainfall intensity increases due to climate change, flooding could result in uncontrolled releases of polluted water if the plant's drainage systems are not designed to handle extreme weather. This includes risks associated with coal stockyard runoff, ash yard runoff, and oily water drains. To address this risk, the plant's drainage and storage ponds must be designed to accommodate extreme rainfall volumes based on historical data. Additionally, a zero effluent discharge policy will be implemented for the ash yard to prevent environmental contamination.

Flooding Impacting Accessibility to the Site

Flood events could disrupt site access by damaging or blocking key roads, such as the D2001 provincial road and the R33. Historical flood events in 2008 and 2014 caused road closures and damage, affecting access to the Thabametsi Power Plant. To mitigate this risk, upgrading the access roads is necessary to ensure reliable transportation during both construction and operational phases. This proactive approach will help prevent disruptions to plant operations and ensure that the site remains accessible even during extreme weather events.

Adaptation Measures

Proposed adaptation measures include further studies, continuous risk monitoring, and potential infrastructure modifications such as flood defenses and water conservation measures. Some interventions, like broader water resource management, fall outside the project's control. A structured risk management process is recommended, integrating adaptation tracking into plant-level risk registers and ensuring ownership of the climate risk strategy. Ongoing updates and collaboration with regulatory bodies will be essential to enhance the plant's resilience to future climate challenges.

8.2. Grid Resilience Under the Threat of Fires, Heatwaves, and Cyclones

The effects of climate change on electricity networks are becoming more concerning, driven by extreme weather events like wildfires, tropical cyclones, severe storms, as well as rising temperatures.

Similar to Australia, where electricity transmission spans thousands of kilometers. South Africa's Eskom transmission and distribution networks exceed 300,000 km. These networks, which cover various climate zones, are susceptible to a range of meteorological conditions, making them vulnerable to diverse environmental factors.

An investigation of the Eskom transmission network in 2012 identified four main causes of transmission faults, **including two climate-related factors: lightning and fire.**

- **Wildfires, intensified by extended fire seasons, which increased by 18.7% globally from 1979 to 2013 due to droughts as well as rising temperatures, represent a direct threat to electricity infrastructure in South Africa.** For instance, in Australia, the 2019-2020 bushfires led to widespread power outages, damaging transmission and distribution lines. Similarly, in North America, wildfires regularly disrupt power transmission lines, with significant outages recorded in California during the 2021 southern Oregon wildfire.

Studies indicate that by the mid-21st century, rising temperatures could reduce transmission capacity in the United States by up to 5.8%, increasing the likelihood of power outages. Weather-related electrical faults in the USA are estimated to cost between USD 20–55 billion annually.

- **Tropical cyclones and severe storms** also contribute to the vulnerability of electricity networks, in particular in the Western Cape. These storms can damage transmission lines, poles, and transformers by toppling trees and branches, leading to extensive power outages. In Japan, Typhoon Faxai and Typhoon Hagibis caused major blackouts in 2019, while in Korea, three successive cyclones in 2020 led to significant power disruptions.

Following the destruction caused by Cyclone Idai in March 2019, Electricidade de Moçambique (EDM) announced a \$10 million project to rehabilitate power transmission lines in central Mozambique. Funded by the governments of Mozambique and Norway, the initiative aims to enhance the region's electricity grid resilience. The project will replace high-voltage transmission towers and install new components and conductors to improve the grid's capacity, particularly along the 30-kilometer line from Dondo to Beira, including the Munhava substation.

8.3. Mitigating Flooding Risks in Substations

Industrial sites typically include substations as a key component of their power infrastructure, ensuring a reliable and appropriately configured power supply. **Flood hazards present the biggest risks for such energy infrastructure**, including structural and material damage, power outages, fires, and system failures.

To mitigate flooding risks, substations can adopt strategies such as raising equipment above expected flood levels, relocating facilities from flood-prone areas, and retrofitting with flood protection measures like levees and concrete walls.

The following examples illustrate adaptation efforts:

- In 2010, severe river flooding in Rhode Island (USA) affected 67 substations. Risk assessments and strategies to elevate or relocate these substations were implemented to prevent future flooding.
- The AltaLink Barrier 32 substations in Alberta (Canada) was destroyed by flooding in 2013. As a result, substations were rebuilt with designs focusing on enhanced resilience, and future construction in flood-prone areas was avoided.
- National Grid, operating in the UK and parts of the USA, identified 47 substations in one-in-100-year flood zones. Using flood risk data, the company prioritised 13 substations for rebuilding and elevation, ensuring they could withstand floods of up to one-in-1,000-year events.
- Coastal facilities in the USA, vulnerable to hurricanes and storm surges, used the Seas and Lakes Overland Surges (SLOSH) model to assess storm surge risks. Substations were elevated to withstand Category 3 hurricanes, with heights reaching up to 7.60 meters. In areas where elevation was impractical, levees and floodwalls were installed. Additionally, spare equipment was kept for rare Category 4 and 5 hurricanes.

8.4. Impact of Increased Temperatures on Solar PV Productivity

Most industrial players in South Africa are exploring solar PV solutions as part of their energy transition, and the food and beverage industry is no exception.

Solar power is highly dependent on sunlight, which can be disrupted by changing weather patterns, increased cloud cover, and extreme climate events such as storms and floods that damage infrastructure. **High temperatures during heatwaves reduce solar panel efficiency by 0.3% to 0.5% for each degree above 25°C.** Solar panels can reach up to 70°C, causing a generation decline of 13.5–22.5% during extreme heat events.

Wildfires also pose a significant threat to solar PV systems by producing smoke that scatters solar radiation, reducing generation by 10–30%. Additionally, physical damage to solar panels and infrastructure occurs, **with wildfire-related events accounting for 50% of solar asset damage claims in the USA.**

Tropical cyclones also present risks, with **high winds and flying debris causing physical damage to solar panels**, as seen in storms like Tropical Cyclone Faxai in Japan (2019) and Hurricane Maria in Puerto Rico (2017).

8.5. Impact of Thermal Stress and Water Instability on Bioenergy

Utilising biomass for Combined Heat and Power (CHP) is also considered by many agro-processing industrial players as part of their decarbonisation journey. The government's Renewable Energy Independent Power Producer Procurement Program (REIPPPP) has facilitated the development of biomass projects by providing a framework for Independent Power Producers (IPP).

In South Africa, **biomass plants** primarily utilise agricultural residues such as sugarcane bagasse and maize stover, forestry residues like wood waste from sawmills, and energy crops

like eucalyptus and willow. Animal waste, such as manure, is processed for biogas production, while municipal organic waste, including food and garden waste, is also utilised.

In a recent study conducted by agricultural economists in South Africa, it was found that **bioenergy from sugarcane trash, which has untapped potential, could significantly contribute to renewable energy production, in particular for small scale players.**



- **Sugarcane Production:** South Africa produces 2.2 million tons of refined sugar annually, with 2.09 million tons from small-scale farmers (11% of national production).
- **Sugarcane Trash:** 13-30% of sugarcane is waste (leaves and tops), with 90% burned, emitting significant greenhouse gases.
- **Environmental Impact:** Burning sugarcane trash contributes to 725 tCO₂-e emissions annually, equivalent to burning 368 tons of coal.
- **Bioenergy Potential:** Converting sugarcane trash into bioenergy could generate 180.1 MW, powering 100,000 homes.

Climate change poses substantial challenges to bioenergy production by impacting the availability and quality of biomass. **Biomass, sourced from agriculture and forestry, is vulnerable to droughts, irregular rainfall, and rising temperatures**, which can reduce crop yields and biomass supply, threatening its long-term viability.

- **Increased Droughts:** More frequent and intense droughts reduce water availability, impair photosynthesis, and lower biomass yields. Crops like sugarcane, switchgrass, and miscanthus, essential for biofuel production, are especially affected, with regions like the United States and Brazil facing reduced biomass yields.

- **Changes in Precipitation Patterns:** Altered rainfall patterns impact biomass production. Excessive rainfall can lead to waterlogged soils, while reduced rainfall causes depletion of soil moisture. These changes affect crop growth and alter the chemical composition of bioenergy crops, such as sugar content and lignin distribution, ultimately impacting bioenergy efficiency.

8.6. Opportunities and Challenges in Gas Cogeneration

Although small in scale, the oil and gas industry in South Africa plays a crucial role in meeting the country's energy needs. With limited domestic oil reserves, **South Africa depends heavily on imports.** A significant portion of the country's natural gas supply comes from Mozambique via the Rompco pipeline, which connects Mozambique's gas fields to South Africa. This imported gas is primarily utilised in power generation and industrial sectors.

The government's Integrated Resource Plan (IRP) emphasises the strategic importance of integrating natural gas into power generation as a key approach to reducing the country's carbon footprint. **Gas cogeneration, which produces both heat and electricity, is considered a viable alternative to coal-fired boilers in the food processing sector.** In the developed world, natural gas remains a significant energy source for the food and beverage industry, generating 50-60% less CO₂ per unit of energy compared to coal, thereby supporting climate change mitigation efforts.

Globally, the oil and gas infrastructure face multiple climate-related threats.

- **Tropical cyclones disrupt production, refining, and supply chains**, particularly affecting coastal facilities that are more vulnerable to storm surges and rising sea levels. One-third of refineries are located in low-lying areas, including the Pande and Temane gas fields in Mozambique. Events like Hurricane Ida (2021) halted 96% of crude oil and 94% of natural gas production in the Gulf of Mexico, leading to reduced exports, supply shortages, and price increases.

- **Rising temperatures** threaten transport infrastructure globally. In particular, heat expansion increases pipeline rupture risks. CHP systems, which are essential for heat production, are particularly vulnerable to rising temperatures. As ambient temperatures rise, the efficiency of heat recovery from exhaust gases declines, reducing the thermal output for heating purposes. Furthermore, elevated cooling water temperatures can hinder heat transfer efficiency in heat exchangers, negatively affecting the quality of the delivered heat. **Gas engines used in these systems typically have efficiency warranties that apply only when operating temperatures remain below 35°C.**

8.7. Mapping Climate Vulnerabilities in Energy Production and Distribution Systems

Based on a recent study by the International Energy Agency, **Figures 26 and 27** outlines climate change risks to power systems under two scenarios: SSP2-4.5 and SSP5-8.5. **The analysis shows that under the SSP5-8.5 scenario, Thermal Stress and Water Instability have an impact on most energy systems.**

	Coal	Gas	Oil	Nuclear	Hydro	Solar	Wind	Grid
Temperature	●	●	●	●	●	●	●	●
Precipitation (dry)	●	●	●	●	●	●	●	●
Precipitation (wet)	●	●	●	●	●	●	●	●
Sea Levels	●	●	●	●	●	●	●	●
Wind (cyclones)	●	●	●	●	●	●	●	●
Wild Fire	●	●	●	●	●	●	●	●

Figure 26: Energy Systems Vulnerability - Low Emissions Scenario SSP2-8.5, adapted by Iroko Africa¹³

	Coal	Gas	Oil	Nuclear	Hydro	Solar	Wind	Grid
Temperature	●	●	●	●	●	●	●	●
Precipitation (dry)	●	●	●	●	●	●	●	●
Precipitation (wet)	●	●	●	●	●	●	●	●
Sea Levels	●	●	●	●	●	●	●	●
Wind (cyclones)	●	●	●	●	●	●	●	●
Wild Fire	●	●	●	●	●	●	●	●

Figure 27: Energy Systems Vulnerability - High Emissions Scenario SSPR-8.5, adapted by Iroko Africa¹⁴

Figures 26 and 27 illustrate climate change risks to power plants and electricity grids on a global scale. Two scenarios are presented: SSP1-2.6 for low emissions and SSP5-8.5 for high emissions. Climate risk levels are categorized into five tiers, represented by color coding: **dark green** for very low risk, **light green** for low risk, **yellow** for moderate risk, **orange** for high risk, and **red** for very high risk. **Grey** cells indicate unavailable data. The risk levels are assessed based on three factors: hazard, exposure, and vulnerability. Hazard and exposure are quantified using GIS analysis, while vulnerability is evaluated through qualitative research.

The effects of climate vulnerabilities on energy production and distribution systems pose significant challenges for the agro-processing industry. These vulnerabilities often lead to **more frequent and prolonged power outages** due to extreme

weather, which can disrupt energy infrastructure. Additionally, **rising energy costs** driven by these disruptions, as well as increased demand for sustainable energy alternatives, place further financial strain on agro-processing operations.

Furthermore, **the instability of energy supply reduces the reliability and security of production processes**, making it harder for the industry to maintain consistent output and meet market demands. This can also hinder investments in advanced processing technologies that require a stable energy supply, ultimately affecting productivity, efficiency, and competitiveness in the sector. Overall, these challenges threaten the sustainability and resilience of agro-processing businesses, making it critical to address energy-related climate vulnerabilities proactively.

8.8. Impact of Power Generation on Water Resources

Electric power production is a major driver of water stress, and this issue is expected to worsen due to growing energy demands and climate change. **While energy transition pathways focus on meeting climate goals, they often overlook water resource implications, with some solutions like Bioenergy with Carbon Capture and Storage (BECCS) being highly water-intensive.**

In a 2019 study published in Renewable and Sustainable Energy Reviews titled "Water Use of Electricity Technologies: A Global Meta-Analysis", data were gathered from 910 publications,

with fewer than 20 from Africa, including 32 Life Cycle Analysis (LCA) studies. These publications were selected based on three criteria: (1) reporting water use across the entire life cycle or specific stages, (2) distinguishing between water consumption and withdrawal, and (3) specifying the energy type. **Table 11** displays water consumption in liters per megawatt-hour (L/MWh) for various technologies.

Energy Type	Median Water Consumption (L/MWh)
Biomass	85100
Hydropower	4961
Oil	3220
Nuclear	2290
Coal	2220
CSP (Concentrated Solar Power)	1250
Geothermal	1022
Natural Gas	598
PV (Photovoltaic Solar)	330
Wind	43

Table 11: Water Consumption across Energy Generation Types, adapted by Iroko Africa

Table 11 shows that biomass has the highest median life cycle water consumption at 8.5×10^4 L/MWh, significantly surpassing other energy types. Coal power plants exhibit relatively high-water consumption but with low variability. Wind power, typically seen as having minimal water use, can reach up to 700 L/MWh when accounting for both direct and indirect material inputs.

Based on the literature review, the list below summarises the key factors influencing water use in power production.

- **Cooling and Power Type:** Main drivers of water use.
- **Resource Quality:** Heat content of fuel impacts water consumption.
- **Power Plant Specifications:** Conversion efficiency, capacity factor, and plant lifetime affect water usage.
- **Environmental Conditions:** Ambient temperature, direct normal irradiation, wind velocity, evaporation rate, etc., influence operational water use.
- **Conversion Efficiency:** Significantly impacts operational water consumption.
- **Cooling Technology:** Wet cooling reduces water consumption but increases costs and reduces efficiency.
- **Fuel Heat Content:** Important for coal, natural gas, and biomass, with biomass generally having lower heat content.
- **Water Source:** Freshwater vs. seawater for cooling varies regionally, influencing water consumption.
- Water scarcity is also a key driver, **with recent studies giving it increasing attention, though the number of studies remains limited.**



Impact of Carbon Capture and Storage on Water Use in Power Plants

Carbon Capture and Storage (CCS) significantly increases water use in thermal power plants, particularly those using natural gas and biomass with combined cycle cooling. CCS systems require additional water for operation and reduce efficiency, leading to higher water consumption compared to plants without CCS.

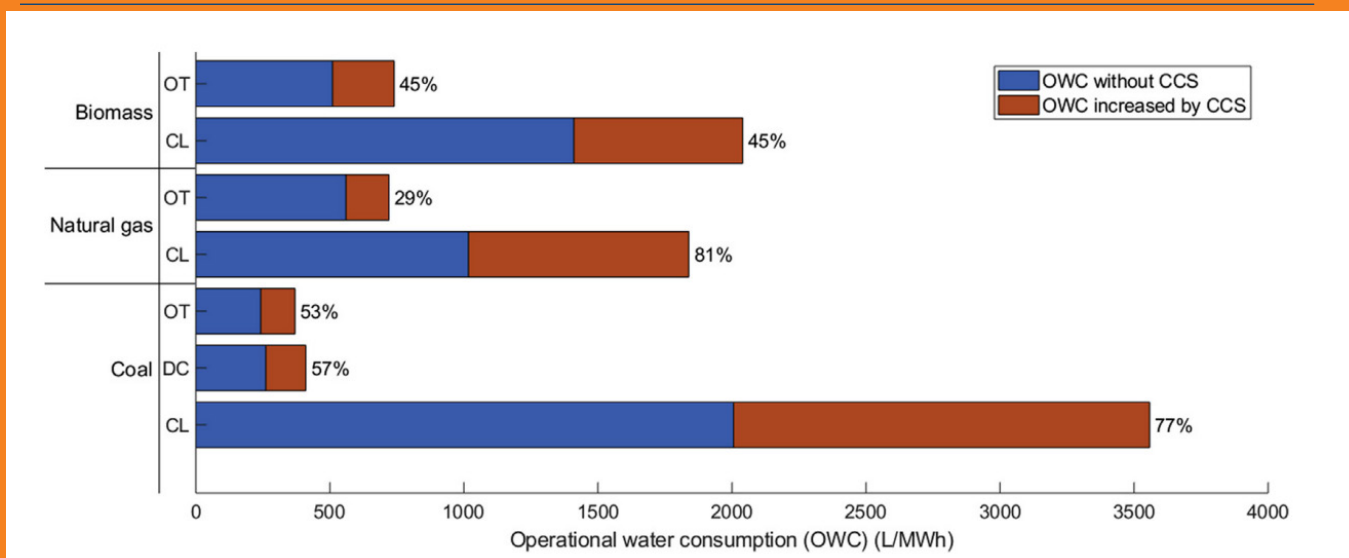


Figure 28: Water Consumption due to CCS Addition for Different Fuels and Cooling Types, by Iroko Africa.¹⁵

Key: CL closed-loop cooling, HC hybrid cooling (combining wet and dry cooling), OT once-through cooling, and DC dry cooling. Colours map to fuel type for the estimate.

8.9. Water Use in Eskom's Power Generation

Eskom accounts for around 2% of South Africa's annual freshwater consumption, primarily used for cooling its coal-fired power plants, while agriculture consumes about 70% of the country's water.

Water is a vital resource for Eskom's electricity generation, especially for its inland coal-fired power stations in **Mpumalanga, Free State, and Limpopo—regions expected to face the highest temperature increases.** On average, Eskom's power stations consume **320,000 million liters (ML)**

of water per year. This water is sourced from multiple supply systems and is primarily used for:

- **Cooling** (the largest consumption)
- **Steam generation**
- **Ash handling and disposal**
- **Washing and cleaning**
- **Air emissions control and abatement**



Drought Escalates Tensions Between Agriculture and Coal in Limpopo

Despite the introduction of Air-Cooled Condenser (ACC) technology to boost water efficiency, the 6x800MW Medupi coal-fired power plant in Limpopo consumes over 22.7 billion liters of water annually, heavily impacting the region's rivers. Eskom's latest Sustainability Report highlights that efforts to reduce water usage at coal plants have yielded limited success. In the face of persistent drought, tensions have escalated between the agricultural and coal industries over the region's dwindling water supply. Previous informal agreements between farmers and coal companies have given way to disputes, with water access now a point of contention between sectors critical to the local economy.

The Vaal River Eastern Sub-System (VRESS) supplies water to eleven of Eskom's power stations and is part of the Integrated Vaal River System (IVRS). The following water schemes or sub-systems supply water to Eskom¹⁶:

- Komati Water Scheme
- Usutu Government Water Scheme
- Usutu-Vaal Government Water Scheme Phase 1 & 2
- Slang Water Scheme

Eskom's water supply schemes have become interconnected, functioning as a unified system. While the Department of Water and Sanitation (DWS) still assesses individual scheme yields, system modeling considers the combined yield. The Vaal River Eastern Sub-System (VRESS) is reinforced by the Vaal River

Eastern Sub-System Augmentation Project (VRESAP) pipeline, which transfers up to 160 million m³ annually and links VRESS to the Lesotho Highlands Water Project. Eskom also sources water from the Mokolo system for Matimba and Medupi power stations, which will later connect to the Crocodile West system (WCWAP), using return flows from Gauteng effluent treatment plants, further integrating it with the IVRS.

Eskom holds a bulk water use license for the VRESS, allowing the withdrawal of 360.3 million m³ per year. This allocation covers eleven power stations and potential future use at the Underground Coal Gasification (UCG) plant near Majuba, as shown in Table 12. The license remains valid until October 31, 2025, with a five-year review cycle.

Water User	Water Scheme	
Arnot	Vaal River Eastern Sub-System	Komati
Duvha*		
Hendrina		
Komati		
Camden		Usutu
Kriel*		
Transfer to Komati		Usutu-Vaal Phase I
Tutuka		
Matla		
Kriel*		
Duvha*		
Kendal		
Kusile		
Heyshope to Usutu		Usutu-Vaal Phase II
Majuba		
Transfer to Grootdraai	Slang	
Lethabo		
Grootvlei	Vaal	
Transfer to Usutu-Vaal	MCWAP	
Matimba		
Medupi*		

Table 12: Water Schemes per Power Station, adapted by Iroko Africa



The Impact of Climate Change on the Vaal Catchment's Intra-Annual Water Availability

In a recent study published in the *Journal of Water and Climate* in 2020, the authors reveal that climate change significantly impacts intra-annual water availability in the Vaal catchment, exacerbating existing stressors such as population growth, economic expansion, and governance challenges. Using the Water Evaluation and Planning (WEAP) model, they analysed water use scenarios under the relevant Shared Socioeconomic Pathways (SSPs) for climate scenarios aligned with SSP2 and SSP5, confirming that the catchment is water-stressed, with shortages projected for winter and many summer months beyond 2040.

Temperature increases (0.07–5°C) are expected to reduce precipitation (0.4–30.2%), intensifying water scarcity. The agricultural sector, particularly maize production, is most vulnerable due to rainfall variability. None of the future scenarios fully meet intra-annual demand, and climate change will further exacerbate water deficits.

To mitigate these shortages, the study recommends inter-basin transfers, wastewater reuse, and improved conservation strategies. The findings highlight the urgent need to update the Vaal water management strategy. The WEAP model effectively demonstrated the interconnected influence of climate and socioeconomic

stressors, underscoring the importance of integrated water resource planning.

Methodological challenges included limited hydro-meteorological data and a lack of up-to-date reconciled data.

The authors suggest that future research should incorporate higher-resolution climate data and more recent observations to refine predictions. Overall, a combination of adaptive measures and demand management is necessary to ensure sustainable water security in the Vaal catchment.

This study aligns with recent events in the Vaal River catchment area, where significant concerns about water scarcity have been raised. In 2012, senior managers from Eskom warned that a major drought within the next eight years could severely affect the region's agricultural and industrial output. Fast-forward to 2024, the region faced a dry summer and heatwave, compounded by maintenance on the Lesotho Highlands Water Project, which led to the Vaal Dam running dry. However, by January 17, 2025, the Vaal Dam's water storage level surged from a concerning 24.3% to a much healthier 50.53%, providing some relief. This surge has been a critical development, as experts had previously warned that water levels could dip below

8.10. Climate Risks in Energy System Design

A key takeaway from the above analysis is that no single solution can address both climate mitigation and adaptation. **It is crucial to integrate climate risks into energy system design to effectively identify, assess, and implement adaptation strategies.**

	Geothermal Energy	Thermal Solar	Biogas	Biomass	Solar/ Wind
Laundry	●	●	●	●	●
Scalding	●	●	●	●	●
Evaporation	●	●	●	●	●
Cooking	●	●	●	●	
Pasteurization	●	●	●	●	
UHT			●	●	
Smoking	●	●	●	●	
Cleaning	●	●	●	●	
Drying	●	●	●	●	
Refrigeration	●				●
Con/Freeze	●				●
Washing	●	●	●	●	
Frying			●	●	
Roasting		●	●	●	
Fermentation	●	●	●	●	●
Aquaculture	●	●	●	●	●

Technology covering part of the temperature levels of uses	●
Technology covering all temperature levels of use	●
Technology for producing electricity	●

Figure 29: Mapping of Energy Options for the Food Processing Industry, adapted by Iroko Africa;
Source: enea consulting

- **Thermal Solar:** this solution is **particularly suitable for processes requiring medium-temperature heat, commonly found in the mill and beer sectors**. It is easier to install than biogas or biomass solutions.
- **Solar PV:** Solutions applicable to all sectors.
- **Biomass:** this is **limited to processes that require a large and constant amount of heat**.
- **Biogas:** the use of biogas is **particularly suited to sectors that have methane-producing waste**.



Two definitions found in the literature outline the features of a climate-resilient energy system, based on two frameworks.

Building Resilience in Utilities

- *Resistance:* Preventing damage
- *Reliability:* Designing systems to operate under a range of conditions
- *Redundancy:* Availability of backups or spare capacity
- *Recovery:* Enabling a fast response to and recovery from disruptive events

Climate-Resilient Energy System

- *Readiness:* Anticipating climate changes
- *Robustness:* Withstanding gradual shifts in climate patterns
- *Resourcefulness:* Maintaining operations during extreme weather events
- *Recovery:* Restoring functionality after climate-induced disruptions

8.11. Energy-Water-Climate Nexus

Figure 30 illustrates the energy and utility flows across different functional areas of a food and beverage facility, emphasising the importance of optimising utilities for cost and energy savings.

Key Elements in the Diagram

1. Utilities Supply (Left Side)

- The facility receives different utility inputs:
 - Fuel (likely for boilers)
 - Electricity (for overall operations)
 - Water (for processes and cooling)
 - Nitrogen (possibly for packaging or inerting)

2. Buildings and Functional Areas

- **Building 1** (Utility Systems)
 - Contains chiller plant, air compressors, and water treatment systems, which are essential for process cooling, compressed air for operations, and clean water for production.
- **Building 2** (Administration & Boilers)
 - Supplies energy (fuel, electricity, water, nitrogen) to other buildings.
 - Boilers are a key component, likely providing steam or hot water for production processes.
- **Building 3** (Production Processes)
 - Houses multiple processing stages (Stages 4 to 8).
 - Receives utilities from Building 1 and 2 for various production needs.

3. Process Flow & Product Output (Bottom Part of the Diagram)

- Raw materials enter the system.
- Different processing stages transform them into final products (Product A, B, and C).
- Utility consumption is measured at multiple points (M – Measurement points) to track efficiency.

Key Takeaways

- **High reliance on utilities:** The facility depends on multiple utilities (fuel, electricity, water, nitrogen) that need to be managed efficiently.
- **Energy-intensive processes:** Boilers, chillers, air compressors, and water treatment are major consumers of energy.
- **Measurement points throughout:** Monitoring consumption at key points can help improve energy efficiency and reduce waste.
- **Potential for optimisation:** Opportunities for energy efficiency improvements could include heat recovery, renewable energy integration (solar PV, biogas), and better process automation.

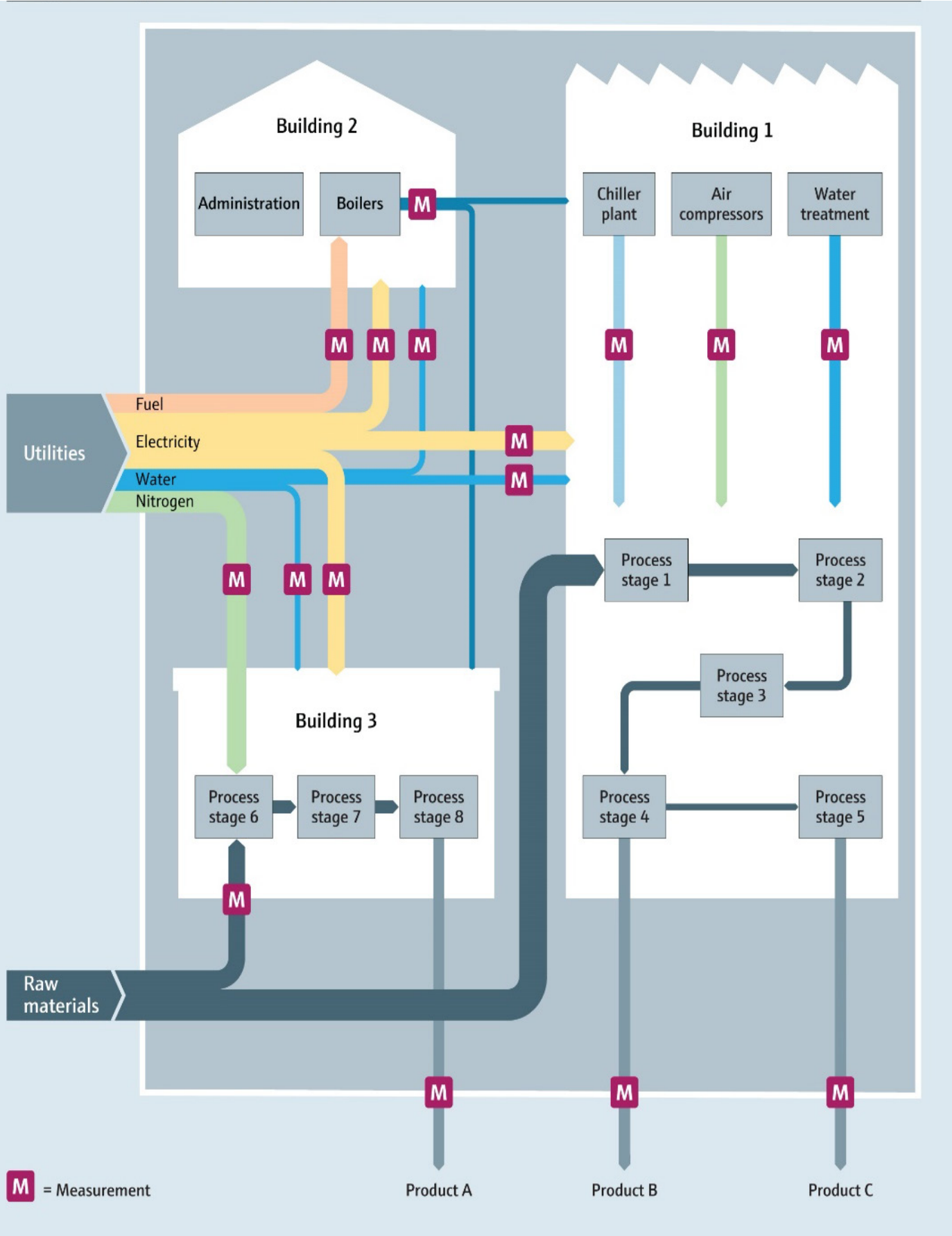


Figure 30: Energy and Utility Flows across Different Functional Areas of a Food and Beverage Facility;
Source: Endress + Hauser

09

Energy Efficiency Measures

9.1. Energy Efficiency Measures: Bridging Mitigation and Adaptation

Understanding the distinction between climate mitigation and adaptation is essential for the energy sector. Although the sector is mainly focused on mitigation strategies to lower carbon emissions, **opportunities for adaptation are frequently overlooked**. Based on a study from GIZ in 2017, **Figure 31** illustrates the differences and synergies between interventions in the energy sector.

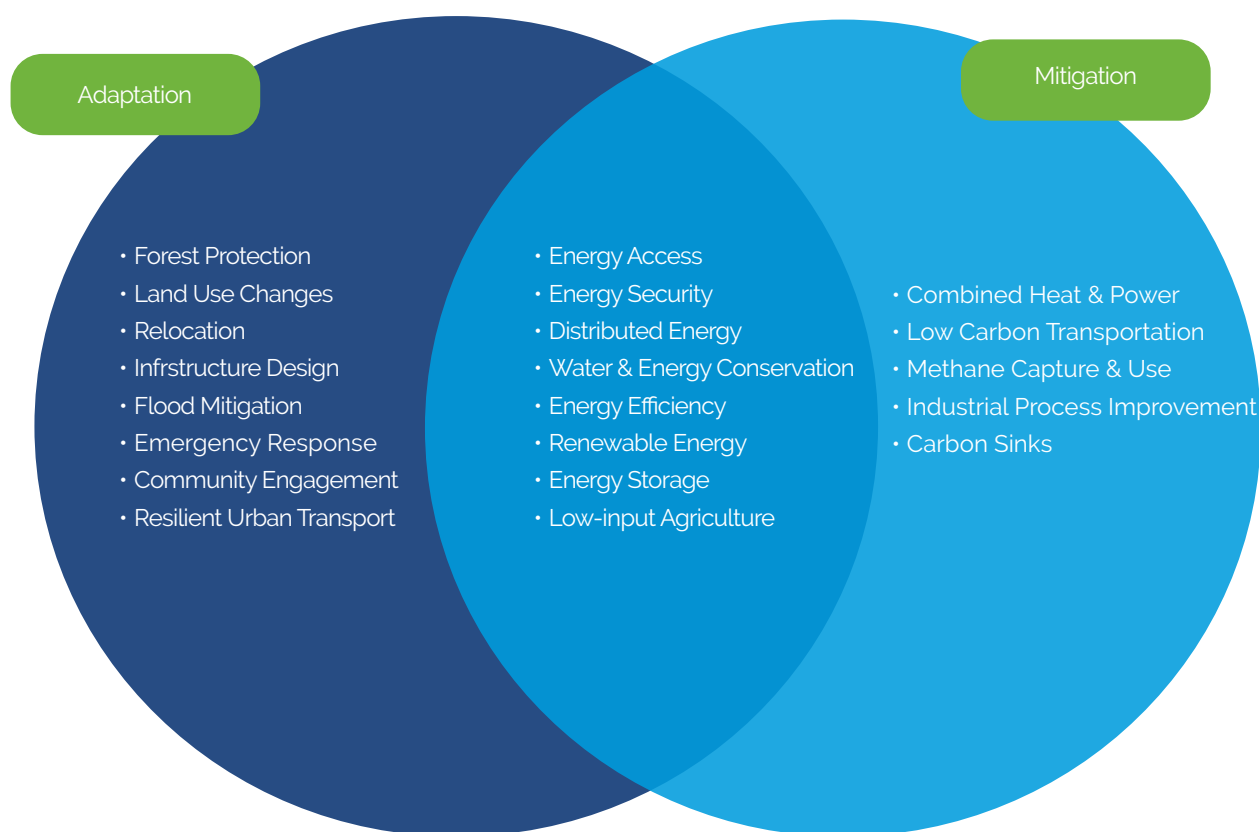


Figure 31: Climate Change Adaptation and Mitigation Intervention Distinctions and Synergies in the Energy Sector, adapted by Iroko Africa¹⁷

Industrial Energy efficiency programs not only **lower emissions but also enhance the resilience of energy systems by decreasing vulnerability to climate hazards.**

Using the Climate Change Simulator (EN-ROADS) developed by the Massachusetts Institute of Technology (MIT), **a 3% annual increase in global industrial energy efficiency from 2030 is projected to impact key climate indicators as follows: the temperature change by 2100 will decrease from 3.3°C to 3.1°C**, the energy intensity of GDP (measured in Exajoules per trillion USD) will reduce from 1.32 to 0.94, and CO₂ net emissions will drop from 5 gigatons per year to 3.6 gigatons. In comparison, a positive move from 3.3°C to 3.1°C could be achieved by implementing a coal tax of \$60 per ton starting in

2030, alongside a subsidy of -\$0.02 per kWh for solar PV from 2030 onwards.

A recent study on Carbon Voluntary Market Trends between 2022 and 2023 revealed that **industrial energy efficiency projects saw the most growth in 2023, with transaction volumes increasing by up to 43% compared to 2022.** In contrast, Renewable Energy Projects and Waste Disposal Projects experienced declines of 69% and 77%, respectively, over the same period.

9.2. Overview of Energy Efficiency Technologies in Food Processing Industry

Drawing on experience and a review of the literature, this chapter explores various options for improving energy efficiency, discussing their relevance and potential for scalability.

- **Thermal Efficiency:** Cross-sector solutions for industries with high heat **demands offer a more appealing return on investment than renewable heat production**, such as the substantial potential for recovering waste heat from processes and equipment. For example, in a poultry factory in South Africa, waste heat recovery from compressors can replace a 100 kW thermal capacity, with capital expenditure (CAPEX) amounting to 25% of the CAPEX required for a thermal solar system producing the same capacity.
- **Electrical Efficiency:** This is especially important for **electricity-intensive sectors** like meat and fish processing, which have significant cooling requirements, as well as for cross-cutting applications in buildings, such as lighting and air conditioning.
- **Thermal Solar:** This solution is particularly suitable for processes requiring medium-temperature heat, commonly found in the mill and beer sectors. It is easier to install than biogas or biomass solutions
- **Solar PV:** Solutions applicable to all sectors
- **Biomass:** This is limited to processes that require a large and constant amount of heat.
- **Biogas:** The use of biogas is particularly suited to sectors that have methane-producing waste



High-temperature waste heat recovery from thermal processes is particularly relevant. Key applications include blanching, boiling, smoking, and washing. It is especially pertinent for evaporation, cooking, pasteurization, and drying.

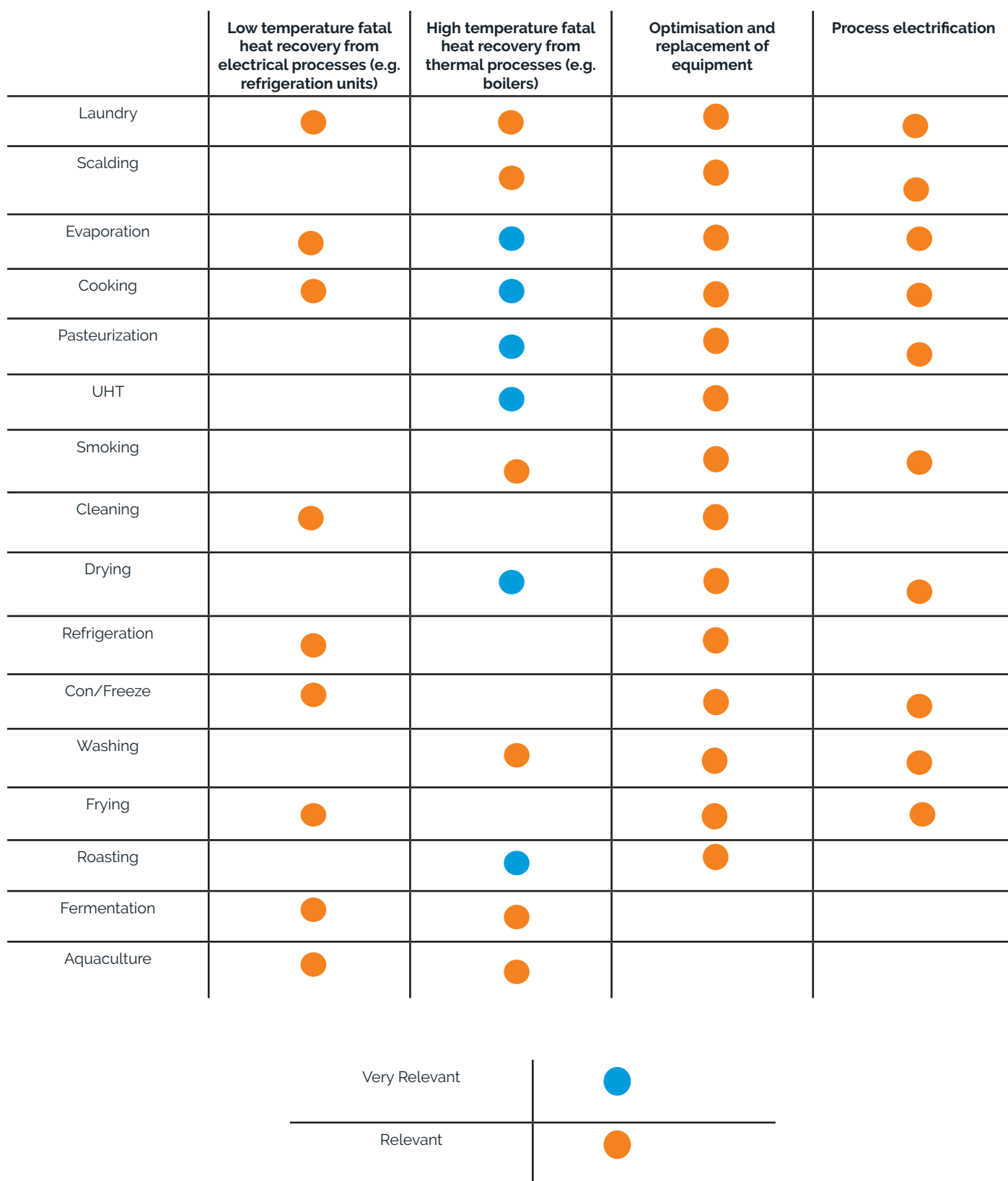


Figure 32: Mapping of Energy Efficiency Options for the Food Processing Industry, adapted by Iroko Africa;
Source: enea consulting

9.3. The Critical Role of Thermal Optimisation in Enhancing Industrial Processes

In the food and beverage industry, including bakeries, dairies, breweries, and ready-to-eat food manufacturers, optimising utilities consumption is vital due to processes like shock freezing, pasteurisation, sterilisation, heating, cooling, and cleaning. Reducing the use of utilities such as steam, boiler systems, compressed air, and water heating and cooling is essential, with thermal process engineers playing a crucial role in driving these efforts. **Table 13** provides an overview of different technologies applied in the food processing industry.

Technology	TRL	CAPEX	ROI
Pinch Analysis: Used to determine minimum process heating and cooling needs prior to design.	++	++	++
Falling Film Evaporators: Can help reduce energy demand in the dairy industry.	++	-	++
Heat Recovery Systems: Reduce energy usage in thermal processes.	++	-	+
Supercritical Extraction: Can replace concentration through boiling, reducing energy use.	+	--	+
Membrane Filtration: Increases efficiency in dairy processes.	+	--	+
Osmotic Pre-Treatments: Decrease heating loads and times in drying processes.	+	+	++
High Pressure Processing (HPP): A non-thermal process that reduces energy use and environmental impact.	+	--	+
Ohmic Heating (OH): Emerging technology for increasing efficiency in food processing.	--	--	+
Microwave Heating (MWH): Used for drying, thawing, and pasteurizing, and as part of hybrid processing technologies.	-	-	+
Microwave-Assisted Freezing: A hybrid processing technology that combines microwave heating with freezing.	-	--	-
Ultraviolet Light (UV): A non-thermal process with commercial potential for food processing.	+	+	+

Table 13: Energy & Process Technologies in the Dairy Industry, adapted by Iroko Africa

9.4. Resilient Energy Solutions through Diversification, Flexibility and Decentralisation

- **Energy diversification eliminates reliance on a single generation source** to enhance security of supply. Diversification makes the energy system less vulnerable to climate variability and changes, particularly fluctuations in water availability.
 - **Technologies like energy storage, smart grids, and other flexibility measures** enable energy load shifting, which is crucial for managing demand.
 - **Distributed energy systems**, as opposed to centralised systems, increase resilience. These systems are less vulnerable to climate change impacts because they are not interconnected and are not dependent on each other, reducing climate-related risks.
- Industrial Energy efficiency programs not only **lower emissions but also enhance the resilience of energy systems by decreasing vulnerability to climate hazards.**



Mitigating Heat Stress in the Poultry Industry - Challenges and Solutions

Optimal poultry housing requires maintaining ambient temperatures within the thermal neutral zone, which varies by bird type and age. For instance, laying birds achieve maximum egg production at 13–24°C, with optimal feed conversion at 21–24°C. Temperatures above 24°C reduce egg size and production, while temperatures exceeding 38°C can be fatal. High humidity exacerbates heat stress, leading to hyperthermia. Conversely, temperatures below 18°C impair feed efficiency, and extreme cold conditions (<LCT) cause hypothermia, diverting energy to metabolism.

An increase in temperature poses a significant threat to the poultry sector due to the high energy demands required to maintain optimal housing conditions. Cooling requirements in warmer regions necessitate increased ventilation rates, ranging from 2 L/s per bird in cold regions to 8 L/s per bird in warm regions. Inadequate ventilation can lead to heat stress in birds, resulting in reduced feed intake, slower growth, and lower egg production.

Higher ambient temperatures also exacerbate the production of heat, moisture, and contaminants, such as dust and gases, in poultry barns, which worsens air quality and directly impacts bird health and welfare. Both young birds, requiring higher ambient temperatures, and mature birds, needing higher ventilation rates, are particularly vulnerable if temperature control measures fail.

Housing Design for Energy Reduction:

- Optimise building geometry and orientation to maximise passive daylight and solar heat gain.
- Increase insulation of the building envelope to maintain desirable indoor temperatures without supplemental heating.
- Metabolic heat from birds can reduce the need for additional heating in well-insulated facilities.
- Ventilation systems should be carefully controlled to manage both electrical and thermal energy consumption and bird health.
- Natural ventilation can supplement mechanical ventilation, reducing energy use and maintaining air quality, though it may not be suitable as a standalone strategy in extreme climates.

Energy Efficiency Measures:

- **Heating:** Heat pumps (air source, ground source, water source) are energy-efficient alternatives for heating and cooling.
- **Ventilation:** Optimal system selection, maintenance, and retrofitting with energy-efficient components like HRVs can significantly reduce energy consumption and GHG emissions.
- **Lighting:** LED systems with appropriate spectral characteristics can save 80–85% of energy compared to traditional lighting.
- **Sensors:** Real-time data collection via sensor networks and CFD models optimise energy efficiency by monitoring relative humidity, temperature, and light intensity.

9.5. Case study 1 : Milk Production (France)

The case study involves a production site with 11,500m² of roofs and 4.75 hectares dedicated to plant-based milk production (soya, oats, rice, almonds, chocolate) operating 24/7, relying on 14.1 GWh of electricity from the grid (scope 2 GHG emissions) and 37.3 GWh of heat from gas boilers (scope 1 GHG emissions), managing water temperatures from 60 to 150 degrees, as illustrated in **Figure 33**.

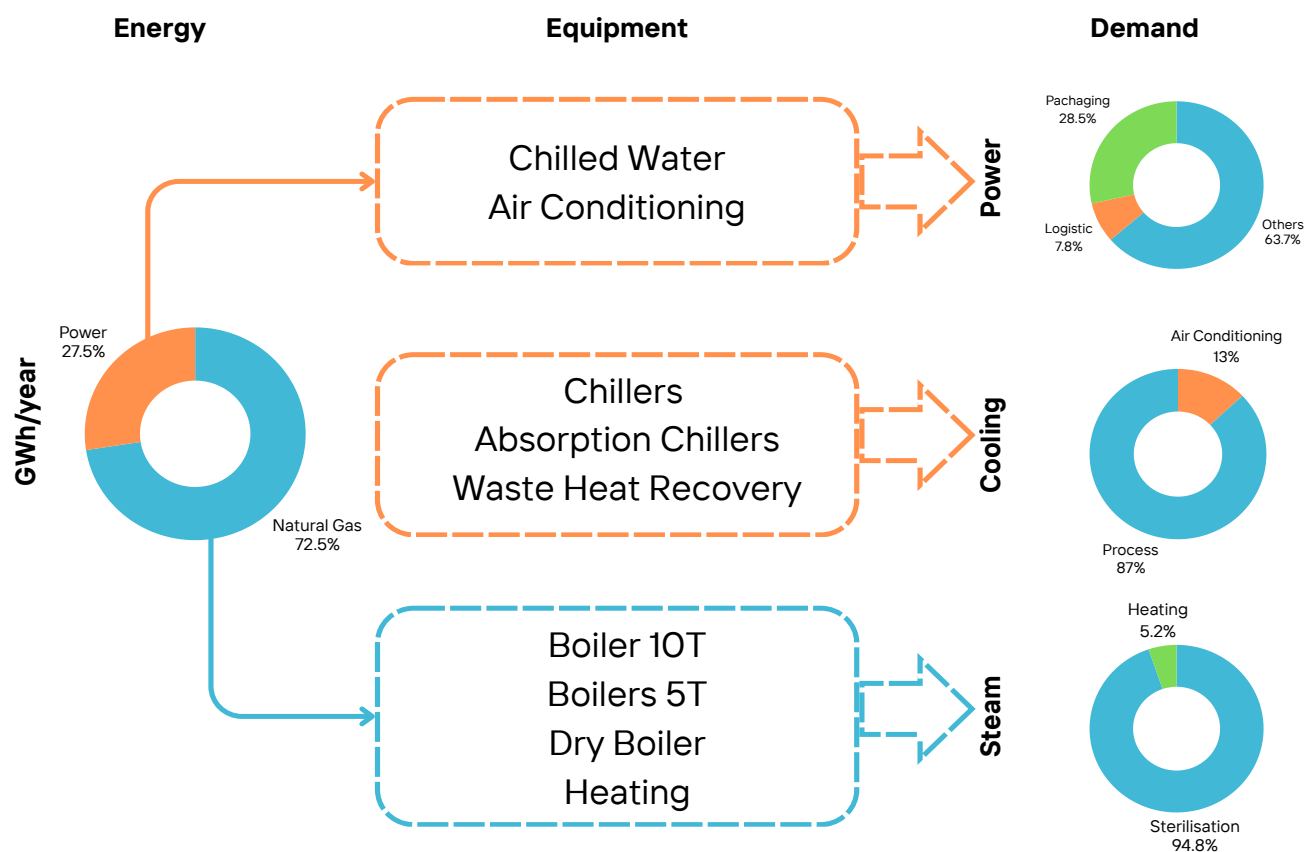


Figure 33: Energy Consumption Profile in Dairy production, by Iroko Africa

Energy Saving Profile: **Achieving a 43% reduction** in energy consumption through Mechanical Stream Reconversion Technology.

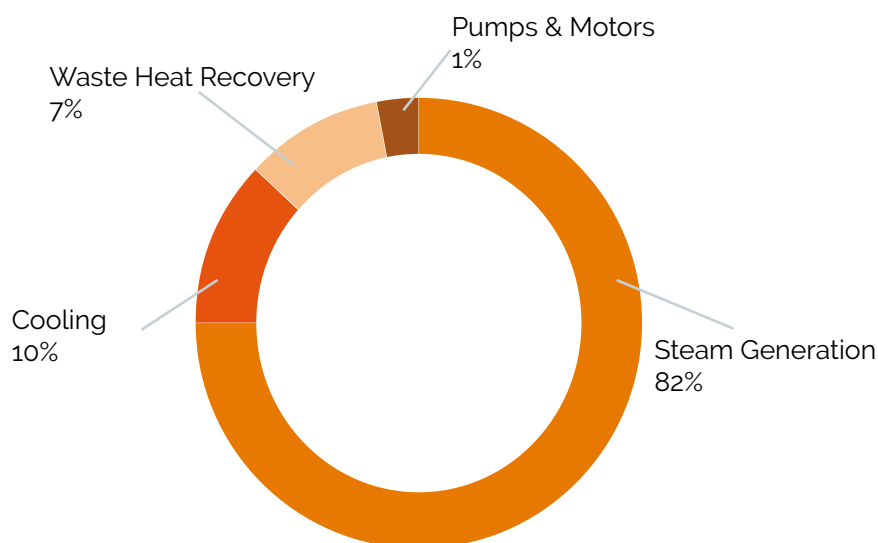


Figure 34: Energy Saving Profile in Dairy Production, by Iroko Africa

Mechanical Steam Reconversion Technology:

This is the process where steam generated from a boiler is used to drive a mechanical device such as a turbine or an expander to produce mechanical power. This process typically improves energy efficiency by recovering waste heat and converting it into mechanical energy, which can then be used to generate electricity or provide additional heat. In industrial settings, such as a production site with significant steam requirements, this technology can help optimise energy usage and reduce overall operational costs.

9.6. Case Study 2: Chicken Abattoir (Nothorn Cape)

The case study involves a chicken abattoir that processes 135,000 chickens per day for the South African local market. Operating for 20 hours per day, 6 days per week, the abattoir relies on a combination of grid connection, diesel generators, and coal-fired boilers. The production of hot water at 65°C and cooling at -40°C are both critical for the abattoir processes.

Energy Consumption Profile:

The facility requires 110 MWh of energy per day, distributed in the following proportions:

- 45% from Coal-Fired Boilers
- 40% of Power from the National Grid
- 15% from Diesel and Paraffin

Energy Savings Profile:

A detailed energy efficiency audit conducted at the facility revealed that over 60% of the energy consumption measured at the meter could be saved. This includes 49% from replacing grid electricity with off-grid renewable energy and 51% from energy consumption reductions achieved through 17 energy optimisation initiatives, including:

1. Implementation of renewable energy projects such as a Solar PV Hybrid system and thermal solar energy.
2. Heat recovery systems on chillers and compressed air equipment.
3. Energy preservation initiatives like air locks insulation and insulation of hot and chilled water piping.

Waste Heat Recovery Technologies:

- **Compressed air equipment generates heat that can be recovered to produce hot water up to 60°C.** In this case study, it was found that the heat recovery system on the facility's 85kW compressor was able to generate sufficient hot water for all the ablution facilities, replacing the need for 21 geysers.
- For industrial chillers, the **heat released from the condenser can be harnessed and used for domestic hot water production**, typically at temperatures between 50°C and 55°C. When coupled with thermal solar collectors, this recovered heat can replace over 75% of the energy required by the facility's coal-fired boiler.

9.7. Case Study 3: Malt Factory (Gauteng)

This case study involves a new greenfield production site dedicated to malt production operating continuously 24/7.

Energy Consumption Profile:

The site requires consumption of 41 MWh/d of power and 224 MWh/d of hot air at temperatures up to 85°C. Following a concept study analyzing six different energy systems, including biogas, thermal solar, heat batteries, gas cogeneration, solar PV with Battery Energy Storage System (BESS), the client has decided to proceed with a hybrid energy system. This system will consist of 4.5 MW gas generators with waste heat recovery, a 3 MWp solar photovoltaic (PV) plant, a BESS, a high-temperature heat pump, and an Energy Management System.

About the Energy Management System Technology:

The EMS integrates photovoltaic (PV) plants, battery storage, and gas generators using an advanced control algorithm. This system manages genset operations, setpoints, battery charging, and load management based on real-time data from the Production Management System (PMS), which monitors and processes behaviors. This integration optimises energy use, reduces gas consumption, and extends battery lifespan, resulting in **additional energy savings of up to 25%**. The inclusion of satellite communication enhances the system's resilience and flexibility, enabling it to adapt to varying weather conditions and potential impacts of climate change. This ensures stable and efficient energy management, improving



Impact of Thermal Stress on the Cold Chain

It is estimated that 40% of all food requires refrigeration, and refrigeration accounts for 15% of global electricity consumption. In the food processing industry, the largest electricity consumption comes from motors, with refrigeration being the primary source of energy use.

However, the rise in ambient temperatures due to climate change exacerbates the challenges faced by cold-chain systems. As average temperatures increase, refrigeration systems will be subjected to higher heat loads, requiring longer operational periods and increased energy consumption. In systems capable of handling these higher loads, the extended operation will further increase energy use.

These challenges highlight the critical importance of understanding and addressing the impacts of thermal stress within the cold chain to ensure food safety and quality, while also managing energy efficiency.

Other Technologies considered:

Trigeneration, Sorption/Adsorption Systems, Thermoelectric, Stirling Cycle, Thermoacoustic and Magnetic Refrigeration.

10

South African Water Consumption

The national average consumption was 237 liters per capita per day (L/c/d) in 2021. If current trends continue, the country could face a water supply-demand deficit of 2.7 to 3.8 billion m³ annually by 2030, equivalent to 17% of its available water resources¹⁸. This crisis is driven by low water tariffs, inefficient use, poor cost recovery, leakage losses, and inappropriate infrastructure. This growing vulnerability is compounded by the rising water demand across South Africa. Water resources are the most vulnerable component to climate change, rather than the hydraulic system itself.

South Africa is using 98.6% of the total water supply available nationally. South Africa's water supply comes mainly from surface water (77%), like the majority of African countries, supplemented by water from various other sources:

- desalination (14%)
- groundwater (9%)
- return flows (0.5%)
- acid mine drainage (0.1%)

Surface water is limited and highly vulnerable to contamination and to climate change impacts :

- **High temperatures:** Surface water evaporation promotes the development of pollutants, increases demand, and leads to the degradation of water quality and availability.
- **Drought:** Resource depletion, along with high concentrations of pollutants and sediments, leads to the degradation of water quality and availability.
- **Variability in rainfall:** Changes in the flow of water resources result in the degradation of water quality and availability.
- **Strong rainfall:** Increased runoff leads to higher pollution levels and sedimentation, degrading water quality.
- **Strong wind can impact its quality:** Increased pollution leads to the degradation of water quality.

11

Food Processing Industry: Water Consumption

The agro-processing sector alone consumes approximately 130 million m³/year, with food and beverages accounting for 55% in 2019, without considering the production of the raw material, which also consumes a great deal of water.¹⁹ South African Industry faces significant risks from water supply challenges, with **the World Economic Forum ranking water crises as the second-highest business risk in 2019, after unemployment.**

Water is a critical resource for the food processing industry, integral to nearly every stage of its operations. Industries often rely on Water Services Authorities (WSAs), for water supply and sanitation. However, many WSAs lack the capacity to provide these services consistently.

The Green Drop Reports highlight that approximately 39% of wastewater treatment plants and 26% of water treatment plants are in critical condition, requiring urgent improvements and climate change adaptation. Despite some positive progress, this situation still poses significant risks to potable water quality, which can directly impact businesses, especially those that rely on high-quality water for their operations. Consequently, industries must adapt by diversifying their water supply sources and finding alternatives to reduce their water consumption to ensure business continuity.

Figure 35 illustrates the water balance in the food processing industry.

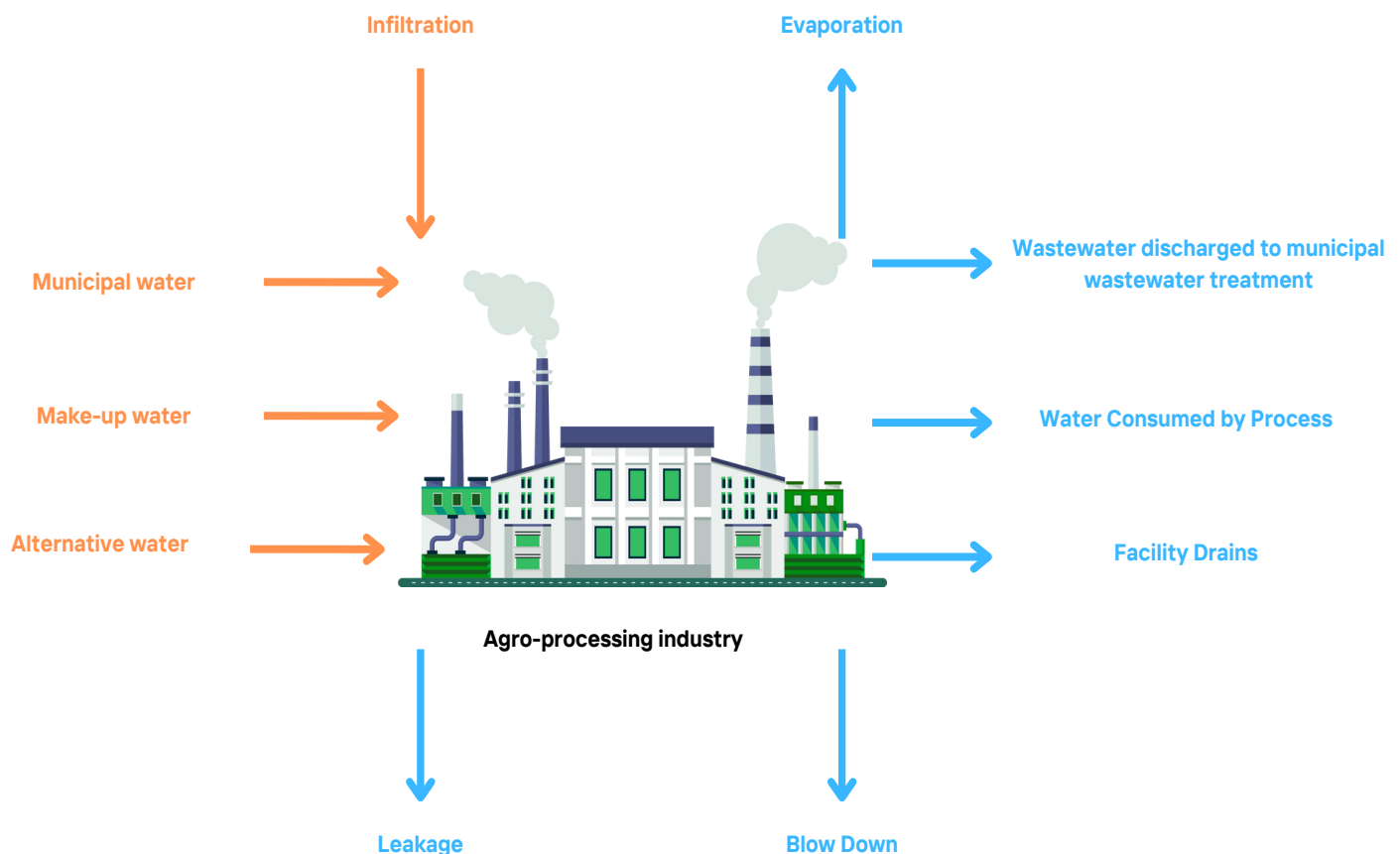


Figure 35: Process Water Balance, by Iroko Africa

Figure 36 shows water consumption in the food processing sector.

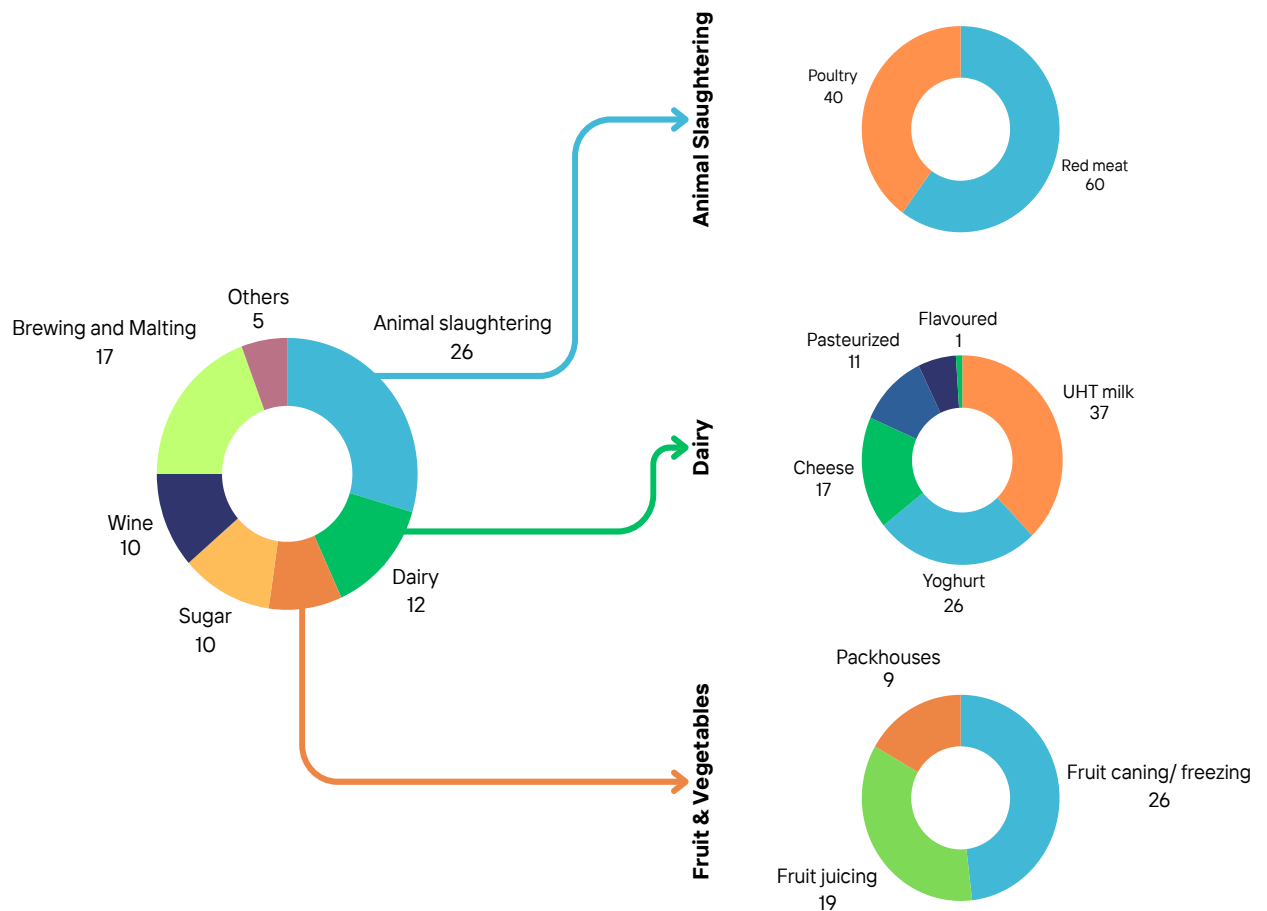


Figure 36: Water Usage (%) in the Food & Beverage per Sector, adapted Iroko Africa²⁰

Zoom 1 : Water usage differs across sectors, but one common factor is the high water consumption for cleaning in Agro-processing industry. The figures below illustrate the water use per activity per sector

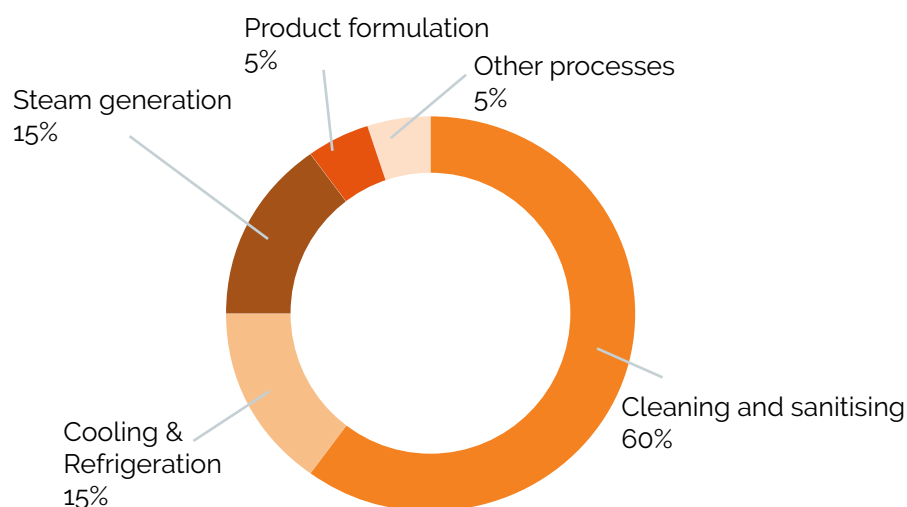


Figure 37: Water Consumption in Dairy Industry, by Iroko Africa

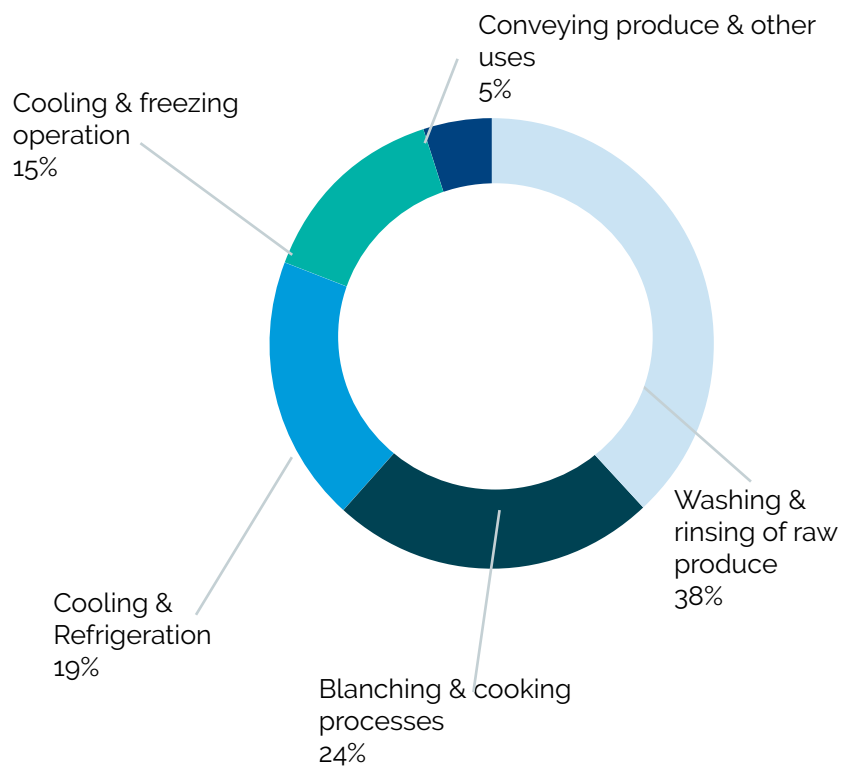


Figure 38: Water Consumption in the Fruit and Vegetable Sector, by Iroko Africa

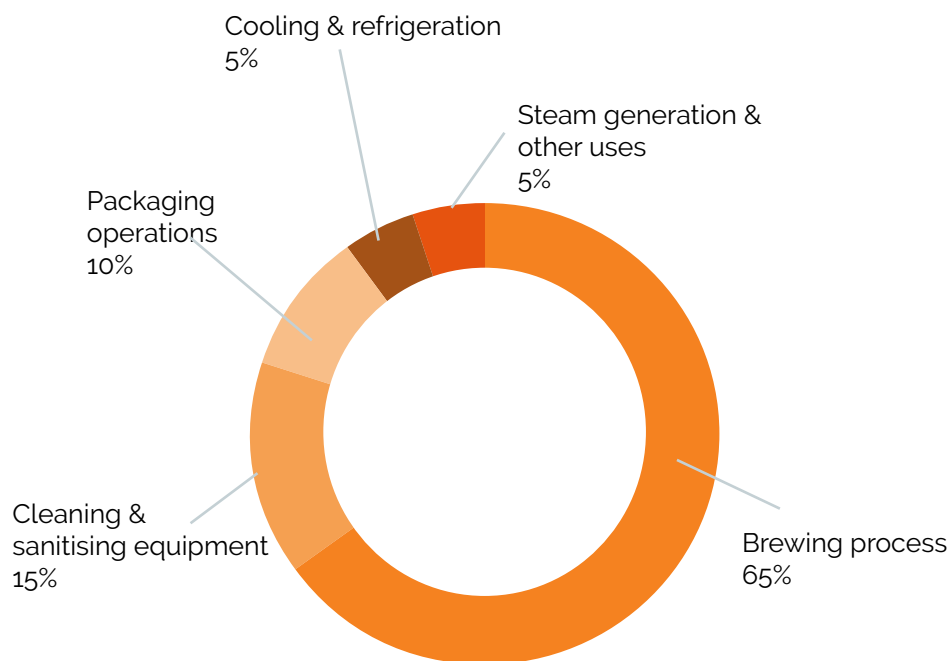


Figure 39: Water Consumption in Brewing and Malting, by Iroko Africa

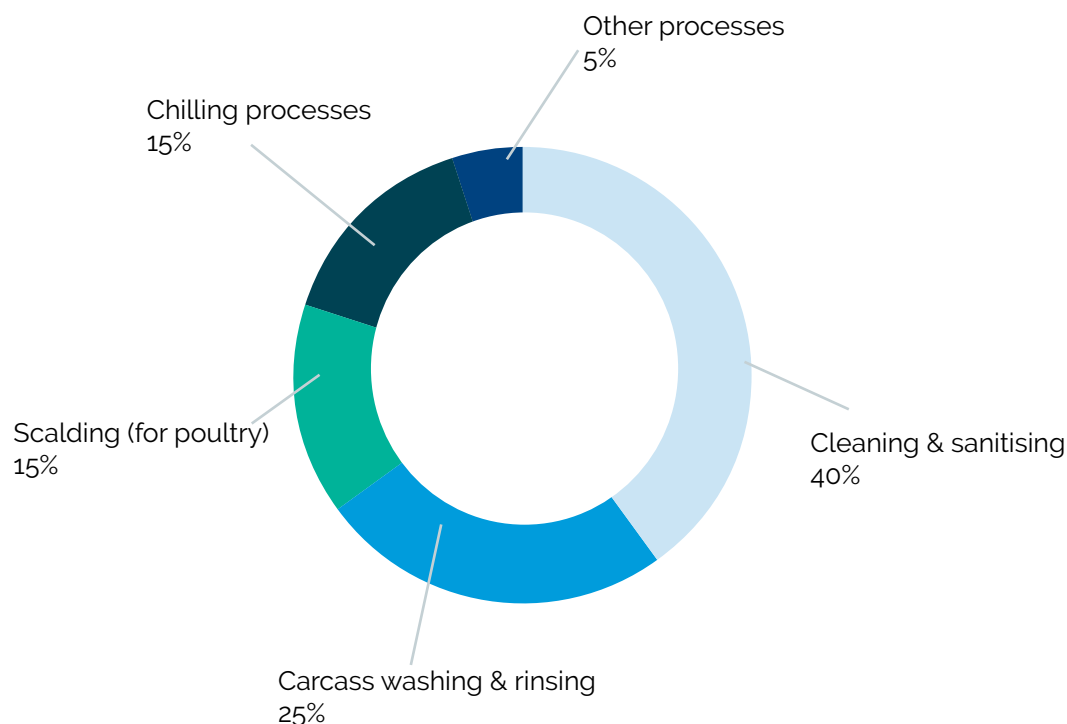


Figure 40: Water Consumption in Animal Slaughtering, by Iroko Africa

Zoom 2 : Alternative Water Supply

• Rainwater harvesting

Despite its potential, rainwater harvesting is frequently overlooked by businesses, especially where potable water remains cheap in the short term. **Rainwater harvesting (RWH) is a low cost-effective method²¹**. With minimal or no treatment, it can be used for industrial processes, toilet flushing, washing, or irrigation. With a proper treatment to reach the potable standard, it can be used in the production process as an alternative.

Online tools, like **the WETEC calculator**, can help determine a facility's rainwater harvesting potential and the amount of water it could save. The calculator also recommends the appropriate tank size based on local rainfall data, enabling businesses to optimise their rainwater collection systems effectively²².

• Groundwater

Groundwater is rarely used by food processing industries in comparison to its availability, often due to the complexity and cost of installation. However, groundwater is less vulnerable to climate change and is often of superior quality compared to surface water, provided that boreholes are properly constructed and protected to prevent contamination.

Accessing this resource requires a geohydrological analysis. The deeper the aquifer, the higher the investment required for drilling and for operating pumps capable of managing higher lift heights.

The Limpopo, Olifants, and Inkomati in the Northern Interior, The Pongola-Umzinkulu in KZN in the east, The Vaal in the central interior, The Mzimvubu-Tsitsikamma in the South-East and The Breed-Gouritz and Berg Olifants in the South West have higher ground water potential. The Orange in the North-West has poor groundwater potential but in some areas of this zone groundwater is the main source²³.



A 2017 Water Research Commission study of 26 small poultry agro-processors relying on private boreholes revealed declining water quality, dried-up boreholes, and limited testing knowledge. High drilling costs and unsuccessful government funding requests hindered access to alternative water sources.

12

Climate-Resilient Water Technologies

“

In the fruit and vegetable agro-processing industry, only 47% of facilities utilise secondary treatment. Even fewer, just 16%, implement tertiary treatment, a critical polishing step.

Industries often face high variability in municipal water costs and inconsistent quality, prompting them to adopt private **water treatment systems** that increase operational expenses. In the food processing industry, water treatment requirements vary depending on the source quality and specific industrial applications.

Wastewater treatment generally consists of three stages: **primary, secondary, and tertiary treatment**. However, not all stages are always required, as their use depends on the characteristics of the wastewater and the desired effluent quality. The primary goal is to treat production effluents to meet **municipal wastewater standards**, which can vary significantly between municipalities.

Climate hazards impact water resources and water technologies, which can have significant consequences for the food processing industry. This may lead to production shutdowns due to compromised water quality. **Table 14** evaluates the main technologies used and provides adaptation measures.

Technologies	Climate Hazards	Consequences	Adaptation Measures
Process Water Treatment	• Increased salinity, • Flooding, • Storms, • Water scarcity, • Drought, • Heavy rainfall	Water quantity and quality change could lead to ineffective treatment and could damage the plant's operations. Additionally, such changes can compromise the quality of the effluent	• Water source diversified • Advanced sensors to monitor flow and quality in real time, • Process automation
Wastewater Treatment	High temperatures	Decreases the performance of biological processes	Adjusting habitat conditions Integrating advanced aeration techniques to optimise microbial efficiency
	Heavy rainfall or flooding	• Overloaded, leading to inadequate treatment. This can have consequences for municipal networks, as industrial wastewater may no longer meet the treatment standards of municipal facilities. In more extreme cases overflows can occur, releasing large quantities of polluted water into the environment.	• Storm runoff systems to retain and collect rainwater (which can be reused). • Advanced separation technologies • Advanced sensors can be deployed to monitor flow and quality in real time, • Process automation to improve responsiveness. • Overflow basins to capture any excess water.
Cooling Towers	High temperatures	• Increase cooling demand, • Straining water resources, • Evaporation losses in cooling towers	Vapor recovery system
Boiler	High temperatures Irregular Rainfall	• Decreased water quality due to pollution or salinity increases the risks of scaling and corrosion, which reduces boiler efficiency. • Increasing evaporation and water demand	Implementation of sensors for water quality and temperature monitoring,
Clean-in-Place (CIP) Systems	Water Scarcity	Hinder proper cleaning processes, affecting hygiene and safety	Implementation of a Dry CIP
Pumping Systems	• Flooding, • Water scarcity, • Higher water temperature, • Storms	• Increased the risk of overheating • Reduced pump lifespan	• Protection for the pump • Solar system
Water Storage	Heavy rainfall	Storage basin overflow, Variation in quality and quantity	• Overflow control systems • Sensors to monitor water levels and temperature in basins • Covering water storage tanks • Underground storage
	High temperatures	• Water's evaporation • Bacteria and algae's development	
Rainwater Harvesting (if implemented)	• Rainfall variability • Flooding	• Reduce the effectiveness of harvesting systems • Lead to overflows during storms	• Implement overflow control systems, • Sensors to monitor water levels
Groundwater (if implemented)	• Reduced rainfall • Prolonged Droughts	• Lower recharge rates • Depleting aquifers	• Artificial Recharge (with rainwater harvesting for example • Sustainable Extraction
	Sea level	Saltwater intrusion in coastal aquifers	Coastal Protection

Table 14: Technology Vulnerabilities to Climate Hazards and their Adaptation Measures, by Iroko Africa

13

5 R' of Water Efficiency Management

The 5 R's of water efficiency - **Reduce, Reuse, Recycle, Recover and Rethink**—are fundamental principles in sustainable water management and can be applied to every industry. The actions of the 5R's are adaptation measures, like those listed previously, that enhance resilience to climate change.

Reduce water use through efficient practices. **Reuse water** for secondary applications. **Recycle** by treating wastewater for repeated use. **Recover** valuable resources, like heat or nutrients, from water during processes, enhancing sustainability and minimizing waste. Rethink habits and processes to optimize water consumption.

13.1. Reduce - Metering and Monitoring – Smart Metering

Real-time monitoring, using advanced sensors and Internet of Things (IoT) systems, provides crucial advantages for water management, enabling efficiency, leak detection and reduction of water losses, real-time water consumption and quality insights and cost reduction. This approach is suitable for both large and small agro-processing industries. Implementing real-time monitoring is considered a low-cost intervention due to the relatively low installation costs. It can lead to water savings of over 30% and typically achieves a payback period of less than three years.²⁴

Metering programs not only lead to financial savings but also help ensure legal compliance. Many companies need metering to obtain or renew water permits and discharge licenses, often on a 3-year cycle. Regulations cover groundwater and river water extraction and require detailed water balances and minimisation programs to meet national efficiency goals in South Africa.



In 2017, Excellent Meat implemented a water monitoring system and installed five smart water flow meters to track their water consumption and detect leaks, with support from the National Cleaner Production Centre and Energy Assist. Between 2017 and 2020, the company achieved a 30% reduction in water consumption, resulting in an estimated total saving of R1,500,312, with an initial investment of just R360,958.

13.2. Water Reuse, Recycle and Recover Metering

The majority of water ends up as wastewater in the agro-processing industry, such as 75-95% in the dairy industry and 70-90 % in animal slaughtering⁴. **Water reuse, recycle and recover is an effective strategy to alleviate pressure on water resources, with various types of water being suitable for use depending on the intended purpose.** Thorough plant inspections, water-use surveys, and water balance calculations are essential to identify potential areas for water reuse, recycle and recover.

Once these opportunities are recognised, further investigations determine the environmental and financial feasibility of various methods.

These strategies deliver long-term savings, with a payback period of 7 to 8 years and 45-70% of wastewater recovered.²⁵

•**Process water reuse:** Modification to allow water circulation in a closed-loop system, potentially **reducing water consumption by 5-10%.**²⁶



Internal reuse example: CIP (Cleaning in Place) is a common process used to clean pipes, during which rinse water is used. This rinse water can be captured and, with basic treatment, reused in the wash cycle of the next CIP cleaning cycle.

- **Wastewater recycle** : Wastewater may need treatment to meet either potable or non-potable standards before reuse. The treatment depends on the intended use. The wastewater can be re-used for processes, landscaping, water features, Building Facilities (air conditioning, toilet flushing), cleaning.

In South Africa, effluent recycle is supported by a push toward zero liquid discharge (an advanced water management technology designed to eliminate liquid waste by recovering all water for reuse) and it has been highlighted in the GreenCape Market Intelligence Report (2018)²⁷, which states that the total Gross Value Add (GVA) for moderate and highly water-intensive users in the Western Cape Province in 2016, excluding agriculture, was estimated at R155 billion²⁸.



Most wineries use their cellar wastewater for irrigation, but they are generally required to pre-treat the wastewater. At least 70% of wineries carry out preliminary or primary treatments before.

- **Water recover** : Modifying processes to recover steam involves capturing waste steam produced during industrial operations and reusing it within the system.

Figure 41 illustrates the water journey and reuse opportunities in an food processing industry.

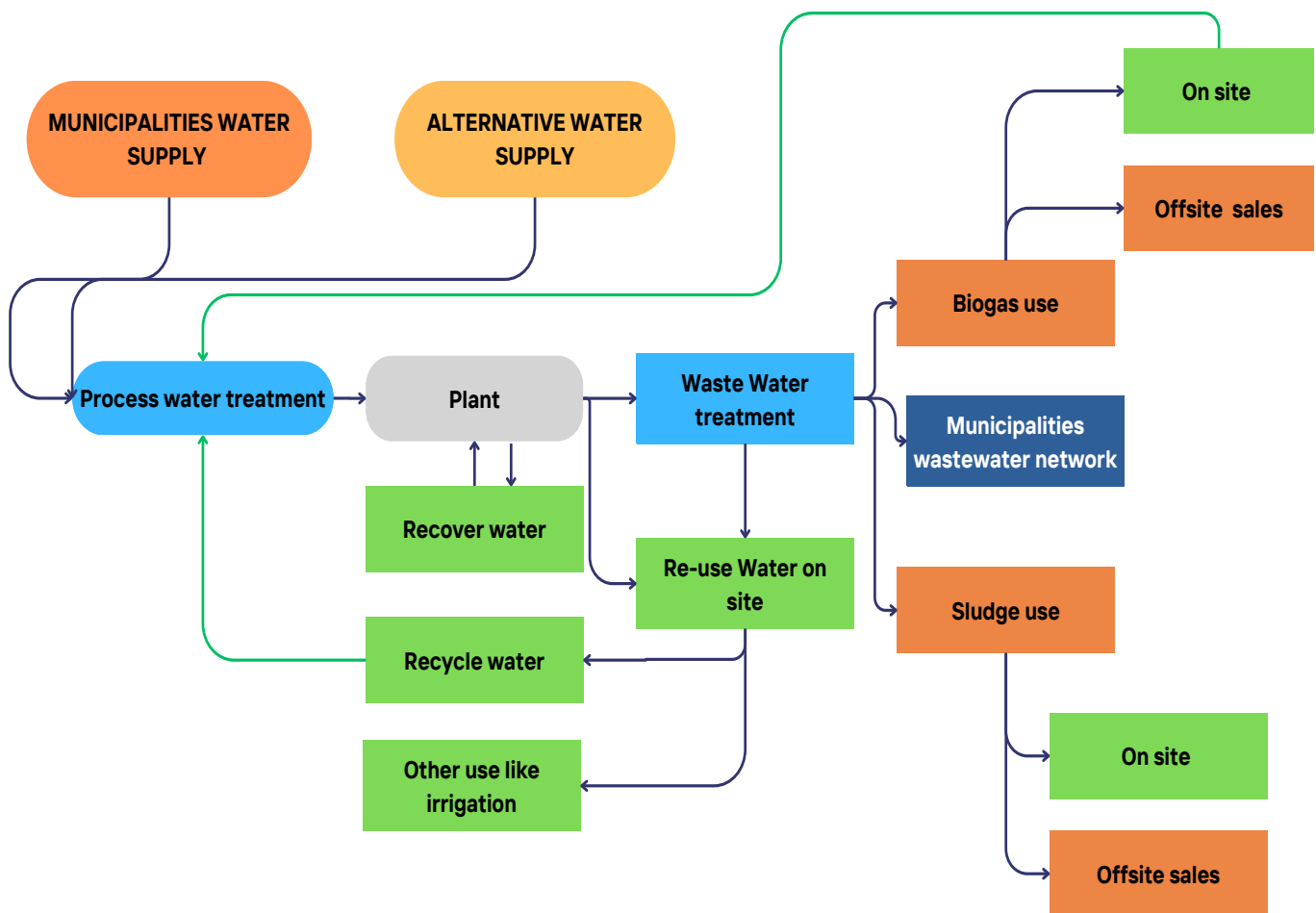


Figure 41: Water Journey in the Agro-Processing Industry and its Reuse, by Iroko Africa

Case study

- Nestlé South Africa: Implemented water recycling in its dairy plant, reducing water use by 50%.
- WOODLANDS DAIRY: Water cycle optimisation allows for 60% of the water used in the factory to be recycled, resulting in a 44% reduction in municipal water demand.
- A dairy company in the Western Cape implemented a system to recover and reuse water used for cooling pistons at one of their facilities. The system cost ZAR 200,000 and resulted in a ~20% reduction in water consumption (1 liter per kilogram of product).
- Similarly, a soft drink manufacturer invested ZAR 140,000 in a system to recover and reuse rinse water from their bottling plant. Alongside a staff awareness campaign, this initiative reduced their water consumption by 27% (36,000 cubic meters per year) and decreased wastewater production by 61%.



Reusing water can offer additional benefits beyond water savings.

- During wastewater treatment, anaerobic treatment can be implemented. A by-product of anaerobic digestion is the production of biogas. This gas can either be released into the atmosphere, captured, and bottled for later use or sale, burned for heat energy, or converted into electricity.
- The sludge from wastewater treatment can also be repurposed in most cases. It can be used as fertiliser in agriculture, either applied on-site or sold for external use.
- Solid residues from wastewater treatment can be valorised using mechanical methods such as rotary drum filters, like malt residues in breweries. These residues are reused primarily as agricultural fertilizer, an energy source (biogas), or animal feed.

13.3. Rethink: Process Optimization

To build resilience against climate change and water scarcity, industries must rethink their processes to reduce water consumption and dependence without compromising processes or product quality.

Actions can range from simple, cost-effective measures to more complex and resource-intensive initiatives as shown in **Table 15**²⁹.

Actions/Innovations	Technological Readiness	Cost	Time-to-Market
Metering and Monitoring	High	Medium	Quick
Self-cleaning and low fouling membranes	High	High	Medium
Water reuse technologies	High	High	Long-term
Waste to heat	High	High	Medium
AI-driven forecasting	Low	High	Long-term
Implementing basic water-efficient retrofits	High	Low	Quick
Transitioning to dry cleaning methods	High	Low	Quick
Rainwater use	High	Medium	Quick-Medium
Groundwater use	High	Medium - High	Medium – Long term
Closed-loop process water use, such as condensed steam reuse	High	Medium to high	Quick -Medium
Equipment upgrades and innovation Ex: In Fruit and vegetable agro-processing industry: New technologies in wet processes such as blanching, cooking, and chilling help minimize water usage.	High	Low to High	Quick
Optimising the organisation ex: Scheduling of animal delivery to achieve continuous slaughtering operations and minimise cleaning	High	Low	Quick

Table 15: Water Schemes per Power Station, adapted by Iroko Africa



The adoption of the 5 R' strategies is relatively limited to date, largely due to the poor business case and high capital costs but the opportunities are growing because it is critical for industries to reduce, reuse, and recycle water for their climate change adaptation and as part of their sustainability efforts. It not only helps preserve valuable resources but also enhances resilience to droughts or heavy rainfall for example.

14

Business Opportunities in Addressing Climate Change

Climate resilience fosters innovation by encouraging companies to move beyond traditional business practices. Whether through restoring wetlands, leveraging advanced climate modeling, or transforming supply chains, organisations are exploring new ways to manage climate impacts. **The private sector is well-positioned to drive these innovations, not only enhancing environmental sustainability but also creating new business and job opportunities in improving Readiness, Robustness,**

Resourcefulness and Recovery. By pioneering climate resilience strategies, companies can unlock new revenue streams and gain a competitive edge in a changing market. The areas being addressed represent examples of business opportunities, as shown in **Table 16**.

Category	Action	Roles
Readiness	Conduct Climate Risk and Impact Assessment	Environmental Analysts, Risk Managers
	Ensure Climate Proofing in Design and Performance	Engineers, Designers, Sustainability Experts
	Enhance Knowledge about Climate Risks and Impacts	Training Coordinators, Climate Specialists
	Mainstream Climate Resilience into Relevant Regulations	Policy Makers, Regulatory Authorities
Robustness	Switch to Water and Heat/Cooling Resilient Production Processes	Process Engineers, Production Managers
	Improve Thermal and Electrical Energy Efficiency	Energy Managers, Engineers
	Use Smart Technology for Better Energy and Water Management	IT Managers, Operations Teams
Resourcefulness	Diversify Energy and Water Sources	Resource Managers, Energy Consultants
	Switch to Climate Resilient Materials	Procurement Managers, R&D Teams
	Mobilise Climate-related Finance and Investments	Financial Analysts, Investment Managers
Recovery	Better Monitor for Early Warning and Emergency Response	Emergency Response Teams, Safety Managers
	Support Adequate Climate Insurance	Insurance Advisors, Risk Managers
	Ensure Emergency Preparedness	Crisis Management Teams, Operations Leaders

Table 16: Job opportunities in Addressing Climate Change, by Iroko Africa

14.1. Climate Change and Grid Management Technologies

These technologies encompass advanced software and hardware solutions designed to enhance the operation and resilience of electricity grids. They facilitate the integration of distributed energy production assets and ensure efficient energy routing, particularly during periods of extreme grid stress.

These technologies can be broken down into the following services:

- **Climate-Energy Integrated Services**

- **Development of Climate-Energy Integrated Models:** Design spatio-temporal models that integrate climate, weather, and energy systems to assess superimposed risks and improve power system resilience.
- **Risk Analysis with Climate Extreme Scenarios:** Incorporate high-resolution climate hazard projections into stress testing and robust optimization to enhance power system resilience under extreme events.
- **Standards for Climate-Resilient Microgrids:** Establish guidelines for planning and operating microgrids that adapt to climate extremes and maintain dynamic stability.

- **Climate-Coupled Planning Services**

- **Metrics for Climate-Coupled System Planning:** Develop comprehensive metrics to plan renewable expansions and microgrid transitions, ensuring climate resilience and economic efficiency.

- **Climate-Integrated Cost-Benefit Analysis:** Conduct detailed analysis for renewable investments, integrating climate data to optimize power reserve and market adaptability.

- **Weather-Coupled Operation Services**

- **Real-Time Weather-Informed Operations:** Utilise high-resolution weather models for pre-event scheduling and real-time dispatch to manage power imbalances during weather extremes.
- **Coordination of Multi-Microgrids:** Develop strategies to optimise operations of interconnected microgrids under spatio-temporal weather hazards and extreme conditions.

14.2. Climate Change and Insurance

The increasing demand for climate risk insurance is closely aligned with the evolving regulatory frameworks in key countries like Mauritius, Kenya, and South Africa, which are at the forefront of developing climate risk regulations.

Data gaps and inadequate climate risk modeling are significant barriers to progress in the sector, with experts estimating that **70% of climate risk models are ineffective due to a lack of reliable historical data**. To address these challenges, it is crucial to strengthen centralised data repositories and enhance counterparty-level data sustainability. Additionally, both ministries and the private sector face a shortage of skilled professionals, highlighting the urgent need for targeted climate risk training programs tailored to South Africa's specific context.

Key steps for Strengthening Climate Risk Insurance include:

- **Strengthen Regulatory Frameworks:** Build comprehensive climate risk insurance regulations to align with global standards and ensure the market's growth.

- **Enhance Data Infrastructure:** Improve data collection, centralised repositories, and counterparty-level data sustainability to ensure accurate climate risk modeling and decision-making.

- **Develop Parametric Insurance Products:** Promote the adoption of parametric (index-based) insurance, particularly for energy and agriculture-related risks, offering efficient and accessible coverage.

- **Targeted Climate Risk Training:** Provide specialised training to develop local expertise in climate risk management within both the private sector and government agencies.

- **Public-Private Partnerships:** Foster collaboration between the government, insurance companies, and international organisations to expand climate risk insurance offerings and solutions.

14.3. Climate Change and Finance

A recent study by Boston Consulting Group (BCG) reveals that investment is increasingly flowing toward companies focused on Adaptation and Resilience solutions, with technologies addressing resilience, mitigation, and sustainable development goals attracting the most funding. The top five subsectors—precision farming, sustainable farming, sustainable batteries, novel foods, and energy efficiency technologies—offer notable climate mitigation benefits, with energy resilience capturing 30% of the total funds.

The growing emphasis on financing adaptation is creating new job opportunities, as investors, governments, and regulators require the private sector to disclose climate-related risks. With over 40 countries already mandating climate-related financial disclosures for large financial institutions, this movement is setting a precedent for other industries. Financial institutions are adopting alternative valuation methods that integrate physical risks, which in turn is driving demand for

professionals skilled in climate risk management, adaptation strategies, and resilience planning.

Facilitating Private Investment in Resilience:

- Encourage climate information disclosure to improve access to finance.
- Provide public incentives and co-financing for resilience-building investments.
- Use performance-based regulations to stimulate investments in resilience.
- Introducing financial support mechanisms like grants and loans for resilience investments, particularly in critical infrastructure.

14.4. Climate Change and Artificial Intelligence

Climate data management is a key challenge in developing projects and resilience strategies, offering new opportunities for improved management, accessibility, and business growth. This challenge creates a wide range of business and job opportunities across various sectors.

- **Climate Risk Modelling/Forecasting:** Developing AI-driven models for predicting climate impacts on businesses, infrastructure, and ecosystems.
- **Enhanced Climate Data Analysis:** Using AI to process large-scale climate data for better decision-making and policy design.
- **Predictive Maintenance for Infrastructure:** AI systems that predict maintenance needs for critical infrastructure, based on climate data and environmental stressors.
- **AI for Renewable Energy Integration:** AI technologies that enhance the integration of renewable energy sources into power grids, ensuring resilience during extreme weather events.

- **Energy Efficiency and Management Systems:** Developing AI tools to optimise energy consumption and improve the resilience of energy grids in response to climate impacts.
- **Water Management and Conservation:** AI systems that help manage water resources, optimizing climate variability and scarcity.
- **Supply Chain Optimisation:** AI tools that help businesses adapt supply chains to climate risks, ensuring resource availability and minimizing disruptions.
- **Climate-Resilient Insurance Solutions:** AI-powered platforms for creating new insurance products that adapt to climate-related risks, such as flood or drought coverage.
- **Climate Impact Analytics for Financial Institutions:** AI-driven analytics to help financial institutions assess and disclose climate-related risks to their portfolios.
- **Disaster Response and Recovery Tools:** AI-powered systems to improve disaster response, forecast damage, and streamline recovery efforts for post-climate events.



15

Conclusion

Based on market analysis insights, sector-specific energy and water consumption profiles, and climate risk assessments related to thermal stress and water instability across South Africa's provinces, **Figure 42** presents a 2x2 matrix. The Y-axis represents the Relative Importance of the Sector in South Africa, measured by market value, while the X-axis indicates Relative Energy and Water Intensity. The size of each sector reflects its Vulnerability to Thermal Stress and Water Instability. Additionally, an exacerbation factor (**Table 17**) has been applied to account for localisation effects and the heightened vulnerability of small businesses.

Sector	Relative Market Size (1 to 5 Scale)	Relative Energy & Water Intensity (1 to 5 scale)	Relative Vulnerability to Thermal Stress and/or Water Instability	Exacerbation Factor
Fruit and Vegetable	5	3	Very High	SMMEs
Beverage	4	5	Medium - High	SMMEs
Dairy	3	4	High	
Poultry	2	4	Very High	Localisation
Red Meat	2	3	Medium - High	
Sugar	2	3	Very High	Localisation

Table 17: Vulnerability of Food Processing Sector in South Africa, by Iroko Africa

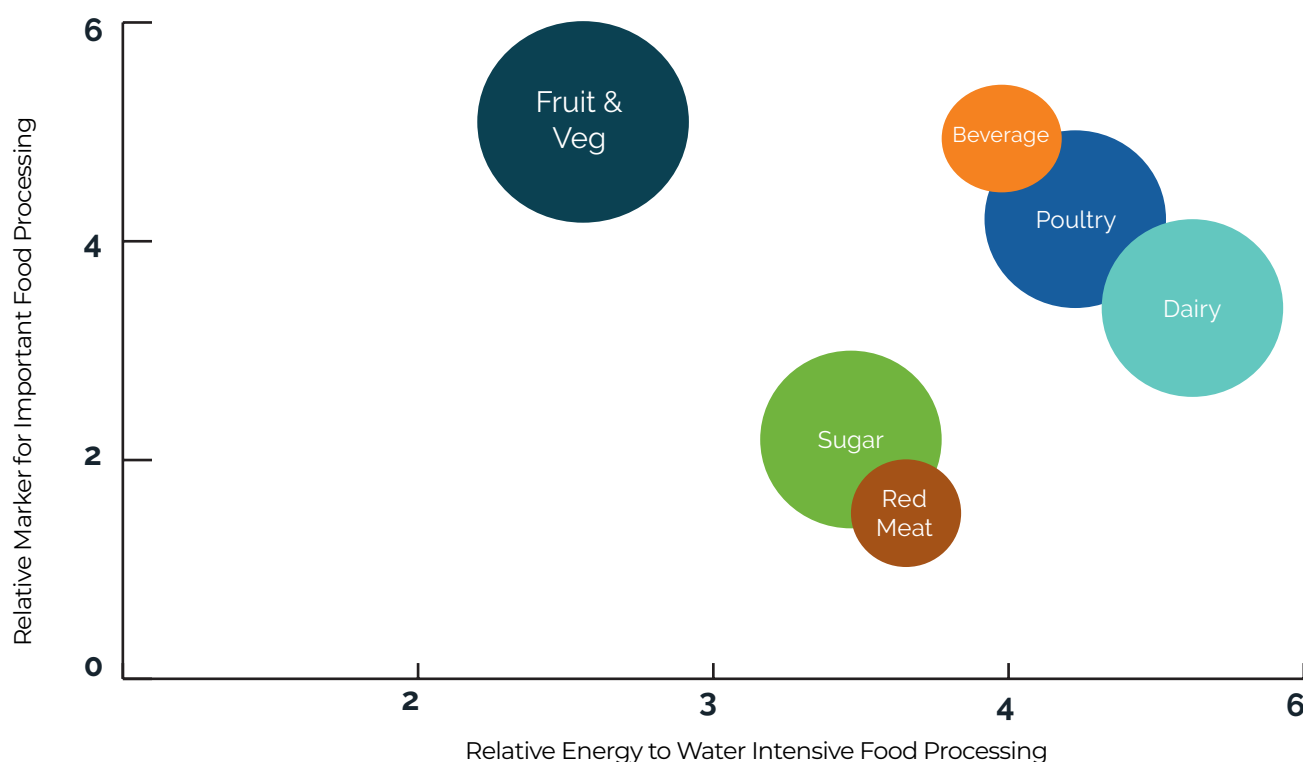


Figure 42: 2x2 Matrix Market Value, Energy and Water Intensity, and Climate Vulnerability, by Iroko Africa

The agro-processing industry in South Africa, like many other industrial sectors, depends heavily on energy- and water-intensive processes for electricity and heat generation. Currently, its energy mix is dominated by **coal-fired power from ESKOM** for electricity and **on-site coal-fired boilers** for heat. This reliance on coal leads to **high carbon emissions** and exposes the industry to growing climate risks, including **thermal stress, water scarcity, and extreme weather events (such as storms and flooding)**.

To enhance **energy security and reduce carbon emissions**, industry players are exploring alternative energy sources such as solar PV, bioenergy, and gas. While these technologies are often evaluated for their impact on energy security and emissions reduction, their vulnerability to climate change and the potential benefits of energy efficiency measures are frequently overlooked.

The energy-water-climate nexus highlights the interdependencies between energy systems, water resources, and climate change. Addressing this nexus is crucial as the sector faces multiple concurrent challenges:

- **Energy security risks** – ESKOM's supply constraints and rising electricity costs. **Water security risks** – Municipal water supply challenges and increasing scarcity due to climate change.
- **Decarbonisation pressure** – The need for fuel switching to reduce emissions.
- **Industrial resilience** – Strengthening long-term sustainability by integrating climate adaptation strategies.

To optimise investments and minimise unnecessary CAPEX, energy and water efficiency should be prioritised before considering fuel switching. A holistic strategy that integrates:

- **Efficiency improvements**
- **Low-carbon technologies**
- **Climate resilience measures**

16

Recommendations

Recommendations can be provided at various levels, as illustrated in **Table 18**:

Recommendation	Details	Key Stakeholders
Conduct a focused climate risk analysis and adaptation strategy for regional food processing clusters	Better understand the climate profile in relation to specific industries and specific climate hazards, as follows:	Regional food industry leaders, Climate experts, Government bodies
	• Sugar and Dairy industry in KwaZulu-Natal: Focus on storm and flooding risks.	
	• Poultry industry in Northern Cape and North West: Address thermal stress impacts.	
	• Fruit & Vegetable industry in Limpopo: Examine the effects of thermal stress.	
	• Fruit & Vegetable industry in Western Cape: Assess the impact of water scarcity.	
Map water, energy, and production sites	Identify all water, energy, and production sites in KwaZulu-Natal, conducting a detailed risk assessment for flooding and cyclones, and integrating lessons from Mozambique's experience.	Municipal authorities, Energy sector, Water management teams
Integrate climate risk analysis into energy and water projects	Systematically integrate climate risk assessments into all greenfield energy and water projects to ensure resilience against climate impacts in future developments.	Energy sector, Water authorities, Engineering firms
Conduct research on thermal energy efficiency	Research and develop guidelines to improve thermal energy efficiency for sectors that rely heavily on heat, including studies on fuel-switching from coal-fired boilers.	Energy researchers, Industry stakeholders, Policy makers
Research impact of thermal stress on animals	Conduct research to assess the impact of thermal stress on animals in agricultural sectors, focusing on health, productivity, and welfare in the context of changing climate conditions.	Agricultural scientists, Veterinarians, Climate experts
Implement mandatory measures for efficiency improvements	Enforce mandatory efficiency measures for the use of water, thermal energy, and electricity, focusing on reducing waste and enhancing resource conservation.	Regulatory bodies, Energy, and Water management entities
Analyse thermal stress impacts on refrigeration sectors	Assess the impact of thermal stress on sectors reliant on refrigeration, exploring its effect on energy capacity and implementing flexibility measures to manage peak loads.	Refrigeration industry, Energy providers, Climate experts
Conduct climate risk analysis for mechanical and electrical equipment	Analyse the impact of climate risks on mechanical, electrical, and electronic equipment, focusing on limitations due to high temperatures and potential failure points.	Equipment manufacturers, Climate risk analysts, Industrial operators

Recommendation	Details	Key Stakeholders
Promote water reuse and recycling	Increase funding and enforce regulations to encourage water reuse and recycling across industries and municipal systems, reducing pressure on local water resources.	Municipal authorities, Water recycling companies, Environmental NGOs
Diversify and expand municipal water supply and energy sources	Expand and diversify municipal water and energy supply sources to ensure stability and sustainability, integrating lifecycle analysis of critical minerals and water consumption per MWh in energy strategy development.	Municipal authorities, Energy sector, Water management agencies
Implement climate resilience strategy for ESKOM	Reformulate ESKOM's climate resilience strategy, focusing on enhancing sustainability in power generation, transmission, and distribution amidst climate risks and ensuring long-term stability.	ESKOM, Government, Energy regulators, Infrastructure planners
Adopt flexible and diversified energy solutions	Promote flexibility measures such as energy storage, demand response, and renewable energy integration to ensure a diverse and resilient energy mix that can respond to climate-related challenges.	Energy companies, Utility operators, Government, Researchers
Develop adaptation plans for extreme weather events	Create specific adaptation plans to address the impacts of extreme weather events such as heatwaves, floods, and storms, ensuring continuity of essential services.	Local governments, Emergency response teams, Energy providers
Map water, energy, and production sites	Identify all water, energy, and production sites in KwaZulu-Natal, conducting a detailed risk assessment for flooding and cyclones, and integrating lessons from Mozambique's experience.	Municipal authorities, Energy sector, Water management teams
Promote diversification of water and energy sources	Promote diversification of water and energy sources to reduce dependency on a single supply, ensuring sustainable access to both in light of climate risks.	Municipalities, Water authorities, Energy companies
Ensure integration of lifecycle analysis in energy strategy	Incorporate lifecycle analysis of critical minerals into energy mix strategies, assessing their environmental impact and resource availability in the context of future energy demand.	Energy policymakers, Mining sector, Environmental analysts
Implement AI-driven climate adaptation strategies	Leverage AI technologies to model and predict climate risks, develop adaptive solutions, and optimise resource management for energy and water sectors in response to climate change.	AI technology providers, Climate experts, Government, Energy, and water sectors
Provide education on the energy-water-climate nexus	Develop and implement educational programs focused on the interconnections between energy, water, and climate change, targeting key stakeholders across industries and sectors.	Educational institutions, Government bodies, Industry leaders

Table 18: Key Recommendations per Target, by Iroko Africa

17

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Appendix





Appendix 1 - Poultry Case Study: Climate Risks and Adaptation

The section below presents the results of a study using the OCARA Methodology.

Henwil – Poultry Agro-Processing Industry

Henwil Chicken is a South African poultry producer located in the North West Province. The company has a daily processing capacity of over 135,000 chickens. The factory is situated on a 6 km² site, with the production area occupying 17,000 m².

Henwil Chicken is located on an aquifer, which allows the company to source its water. Recently, the company installed a wastewater treatment system that enables them to recycle 30% of their water, while the remaining 70% is released to replenish the aquifer.

Scope A: Direct Internal Processes

- Chicken slaughtering
- Processing
- Packaging
- Cold storage (e.g., refrigeration)
- Waste recycling (feathers, blood, etc.) to produce chicken feed
- Employee housing
- Three boreholes (with a consumption of 1,400m³/day)
- Water storage
- Backup fuel generator
- Coal-fired boiler
- Chiller

Scope B: Infrastructure and Supporting Services

- Supply of chickens
- Delivery of chickens to retailers
- Grid electricity

Climate change affects not only the internal operations of businesses but also their entire value chain. The current resilience analysis includes two scopes:



There are four processes involved in cold production:

- 17°C for the building
- 5°C for refrigerators
- -40°C for deep freezers
- -17°C for freezers

The first two are vital processes, unlike the latter two. Maintaining a temperature of 17°C in the building ensures good working conditions and proper hygiene. The refrigerators are used for storing products.

To conduct this climate risk assessment, three main hazards were considered: thermal stress, water scarcity, and wind speed. These natural hazards were analysed under two different scenarios: **SSP2-4.5 (Table 19)** and **SSP5-8.5 (Table 20)**, from the present day to 2100.

Variable	Near Term (2021-2040)	Medium Term (2041-2060)	Long Term (2081-2100)
T>35°C (Nb of days)	29.6	39.5	62.3
Max T (°C)	37.0	37.9	39.3
Precipitation (mm)	58.6	57.5	57.2
Wind Speed (m/s)	4.2	4.2	4.2
Consecutive Dry Days (Days)	54.0	58.0	60.0

Table 19: Data on scenario SSP2-4.5

Variable (Units)	Near Term (2021-2040)	Medium Term (2041-2060)	Long Term (2081-2100)
T>35°C (Nb of days)	36.6	57.4	152.1
Max T (°C)	37.5	39.0	42.7
Precipitation (mm)	58.6	57.3	55.3
Wind Speed (m/s)	4.2	4.3	4.5
Consecutive Dry Days (Days)	54.0	59.0	71.0

Table 20: Data on scenario SSP5-8.5

Thermal Stress: Under SSP2-4.5, the number of days with temperatures exceeding 35°C is projected to increase from 29.6 in the near term to 62.3 in the long term. The maximum temperature is expected to rise from 37.0°C to 39.3°C. SSP5-8.5 shows a more dramatic increase, with days above 35°C rising from 36.6 to 152.1, and maximum temperature reaching 42.7°C by 2081-2100.

Water scarcity: Both scenarios project a slight decrease in precipitation. Under SSP2-4.5, it drops from 58.6mm to 57.2mm, while SSP5-8.5 shows a more pronounced decline to 55.3mm.

Wind Speed: Wind speed remains relatively stable under SSP2-4.5 at 4.2 m/s. SSP5-8.5 projects a slight increase from 4.2 m/s to 4.5 m/s in the long term.

Comparison: SSP5-8.5 consistently projects more extreme changes compared to SSP2-4.5, particularly in temperature-related variables. The number of hot days (T>35°C) in SSP5-8.5 is projected to be nearly 2.5 times higher than in SSP2-4.5 by 2081-2100.

These projections suggest Henwil may face increased thermal stress, potential water scarcity, and minimal changes in wind patterns.

Adaptation Capacity

To implement effective adaptation measures, it is crucial to identify the company's vital processes, those that could lead to a production shutdown—so that we can prioritise them. This involves assessing their resilience to the region's main climate hazards. Since wind patterns remain stable, they were not considered in the subsequent analysis.

As shown in **Figure 43**, two critical processes have been identified:

- Chicken supply chain: This process is particularly resilient to thermal stress. Delivery trucks can wait in full sunlight within a buffer zone before entering the plant. However, high temperatures may affect the quality of the chickens during transport.
- Water pumping system: This system becomes faulty in the event of water scarcity, posing a significant risk to operations.

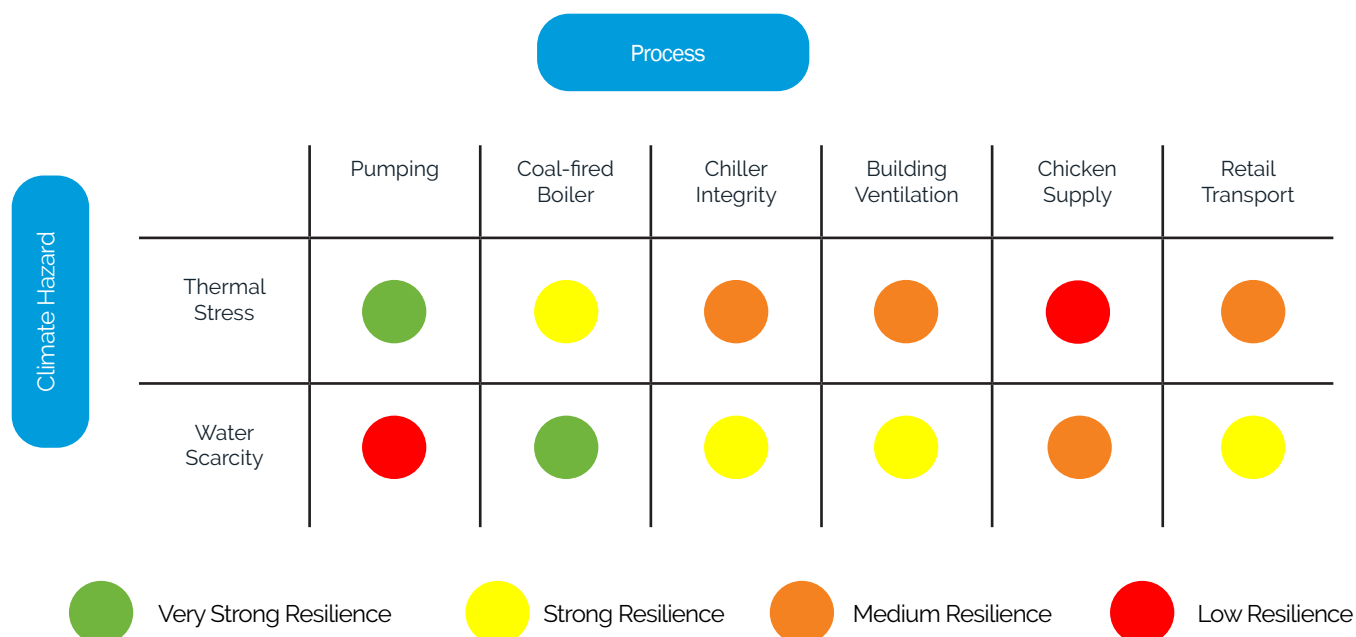


Figure 43: Business resilience analysis (non-exhaustive), by Iroko Africa

Adaptation Measures

Henwil is aware of its vulnerability to climate change, particularly regarding water resources and rising temperatures. While the company has already taken measures, significantly increasing its resilience requires a multi-level adaptation plan, including a review of water management, design, materials, and equipment.

For Henwil, the two main priorities are water consumption—due to its extensive use in production—and cooling management to maintain sanitary conditions.

The financial commitment is considerable, as are the consequences of climate change, which could potentially lead to production shutdowns. Henwil must therefore integrate these adaptation measures into its development and financial plan to better anticipate future scenarios.

Figure 44 presents adaptation measures for the main categories in a cost-benefit matrix.

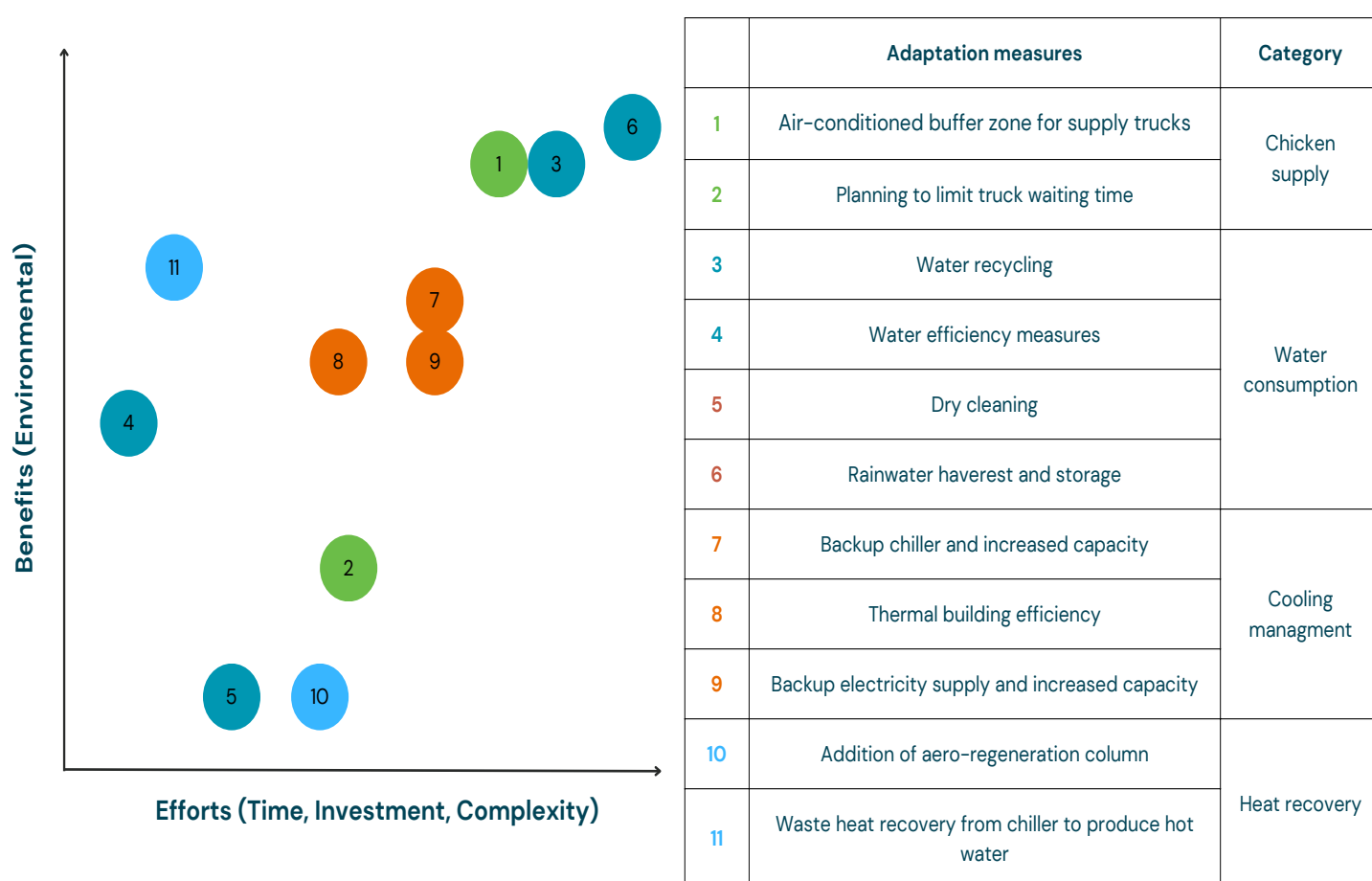


Figure 44: Recommendations for adaptation measures for Henwil, by Iroko Africa



The addition of an aero-regeneration column is an easy-to-implement adaptation solution that appears to offer significant benefits at first glance. However, it demands a considerable amount of water, which is already under strain.



Appendix 2 - Interview Questions on Water Management in the Agro-Processing Industry

Which agro-processing sector consumes the most water?

What is the water used for?

Which process consumes the most water?

What water technologies are currently used in the agro-processing industry?

Are these hydraulic technologies complicated to implement? Are they expensive?

Are these technologies resilient to climate change?

What impact will climate change have on these technologies?

What type of water is most vulnerable/impacted?

What are the water sources in SA? groundwater? surface water?

What is the water supply network in SA? Public network? Private borehole?

What technological innovations can boost the resilience of hydraulic systems?

Known case studies ?

What are the challenges and opportunities associated with adopting these solutions, including regulatory aspects?

How do these innovations compare in terms of technological readiness, cost, and time-to-market?



Appendix 3 - Transcript of Interview 1 with TAKATS'EAU

Date: November 29, 2024

M. Pourceau: Interviewee – TAKATS'EAU CEO

Sector: Water Management (including innovative technologies)

Agathe Leroux: Interviewer

Key Topics

Water Usage in Industrial Sectors

• High Water Consumption Industries:

- **Dairy Processing:** Water is heavily used for equipment cleaning, pasteurization, and cooling.
- **Fruits and Vegetables:** Washing, peeling, and canning require significant water usage. For instance, pineapple canning projects in Benin demonstrate the scale of water demands.
- **Sugar Production:** Water is essential for sugarcane extraction and refining.
- **Meat Processing and Slaughterhouses:** Used for cleaning carcasses and effluent management. However, only 30% of South African municipalities enforce strict effluent guidelines.
- **Beverage Manufacturing:** Water is used extensively for bottling and cleaning.

• Challenges in Water Management:

The majority of municipalities lack stringent regulations, leading to unchecked effluent discharge and limited incentive for recycling initiatives.

Water Treatment and Recycling Technologies

• Pre-treatment Processes:

- Groundwater often needs pre-treatment, including filtration, disinfection (chlorination or UV), and reverse osmosis for polishing.
- Advanced filtration techniques, such as ultrafiltration and membrane systems, are employed depending on contamination levels.

Effluent Management:

- Technologies for effluent treatment include coagulation, flocculation, and biological processes for separating solids, fats, and liquids.
- Mechanical methods like rotary drum filters are used to recover and valorize solids, such as malt residue in breweries.

Recycling and Reuse:

- Treated effluents are increasingly recycled to reduce reliance on freshwater sources.
- Circular systems in industries, such as slaughterhouses, achieve significant water savings, though regulatory hurdles in some regions limit adoption.

Impact of Climate Change

• Effects on Water Resources:

- Surface water is particularly vulnerable to droughts and contamination during periods of low rainfall.
- Groundwater recharge rates are slower, and quality degradation can occur due to over-extraction and industrial activity

• Technological Adaptation:

- Changes in water quality due to climate conditions necessitate flexible and adaptive treatment processes.
- Advanced sensors and IoT systems enable real-time monitoring and optimization of water treatment plants.
- Decentralized Water Treatment Solutions
- The interview highlighted a trend toward decentralized treatment systems, especially in regions with weak municipal infrastructure.
- These systems offer industries greater control over water quality and reduce dependency on centralized municipal services.
- Innovations in IoT and automation are enhancing the efficiency of such systems, minimizing human intervention, and reducing costs.
- Regulatory and Economic Considerations

• Regulatory Challenges:

- South Africa's fragmented regulatory environment creates inconsistencies in water management.
- Europe's stricter standards often discourage the reuse of treated water, unlike South Africa, where less stringent rules encourage innovation.

• Economic Impacts:

- High variability in municipal water prices and quality often forces industries to invest in private treatment systems, increasing operational costs.
- Despite these challenges, decentralised and circular systems can offer ROI within three years, making them attractive investments for forward-thinking companies.

• Case Studies and Practical Examples

- **Coca-Cola:** Successfully implements sustainable practices, including groundwater treatment and water recycling, as part of its global environmental commitments.
- **Challenges in Slaughterhouses:** Some facilities in South Africa, fail to meet even basic water treatment standards due to lax regulatory enforcement.



Appendix 4 - Transcript of Interview 2 – Water Geothermal Sustainability

December 2, 2024

Timothée Dupaigne: Interviewee - Expert hydrogeology and geothermal energy

Sector: Hydrogeology and Water Sustainability Consulting

Agathe Leroux: Interviewer

Key Topics

Impact of Climate Change on Water Resources and Technologies

- **Effects on Water Resources:**
 - Surface water is heavily impacted by evaporation due to higher temperatures.
 - Extreme weather patterns lead to erratic rainfall, increasing runoff and reducing groundwater recharge.
 - Annual groundwater sources are more sensitive to climate variability compared to multi-year reserves.
- **Technological Adaptations:**
 - Industries must invest in technologies to monitor water availability and quality.
 - Systems like IoT-enabled monitoring and AI-driven resource management are essential for sustainable water use.
 - Water Treatment Processes and Reuse
- **Key Water Treatment Techniques:**
 - Reverse osmosis, ultrafiltration, and UV disinfection are widely used to purify industrial water.
 - Effluent treatment technologies, such as coagulation and filtration, help industries meet regulatory standards.
- **Reuse of Treated Effluents:**
 - Recycling treated effluents is a viable option but has limitations due to the accumulation of dissolved contaminants over repeated cycles.
 - Proper effluent treatment before groundwater recharge is crucial to avoid long-term contamination.
 - Challenges in Industrial Water Management
- **Leakage and Efficiency:**
 - Industrial sites often experience significant water losses due to leakage, sometimes exceeding 20-30%.
 - Addressing leaks through monitoring systems is cost-effective and critical for water conservation.
- **Decentralised Water Management:**
 - Industries relying on municipal water are increasingly adopting private boreholes to ensure supply stability.
 - Investment in artificial recharge of aquifers is gaining attention as a sustainable water source management strategy.

Regulatory and Cost Considerations

• Regulation Challenges:

- In South Africa, fragmented water regulations and varied municipal enforcement led to inconsistent water quality and availability.
- Industries face hurdles in reusing effluent due to regulatory constraints, unlike in regions with more lenient policies.

Economic Impacts:

- The cost of drilling deeper boreholes is significant but manageable for industries. Investments often pay off by reducing reliance on public water supplies.

Case Studies and Innovations

• Global Practices:

- Artificial aquifer recharge techniques used in Jordan and the United States were highlighted as successful examples.
- Israel's water recycling initiatives demonstrate the potential for resource optimization in water-stressed areas.

Impact of Climate Change

• Effects on Water Resources:

- Surface water is particularly vulnerable to droughts and contamination during periods of low rainfall.
- Groundwater recharge rates are slower, and quality degradation can occur due to over-extraction and industrial activity

• Technological Adaptation:

- Changes in water quality due to climate conditions necessitate flexible and adaptive treatment processes.
- Advanced sensors and IoT systems enable real-time monitoring and optimization of water treatment plants.
- Decentralized Water Treatment Solutions
- The interview highlighted a trend toward decentralized treatment systems, especially in regions with weak municipal infrastructure.
- These systems offer industries greater control over water quality and reduce dependency on centralized municipal services.
- Innovations in IoT and automation are enhancing the efficiency of such systems, minimizing human intervention, and reducing costs.
- Regulatory and Economic Considerations

• Regulatory Challenges:

- South Africa's fragmented regulatory environment creates inconsistencies in water management.
- Europe's stricter standards often discourage the reuse of treated water, unlike South Africa, where less stringent rules encourage innovation.

• Economic Impacts:

- High variability in municipal water prices and quality often forces industries to invest in private treatment systems, increasing operational costs.
- Despite these challenges, decentralized and circular systems can offer ROI within three years, making them attractive investments for forward-thinking companies.

• Case Studies and Practical Examples

- **Coca-Cola:** Successfully implements sustainable practices, including groundwater treatment and water recycling, as part of its global environmental commitments.
- **Challenges in Slaughterhouses:** Some facilities in South Africa, fail to meet even basic water treatment standards due to lax regulatory enforcement.



Appendix 5 - Transcript of Interview 3 - VEOLIA

December 4, 2024

Xavier: Interviewee - Chief Development Officer

Sector: Large-Scale Water Utility

Agathe Leroux: Interviewer

Key Topics

Impact of Climate Change on Water Resources and Technologies

• Effects on Water Resources:

- Surface water is heavily impacted by evaporation due to higher temperatures.
- Extreme weather patterns lead to erratic rainfall, increasing runoff and reducing groundwater recharge.
- Annual groundwater sources are more sensitive to climate variability compared to multi-year reserves.

• Technological Adaptations:

- Industries must invest in technologies to monitor water availability and quality.
- Systems like IoT-enabled monitoring and AI-driven resource management are essential for sustainable water use.
- Water Treatment Processes and Reuse

• Key Water Treatment Techniques:

- Reverse osmosis, ultrafiltration, and UV disinfection are widely used to purify industrial water.
- Effluent treatment technologies, such as coagulation and filtration, help industries meet regulatory standards.

• Reuse of Treated Effluents:

- Recycling treated effluents is a viable option but has limitations due to the accumulation of dissolved contaminants over repeated cycles.
- Proper effluent treatment before groundwater recharge is crucial to avoid long-term contamination.
- Challenges in Industrial Water Management

• Leakage and Efficiency:

- Industrial sites often experience significant water losses due to leakage, sometimes exceeding 20-30%.
- Addressing leaks through monitoring systems is cost-effective and critical for water conservation.

• Decentralized Water Management:

- Industries relying on municipal water are increasingly adopting private boreholes to ensure supply stability.
- Investment in artificial recharge of aquifers is gaining attention as a sustainable water source management strategy.

Regulatory and Cost Considerations

• Regulation Challenges:

- In South Africa, fragmented water regulations and varied municipal enforcement led to inconsistent water quality and availability.
- Industries face hurdles in reusing effluent due to regulatory constraints, unlike in regions with more lenient policies.



Mail :

edelevallee@manergy.fr
irokoafrika@manergy

Address :

Colab, Menlyn Maine
Pretoria, South Africa