GTAC/CBPEP/EU project on employment-intensive rural land reform in South Africa: policies, programmes and capacities

Thematic study
Climate change and its impacts on the feasibility and sustainability of small-scale systems of agricultural production, in communal areas and on farms transferred through land reform

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31 March 2020

FUNDED BY THE EUROPEAN UNION

Abbreviations and acronyms

CBPEP	Capacity Building Programme for Employment Promotion
CHDM	Chris Hani District Municipality
DEA	Department of Environmental Affairs
GHG	Greenhouse gas
GTAC	Government Technical Advisory Committee
IPCC	International Panel on Climate Change
RCP	Representative Concentration Pathways
UWC	University of the Western Cape
ZAR	South African Rand

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Executive summary

This paper is intended to provide context and support discussion on the potential impacts of climate on small-scale farming systems in South Africa and the resulting socio-economic impacts, including in the context of black smallholder farmers in communal areas and on farms transferred thorough land reform. The paper includes detailed consideration of the potential socio-economic impacts of climate change on smallholder and small-scale commercial farmers at four pilot study sites (Matzikamma and the Western Cape; Greater Tzaneen and Limpopo; Sakhisizwe and the Eastern Cape; Inkosi Langalibalele and KwaZulu Natal) and the associated local value chains/commodities (including livestock products, subtropical tree crops, sugarcane, vegetables and fruit).

Studies of historical climate trends in South Africa show that the country has experienced widespread and statistically significant temperature increases over the last century. Climate change projections indicate that these trends will continue, where temperature increases of between 2-3°C, or up to 3-4°C, may be expected by the mid-century future (depending on the rate of future greenhouse gas emissions). Predicted changes in rainfall are less clear. The majority of models predict a long-term decrease in average annual rainfall, while a minority of models predict that certain areas (particularly in the sub-tropical, high rainfall regions of Kwa-Zulu Natal, Limpopo and Mpumalanga provinces) may experience increased intensity of rainfall and/or unusually high rainfall events.

Most climate projections, particularly under a scenario of unabated greenhouse gas emissions, suggest that southern Africa will be both warmer and drier by the end of the century. The general increase in average temperatures will be characterised by increases in the number of very hot days and heat waves. The effect of high temperatures combined with reduced rainfall, prolonged dry spells and droughts will result in multiple negative impacts on agriculture and related sectors such as water, biodiversity and human health.

The overall impact of climate change on agriculture and other land-based livelihoods, as well as the potential options to cope and adapt, are highly context-specific.

All scenarios considered in the provincial case studies indicated that multiple market-oriented value chains are highly vulnerable to the combined effects of heat and water stress. Direct negative impacts will include reduced annual production, quality and shelf-life of horticultural products (including high-value export produce). Production of various livestock products is also likely to be constrained, through direct stress impacts on animals as well as indirect effects such as forage/pasture availability and pests and disease.

Possible scenarios for the effects of climate change on smallholder farming systems described in the four provincial case studies, include long-term negative effects such as decreased crop and livestock production; loss of livestock and productive assets; decreasing land value; loss of agricultural jobs; landscape/district-level changes in patterns of land use and cropping; landscape/district-level changes in size and composition of livestock herds, grazing resources and land use.

Climate change will have a range of impacts on South Africa's terrestrial ecosystems and biomes. In particular, the grassland biome is likely to become increasingly degraded and fragmented, and may be replaced by semi-arid Savanna, Nama- and Succulent Karoo. The shift or reduced range of certain biomes is likely to have multiple secondary effects on the sectors (eg. livestock production) that rely on the ecosystem services provided by these biomes. In the long-term, the combined effects of reduced rainfall and declining crop productivity are likely to promote a large-scale shift in the smallholder farming sector, with a decreasing importance of crop cultivation and increased emphasis on livestock production. It is anticipated that the expansion of the Savanna, Succulent Karoo and Nama Karoo biomes will be accompanied by a gradual shift towards livestock, particularly in favour of hardy, locally-adapted small ruminants (goats, sheep). The transition of the national livestock herd towards small ruminants may result in unforeseen ecological impacts but will simultaneously create new opportunities and niches in emerging value chains based on small livestock.

Given the current and future vulnerability of South Africa's agricultural sector, proactive adaptation interventions are required to support the response of small-scale farming communities to climate change and variability. A wide variety of adaptation options are available to support smallscale and subsistence farmers to respond to the risks posed by climate change, including measures based on, *inter alia*:

- farm management and technology;
- financial instruments;
- diversification on and beyond the farm;
- government interventions; and
- knowledge management and networks.

However, it is noted that many effective adaptation technologies are capital-intensive and require periodic maintenance, or are best supported with access to training, skills, or support networks. Consequently, there will be an urgent need to provide farmers with sustained support, resources and capacity-building to ensure that effective, locally appropriate adaptation measures can be sustained.

From the perspective of potential long-term climate change impacts on land reform and rural development, several key areas of concern are identified and discussed in the paper. A broad risk to land reform and rural development is that sustained long-term climate change impacts may undermine the production of specific commodities to the point that other actors (e.g. processors, commercial farmers) leave the value chain. These outcomes may result in a decline in the local value of agricultural lands, potentially leaving smallholders and land reform beneficiaries 'stranded' in an obsolete and unsustainable value chain. In the long term, sustained climate change impacts that undermine the production of a given commodity will act as a barrier to the growth and development of aspiring market-oriented smallholders and small-scale agri-businesses. Finally, from the perspective of food security and nutrition, climate change is expected to cause multiple negative impacts on subsistence-oriented households that are mainly focused on production to support household food needs. It is strongly recommended that policy measures, focused on the impacts of climate change on the smallholder farming sector, distinguish between the impacts, risks and needs of market-oriented versus subsistence-oriented farmers.

1 Introduction

Undertaken in support of the ongoing UWC-led study "Employment-intensive rural land reform in South Africa: policies, programmes and capacities", the following review paper considers the potential impacts of climate change on smallholder farming systems in South Africa, with particular consideration to the socio-economic impacts of climate change on small-scale systems of agricultural production, in communal areas and on farms transferred through land reform. In particular, the paper informs the policy implications of climate change on the feasibility and sustainability of small-scale farming systems in South Africa, as practiced by black farmers in communal areas and on farms transferred thorough land reform.

The main emphasis will be on the farming systems of market-oriented and surplus-producing smallholders (utilizing mainly family labour) and small-scale commercial farmers (employing wage labourers) for commodities including livestock products, fresh produce (vegetables and fruit), and sugar cane. The paper includes specific consideration of four pilot study sites (Matzikamma and the Western Cape; Greater Tzaneen and Limpopo; Sakhisizwe and the Eastern Cape; Inkosi Langalibalele and KwaZulu Natal) and the associated local value chains/commodities.

It should be emphasised that this review paper cannot, and does not intend, to provide an accurate prediction of the likely effects of climate change in each study region. As the reader will note, a range of potential scenarios should be considered in each site-specific context, all of which are possible and none of which are certain. Rather, the intention of this paper is to provide context for discussion and inform policy recommendations with an improved understanding of the potential future climate scenarios and resulting socio-economic impacts to be considered.

The following section (Context – climate change and potential impacts on agriculture) aims to introduce a preliminary framework for conceptualising the impacts of climate change and the range of potential future climate scenarios to be considered. Subsequently, Section 3 (Observed and predicted trends for climate change in South Africa), provides a summary of recent observations and updated projections for future climate change in South Africa, including the four pilot study sites (Matzikamma and the Western Cape; Greater Tzaneen and Limpopo; Sakhisizwe and the Eastern Cape; Inkosi Langalibalele and KwaZulu Natal, where information is available). Section 4 discusses the range of potential socio-economic impacts of climate change on the study region and resultant implications for rural development and land reform, within a framework of uncertainty and multiple future scenarios. Finally, Section 5 will consider the potential opportunities and adaptation options for each study region, including strategies to reduce exposure or increase resilience to climate risks.

2 Context – Climate Change and potential impacts on agriculture

As a result of the reliance of all crop and livestock production systems on predictable, adequate climatic conditions and functioning ecosystems, agriculture is widely considered as being among the most vulnerable sectors to the potential effects of climate change. Even without consideration of the unpredictable future impacts of climate change, the relationship between historical variability in climate, and the resultant impacts on staple crops, can be easily discerned in annual crop production statistics throughout the Southern African region (for example, through comparison of annual maize harvests in contrasting El Nino and El Nina cycles). The impacts of climate variability or unexpected climate shocks (such as droughts, flash floods, heat waves or hail storms) on land-based economic activities and associated livelihoods can be severe, both as a result of effects on critical natural resources such as soil and water, as well as on the production, quality and value of crops and livestock.

The overall impact of climate change on land-based livelihoods is a complex outcome of multiple stresses and sensitivities, and is highly specific to local context. Most farming systems are characterised by a high degree of local specialisation, having evolved within a specific local economic, environmental and climate context. Each has developed to incorporate a set of activities and coping mechanisms[1] based on past experiences. However, these systems are vulnerable to shocks such as rapid socio-economic change, environmental degradation and unpredictable or extreme weather. Well-established coping mechanisms may become less effective or even undesirable, while emerging approaches and new technologies may be inaccessible without significant capital, skills and/or programmatic assistance. Therefore, the specific vulnerabilities and risks faced by smallholder farmers, as well as the potential options to cope and adapt, are highly context-specific and not easily generalised.

2.1 Context of climate change and complexity of predicted impacts on agriculture

Agro-ecological systems are highly dynamic and sensitive to unforeseeable socio-demographic, political and market-related factors as well as a matrix of environmental i.e. climatic and bio-geographic factors. Consequently, the potential impacts of future climate changes on a given farming system or community – for example, direct impacts on the productivity of these systems, and the resulting long-term changes in land use and ownership – are inherently unpredictable and subject to increasing complexity across the following 'order' of impacts, listed below.

1st order impacts: these include predicted changes to basic climatic parameters e.g: increased temperatures, decreased/increased volume of annual rainfall, changes to the timing or duration of the rainy season.

2nd order impacts: these include the predicted changes to physical and chemical processes that regulate the agro-ecological environment, resulting from the 1st order impacts e.g. reduced volume of rainfall at the watershed/catchment level, increased rate of evapo-transpiration of water.

3rd order impacts: the cumulative impacts of 1st and 2nd order impacts on ecosystems and the biotic environment e.g. effects of reduced rainfall and increased soil erosion on water quality in river systems, processes relating to soil nutrient cycle and fertility, the effect of increased temperatures and water stress on productivity of crops, livestock, sensitive grazing areas, future distribution of common pests and diseases.

4th order impacts: the final "knock-on" effect of summed climate change impacts on farming households and communities. These may include impacts such as poor health and nutrition, loss of income and livelihoods, entrenched poverty, social conflict and rural migration. The latter category of impacts is likely to interact strongly with other drivers of change (e.g. economic, political and technological factors) at local to global scales.

The categorisation of impacts listed above is suggested as a useful framework to conceptualise the possible effects of climate change on South Africa's diverse smallholder and subsistence farming sector, where each successive 'order' of impact is increasingly unpredictable and uncertain (i.e. impacts of the 1st order can be predicted with the highest degree of certainty, while 4th order impacts can be predicted with the lowest degree of certainty).

A selection of the observed and predicted trends for climate change in South Africa are summarised in Section 3. The majority of the climate predictions available in the scientific literature are at the 1st and 2nd order e.g. changes to temperature and rainfall, from within which a number of possible, and

[1] e.g. land preparation techniques; choice of crop and livestock combinations; timing of activities such as planting, weeding, harvest.

sometimes contradictory, future climate scenarios can be considered (e.g. “Scenario 1: hotter and drier” vs. “Scenario 2: hotter and wetter”). The potential scenarios for 3rd and 4th order impacts of climate change on the pilot study regions will be explored in Section 4. Potential approaches to minimise the impacts and adapt to the potential future climate will be considered in Section 5.

3 Observed and predicted trends for climate change in South Africa

3.1 Observed changes at national level

Studies of historical climate trends in South Africa show that the country has experienced widespread and statistically significant temperature increases over the last century (MacKellar, New and Jack, 2014; Kruger and Nxumalo, 2017; DEA, 2018). The strongest warming was observed in the drier western parts of the country, in the Western Cape and Northern Cape, and in the Eastern parts of the country, in Limpopo and Mpumalanga, and extending southwards to the coastal areas of KwaZulu Natal (DEA, 2013; Kruger and Nxumalo, 2017; DEA,2018). The observed rate of warming in these parts of the country has been 2°C per century – in the order of twice the global average. Maximum daily temperatures increased significantly in the Western Cape, east coast of KwaZulu Natal and Gauteng, while the central interior experienced a relatively small warming trend (DEA, 2018), and there has been a general increase in extreme warm events and a decrease in extreme cold events across the country (Kruger and Nxumalo, 2017).

The most evident trend for rainfall over the period 1921-2015 is a statistically significant increase in rainfall over the southern interior regions, extending from the western interior of the Eastern Cape and eastern interior of the Western Cape northwards into the central parts of the Northern Cape (Kruger and Nxumalo, 2017; DEA, 2018). This trend is attributed to an increase in summer rainfall over the southern interior of the country (Kruger and Nxumalo, 2017). Extreme daily rainfall events also increased in these areas, as well as in the North West, Free State and Gauteng. Recorded trends in annual average rainfall are statistically insignificant for the remainder of the country, except in the northern parts of the Limpopo Province, which experienced statistically significant negative trends in rainfall over the last century. This negative trend is largely attributed to decreasing trends in autumn rainfall in Limpopo (DEA, 2018). Most of the country experienced increases in the intensity of daily rainfall, conforming to global results (Kruger and Nxumalo, 2017).

3.2 Future projections

Climate change projections indicate that many of these trends may continue. A number of studies have been conducted to determine the projected climate change futures for South Africa under various greenhouse gas (GHG) concentration scenarios, known as Representative Concentration Pathways (RCPs)[2] (Kruger et al, 2019). Under a moderate GHG concentration scenario (RCP4.5) for the mid-future period of 2040-2060, temperature increases of between 2 and 3 °C are projected for the country, with the greatest warming expected to occur over the western interior regions. Projected warming under RCP8.5 (a low mitigation, and high GHG concentration scenario) by the near-future ranges from 3-4 °C over the western and central interior, and exceeds 4 °C over some of the western parts of the country. For the far-future period of 2080-2099 under RCP8.5, temperatures are projected to increase by 4°C over the entire interior of the country, and by as much as 6°C in the western, central and northern parts of the country (DEA, 2013; DEA, 2018). These drastic temperature increases will likely be associated with major increases in the number of very

[2] A Representative Concentration Pathway is a greenhouse gas concentration trajectory adopted by the IPCC for climate modelling and research. The two most commonly used RCPs are RCP 4.5, where emissions peak around 2040 and then decline (this is a moderate concentration scenario), and RCP 8.5, where emissions continue to rise throughout the century (a high concentration scenario).

hot days, and heat-wave days, with devastating impacts on water, agriculture, biodiversity and human health. Temperature increases under the moderate emissions scenario of RCP4.5 are still likely to be drastic by the end of the century, but significantly smaller, and may be constrained to 2.5 to 4°C in the interior. Nevertheless, even under a moderate GHG concentration scenario, South Africa is likely to experience a comparatively large (relative to the global average) increase in near-surface temperatures (DEA, 2018).

Projections for precipitation are less certain in terms of direction and magnitude. For the mid-future under both RCPs (high and low emissions scenarios), most projections show decreased rainfall, particularly under RCP 8.5. However, under RCP4.5, a number of projections show increased rainfall through to the end of the century over the eastern and central interior regions. The majority of projections for the end of the century under RCP 8.5 show significant drying over much of southern Africa. Extreme convective rainfall events are also projected to increase under RCP8.5 over the interior regions, even in the presence of a generally drier climate. In general, the projections suggest that the southern African region will be both warmer and drier under low-mitigation futures by the end of the century (DEA, 2018).

3.2 Projected ecosystem- and biome-level risks of climate change

Climate change will have a range of impacts on South Africa’s terrestrial ecosystems. The country’s terrestrial ecosystems are delineated into nine biomes, including: Grassland, Fynbos, Succulent Karoo, Albany Thicket, Savanna, Nama Karoo, Desert and Indian Ocean Coastal Belt. Each of the biomes has a specific climate envelope within which it is able to thrive. Climate change induced changes in temperature and rainfall will influence the area in which particular biomes are able to occur and may result in spatial shifts or changes in the extent of biomes, putting stress on the ecosystem and the sectors which are reliant on the underlying ecosystem services. Table 1, below, summarises the predicted climate change impacts and associated agricultural implications for South Africa’s biomes (adapted from South Africa’s Third National Communication (DEA, 2018)).

Figure 1, next page, depicts the potential spatial shifts in South Africa’s biomes under low, intermediate and high emission scenarios. The biomes discussed in Table 1, below, only include those identified as being of significant agricultural importance, and are listed in order of predicted vulnerability to climate change.

Table 1: Risks and trends predicted for South Africa’s climate-vulnerable biomes

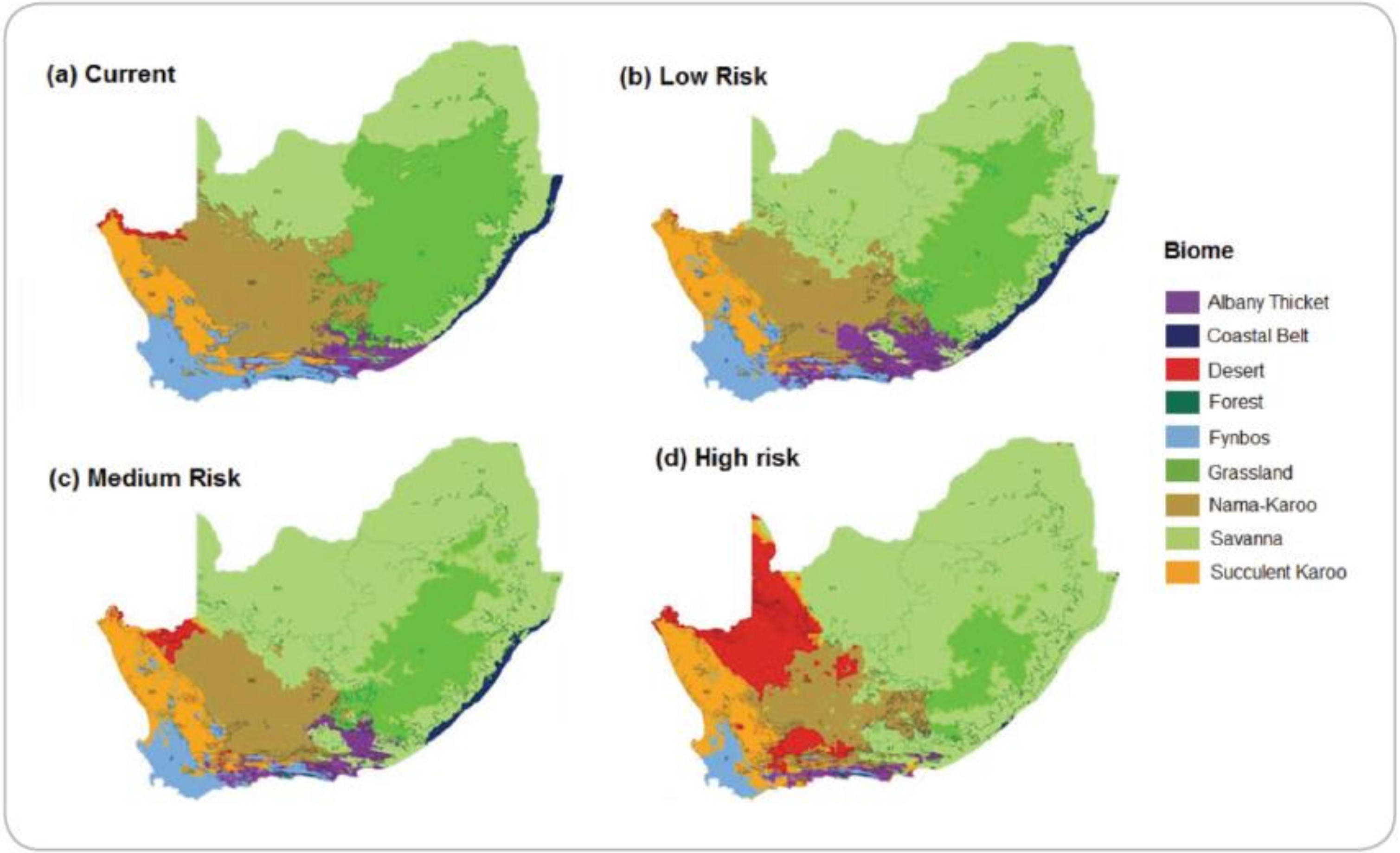
Vulnerability	Biome	Climate risks and agricultural implications
Highest	Grassland	Significant shrinkage of the biome’s spatial area and reduction in the condition of the biome Increased temperature and rising CO_2 levels may increase the cover of shrubs and trees and will result in the invasion by savanna biome Increased opportunities for bush encroachment, invasion of woody invasive alien plants, with major implications for grazing and water delivery from highland catchments Mixed effects on biodiversity C_4 grasses likely to have a competitive advantage over C_3 grasses. C_3 and C_4 grassland dynamics need to be better understood in terms of their impact on the carrying capacity of grasslands for livestock *Eragrostis curvula,* one of the most important pasture grasses, expected to undergo loss in production area in the eastern parts of its current range, but significant increases in climatically suitable areas in the west. Yields to decrease by ~10% in an arc north to southeast around the core current growth areas, and to increase by 4-5 t/ha/season within the core area.

Vulnerability	Biome	Climate risks and agricultural implications
		Implications: while there may be an expansion in area that is climatically suitable, the area of actual production may decrease. Towards the mid-Century, Kikuyu yields projected to decrease in an arc from the northwest through to the southeast around the core suitable area, but to increase by up to 3–5 t/ha/season in the core area. Towards the end of the Century, the climatically suitable area for Kikuyu likely to become spatially more compact. Increased temperatures may increase range or season of pathogens, pests and vectors of crop/livestock diseases Increased temperatures and increased evaporation will increase livestock water requirements and incidence of heat stress. This may hinder sectors such as dairy Intense rainfall coupled with overgrazing will intensify soil erosion and land degradation Increased intensity and frequency of fires
High	Fynbos	Increased intensity and frequency of fires Increased risk of invasive alien species. In lowland ecosystems, invasive grasses may benefit from higher CO_2 availability and outcompete indigenous species. Unpalatable invasive grasses will reduce availability or quality of grazing. Reduced rainfall and groundwater recharge will negatively affect crop production in grain, deciduous fruit and other horticultural crops The north-eastern regions of the biome projected to be replaced by Albany Thicket and Succulent Karoo, under all climate scenarios. Winter wheat yields projected to increase slightly by mid-century, but decrease towards the end of the century.
Medium	Nama Karoo & Desert	Large portions of Nama Karoo will be replaced by Savanna and Desert biomes Temperatures expected to exceed comfort thresholds for most species of livestock High temperatures, coupled with unseasonal or extreme rainfall events, may increase incidence of pests and pathogens in particular areas Possibility of higher frequency of extreme rainfall events has implications for livestock and crop production, as well as disaster management
	Succulent Karoo	Extreme high temperatures will constraint livestock productivity Higher temperatures may result in reduced range of succulent plant species Reduced rainfall, increased frequency of drought may reduce forage quality and quantity
	Savanna	Extreme high temperatures will make domestic livestock production increasingly difficult Increased summer rainfall and rising CO_2 will increase bush encroachment and lead to expansion of the biome into the Grassland and Indian Ocean Coastal Belt biomes Rising CO_2 will also lead to high risk of alien woody plant invasion, particularly in highly degraded rangelands
	Albany thicket	This biome is least threatened. Only under high risk climate scenarios will it be negatively impacted in terms of its range (see Figure below). Extreme high temperatures will make livestock production increasingly unviable Increased summer rainfall and rising CO_2 will cause encroachment of savanna-like species in the northeast More intense rainfall will cause soil capping, flash flooding, erosion and poor recharge

The projections of biome shifts under low, medium and high risk climate scenarios[3] to ~2050 are illustrated in the figure below.

[3] i.e. future scenarios which assume a low, intermediate or high rate of future CO_2 emissions

Figure 1: Predicted shifts in South African ecosystems and biomes as a result of climate



Source: South Africa's Third National Communication, DEA, 2018

3.3 Climate change in the study regions

Observed changes in climate and future projections for the 4 regions included in the broader CBPEP/GTAC project are described below.

3.3.1 Matzikamma and the Western Cape

The sub-sections below summarise the observed (3.4.1.a) and future predicted (3.4.1.b) climate change trends in the Matzikamma municipality and the Western Cape province. The potential impacts of climate change on agriculture are analysed and presented in the following section (3.4.1.c, next page), following the convention of ascending "1st to 4th" order of impacts (described in Section 2, above). Potential impacts identified from the literature review are signified by red-coloured reference notes, which are reflected in the corresponding numbered references in a chart of impacts (Figure 2, Section 3.4.1.c, below).

Observed changes

The Western Cape has experienced an alarming rate of temperature increase of more than 2°C in some locations over the period 1931-2015 **[1]**. Other recent trends in the province, as observed using the weather station network, include higher maximum and minimum temperatures **[1]**, an increase in the occurrence of extreme warm events **[1]**, an increase in the number of days with extreme rainfall **[2]**, and reductions in the number of rain days in autumn and summer in some areas **[3]** (Western Cape Government, 2016; DEA, 2018). Recent climate-related extreme events include extended drought periods **[3]** (notably the 2015-2017 multi-year drought), flash floods **[4]** caused by torrential rains that were linked to direct economic losses of over R5 billion, and hailstorms that resulted in significant crop yield- and job-losses (Western Cape Department of Environmental Affairs and Development Planning, 2013; Wolski et al, 2018).

Future projections

Climate modelling for the Western Cape shows that the province will almost certainly experience increased temperatures **[1]**, within the range of 1.5 °C to 3 °C by 2040-2060, depending on the model and location. In comparison, rainfall projections are less certain. Almost all Global Circulation Models project some degree of reduced rainfall **[3]** across the province in the 2040-2060 period. However, downscaled projections show high uncertainty and stronger indications of increased orographic (mountain) rainfall in spring **[2]**. As a result, both increased and decreased rainfall should be considered as possibilities for the Western Cape. Regardless of the uncertainty in the direction of change in rainfall, it is likely that climate change will result in shifts in locally important climate systems, including a poleward contraction of storm tracks in the winter, changes in the spatial distribution of rainfall, as well as changes in seasonal cycles and rainfall extremes. These changes pose significant threats to several agricultural commodities in the Western Cape (Western Cape Government, 2016).

The Matzikamma Local Municipality is expected to experience medium to high range warming **[1]**, as well as an increase in the frequency and severity of droughts **[3]**, floods **[4]** and wildfires **[5]**. While there are no projections for rainfall available at the local municipality level, the projected increases in average temperature will likely cause evaporation rates to increase, exacerbating water insecurity in this already water-scarce area **[6]**. This is particularly concerning given that much of the groundwater in the region is of poor quality given high levels of salinity **[7]** (DEA, 2018).

Potential impacts of climate change on agriculture

At least two potential future climate scenarios are projected for the Western Cape. For simplicity, these can be summarised as:

- Scenario 1, "Hotter and Drier"; and
- Scenario 2, "Hotter and Wetter".

It should be noted that these two scenarios are not necessarily mutually exclusive, and both may occur simultaneously within different districts or regions of the Western Cape. Furthermore, an intermediate scenario (one in which periods of extended drought are offset by extended wet spells or torrential rainstorms), should be considered. The Western Cape's recent experiences of the sustained drought in the period ~2016–2018 are suggested as a useful basis for assessing potential future impacts of climate change under Scenario 1, which is considered further below. These potential impacts are described in the text below (signified by red-coloured reference numbers), and represented graphically in the Impacts Chart (Figure 2, next page).

Scenario 1, "Hotter and Drier": Decreased average annual rainfall, increased frequency and severity of droughts

The widespread effects – environmental, socio-economic and political – of the sustained droughts in the Western Cape (~2016–2018) provide a useful basis for considering future scenarios of climate change. From the perspective of the Western Cape's agriculture sector, the impacts of the drought experienced by farmers and water users across the province may provide illustrative examples of the potential effects of climate change on various crops and value chains, as well as the 'knock-on' effects on surrounding communities. It should be noted that the perceived and observed impacts of the drought cannot necessarily be attributed entirely to climate change (where factors such as governance and management of water resources, on-farm practices, normal inter-annual variability in rainfall are also likely to influence outcomes) but are still useful examples of the potential impacts of long-term climate change.

The impacts of the 2016–2018 drought had multiple negative effects on sectors including livestock production, cereals and grains, various temperate fruits, table grapes and wine grapes. For example, fruit farmers experienced significant drought **[8]** and heat-stress **[9]** related impacts on fruit quality **[10]** and exports **[11]** in the 2016, 2017 and 2018 seasons (Zwane, 2019). Statistics from VinPro's annual report[4] state "The 2019 wine grape crop … has shrunk for the second consecutive year and 2019 represents a record low since 2005" **[10]**. In the case of the Olifants River region, VinPro statistics indicate that grape producers were affected particularly negatively, noting that in the 2019 season "*a second consecutive smaller harvest following a record low in 2018, due to the after-effects of the drought*". Commercial livestock farmers had to procure additional feed due to drought-induced shortages of fodder **[12; 13]**.

Satellite imagery[5] of farmland in the Lower Olifants and Groenland Water Management was used to analyse changes in biomass growth and assess immediate and long-term impacts of the Western Cape's drought. While the study found that farms in the Groenland area received adequate rainfall and did not experience dramatic decreases to production, the Lower Olifants area was limited to ~20% of the normal quota for irrigation water**[6]**, and as a result experienced a decline of ~25% of plant growth compared to the previous year**[10]**. Furthermore, analysis of the changes in land cover

[4] http://vinpro.co.za/wp-content/uploads/2019/05/SA-WINE-HARVEST-REPORT-2019_6May2019.pdf

[5] Based on data gathered via the www.fruitlook.co.za web portal

in the Lower Olifants region in the period 2017 – 2018 estimated that as many as 200 fields (accounting for ~5% of the vineyards and orchards in the area) were cleared over a one-year period **[14]**, presumably by farmers who could no longer afford to maintain these lands[6]. In the mid- to long-term, the implications for drought- or other climate-related impacts on agricultural systems may include a decline in the returns and valuation of agricultural land **[15]**, and resulting changes in land use and ownership at the landscape scale **[16]**. In addition, land use change is also likely to be driven by changes in crop or cultivar selection as poorly adapted crops become unviable and alternative, climate-resilient crops are identified.

The coordinated efforts of water users to respond to the water supply crisis – ranging from individual urban households, industrial users and agricultural Water User Associations – provides several discussion points for the possible implications for future water management and governance. For example, at the height of the City of Cape Town's water crisis (~2018), the Groenland Water Users Association (largely representing commercial fruit growers in the Elgin and Grabouw areas) voluntarily agreed to forego the use of ~7million cubic meters of water, which was subsequently pumped to the Steenbras Dam for use by the City's residents. This case provides a positive example of the potential impacts of collective action as well as a reminder of the need for well-functioning structures to represent, organise and communicate between disparate groups of stakeholders. However, this case also demonstrates that agriculture and other water-intensive sectors should anticipate increasing competition with other water users and reduced allocations for irrigation **[6]**.

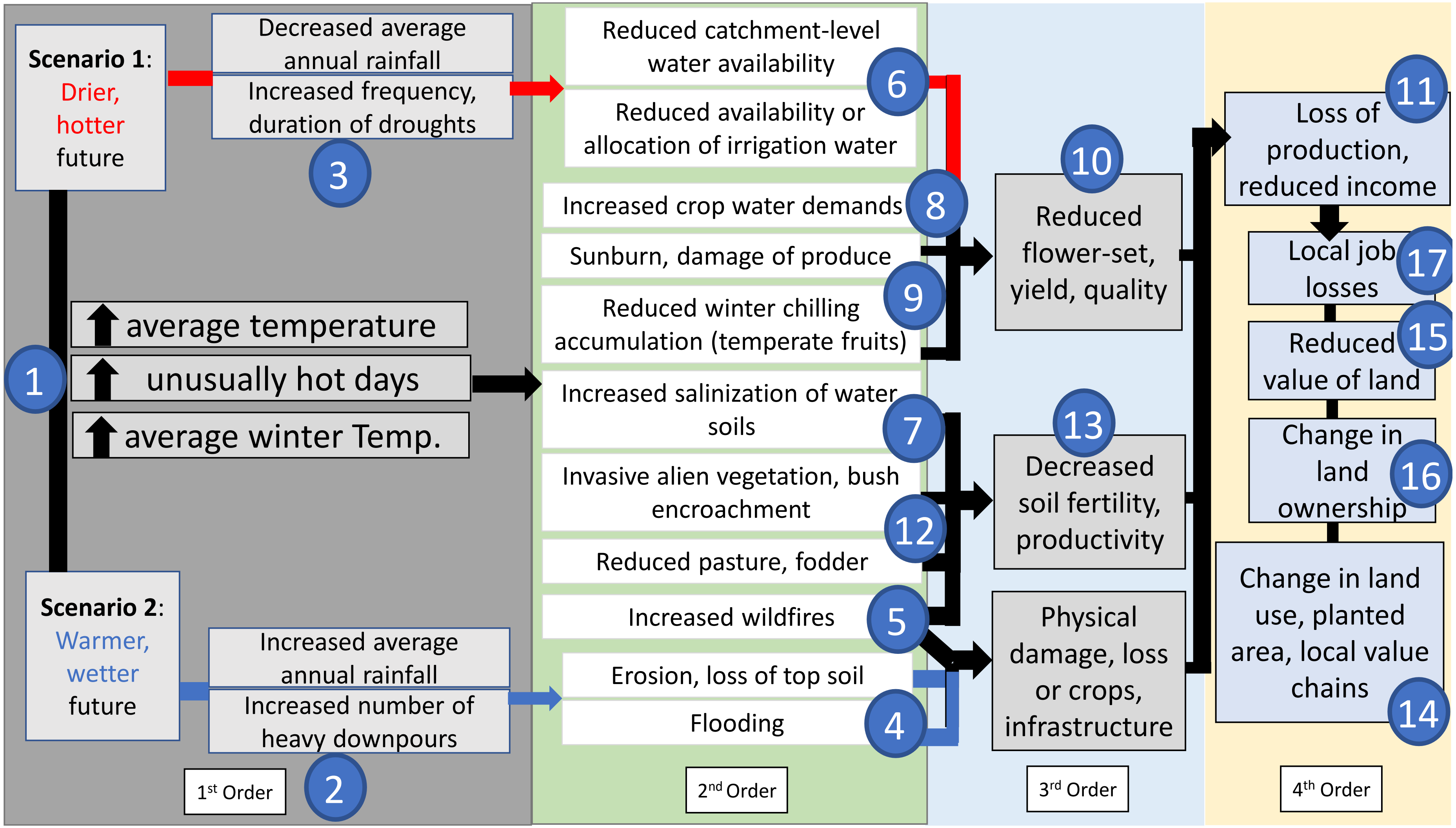
In terms of macro-economic impacts of the 2015-2018 drought, the Western Cape's Department of Agriculture estimated resultant losses of up to ZAR6 billion **[11]**, in addition to a loss of +-30,000 jobs from the irrigated farming sector[7] **[17]**. In the vicinity of Ceres, an 80% reduction in potato production and 50% reduction in onion production **[11]** translated into a R40 million loss in wages to seasonal workers **[17]** (Zwane, 2019).

Summary: Potential impacts of a hotter, drier future on agriculture in Western Cape and Matzikamma
The primary drivers of future climate change impacts are the combined effects of: i) increased average temperatures, increased frequency of heat waves; and ii) reduced average rainfall, increased frequency of droughts. Crop water demands will increase relative to historical averages, while stored water resources will be increasingly constrained at the catchment level, limiting the availability of irrigation. Heat and water stress, particularly during unusually hot periods, will result in impacts on horticultural and fruit crops such as poor fruit quality, sunburn and resultant impacts on shelf-life and marketability. At the landscape scale, sustained heat stress and reduced rainfall will have multiple unpredictable ecological impacts on soil and vegetation – for example, alterations to the soil nutrient cycle and organic matter content, reduced production and quality of pasture and forage resources, increased soil erosion, and bush encroachment and invasive alien vegetation.

The combined effect of these impacts will reduce the productivity of most crops, especially where supplementary irrigation is not practiced. The resultant decreases in production and quality of produce will reduce annual income at the farm and district level. If this effect is sustained, reduced farm income results in a loss of permanent and seasonal jobs and a decline in the value of

[6] https://www.wineland.co.za/what-was-the-impact-of-the-2017-18-drought-a-case-study-using-fruitlook-data/
[7] DoA (2017). Informing the Western Cape agricultural sector on the 2015 – 2017 drought, A Drought Fact Sheet. Western Cape Department of Agriculture, November 2017 http://www.elsenburg.com/sites/default/files/services-at-a-glance-forms/2017-12-13/drought-fact-sheet-final.pdf

agricultural land. Specific crops or varieties which are unproductive or poorly suited to future climate conditions will be removed – the latter areas may be replanted to alternative climate-resilient varieties, converted to alternative land uses (e.g. livestock, ecotourism) or left fallow and unproductive. The further societal impacts of decreasing land value, loss of agricultural jobs, and landscape/district-level changes in patterns of land use and cropping, depicted in the Impact Chart (Figure 2), are considered further in the following section.



Scenario 1: Drier, hotter future
Decreased average annual rainfall
Increased frequency, duration of droughts
3
average temperature
unusually hot days
average winter Temp.
1
Scenario 2: Warmer, wetter future
Increased average annual rainfall
Increased number of heavy downpours
2
1st Order
Reduced catchment-level water availability
6
Reduced availability or allocation of irrigation water
Increased crop water demands
8
Sunburn, damage of produce
9
Reduced winter chilling accumulation (temperate fruits)
Increased salinization of water soils
7
Invasive alien vegetation, bush encroachment
12
Reduced pasture, fodder
Increased wildfires
5
Erosion, loss of top soil
Flooding
4
2nd Order
10
Reduced flower-set, yield, quality
13
Decreased soil fertility, productivity
Physical damage, loss or crops, infrastructure
3rd Order
11
Loss of production, reduced income
Local job losses
17
Reduced value of land
15
Change in land ownership
16
Change in land use, planted area, local value chains
14
4th Order

3.3.2 Greater Tzaneen and Limpopo

Observed changes

The Limpopo Province is already experiencing changes to its climate. During the period 1931-2015, a temperature increase equivalent to a rate of 1°C per century was recorded, with the number of hot days increasing at a rate of ~1 day per decade over the same period **[1]**. Weather stations in the northern parts of the province have recorded statistically significant decreases in annual precipitation (DEA, 2018). Trends perceived by smallholder farmers in the Mopani (under which Greater Tzaneen falls) and Vhembe District Municipalities include prolonged droughts **[2]**, heat waves **[1]**, increased dry seasons and reduced rainfall seasons over the past decade. The perceived impacts of recent climate variability includes new pest invasions and crop disease outbreaks, human disease outbreaks **[3]**, frequent livestock deaths, crop failure, reduced yield and resulting food insecurities **[4]**.

Farmers in the area reported that over the last ten years, low rainfall or drought periods have resulted in decreased storage of water for irrigation**[5]**. A trend towards delayed onset of the rainfall season results in challenges to the timing of crop establishment, where many farmers have resorted to delaying their planting seasons until it is too late in the season to plant**[6]** (Ubisi et al, 2017). This experience is similar to the perceived negative impacts on crop yields associated with higher temperatures and drought reported by potato and cabbage farmers in Limpopo and Gauteng (Elum, Modise and Marr, 2017). In October 2019, in the Mopani District of Limpopo, the effects of drought were so severe that the Tzaneen Dam level was down to 8%, and the allocation of water to farmer members of the Letaba Water Users Association was reduced to 30% of the usual allocation (Bunce, *unpublished*).

Future projections

Climate change models suggest that many of these observed and recorded climatic trends in the Limpopo Province will continue. Temperatures are projected to increase by a range of ~1-2°C, or up to ~2-5°C between 2040 and 2060, depending on the assumed future greenhouse gas emission scenarios. By the period 2080-2100, temperatures are projected to increase by 3-6°C, or up to ~ 4-7°C, depending on the future emission scenarios **[1]** (DEA LTAS climate trends, 2013). There is less certainty with regard to rainfall projections in the province, with some models projecting decreases in rainfall, and others predicting increases (DEA Mopani, 2016; LEDET, 2016). The majority of models suggest that the province will become drier with increased occurrence of El Nino-induced drought events **[2]**. This would render conditions in Limpopo increasingly less viable for dryland agriculture and livestock production. Given the high percentage of small-scale farmers dependent on rain-fed agriculture in the region, Limpopo has been identified as the most vulnerable province in South Africa in terms of climate change impacts on agriculture. Alternative projections produced by a small minority of climate models project a wetter future for the province due to the greater frequency of intense tropical lows and cyclones making landfall **[7]**. This would result in periodic devastating flood effects (LEDET, 2016; DEA TNC, 2018) **[8]**.

In the Mopani District Municipality, within which the Greater Tzaneen Local Municipality falls, climate change is predicted to result in a decrease in the total suitable area for certain crops, notably including maize, while conditions for other crops such as lemons will become totally unviable. Increased temperatures may also result in a decline or loss of fragile grassland areas within the municipality as well as a loss of livestock (LEDET, 2016).

Potential impacts of climate change on agriculture

As described above, at least two potential future climate scenarios are projected for the Eastern Cape. For simplicity, these can be summarised as:

- Scenario 1, "Hotter and drier"; and
- Scenario 2, "Warmer with more flood events" (minority of models).

Following the convention of the descending order of impacts described in Section 2, the 1st , 2nd and 3rd order impacts identified from the literature review (above) are presented graphically below, considering both Scenarios 1 and 2. Given that the main focus of the study area's agricultural sector is sub-tropical fruit and nuts, particular attention has been given to the impacts on macadamia and avocado production.

Avocado

Higher temperatures and increased drought incidence have already had an observed impact on avocado production in South Africa, with famers reporting early maturation times and reductions in yield **[9]** (Randela, 2018).

Temperature can affect avocado production in many ways. A reduction in diurnal temperature difference (the difference between daytime maxima and nighttime minima) decreases the chances of male and female flower parts being open at the same time **[10]**, thus reducing the scope for successful pollination and fruit formation **[11]**. As already observed in South Africa, warmer temperatures may result in earlier maturation of fruit, and may reduce the period that fruit can be stored on the tree before quality declines **[9]**, thus resulting in a shift of harvesting time **[6]**. An increase in the number of heat-stress days **[12]** and resultant increase in crop water demand **[13]** may result in multiple adverse effects on the crop, particularly if heat and water stress coincides with the flower or fruit development stages. Impacts include *inter alia* reduced fruit size **[11]**, increased sunburn damage **[14]**, pollination failures, reduced fruitset, variable size or quality **[11]**, and reduced retention of fruit/pollinated flowers **[9]** (Randela, 2018; Howden, Newett and Deuter, 2005).

Conditions associated with Scenario 2 **[7]**- more intense rainfall events, coupled with warmer temperatures - increase the risk of spread and proliferation of *Phytophthora cinnamomi,* the agent that causes phytophthora root rot (Howden, Newett and Deuter, 2005) **[15]**. This disease is the most severe and damaging disease in avocado plantations in South Africa, and its effects may cripple production.

Macadamia

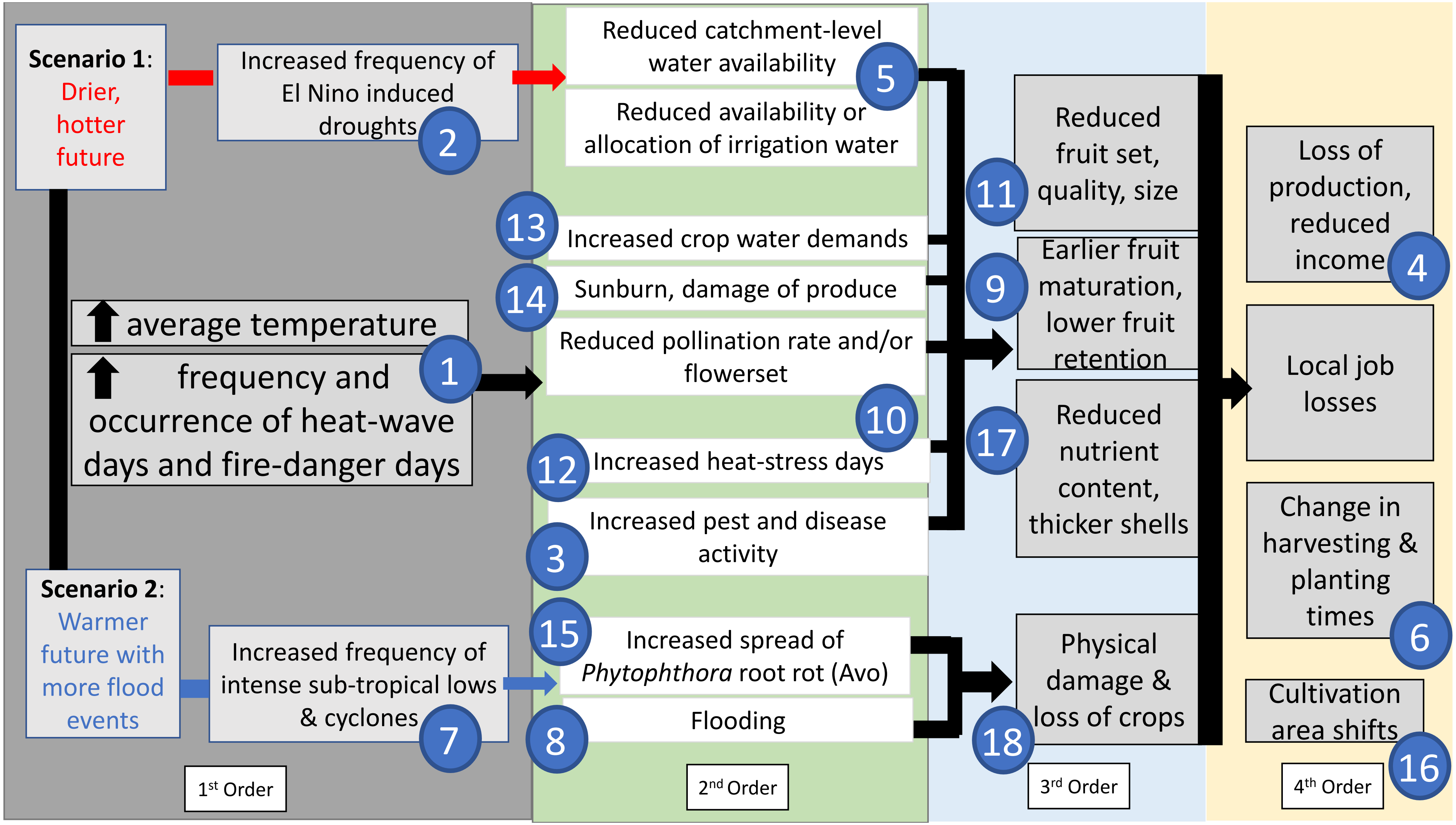
Despite the economic importance of the industry, little is known about the potential vulnerability of macadamias to the impacts of climate change, and as a result, the implications for the future sustainability of South Africa's production sector are unclear. In the international literature, there are only a handful of studies that have assessed climate change impacts on the crop, and consistently indicate shifts in areas that are considered suitable for establishment **[16]**. For example, studies in Nepal (Barrueto et al, 2018), eastern Australia (Powell, Accad and Shapcott, 2014) and Hawai'i (Gross, 2014) have generally predicted a shift in suitable niches towards areas characterised by relatively high precipitation and lower temperatures, typically at higher elevations.

Generally, macadamias require cool temperatures for flowering to be induced (Barrueto et al, 2018). As a result, gradual increases in average temperature and increased frequency and occurrence of heat-wave days **[1]** may result in reduced set and formation of flowers **[11]**. Other potential physiological impacts of high temperatures include lower kernel recoveries (i.e. thicker shells), reduced kernel nutrient content [17], the shedding of fruit [9], and depressed vegetative growth, which potentially reduces production, particularly under conditions of moisture stress. With sufficient water availability, however, trees might still be able to produce fairly good crops. At the same time, the soil must not be waterlogged, and flooding (as expected under Scenario 2) occurring over more than five consecutive days can severely damage trees [18] (Barrueto et al, 2018).

Summary: Potential impacts of a hotter, drier future on agriculture in Limpopo and Greater Tzaneen

The primary drivers of future climate change impacts are the combined effects of: i) increased average temperatures, increased frequency and occurrence of heat waves; and ii) increased frequency of droughts. A hotter, drier future is the most likely scenario for the Province, but a minority of models predict a warmer future with increased incidence of flood events. Under the hotter, drier scenario, crop water demands will increase relative to historical averages, while stored water resources will be increasingly constrained at the catchment level, limiting the availability of irrigation. Heat and water stress will result in a number of impacts on subtropical fruit and nut crops, including a reduction in fruit quality, fruit set and size, nutrient content, and an increase in damage due to sunburn.

The combined effect of these impacts will reduce the productivity of most crops, especially where supplementary irrigation is not practiced. The resultant decreases in production and quality of produce will reduce annual income at the farm and district level. If this effect is sustained, reduced farm income results in a loss of permanent and seasonal jobs and a decline in the value of agricultural land. Specific crops or varieties that are unproductive or poorly suited to future climate conditions will be removed – the latter areas may be replanted to alternative climate-resilient varieties, converted to alternative land uses (e.g. livestock, ecotourism) or left fallow and unproductive. The further societal impacts of decreasing land value, loss of agricultural jobs, and landscape/district-level changes in patterns of land use and cropping, depicted in the Impact Chart below, are considered further in the following section.


Scenario 1: Drier, hotter future
Increased frequency of El Nino induced droughts
2
Reduced catchment-level water availability
5
Reduced availability or allocation of irrigation water
13
Increased crop water demands
14
Sunburn, damage of produce
average temperature
frequency and occurrence of heat-wave days and fire-danger days
1
Reduced pollination rate and/or flowerset
10
12
Increased heat-stress days
Increased pest and disease activity
3
Scenario 2: Warmer future with more flood events
Increased frequency of intense sub-tropical lows & cyclones
7
15
Increased spread of *Phytophthora* root rot (Avo)
Flooding
8
Reduced fruit set, quality, size
11
Earlier fruit maturation, lower fruit retention
9
Reduced nutrient content, thicker shells
17
Physical damage & loss of crops
18
Loss of production, reduced income
4
Local job losses
Change in harvesting & planting times
6
Cultivation area shifts
16
1st Order
2nd Order
3rd Order
4th Order

3.3.3 Sakhisizwe and the Eastern Cape

The sub-sections below summarise the observed (3.4.1.a) and future predicted (3.4.1.b) climate change trends in Sakhisizwe and the Eastern Cape province. The potential impacts of climate change on agriculture are analysed and presented in the following section (3.4.1.c, next page), following the convention of ascending "1st to 4th" order of impacts (described in Section 2, above). Given that mixed farming, with a major focus on livestock production amongst small-scale farmers, is widely practiced across the municipality, the discussion of potential impacts on agriculture is primarily focused on the perspective of livestock producers. Potential impacts identified from the literature review are signified by red-coloured reference notes, which are reflected in the corresponding numbered references in a chart of impacts (Figure 4, Section 3.4.1.c, below).

Observed changes

A lack of long-term data for the Eastern Cape hinders an extensive analysis of the historical trends in temperature and extreme temperature events. However, there is some evidence that strong warming of 2 °C per century over the period 1931-2015 occurred in the western interior of the province [1]. These parts of the province also appear to have experienced statistically significant increases in total annual rainfall as well as an increase in extreme daily rainfall events [2] (DEA, 2018). Impacts of increasing climate variability on the agricultural sector have already been observed in the Chris Hani District Municipality (CHDM), within which Sakhisizwe falls (DEA CHDM, 2018). The area has been impacted by the effects of severe recurrent drought conditions [3], the introduction of water rationing measures, and the recent declaration of a Provincial State of Drought Disaster in 2019/20. Similar conditions have prevailed in other areas of the Eastern Cape. For example, smallholder crop farmers in the Amathole District perceived a drastic increase in temperatures [1] and a decline in rainfall [3] over a ~25 year period, with perceived attendant problems of drought, heat waves, deteriorating soil quality [4], increasingly unsuitable conditions for crop production [4], and increased pest and disease pressure [5] (Popoola, Monde and Yusuf, 2018).

Future projections

Climate change models suggest that temperatures in the Eastern Cape will rise by 1.5°C by 2040-2060, with an associated increase in the frequency and length of hot spells in summer and a decreased frequency and duration of cold spells in winter. This warming trend will be associated with an increase in evaporation and evapotranspiration, with possible impacts on soils and crops. Higher temperatures may also result in a stronger heat low pressure which may result in more intense rainfall events [2], even if long-term annual rainfall totals do not change. An alternative scenario projected by climate models is that these higher temperatures may be accompanied by an increased frequency of dry years, with multi-year droughts occurring more often in the province [3] (DEA TNC, 2018). Despite the negative outlook for climate change impacts in the Eastern Cape as a whole, the CHDM Climate Change Vulnerability Assessment and Response Plan (2018) points to possible positive climate change impacts on agriculture in the Municipality. Based on the 2013 Long Term Adaptation Scenarios Flagship Research Programme's (LTAS) projections of potential increased rainfall in the CHDM area, it is suggested that conditions could become more favourable for enhanced agricultural output of maize, soybean and sugar cane. However, the Vulnerability Assessment and Response plan also points to a possible drier future for the area, which may negatively impact agricultural production in CHDM (DEA, 2018).

Potential impacts of climate change on agriculture

As described above, at least two potential future climate scenarios are projected for the Eastern Cape. For simplicity, these can be summarised as:

- Scenario 1, “Warmer and drier”; and
- Scenario 2, “Warmer”.

Following the convention of the descending order of impacts described in Section 2, the 1st , 2nd and 3rd order impacts identified from the literature review (above) are presented graphically below, considering both Scenarios 1 and 2, with particular consideration to various forms of livestock production.

Although the impact of climate change is projected to be significant, there is limited research regarding the impacts of climate change on livestock production (Descheemaeker et al, 2016; Rojas-Downing et al, 2017). Broadly, climate change is expected to have both direct and indirect impacts on livestock, including changes to the quality and quantity of feed resources [4], vulnerability to livestock pests and diseases [5], heat stress [6] and the availability and quality of water [7] (Thornton, Steeg and Herrero, 2009; Rojas-Downing et al, 2017).

One of the most evident impacts of climate change on livestock production occurs through changes in feed resources [4]. Climate-induced changes in the primary productivity of feed crops, rangelands and pastures, as well as the species composition of the rangelands and pastures, influences feed quality and quantity. This particularly impedes the ability of smallholders to manage dry-season feed deficits with resultant impacts on production and quality of meat, dairy, eggs etc. [8] (Rust and Rust, 2013; Descheemaeker et al, 2016). Increased frequency of extreme events may reduce farm productivity, assets, income and food security [10], increasing the likelihood of smallholders falling into poverty traps (Descheemaeker et al, 2016).

The predicted changes in the Eastern Cape’s mean climate, including increases in average temperature, increased frequency and length of hot spells, and, in the case of Scenario 1, reduced rainfall and prolonged droughts, will affect the availability and quality of water resources [7]. These changes in the availability and quality of irrigation water and livestock drinking water will strongly impact livestock production and the quality of meat, dairy and egg products [8]. Of particular concern under Scenario is the potential for entire herds of animals to be lost to the impacts of multi-year droughts, from which it may take a smallscale farmer several years to recover and restock herds [9] (Descheemaeker et al, 2016). Studies conducted in Borana, in southern Ethiopia have shown that rainfall variability and prolonged droughts have significant impacts on the stability of herd dynamics. The droughts of 1983/84, 1992/93 and 1999/2000 resulted in an average loss of 49% of cattle under communal land use [9], and milk production for household consumption and cattle birth rates were significantly supressed [8] (Tegegn, Assefa and Adene, 2018). Similarly in the Karamoja region in Uganda, pastoralists have perceived reductions in rainfall over the last 10 years [3] (these perceived changes also correspond well with observed climate change trends) and have associated these changes with inadequate water resources and pasture [4], loss of condition or weight of animals [8], death of animals [9], and reduced market prices [10]. The Karamajong pastoralists are responding to these stresses and the recurrent droughts in the region by increasing their mobility and migrating in search of water resources and pasture to sustain their herds [11] (Carabine et al, 2017).

With temperatures projected to rise across the Eastern Cape, it is likely that livestock will experience some degree of heat stress [6]. The response to heat stress and level of tolerance of livestock varies according to species, genetic potential, nutritional status and life stage. Generally, if an animal experiences temperatures outside of its thermal comfort zone, this may result in decreases in forage intake, efficiency of feed conversion, milk production, reproductive performance, fitness and longevity [8] (Thornton, Steeg and Herrero, 2009; Rojas-Downing et al, 2017). At temperatures above 30°C, cattle, sheep, goats and chickens would reduce their feed intake by 3-5% for each unit of temperature increase. In addition to these impacts, heat stress may also trigger the secretion of stress hormones which supress immunological responses and increase the vulnerability of livestock to diseases [5] (Kiunga et al, 2017).

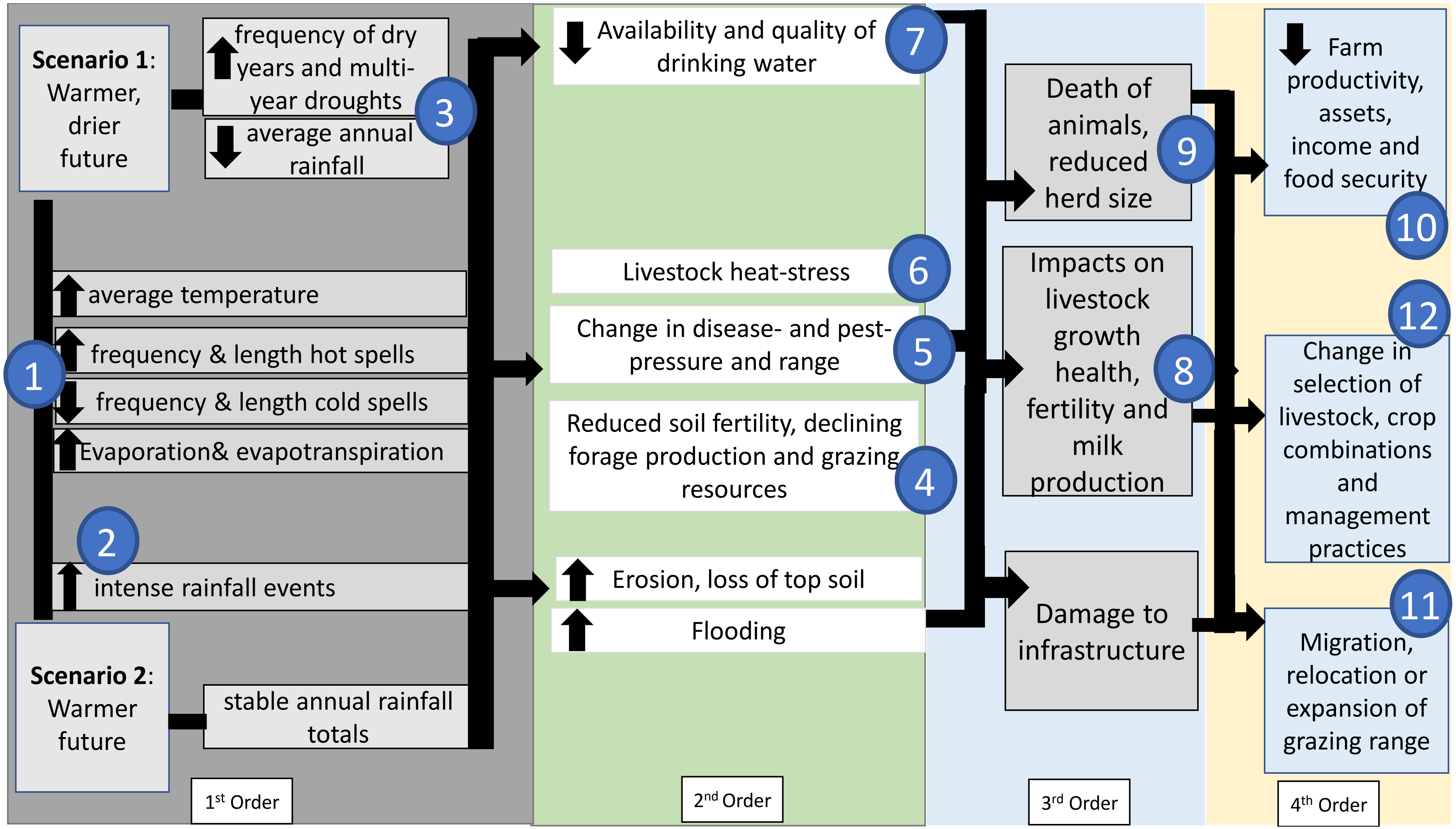
Climate change will affect the geographic range, severity and incidence of infectious livestock diseases [5], both directly and indirectly. For example, direct effects may manifest as the reduced immunity of a heat-stressed animal host to respond to infections, or through the faster growth rates and wider geographic ranges of pathogens and insect vectors (Kiunga et al, 2017). Olwoch et al (2008) predicts that increased temperatures in eastern and southern Africa are likely to increase the habitat and distribution of several tick species. Possible indirect effects of climate change on livestock pests and diseases may include sociocultural and behavioural trends which are beneficial to pests/diseases, or which increase the contact between vectors and hosts. For example, increased rates of migration or the concentration of migration routes used by pastoralists [11] may increase the exposure of livestock to multiple vectors and pathogens [5] (Kiunga et al, 2017).

Beyond the effect of climate change on individual system components (2^{nd} and 3^{rd} order impacts), broader system-level changes to mixed farming and livestock production are anticipated [11]. Mixed farming systems could increasingly shift towards reduced reliance on crops and greater reliance on livestock, particularly small ruminants and poultry which are comparatively climate-resilient and provide a faster return compared to cattle.

Summary: Potential impacts of a hotter, drier future on agriculture in Eastern Cape and Sakhisizwe

The primary drivers of future climate change impacts are the combined effects of: i) increased average temperatures, increased frequency of heat waves; and ii) reduced average rainfall, increased frequency of droughts and dry spells. Evapotranspiration rates (loss of water from soil, plants and surface waters) will increase, resulting in reduced soil moisture and storage of water resources. The productivity of grazing and pasture resources to support livestock production will decrease, particularly during droughts and dry spells. The combined effect of increased temperatures and reduced rainfall will include direct impacts on livestock health and production as a result of heat stress, as well as other indirect impacts resulting from environmental factors such as increased pest or disease infestations.

Cumulatively, these impacts will reduce the production of meat, dairy and egg products to various degrees, resulting in reduced income and food security at the farm and district level. In severe cases, the combined stress of heat, malnutrition and disease will result in the death of animals and a decline in herd size, thereby reducing the wealth and assets of the worst-affected households. The deterioration of grazing resources, particularly in accessible or densely-populated areas, will promote a relocation or seasonal migration of grazed livestock, increasing the possibility of conflict between communities. In the long term, a warmer and drier climate will encourage a shift or a diversification of livestock kept by smallholder farmers, increasingly in favour of small ruminants and hardy, locally-adapted cattle. The further societal impacts of decreased livestock production, loss of assets, and landscape/district-level changes in grazing resources and land use are considered further in the following section.



Scenario 1: Warmer, drier future
frequency of dry years and multi-year droughts
average annual rainfall
3
average temperature
frequency & length hot spells
1
frequency & length cold spells
Evaporation& evapotranspiration
2
intense rainfall events
Scenario 2: Warmer future
stable annual rainfall totals
1st Order
Availability and quality of drinking water
7
Livestock heat-stress
6
Change in disease- and pest-pressure and range
5
Reduced soil fertility, declining forage production and grazing resources
4
Erosion, loss of top soil
Flooding
2nd Order
Death of animals, reduced herd size
9
Impacts on livestock growth health, fertility and milk production
8
Damage to infrastructure
3rd Order
Farm productivity, assets, income and food security
10
12
Change in selection of livestock, crop combinations and management practices
11
Migration, relocation or expansion of grazing range
4th Order

3.3.4 *Inkosi Langalibalele and KwaZulu Natal*

The sub-sections below summarise the observed (3.4.4.a) and future predicted (3.4.4.b) climate change trends in the Inkosi Langalibalele municipality and the Kwazulu Natal province. The potential impacts of climate change on agriculture are analysed and presented in the following section (3.4.4.c, next page), following the convention of ascending "1st to 4th" order of impacts (described in Section 2, above). Potential impacts identified from the literature review are signified by red-coloured reference notes, which are reflected in the corresponding numbered references in a chart of impacts (Figure 2, Section 3.4.4.c, below).

Observed changes

Over the period 1931-2015, KwaZulu Natal experienced drastic warming **[1]**, with some stations reporting temperature increases equivalent to a rate of over 2 °C per century. With respect to precipitation, observed trends are less clear: by some measures, rainfall decreased by ~5.8% over the province between the periods of 1970–1979 and 1997–2006 **[2]** (Blignaut et al. 2009) however, there is no indication of statistically significant trends in annual precipitation totals or daily rainfall extremes (DEA, 2018). The effects of a warming and potentially drying climate were acutely felt during the 2015/16 drought that resulted in the whole of KwaZulu Natal being declared a disaster zone (DEA Uthukela, 2018), with multiple resultant impacts on livestock as well as other agricultural sectors (discussed further in 3.4.4.c, below).

Future projections

Climate change models project two alternative futures for KwaZulu Natal: 1. a hot and dry future; and 2. a hot future with increased rainfall. In the first scenario, under low mitigation, significant temperature increases of 3°C may occur by 2040-2060 **[1]**, with an associated drastic decline in rainfall **[2]**. These conditions will be accompanied by an increase in the occurrence of heatwave days **[3]** and high fire-danger days **[4]**, as well as more El Niño induced drought events **[5]**, such as the one that happened in 2015/16 (DEA TNC, 2018). This would result in significantly reduced yield from the forestry and sugarcane industries, and may make conditions increasingly unsuitable for cattle rearing.

The alternative future predicted by climate models for KwaZulu Natal is similar to the first scenario, but rainfall increases drastically over the province**[6]**, with an associated increase in intense thunderstorms**[7]**, damaging flood events**[8]**, as well pests and diseases that may affect crop, human and animal health**[9]**. In this scenario, the sugarcane and forestry sectors may be less affected. Singels, Jones and Lumsden (2018) show that dryland sugarcane yields may even increase as a result of climate change, and under higher temperature regimes, new areas in the high-lying parts of KwaZulu Natal may benefit from increased suitability by 2046-2065.

In uThukela, the District Municipality within which Inkosi Langalibalele is located, it is expected that increased temperatures **[1]**, drought **[5]** and the increase in frequency and severity of storm events**[7]**, will impact on the types of crops that can be grown and result in the loss of livestock. The projected replacement of the Grassland Biome by the Savanna Biome, even under medium-risk climate scenarios, will also have serious implications for the viability of cattle farming in the municipality (DEA, 2018).

Potential impacts of climate change on agriculture

Two potential future climate scenarios are projected for KwaZulu Natal. For simplicity, these can be summarised as:

- Scenario 1, "Hotter and Drier"; and

- Scenario 2, “Hotter and Wetter”.

It should be noted that these two scenarios are not necessarily mutually exclusive, and both may occur simultaneously within different districts or regions of the province.

As described in the above section on ‘Observed Changes’, the impacts of the 2015/16 drought may be considered an illustrative example of the potential impacts of Scenario 1 (a Hotter and Drier future). In the regional municipalities of uMzinyathi and uThukela, livestock farmers experienced cattle losses of 43%, and goat losses of 29% as a result of drought-induced shortages of drinking water, grazing pastures and leaves for goat browsing **[11, 15]** (Vetter, Goodall and Alcock, *unpublished*). Despite the return of rains in 2016, herds were still recovering in 2019, and in uMzinyathi, cattle numbers were 33% below their 2014 size. Farmers in the area have expressed concern that if droughts were to become a regular occurrence, cattle herds would not be able to recover in the intervening years. Goats on the other hand, appeared to be more resilient, and numbers recovered by 2018 (Vetter, Goodall and Alcock, *unpublished*).

In consideration of the full description given to a “Hotter and Drier” scenario in the case study of the Eastern Cape (see Section 3.4.3), the following section will primarily focus on the potential impacts of Scenario 2, a “Hotter and Wetter future”, in Kwa-Zulu Natal. Given that livestock production is the major focus of agricultural activity in Inkosi Langalibalele, and the importance of sugarcane more broadly in KwaZulu Natal, particular consideration is given to the potential impacts of climate change on livestock and sugarcane under Scenario 2. For additional comments on the projected impacts on livestock under a “Hotter and Drier Future”, readers may refer to the previous case study on the Eastern Cape (3.4.3.c).

Scenario 2, “Hotter and Wetter”: Increase in temperatures, rainfall, intense thunderstorms and flood events.

Livestock

The anticipated rise in temperature, together with increased rainfall and associated humidity, will likely have a direct impact on livestock health by aggravating animal heat stress **[10]**. Livestock are heterotherms, which means that they vary between self-regulating their body temperatures, and allowing the surrounding environment to affect it. When ambient temperatures increase relative to livestock body temperatures, the temperature gradient driving convective heat loss decreases, increasing reliance on evaporative cooling (sweating and panting). However, high relative humidity decreases the effectiveness of evaporative cooling, which means that under increasingly hot and humid conditions, livestock may not be able to dissipate sufficient body heat, and will likely become heat stressed (Sirohi and Michaelowa, 2007). As discussed in the previous section, heat stress may result in decreases in forage intake, efficiency of feed conversion, milk production, reproductive performance, fitness and longevity **[11]** (Thornton, Steeg and Herrero, 2009; Rojas-Downing et al, 2017), and may result in supressed immunological responses to livestock diseases **[9]** (Kiunga et al, 2017). For example, studies in India have reported higher incidence of clinical mastitis in dairy animals during hot and humid weather due to increased heat stress (Sirohi and Michaelowa, 2007).

The projected increase in flooding events **[8]** is also likely to impact on the incidence of livestock diseases **[9]**. For example, floods and the waterlogging of rangelands **[12]** have been associated with outbreaks of infectious diseases such as foot rot and leptospirosis **[13]** (Ahmed et al, 2012; Kiunga et al, 2017). Leptospirosis (causing decreased reproductive performance and milk production) is recognised as an emerging infectious disease that is climate sensitive and is likely to undergo increased occurrence and transmission in a warmer, wetter future as the pathogen favours the moist conditions associated with flooding (Kiunga et al, 2017). The disease is known to occur in South Africa, and is particularly prevalent in the high-rainfall areas of KwaZulu Natal (Hesterberg et al, 2009). Flooding may also cause damage to infrastructure that could cut off livestock farmers from markets, essential services and assistance, such as veterinary services, further exacerbating the spread of disease [14].

The system-level impacts of these changes may reduce farm productivity, assets, income and food security [15]. For example, a study examining the economic impacts of climate change on livestock production in Kenya found that a 1% increase in rainfall would lead to 1.53% -1.19% declines in value of livestock and decrease in revenue of 6% (Kabubo-Mariara, 2009).

In the specific case of sugarcane production, predictions for Scenario 1 ("Hotter, drier future"), suggest that frequent drought will cause water stress and associated reductions in crop growth, and yield of sugarcane[16]. On the other hand, reduced rainfall during the harvesting season may increase the efficiency of harvesting and quality of the crop, reducing the harvesting costs (Chandiposha, 2013).

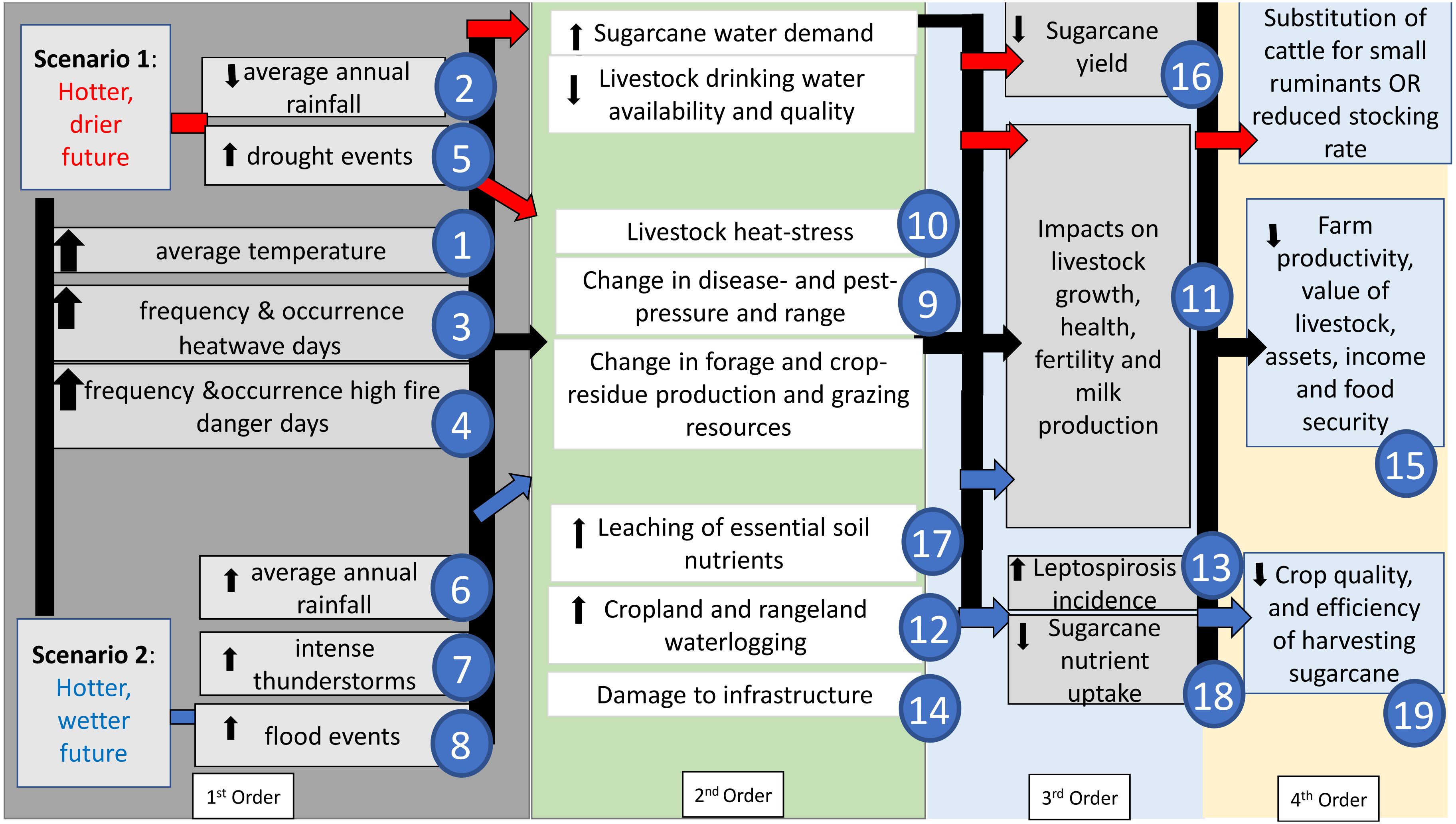
Wetter warmer conditions, under Scenario 2, may be beneficial for plant growth but simultaneously it is predicted that increased rainfall will result in the leaching away of essential nutrients from soils [17]. Periods of intense rainfall or flooding which results in water-logging of soils may deprive the sugarcane root system of oxygen, thereby further impeding nutrient uptake[18]. In contrast to Scenario 1, increased precipitation may reduce the efficiency of harvesting sugarcane, as well as the quality of the crop due to insufficient 'dry-off' during the harvest season [19](Chandiposha, 2013). Changes in rainfall are also likely to be associated with a change in prevalence of sugarcane diseases, pests and weeds [9]. For example, under the warm and dry conditions of Scenario 1, termite and nematode populations are expected to increase (Chandiposha, 2013).

Summary: Potential impacts of a hotter, wetter future on agriculture in Kwa-Zulu Natal and Inkosi Langalibalele

The primary drivers of future climate change impacts are the combined effects of: i) increased average temperatures, increased frequency of heat waves; and ii) increased average rainfall, increased frequency of storms and intense rainfall events. Evapotranspiration rates (loss of water from soil, plants and surface waters) will increase as a result of high temperatures, but may be partly offset by increased annual rainfall. Increasingly intense storms and rainfall events will result in multiple ecological impacts that will hinder agricultural production, including increased rates of soil erosion and loss of topsoil, leaching of soil nutrients and waterlogging. In extreme cases, floods events will result in damage to crops, critical infrastructure (such as homesteads and buildings, transport and telecommunications infrastructure), and loss of livestock and human lives.

The combination of increased temperatures, increased rainfall and intense storm events will result in multiple impacts on both crop and livestock agriculture. Water-intensive crops such as sugarcane may benefit from improved growth as a result of increased temperatures and availability of rainfall. However, conversely, sustained periods of waterlogging will negatively impact on plant nutrient uptake, while excessive rainfall will cause leaching of soil nutrients and fertiliser from soils. The greatest climate-related risk to livestock producers is the increasing incidence of diseases such as foot rot, leptospirosis and other infections that are promoted by warm, humid conditions.

Cumulatively, these impacts will reduce the health and productivity of livestock, particularly meat and dairy, resulting in reduced income and food security at the farm and district level. In severe cases, the combined stress of heat and disease will result in the death of animals and a decline in herd size, thereby reducing the wealth and assets of the worst-affected households. In the long term, a warmer and wetter climate will encourage a shift or a diversification of livestock kept by smallholder farmers, increasingly in favour of small ruminants and hardy, locally-adapted cattle. The further societal impacts of decreased crop and livestock production, loss of assets, and landscape/district-level changes in size and composition of livestock herds, are considered in the following section.


Scenario 1: Hotter, drier future
average annual rainfall
drought events
average temperature
frequency & occurrence heatwave days
frequency &occurrence high fire danger days
average annual rainfall
intense thunderstorms
flood events
Scenario 2: Hotter, wetter future
1st Order
Sugarcane water demand
Livestock drinking water availability and quality
Livestock heat-stress
Change in disease- and pest-pressure and range
Change in forage and crop-residue production and grazing resources
Leaching of essential soil nutrients
Cropland and rangeland waterlogging
Damage to infrastructure
2nd Order
Sugarcane yield
Impacts on livestock growth, health, fertility and milk production
Leptospirosis incidence
Sugarcane nutrient uptake
3rd Order
Substitution of cattle for small ruminants OR reduced stocking rate
Farm productivity, value of livestock, assets, income and food security
Crop quality, and efficiency of harvesting sugarcane
4th Order
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4 Social differentiation and the socio-economic impacts of climate change on small-scale farmers

In the study regions and commodities considered in the case studies (above), the most obvious risk to smallholders (and all farmers) is a loss of production and resultant loss of income. In the hypothetical scenarios discussed in each case study, the loss of agricultural output may occur through a number of mechanisms – for example, a gradual change in climate and growing conditions for preferred crops (e.g. increased temperatures and reduced rainfall), physical damage from sudden or rapid onset events such as heatwaves, hail and floods, and indirect environmental changes such as increased infestation of pests and diseases. As discussed in the previous examples, there remains a large degree of uncertainty and occasional contradictions between modelled climate projections, and consequently, there is a need for decision-makers to consider and plan for the impacts of multiple potential scenarios. Furthermore, any efforts to characterise the climate vulnerability of a system (particularly as applied to subsistence and smallholder farmers) must include explicit consideration of the socio-economic diversity between and within the target group.

4.1 Climate Change vulnerability, sensitivity and adaptive capacity of smallholders

'Vulnerability' to climate change can be defined as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes" (Intergovernmental Panel on Climate Change). As a definition that is broadly applied to diverse contexts, there can be no single "correct" or "best" conceptualisation. In each context, any efforts to define 'Vulnerability' of a sector, area, population etc., also requires a clear definition of the risk in question – i.e. vulnerability of which specific sector, to the impacts of which specific risk?

Vulnerability is generally depicted as the product of the following dimensions:

- Exposure to a given climate-related effect (e.g. heat wave, flood, prolonged dry spell);
- Sensitivity of a system to the given climate-related effect (e.g. the proportion of household food security, income, or livestock herd that is likely to be impacted); and
- Adaptive capacity of the system to respond (e.g. by avoiding the risk entirely, by reducing exposure to the risk, or by becoming more resilient to the risk).

The concept of '**Adaptation**' to climate change includes multiple definitions, including the IPCC's "...adjustment to actual or expected climate and its effects…to moderate or avoid harm or exploit beneficial opportunities" (detailed consideration is given to technical adaptation options in Section 5). In practical terms, adaptation may also be considered as any action intended to reduce the vulnerability of a system to an identified climate risk. In the context of agriculture, all adaptation actions can be categorised either as actions which: i) **reduce the sensitivity**; or ii) **increase the adaptive capacity**; of a given system.

Typically, those farmers and farming communities with the least resources – in terms of financial, technical, infrastructural and political capital – have the lowest capacity to adapt and are thus the most vulnerable to social, environmental and climate changes. For example, in contrast with the well-resourced and capitalised commercial farming sector, the majority of subsistence and smallholder farmers typically do not possess reserves of cash or other assets to buffer against extended periods of stress or to recover from short-term shocks. Even small changes in climate-related risks may result in disproportionate impacts on livelihoods and household wellbeing. In addition, the financial constraints on vulnerable farmers to invest in measures to safeguard or increase their production through, for example, improved inputs and infrastructure, is a widespread barrier to the adoption of alternative, "climate-smart" practices and technologies and other efforts to increase resilience of farmers over the medium- to long-term.

However, while several broad assumptions are frequently made of the general characteristics of smallholder farming households, there are additional complexities and diversity within this group, particularly in terms of each individual's endowments and assets, farming practices, livelihood trajectories and priorities. Oloffson (2020) notes the tendency for policy and development frameworks to "view market-oriented smallholders as largely undifferentiated, as if they were economically, socially, and politically homogenous, assumed to be equally capable of developing along a linear path of expansion and commercialization". Rather, the complex and subtle differences between and within categories of smallholder farmers must be appreciated and understood to adequately respond to the climate vulnerabilities of a strictly defined stakeholder group. Consequently, while the impacts of climate change experienced by a given agricultural community will be comparable at the 1st and 2nd order (i.e. changes in climatic variables, ecological and environmental impacts), the resulting 3rd and 4th order impacts, and the potential options to adapt, are likely to be increasingly distinct and differentiated at the household level.

4.2 Framework to consider social differentiation of climate change impacts on smallholders

In consideration of the difficulty of defining appropriate typologies to characterise the local contexts of each of the four case study sites (in Eastern Cape, Kwa-Zulu Natal, Limpopo and Western Cape, respectively), several typologies (adopted by Cousins and Chikazunga, 2013; Ncube, 2018; Genis, 2019; and Olofsson, 2020) are summarised below and in Table 2 (next page). These typologies are used to derive a simple 'hybrid' framework as a basis for further discussion, also described further in Table 3, below.

The typology described by Van Averbeke and Mohamed (2006) and adapted in Ncube (2018) classified farmers into: "i) *employers*, who employ full time labourers; ii) *food farmers*, devoted mostly to household food production; and iii) *profit makers*, farming primarily to sell produce and generate a significant income". '*Food farmers*' are mainly or totally focused on subsistence-level production to supplement household food consumption. The latter group tends to be conservative and hesitant to incur risks and investments associated with commercial or market-oriented production. '*Employers*' follow an intermediate farming style between risk aversion and risk taking. These farmers are cautious in pursuing more costly approaches or crops. Ncube (2018) found that the latter category of irrigated farmers are not always profitable, and may be better suited to considering diversification of on-farm and off-farm income/livelihoods. '*Profit makers*' are the most willing to take risks in order to increase profits/returns, for example through investments in inputs, water/irrigation, and access to alternative markets.

The typology adopted for differentiation of vegetable farmers in South Africa (Cousins, 2014) suggests four categories: i) subsistence-oriented smallholders; ii) market-oriented smallholders in loose value chains; iii) market-oriented smallholders in tight value chains; and iv) small-scale capitalist farmers. A similar approach is adopted in Olofsson's typology for smallholder tree crop farmers in Limpopo (2020), which categorised farmers into four "clusters": i) welfare dependent petty commodity producer; ii) agricultural petty commodity producer; iii) salaried small-scale capitalist; and iv) agricultural small-scale capitalist. In the latter cases, farmers can be differentiated in terms of the objective of production (e.g. production for household consumption vs. cash income), availability of capital and resources, access and use of labour and inputs (Cousins, 2014; Genis, 2019; Olofsson, 2020).

Sikhipa (2019a, 2019b), cited in Genis (2019), provides a relatively simple typology based on the household's objective of production, and the degree to which the household benefits from non-agricultural income, in the case of mango farmers. In this case, farmers may be categorized as: i) subsistence farmers, who eat the majority of household production and occasionally sell surplus for processing ii) farmers who sell a moderate amount of produce, supplementing their farming activities with supplementary income from work or pension; and iii) farmers who sell the majority of their produce to formal markets, including exports. As noted in Ncube (2018), all these farming styles and livelihood trajectories are dynamic in character, and farmers migrate from one farming style to another depending on their individual circumstances and access to resources.

Based on the above, a simplified 'hybrid' typology is proposed in Table 2, below, adopting three basic categories: i) subsistence-oriented smallholders; ii) market-oriented smallholders; and iii) small-scale capitalist farmers.

Table 2: Typologies for differentiation of South African smallholders

Source				
8	Subsistence-oriented smallholders	Market-oriented smallholders in loose value chains	Market-oriented smallholders in tight value chains	Small-scale capitalist farmers
9	Welfare dependent petty commodity producer	Agricultural petty commodity producer	Salaried small-scale capitalist	Agricultural small-scale capitalist
10	Food farmers	Employers		Profit-makers
11	Subsistence farmers: eat everything grown, occasionally sell to processors	Farmers whose success is based on income from supplementary work or pension		Farmers who sell to formal markets and export
Proposed 'hybrid' typology:				
Subsistence-oriented ←		**Market-oriented** →		
Proposed 'hybrid' typology	1. Subsistence-oriented smallholders	2. Market-oriented smallholders		3. Small-scale capitalist farmers

The typology adopted by Cousins and Chikazunga (2013) [1], among others, is suggested to be a useful approach to defining some of the characteristics of smallholder households under the proposed 'hybrid' typology. Farmers are characterised by factors *inter alia* objective of production (focus on subsistence versus market production), contribution to household income, use of hired and family labour, mechanisation and access to finance and capital. The characteristics of each category of farmer in the proposed 'hybrid' typology are summarised below and in Table 3, next page.

In this proposed typology:

[8] Cousins and Chikazunga (2013)
[9] Olofsson (2019)
[10] Ncube (2018), from Van Averbeke and Mohamed (2006)
[11] Sikhipa (2019a, 2019b), cited in Genis (2019)

'*subsistence-oriented smallholders*' are primarily focused on producing food for household consumption. Agricultural activities contribute little to household cash income but reduce household expenditure on food. Households are largely reliant on family labour, managing small plots with minimal use of (or access to) mechanisation and inputs. This category of farmer typically has limited assets and access to capital.

'*small-scale capitalist farmers*', conversely, are the most market-oriented of the three proposed typologies. The objective of the latter category of farmer is to sell the majority or entirety of farm outputs in formal markets (perhaps with some supplementary production for household consumption). These farms are relatively capital-intensive, dependent on additional hired labour, and characterised by a relatively high rate of mechanisation and use of inputs.

'*market-oriented smallholders*' may be considered an intermediate category within the proposed typology. The latter category of farmer is interested in marketing a moderate or large proportion of farm outputs, in semi-formal or formal markets, while still producing some additional food for household consumption. Households may employ a mix of family and hired labour and are moderately capital- and input-intensive. This category of farmers may include 'part-time' farmers or households with additional sources of income.

Table 3: Simplified 'hybrid' typology for differentiation of South African smallholders and climate change impacts

<table>
<tr><th>Proposed 'hybrid' typology</th><th>1. Subsistence-oriented smallholders</th><th>2. Market-oriented smallholders</th><th>3. Small-scale capitalist farmers</th></tr>
<tr><td>Objective of production</td><td>Subsistence, household consumption</td><td>Mixed, informal or moderate market-oriented production</td><td>Market-oriented production for profit</td></tr>
<tr><td>Proportion of marketed output</td><td>Low
(<25%)</td><td>Moderate
(~25 – 75%)</td><td>High
(~75 – 100%)</td></tr>
<tr><td>Contribution to household income</td><td>Reduced food expenditure</td><td>Moderate</td><td>Significant</td></tr>
<tr><td>Labour</td><td>Minimal, family labour</td><td>Moderate, family and/or part-time hired labour</td><td>Hired labour</td></tr>
<tr><td>Mechanisation, use of inputs</td><td rowspan="3">Low</td><td rowspan="3">Moderate</td><td rowspan="3">High</td></tr>
<tr><td>Capital intensity</td></tr>
<tr><td>Access to finance</td></tr>
</table>

The categories above, while borrowing from the concept of 'social differentiation', are analogous and similar in scope to indicators which are commonly used to assess climate change vulnerability (also discussed in Section 4.1, above). For example, indicators such as 'use of inputs' and 'access to finance' are acceptable metrics to evaluate the adaptive capacity of a farmer to respond to climate change (where these indicators serve as a proxy for the individual's capacity to adopt new or complex techniques, and the ability to invest in upgrades or purchase insurance, respectively).

Similarly, an indicator such as 'contribution (of agriculture) to household income' is a suitable proxy to assess the climate change sensitivity of a system (e.g. a farmer that is strongly reliant on cash income from agriculture is highly sensitive to impacts on market price and quality, or alternatively, a farmer who is mainly reliant on production for household consumption is highly sensitive to impacts on staple crops but less sensitive to market factors).

In consideration of the heterogeneity within South Africa's subsistence and small-scale farmers – ranging from households focused solely on low-input subsistence production to sophisticated market-oriented farms – a complete assessment of the potential impacts of climate change on this sector must acknowledge and account for the distinct differentiation between and within farmers in each context. Therefore, any efforts to plan or respond to the impact of climate change on South African smallholders, rural development or land reform initiatives requires explicit, context-specific definitions of the specific climate change risk or vulnerability as well as the targeted stakeholders or study subjects to be evaluated.

4.3 Differential climate change impacts on smallholders

Based on the frameworks for conceptualising *Vulnerability to climate change* and the generalised *Typology of smallholders* (described here in Sections 4.1&4.2, respectively), it is anticipated that each category of smallholder farmer[12] will differ in their respective vulnerabilities to a specific climate risk. While all farmers in a given location may be exposed to the same climate risk (for example, drought), each category of farmer can be expected to differ in terms of their sensitivity to that risk, and in their capacity to adapt or respond. Furthermore, following an approach which categorises smallholder farmers according to the aims and objectives of their production (e.g. subsistence- versus market-oriented), we assume that the response of each farmer will be driven by different motivations and may not necessarily aim to address or prioritise the same risks.

The hypothetical scenarios described in the four provincial case studies (Section 3.3) include *inter alia*:

- decreasing land value, loss of agricultural jobs, and landscape/district-level changes in patterns of land use and cropping (hotter, drier future in Matzikamma and the Western Cape);
- decreased livestock production, loss of assets, and landscape/district-level changes in grazing resources and land use (hotter, drier future in Sakhisizwe and the Eastern Cape);
- decreased crop and livestock production, loss of assets, and landscape/district-level changes in size and composition of livestock herds (hotter, wetter future in Inkosi Langalibalele and KwaZulu Natal).

While all of the scenarios above were developed in a site-specific context, nevertheless they may be considered a useful reference point for a generalised assessment of the risks of climate change to differentiated groups of smallholders. The following points are based on conjecture and should only be considered an illustrative basis for discussion, particularly with regards to the long-term implications for market-oriented agricultural production, and food security, respectively.

4.3.1 Implications for market-oriented agricultural production

All scenarios considered in the provincial case studies indicated the likelihood that multiple market-oriented value chains are **vulnerable** to the combined effects of heat and water stress. Direct negative impacts will include reduced annual production, quality and shelf-life of horticultural products such as fresh vegetables, table grapes, temperate fruit crops etc. (including high-value export produce). Production of various livestock products is also likely to be constrained, through direct stress impacts on animals as well as indirect effects such as forage/pasture availability and pests and disease. The potential impacts of lost agricultural income will manifest in different ways for each of the three categories of smallholder[13].

[12] subsistence-oriented smallholders, market-oriented smallholders and small-scale capitalist farmers
[13] Ibid

Smallscale capitalist farmers are assumed to be the most reliant on cash income from farming and with the greatest relative investment in inputs, infrastructure etc. – therefore they are likely to have the greatest **sensitivity** to lost income. However, these farmers are also likely to be the most well-resourced (either through successful farming or through other sources of income), capacitated and motivated to invest in adaptation measures – therefore, they have the greatest **adaptive capacity** to respond. In the event that production and/or returns continue to decline, farmers in this category are likely to choose one of the following two options, both of which come with considerable financial risks: i) **invest further in resilience and adaptation measures** e.g. replant with alternative crops/cultivars, install protective shade nets, additional irrigation and water storage, upgraded post-harvest facilities, diversify into non-agricultural activities such as ecotourism and hospitality; or ii) **abandon market-oriented farming** e.g. selling or leasing livestock, assets or the entire farm. In the latter case, there is the additional possibility that long-term declines in agricultural performance or allocation of irrigation rights will result in an increase in the number of properties for sale and a devaluation of agricultural land. This category of smallholder farmer is the most reliant on hired labour, and therefore there is a likelihood that negative impacts on market-oriented farmers will result in job losses that impact on neighbouring communities.

While it is anticipated that ***subsistence-oriented smallholders*** will be impacted by the same range of climatic and environmental factors, it is assumed that these individuals are least involved in market-oriented value chains and therefore will be the least sensitive to negative impacts. However, there may be additional impacts on subsistence-oriented smallholders who are also employed as labour on other farms, particularly in the event that a long-term decline in agricultural production in a given area results in a loss of seasonal or permanent farm jobs.

Of the three categories of smallholder proposed, the potential impacts on ***market-oriented smallholders*** are the most challenging to predict. This category of farmer is characterised as having a mix of subsistence and market-oriented production and may also have the benefit of additional outside income or employment. Depending on the relative proportion of household production that is intended to be marketed, these households are likely to be moderately or strongly sensitive to impacts on market-oriented value chains, as well as impacts on food security. However, relative to the other two categories of smallholder, the market-oriented smallholder households may also have several features that may give them an adaptive capacity advantage. Firstly, these households may have the benefit of additional income sources, which can be used to invest in appropriate resilience/adaptation measures and which will also support households through periods of lost production. In addition, it is likely that these farms are relatively less capital-intensive than commercially-oriented smallholders, and therefore can consider a wider range of alternative options. In the case that long-term agricultural prospects are discouraging and these farmers are not motivated to invest in measures to safeguard production, farmers in this category are likely to choose one of the following two options i) **abandon market-oriented farming** as an unprofitable exercise, **revert solely to limited subsistence** farming for household consumption and/or accumulation of livestock as wealth asset; or ii) **abandon farming** entirely, including selling livestock, assets or entire property. Similar to the impacts predicted for small-scale capitalists, both of the latter outcomes will contribute to losses in seasonal or permanent jobs.

4.3.2 Implications for subsistence and food security

All scenarios considered in the provincial case studies suggest the likelihood that production for subsistence needs will be **vulnerable** to the combined effects of heat and water stress, comparably to the implications for market-oriented products. The most obvious implication of this outcome is the sensitivity of subsistence-oriented households to a loss of food produced for consumption.

These households, characterised by the lowest annual income among the three stakeholder categories, are likely to incur increased costs to purchase replacement food. In addition, these households may face further impacts on food security and nutrition, thereby undermining a range of social development goals. Relative to the other smallholder categories, the subsistence-oriented smallholder has a limited range of options and opportunities to adapt without sustained external assistance. It is assumed that the majority of these farmers have limited employment and income opportunities and may be partly dependent on grants and remittances.

Virtually all feasible adaptation technologies (discussed further in Section 5) are either capital-intensive and require periodic maintenance/replacement (for example, irrigation, improved breeding stock, drought-tolerant seed) or are based on access to training, skills, or support networks (e.g. training and extension advice, demonstration of field practices). In the absence of support from government, civil society partner, 'mentor' relationships with successful farmers etc., it is anticipated that most subsistence farming households (especially those in remote locations) will not access the sustained resources or support necessary to maintain household wellbeing and food security. South Africa's well-established systems for disbursement of social grants may be an appropriate platform for identifying, and where necessary allocating extra support, to subsistence households most in need of support.

Of the remaining two smallholder groups, the smallscale capitalist farmer is likely to be least sensitive to negative impacts of climate change on food security. While it is likely that these farmers will experience a loss of cash income from lost production (described previously), this demographic is unlikely to experience direct food security impacts at the household level. The vulnerability of market-oriented smallholder farmers, who participate in a mix of subsistence and market production, is the most difficult to predict. The latter category of household generally has the benefit of some modest income, which is likely to reduce the worst impacts of climate change on food security. Where food production is inadequate for the household's needs, supplementary food can be purchased.

5 Potential adaptation options, emerging technologies and 'climate-smart' approaches for small-scale agricultural production systems

Given the current and future vulnerability of South Africa's agricultural sector, proactive adaptation interventions are required support the response of small-scale farming communities to climate change and variability. Any assessment of potential adaptation options must acknowledge and account for agro-ecological diversity (Abegunde, Sibanda and Obi, 2020) and the socio-demographic heterogeneity of smallholder producers and their farming systems, production objectives, farming scales and kinds of market orientation (Cousins, 2014). The failures and challenges of multiple initiatives focused on climate change adaptation can be attributed to a lack of consideration of local farming contexts at the inception/design stage (Abegunde, Sibanda and Obi, 2020). Therefore, the design of any adaptation support programmes and policies must ensure close alignment with local context and stakeholders, to ensure that all interventions are appropriate, context-specific and user-(i.e. farmer) driven.

The aim of the following section is not to assess or recommend specific adaptation options for the case study regions, which would require in-depth field-level studies. Rather, the aim of this section is to provide a simple framework and overview of existing practices and generic adaptation options that may be considered for smallholder and small-scale farmers. Given the wide research and policy interest in climate change, numerous approaches to categorising potential adaptation options have been adopted by various review papers, knowledge hubs and toolkits. These include extensive reviews of possible adaptation technologies and approaches, undertaken by *inter alia* United Nations Framework Convention on Climate Change[14], CGIAR [15], South Africa's former Department of Agriculture, Forestry and Fisheries[16], amongst many others. This section follows the classification system developed by the International Food Policy Research Institute (IFPRI, 2010) to categorise adaptation options relevant to small-scale farmers into the following:

- farm management and technology;
- financial instruments;
- diversification on and beyond the farm;
- government interventions; and
- knowledge management and networks.

5.1 Farm management and technology

At the farm-level, adapting to the risks brought about by climate change and variability is possible by adopting autonomous adaptation strategies (e.g. adopting alternative cultivars, mixed farming systems, or soil management practices) and taking on new technologies (e.g. irrigation, shadenets). These autonomous adaptation strategies are informed by farmers' well-established responses to variability in climatic (or market) factors. For example, South African smallscale farmers tend to

[14] UNFCCC, 2014. Technologies for Adaptation in the Agriculture Sector. Technology Executive Committee, UNFCCC.
https://unfccc.int/ttclear/misc_/StaticFiles/gnwoerk_static/TEC_column_L/544babb207e344b88bdd9fec11e6337f/bcc4dc66c35340a08fce34f057e0a1ed.pdf

[15] CGIAR Climate-Smart Technologies and Practices. https://ccafs.cgiar.org/flagships/climate-smart-technologies-and-practices ; and Vermeulen SJ, Dinesh D. 2016. Measures for climate change adaptation in agriculture. Opportunities for climate action in agricultural systems. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). http://hdl.handle.net/10568/71052

[16] Schulze, R (ed.) 2016. Handbook on adaptation to climate change for farmers, officials and others in the agricultural sector of South Africa. Department of Agriculture, Forestry and Fisheries.
https://www.nda.agric.za/doaDev/sideMenu/forestry/docs/Booklet%201%20Agric%20Setting%20Scene.pdf

reduce their investment in crops or even stop planting during dry-spells, instead increasing their focus on livestock production (IFPRI, 2010). Livestock farmers in dry areas have well-established practices that could be termed 'adaptation' strategies, such as measures to diversify their income, shifting to livestock with higher tolerance for water scarcity and heat, installation of boreholes or waterpoints, and intricate schedules for migration or rotating of livestock grazing. In times of severe water stress, farmers also adopt water conservation techniques such as water harvesting and recycling for irrigation (Carabine et al, 2017; Abegunde, Sibanda and Obi, 2020). Farmers in areas with frequent flooding shift to short-cycle crops and the cultivation of cover-crops to reduce soil erosion and water run-off (Nhamo, 2019; Abegunde, Sibanda and Obi, 2020).

Climate resilient technologies and practices that have been identified and developed for small-scale farmers also include water efficient irrigation technologies and strategies such as drip irrigation (slow, efficient delivery of water directly onto crop roots, minimising wastage and evaporative loss), deficit irrigation (irrigation only applied during drought-sensitive growth stages) and solar micro-irrigation (Thornton et al, unpublished; Nhamo, 2019). Stress tolerance in crops and livestock has also been a focus of research and investment, with the promotion of improved breeding stock, both through conventional selective breeding as well as biotechnology. Specific characteristics that have been targeted for crop improvement include heat, drought, water logging, and pest resistance (Vermeulen et al, 2012). These technical responses should not displace consideration and promotion of under-utilised indigenous and traditional crops which are shown to be resilient and which may benefit from further research and strengthening of value chains. Other in-field practices may include the promotion of greater crop diversity and biological control of pests and diseases (Nhamo, 2019).

5.2 Financial instruments

A diverse range of crop and weather index-based insurance schemes, and other financial instruments, are widely promoted as a measure to reduce the risks to smallscale farmers resulting from extreme climate events. Efforts to promote the adoption of improved technologies are frequently undertaken in coordination with efforts to improve farmer's access to credit and markets (Thornton et al, unpublished; Greenberg et al, 2013).

Index insurance products are financial instruments that deliver compensation payouts to farmers for losses to an insured crop or asset, based on a predetermined index, for example rainfall levels, average area yield or livestock mortality rates (Vermeulen et al, 2012). Various examples of these products are increasingly prominent in countries such as China, Mexico, Kenya and India. However, the sustained uptake of index insurance products by smallholders remains relatively limited in most of Southern Africa. Some researchers have questioned whether the promotion of index insurance may unintentionally contribute to existing inequalities. It has also been argued that smallscale farmers and the poor should not have to pay an insurance premium to adapt to climate risks for which they are not responsible (Fisher et al, 2019).

5.3 Diversification on and beyond the farm

Diversification of livelihoods may include both non-agricultural livelihood strategies that are undertaken on the farm (such as the sale of non-timber forest products like wild fruits, basket weaving and small-scale trade), as well as activities that are carried out beyond the farm (such as seasonal employment or migration) (IFPRI, 2010). These livelihood and lifestyle transitions have long been employed by dryland farmers to cope with seasonal changes and extreme events such as prolonged drought (Vermeulen et al, 2012). Historically, migratory patterns within SSA tend to be seasonal, temporary and restricted within rural areas. This pattern is already changing with rapidly increasing migration to urban areas, driven by a range of factors that include climate change (Thornton et al, unpublished). Research in the marginal areas of Tanzania, Uganda and Kenya has shown that livestock farmers are attempting multiple approaches to diversify their livelihoods in response to what they perceive as increasingly variable climate. As their rangelands become increasingly fragmented, restricting the mobility of livestock, and they reach limits to diversification into non-agricultural on-farm activities, there may be no other option other than to migrate to urban areas (Vermeulen et al, 2012). A major concern is that wage levels for poor migrants in urban areas are not likely to provide relief, and may come with a new set of risks (Thornton et al, unpublished). The promotion of skills to related to entrepreneurship, development of micro-enterprises, and basic business administration and management, are frequently included as measures to diversify the livelihoods of climate-vulnerable farmers.

5.4 Government interventions

Major opportunities exist for national and subnational policies that enable adaptation and transformational change at the smallscale farming community level. For example, policies that could aid communities to deal with short- or long-term drought, include the improvement of access and rights to water through investments in rain-water harvesting facilities or farmer-led and community-managed irrigation systems. The development of communal strategies, such as the pooling of financial resources or facilities may also prove useful (Vermeulen et al, 2012; Bunce, unpublished). The specific vulnerabilities of the smallholder farming sector may also be addressed in various ways through public works programmes and public procurement policies. For example, the experience of the flagship Working for Water (WfW) and Working on Fire (WoF) programmes may be used as examples of possible public investment programmes that provide short-term work in rural or underserved communities with positive impacts for environmental protection, water resources and biodiversity protection. Additional examples may include the use of public procurement budgets to source produce from smallholder farmers to supply school-feeding schemes, hospitals, prisons etc.

At the national level, key arenas for policy change may include consideration of subsidies and incentives for crop substitution and farming inputs (e.g. livestock vaccines), investments in improved food system infrastructure (e.g. cold chain and transport facilities), reducing agricultural risks, tenure reform, enhanced good governance and social safety nets (Thornton et al, unpublished; Vermeulen et al, 2012).The main challenge for decision makers will be to deal with the uncertainty of climate projections, and to design adaptation policies that are flexible enough to address a variety of future scenarios (Nhamo, 2019).

5.5 Knowledge Management and Networks

Adaptation strategies based on knowledge management includes macro-level practices (such as practical training for farmers and extension officers) and micro-level practices (such as the use of decision support systems and seasonal climate forecasts). Using networks to promote climate change adaptation involves investing in social networks, collective provision of farm inputs, and collective marketing of produce (IFPRI, 2010).

Local networks have an important role to play in reducing vulnerability and enhancing adaptive capacity. Thomas et al. (2007) found that in rural communities in South Africa, collective action has emerged as an important way for farmers to enhance their resilience. For example, one village established a maize cooperative to address risks and reduce costs, and another village used existing cooperative structures to search collectively for new sources of agricultural income. Therefore, efforts to address the climate vulnerabilities of a community should include the establishment (or strengthening) of a representative network to organise, communicate and coordinate between stakeholders. These may take the structure of Outgrower/Cooperative schemes, farmer clubs and field schools, or build on other existing structures such as school/youth-clubs, faith-based organisations, women’s groups etc.

Other forms of network and knowledge-based interventions may relate to management of technical or sector-specific knowledge. For example, these may include the systems for management and communication of irrigation/water resources, or forecasts generated by hydro-meteorological monitoring networks. In principle, seasonal climate forecasts provide the opportunity to farmers to make adaptation decisions in advance. However, research with smallholder farmers reveals limited uptake and use of seasonal forecasts as, in many cases, there has been widespread communication failure and a mismatch between farmers' needs and the scale, content, format and accuracy of available services (Vermeulen et al, 2012). Therefore, improvement of systems for monitoring and forecasting of weather and climate must continue to be prioritised, in coordination with measures to improve the communication of key messages that are tailored to the end user.

6 Implications for land reform, rural development and associated agricultural commodities

6.1 Implications for land reform

This study has explored the possible impacts of climate change on the beneficiaries of South Africa's land reform processes. However, while the impact on the individual farmer has been considered in detail, the long-term implications for South Africa's rural areas and objectives of land reform remain undefined. The authors propose several areas of key concern to be considered and addressed in the context of potential climate change impacts on land reform and rural development.

6.1.1 Planning for differential impacts of climate change on smallholders

A broad concern with respect to the impacts of climate change on land reform is the need for policy and public interventions to distinguish clearly between the needs of subsistence-oriented households, that are most strongly focused on household food consumption, and those of market-oriented smallholder farmers who are focused on marketing and production of agricultural products. Both categories of farmer, and all of the intermediate categories in between, are expected to experience multiple negative impacts on production. However, the implications of those climate change impacts at the household level, and the motivations and options for the household to respond, are distinct enough to warrant detailed policy consideration and tailored support at the field level.

In addition, there is a need for any policy or intervention that aims to minimise the impacts of climate change on smallholder households to consider and clearly articulate the specific climate change "vulnerability" to be addressed, as well as the intended "outcomes" and indicators of successful adaptation.

6.1.2 Climate change and the depreciation of agricultural lands and value chains

The climate scenarios discussed at the biome level (Section 3.2) and in the case studies (Section 3.3) predict a range of long-term impacts on the productivity of agricultural ecosystems, driven by factors such as degradation of soils and grazing resources, long-term declines in production and limited allocation of irrigation. A broad risk to land reform and rural development initiatives across southern Africa is that, in a scenario in which productivity or profitability of specific local commodities decreases to the point that agricultural enterprises become marginal, increasing numbers of commercial or market-oriented farms may be put up for sale and result in a decline in the valuation of agricultural lands. A long-term change in the value and market for agricultural lands will result in dynamic changes in local land ownership and land use. These outcomes will increase the possibility that land reform efforts may be undermined at a local scale.

In addition, a related concern is that smallholders and land reform beneficiaries in climate-vulnerable sectors face the risk of being stranded with depreciating agricultural assets or investments in an obsolete and unsustainable value chain. In the case of commodities with high upfront costs and/or long payback periods (e.g. orchard and tree crops, infrastructure-intensive horticulture, dairy), well-resourced commercial farms may be able to afford the investment costs and production losses incurred by removing or re-establishing orchards and infrastructure, whereas undercapitalised farmers have comparatively fewer options to transition into new or alternative value chains. In the case of market-oriented commodities which are supplied by a mix of smallscale, cooperative and commercial growers (e.g. subtropical fruits and nuts) or which rely on well-defined value chains of producers, processors, wholesalers and retailers (e.g. wine, dairy, meat, sugar), there is a long-term risk that the entire value chain will be undermined or transformed as commercial producers and processors diversify away from unsustainable commodities. In consideration of these risks, it is strongly recommended that initiatives and policy measures which aim to engage smallholders and land reform beneficiaries in the production of specific commodities must include measures to: i) identify and engage all local participants and stakeholders that support the entire value chain, specifically including larger or commercial producers, wholesalers and offtakers, agri-processors etc.; ii) deliver targeted support to safeguard and strengthen the entire value chain, including measures to promote the engagement of small/emerging producers as well as to strengthen 'links' from farm to marketplace; and iii) prioritise research and development of locally adapted practices, technologies and climate-resilient breeds/cultivars to support long-term sustainability of climate-vulnerable and/or commercially valuable commodities.

6.1.3 Climate change as a barrier to emergence and growth of market-oriented producers

There is a risk that successive or persistent climate change impacts that undermine the production and profitability of a given commodity will act as a barrier to the growth and development of aspiring market-oriented smallholders and small-scale agri-businesses. Any initiative or policy that focuses on small and emerging producers in the development of profitable market-oriented production, or as a sector to promote rural job creation and inclusive growth of the agricultural economy, should prioritise measures to identify and increase the resilience of the most vulnerable producers. In addition to a range of potential adaptation approaches which may be considered (see Section 5), it is strongly recommended that efforts to support the development of emerging market-oriented farmers must include measures to: i) identify and prioritise those aspiring farmers who are specifically motivated to move towards market-oriented production; and ii) provide sustained training, financing, infrastructure and mentorship to these individuals.

6.2 Value-chain and commodity-level implications

6.2.1 Subtropical fruit and nuts

Contradictory future climate scenarios are projected for the regions which support high-value subtropical fruit and nut crops (*inter alia* avocados, macadamias, citrus, mangos, litchis etc.), and may be characterised by a long-term decline in rainfall or alternatively by periods of intense or extreme rainfall.

In all cases, it is anticipated that irrigation demands will increase as a result of higher temperatures. In a scenario in which average rainfall decreases in the long-term, the predictable availability of stored irrigation water is likely to be the limiting factor to production. At the district and provincial levels, any initiative which aims to expand the area of irrigated fruit/nut production will require sustained investment in increased water storage capacity, as well as improved management and governance of water resources. On-farm practices and technologies to be promoted may include efficient irrigation technologies, management and pruning of tree canopies, water harvesting and storage, and assorted soil management practices (e.g. addition of organic material, mulch or cover crops). Farmers with insecure or uncertain access to water may consider diversification of cultivars or adoption of alternative crops.

The combined effects of heat and water stress may have negative impacts on the quality and shelf-life of various fruit products. These may be partially mitigated through modern harvesting techniques and packhouse technologies *inter alia* monitoring of fruit respiration and sugars to optimise harvest time, cooling and cold-chain transport of harvested produce, and sanitary post-harvest handling of produce. The production of high-value subtropical fruits and nuts is likely to remain technically feasible in the long-term future but is likely to become increasingly modernised and capital-intensive.

In the event of extreme or intense rainfall events, most subtropical commodities are likely to experience increased pest and disease pressure during periods of sustained heat and humidity, while periods of waterlogging will promote infection by soil-borne pathogens and diseases. Priority measures may include continuous research and development of disease-resistant rootstock as well as techniques to control or treat infestations in the field, as well as activities to educate extension workers, growers associations and farmers on the detection and control of common diseases.

6.2.2 Fresh vegetables

The production of fresh seasonal vegetables is potentially one of the most diverse and flexible of the commodities considered, and to a certain degree can be practiced in a wide range of climatic and ecological conditions. Producers have the option of multiple crop and cultivar choices and, if provided access to irrigation, may establish crops over several seasons of the year. Farmers are able to respond sensitively to market demands with a comparatively small fixed cost of investment and fast returns (compared to orchard/tree crops, which are comparatively more expensive to establish and are unproductive for several years). Therefore, the promotion of smallscale horticulture and vegetable production has the potential to deliver multiple benefits to smallholder farmers – for example, by diversifying household diet and nutrition, contributing to household cash income, and splitting the farmer's risk by staggering household production across several crops and harvest times – and may be an effective component of a strategy to minimise the impacts of climate change on smallholders.

However, fresh vegetable production and other forms of horticulture are likely to be sensitive to, and limited by, the availability of fresh water for irrigation. In a scenario in which average rainfall decreases or becomes more uncertain in the long-term, the expansion and sustainability of irrigated horticulture will be heavily dependent on continued investment in infrastructure for water storage and supply, improved governance of water resources, and multiple on-farm practices to improve water use efficiency (examples of on-farm technologies discussed under '*Subtropical fruits and nuts*', above).

In addition to the challenge of managing water and irrigation resources, particularly under a scenario of reduced rainfall, another climate change-related challenge to fresh vegetable producers is likely to be the need to protect sensitive or high-value produce from extreme weather. High-value vegetable products such as peppers, tomatoes and salad leaves are sensitive to damage from heat stress and sunburn, which reduces the marketability of produce as a result of cosmetic blemishes, reduced shelf life or undesirable flavours. Other climate-related risks such as unusually strong or hot winds, severe rain and hail storms are also likely to result in damage and loss of marketable produce. Sheltered structures such as shade nets and/or open poly-tunnels are likely to be the most effective protection, however, these options are relatively costly to install and maintain and may not be appropriate for smallscale producers. An alternative approach which may be considered is the establishment of mixed tree-and-crop/agro-forestry systems, wherein a protective canopy of tree or orchard crops are grown in combination with short-cycle horticulture/vegetable crops.

Similar to the examples discussed under '*Subtropical fruits and nuts*', above, a likely challenge to most smallscale or emerging vegetable farmers is the impact of sustained water or heat stress on the shelf life of delicate horticultural products. It is recommended that farmers be trained or educated on beneficial on-farm practices that aim to optimise the timing of irrigation and harvest, as an approach to partially manage the deterioration of harvested produce. In addition to field-level practices, measures to reduce the waste or loss of marketable vegetable produce may include *inter alia* improved access to hygienic, temperature controlled packhouse facilities (e.g. to wash, treat and package fresh produce) as well as marketing facilities.

6.2.3 Sugar cane

The future climate scenarios for the sub-tropical regions which support sugarcane cultivation, notably including large parts of Kwa-Zulu Natal, Mpumalanga and Limpopo provinces, are contradictory and may be characterized by a long-term decrease in average rainfall or alternatively an increase in intense or extreme rainfall events. Relative to other crops and commodities considered, the impacts of climate change on sugar cane production are likely to be mild, and in some cases may benefit from increased yield in response to warmer temperatures. In addition, the extent of area suitable for sugar cultivation may expand by mid- and late-century as a result of increased temperatures, particularly in high-altitude areas which are currently dominated by plantation forestry.

It is likely that the full potential for increased production of sugarcane cannot be realised without increased access to inputs, particularly irrigation and fertiliser. It should also be emphasised that efforts to promote or expand the production of sugarcane should be accompanied by measures to minimise negative environmental impacts on soil and water resources (for example, resulting from increased application and leaching of agro-chemicals, burning of mature crops), particularly in a scenario in which intense or extreme rainfall events contribute to leaching and erosion of soils.

6.2.4 Livestock, dairy and wool production

The impacts of climate change on the livestock sector are likely to manifest in complex combinations. At the landscape scale, climate change will result in shifts in the distribution and composition of ecological biomes with widespread implications for livestock production. South Africa's grasslands, which are a critical resource for grazed cattle production, are considered the most vulnerable of all biomes. Depending on the scale of future greenhouse gas emissions, grasslands are predicted to experience significant degradation and a reduced spatial range, much of which is expected to transition towards savanna. The expansion of the savanna biome is likely to be characterised by increasing encroachment of bush and woody vegetation, increased invasion by alien vegetation species, and a general decrease in the palatability and carrying capacity of grazing resources. There is a further risk that grasslands, as well as other biomes that contribute to livestock production, will be further degraded and their recovery hindered by the effects of sustained grazing pressure, increased heat and water stress, and erosion of fragile topsoils.

The influence of climate change on the availability and composition of grazing resources will be compounded by the direct effects of water and heat stress on animals. Physiological effects on livestock may include negative impacts on forage intake, efficiency of feed conversion, milk production, reproduction and vulnerability to disease. A significant source of climate-related risks to livestock producers is the increasing incidence of diseases such as foot rot, leptospirosis and other infections that are promoted by warm, humid conditions, as well as biome-level shifts in the distribution and seasonality of insect disease vectors such as ticks. In a scenario of increasingly frequent intense rainfall or flooding events, outbreaks of infectious diseases may be expected to occur, particularly in waterlogged areas or under sustained hot, humid conditions.

Cumulatively, these impacts will reduce the production of meat, dairy and eggs to various degrees, resulting in reduced income and food security at the farm and district level. In severe cases, the combined stress of heat, malnutrition and disease will result in the death of animals and a decline in herd size, thereby reducing the wealth and assets of the worst-affected households.

An urgent area for intervention and increased public support is the need to strengthen and expand the network for rural veterinarian services, vaccinations and supporting infrastructure (*inter alia* dipping tanks, crush pens etc.), in anticipation of the widespread impacts of climate change on animal health. Efforts to improve access to veterinarians and healthcare for animals must be accompanied by measures to increase farmer's awareness of emerging diseases, including information on identifying symptoms and possible remedies, as well as identifying additional incentives to encourage farmers to participate and make use of veterinarian services.

At the field level, interventions to support livestock producers during periods of drought and limited grazing may include installation of watering points and water storage infrastructure, development of on-farm 'fodder banks' (e.g. woodlots of fast-growing, leguminous tree species to provide supplementary fodder) or livestock feeding schemes. At the district or landscape level, interventions to safeguard vulnerable grazing resources will be urgently needed. These may include *inter alia* establishment of communal management plans, rotational grazing, seasonal migration, restoration or protection of priority degraded areas, and incentives to reduce stocking rate.

In the long-term, the combined effects of reduced rainfall and declining crop productivity are likely to promote a large-scale shift in the smallholder farming sector, increasingly towards livestock production in favour of crop cultivation. It is anticipated that the expansion of the Savanna, Succulent Karoo and Nama Karoo biomes will be accompanied by a gradual shift towards livestock, particularly towards hardy, locally-adapted small ruminants (goats, sheep) in favour of cattle. The potential impacts of a transition towards intense browsing by small ruminants remains to be seen at the landscape scale, particularly in combination with the increased environmental stresses resulting from climate change. It is highly probable that each biome will undergo further transitions or changes in vegetation dynamics following the expansion or introduction of small livestock production.

The transition of the national livestock herd towards small ruminants may result in unforeseen ecological impacts. However, it is probable that farmers will have the opportunity to benefit from new niches and emerging value chains based on small livestock. These may include production for meat, dairy alternatives (i.e. goat milk), wool, opportunities for post-harvest processing and/or value addition (e.g. refinement and processing of raw wool products, preserving or processing of goat milk products), and opportunities for creation of jobs and income opportunities through related value chains (e.g. suppliers of inputs and services, abattoir and butchery facilities, cold chain service providers, offtakers/wholesalers etc.).

References

Abegunde, V.O., Sibanda, M., and Obi, A. (2019). The Dynamics of Climate Change Adaptation in Sub-Saharan Africa: A Review of Climate-Smart Agriculture among Small-Scale Farmers. *Climate*, 7: 1-23. doi:10.3390/cli7110132

Ahmed, S. A., Sandai, D. A., Musa, S., Hoe, C. H., Riadzi, M., Lau, K. L., & Tang, T. H. (2012). Rapid diagnosis of leptospirosis by multiplex PCR. *The Malaysian journal of medical sciences*, 19(3): 9–16.

Barrueto, A.K., Merz, J., Hodel, E. & Eckert, S. (2018). The suitability of Macadamia and Juglans for cultivation in Nepal: an assessment based on spatial probability modelling using climate scenarios and in situ data. *Reg Environ Change*, 18: 859.

Bett, B., Kiunga, P., Gachohi, C., Sindato, C., Mbotha, D., Robinson, T., Lindahl, J., Grace, D. (2017). Effects of climate change on the occurrence and distribution of livestock diseases. Preventive Veterinary Medicine, 137:119–129. http://dx.doi.org/10.1016/j.prevetmed.2016.11.019

Blignaut, J., Ueckermann, L., Aronson, J. (2009). Agriculture production's sensitivity to changes in climate in South Africa. *South African Journal of Science*, 105: 61-68.

Bunce, B. (Unpublished). Commodity Study of fresh produce under irrigation by small-scale farmers in South Africa.

Carabine, E., Lwasa, S., Buyinza, A., Nabaasa, B. (2017). Enhancing climate change development programmes in Uganda: Karamoja livestock value chain analysis for resilience in drylands. https://www.odi.org/sites/odi.org.uk/files/resource-documents/11595.pdf

CGIAR Climate-Smart Technologies and Practices. https://ccafs.cgiar.org/flagships/climate-smart-technologies-and-practices ; and Vermeulen SJ, Dinesh D. 2016. Measures for climate change adaptation in agriculture. Opportunities for climate action in agricultural systems. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). http://hdl.handle.net/10568/71052

Chandiposha. (2013). Potential impact of climate change in sugarcane and mitigation strategies in Zimbabwe. *African Journal of Agricultural Research,* 8(23): 2814-2818. DOI: 10.5897/AJAR2013.7083

Cousins B and Chikazunga D (2013). Defining smallholder farmers in South Africa. Briefing Note: Innovation Lab. PLAAS, UWC

Cousins, B. 2014. What is a 'smallholder farmer' in South Africa today? Paper for a workshop on 'Opportunities, constraints and innovative approaches in small-scale agriculture in South Africa', C3 Initiative on Strategies to Overcome Poverty and Inequality, Goedgedacht, Western Cape, 6-8 August.

Department of Environmental Affairs. (2013). Long-term Adaptation Scenarios Flagship Research Programme (LTAS) for South Africa, Pretoria.

Department of Environmental Affairs. (2016). Mopani District Municipality: Climate Change Vulnerability Assessment and Response Plan, Pretoria.

Department of Environmental Affairs. (2018). Chris Hani District Municipality: Climate Change Vulnerability Assessment and Response Plan, Pretoria.

Department of Environmental Affairs. (2018). South Africa's Third National Communication Under The United Nations Framework Convention On Climate Change. https://unfccc.int/sites/default/files/resource/South%20African%20TNC%20Report%20%20to%20the%20UNFCCC_31%20Aug.pdf

Department of Environmental Affairs. (2018). UThukela District Municipality: Climate Change Adaptation Summary Report.

Descheemaeker, K., Oosting, S.J., Homann-Kee Tui, S., Masikati, P., Falconnier, G.N., Giller., K.E. (2016). Climate change adaptation and mitigation in smallholder crop–livestock systems in sub-Saharan Africa: a call for integrated impact assessments. *Reg Environ Change*, 16:2331–2343. DOI 10.1007/s10113-016-0957-8

Elum Z.A., Modise, D.M., Marr, A. (2017). Farmer's perception of climate change and responsive strategies in three selected provinces of South Africa, Climate Risk Management 16 (2017), 246–257. http://dx.doi.org/10.1016/j.crm.2016.11.001

Fisher, E. Hellin, J., Greatrex, H., Jensen, N. 2019. Index insurance and climate risk management: Addressing social equity. *Dev Policy Rev*., 37:581–602.

Genis, A (2019). Commodity study. Subtropical fruit production by small-scale farmers in South Africa and employment-intensive land reform. CBPEP/GTAC project: Employment-intensive rural land reform in South Africa: policies, programmes and capacities, Institute for Poverty, Land and Agrarian Studies (PLAAS)

Goudriaan, R., Jarmain, C., Andriessen, M., Abraham, K., Naude, R, Keuck, P. (2019). What was the impact of the 2017-18 drought? – a case study using FruitLook data. https://www.wineland.co.za/what-was-the-impact-of-the-2017-18-drought-a-case-study-using-fruitlook-data/

Greenberg, S. (ed). (2013). Smallholders and agro-food value chains in South Africa: Emerging practices, emerging challenges. Institute for Poverty, Land and Agrarian Studies, School of Government, Faculty of Economic and Management Sciences, University of the Western Cape.

Gross, J. (2014). Assessment of future agricultural land potential using GIS and regional climate projections for Hawai'I Island – an application to macadamia nut and coffee (Unpublished Masters dissertation).University of Hawai'i.

Hesterberg, U W, Bagnall, R, Bosch, B, Perrett, K, Horner, R, & Gummow, B. (2009). A serological survey of leptospirosis in cattle of rural communities in the province of KwaZulu-Natal, South Africa. Journal of the South African Veterinary Association , 80(1): 45-49. http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S1019-91282009000100008&lng=en&tlng=en.

Howden, M., Newett, S., Deuter, P. (2005). Climate Change Risks and Opportunities for the Avocado Industry. New Zealand and Australia Avocado Grower's Conference '05, pp 1-19. http://www.avocadosource.com/Journals/AUSNZ/AUSNZ_2005/HowdenMark2005.pdf

International Food and Policy Research Institute. (2010). Micro-level Practices to Adapt to Climate Change for African Small-scale Farmers. Washington DC.

Kabubo-Mariara, J. (2009). Global warming and livestock husbandry in Kenya: Impacts and adaptations. *Ecological Economics*, 68(7): 1915-1924. https://doi.org/10.1016/j.ecolecon.2009.03.002

Kruger, A.C., Nxumalo, M.P. (2017) Historical trends in South Africa: 1921-2015. *Water SA*, 43(2). http://dx.doi.org/10.4314/wsa.v43i2.12

Kruger, A.C., Rautenbach, H., Mbatha, S., Ngwenya, S., & Makgoale, T.E. (2019). Historical and projected trends in near-surface temperature indices for 22 locations in South Africa. South African Journal of Science, 115(5-6), 1-9. https://dx.doi.org/10.17159/sajs.2019/4846

Limpopo Department of Economic Development Environment And Tourism. (2016). Limpopo Climate Change Response Strategy 2016-2020. http://www.ledet.gov.za/wp-content/uploads/2016/11/Limpopo_Climate_Change-Response_Strategy_-2016_2020_Final.pdf

MacKellar, N., New, M., & Jack, C. (2014). Observed and modelled trends in rainfall and temperature for South Africa: 1960-2010. *South African Journal of Science*, 110(7-8): 1-13. http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S0038-23532014000400014&lng=en&tlng=es.

Ncube B (2018) 'Farming styles, livelihoods and social differentiation of smallholder farmers: Insights from New Forest Irrigation Scheme in Mpumalanga Province of South Africa', *Working Paper 53*. PLAAS, UWC: Cape Town.

Nhamo, L., Matchaya, G., Mabhaudhi, T., Nhlengethwa, Nhemachena, C., Mpandeli, S. (2019). Cereal Production Trends under Climate Change: Impacts and Adaptation Strategies in Southern Africa. *Agriculture*, 9 (3):1-16; doi:10.3390/agriculture9020030

Olofsson, M. (2020). Socio-economic differentiation from a class analytic perspective: The case of smallholder treecrop farmers in Limpopo, South Africa. Journal of Agrarian Change. 2020; 20:37–59

Olwoch, J., Reyers, B., Engelbrecht, F., Erasmus, B. (2008). Climate change and the tick-borne disease, Theileriosis (East Coast fever) in sub-Saharan Africa. *Journal of Arid Environments*, 72. 108-120. 10.1016/j.jaridenv.2007.04.003.

Popoola, O. O., Monde, N., Yusuf, S. F. G. (2019). Climate change: perception and adaptation responses of poultry smallholder farmers in Amathole District Municipality, Eastern Cape Province of South Africa. South African Journal of Agricultural Extension , 47(3), 108-119. https://dx.doi.org/10.17159/2413-3221/2019/v47n3a519

Powell, M., Accad, A. & Shapcott A. (2014). Where they are, why they are there, and where they are going: using niche models to assess impacts of disturbance on the distribution of three endemic rare subtropical rainforest trees of Macadamia (Proteaceae) species. *Australian Journal of Botany*, 62: 322-334.

Randela,M.Q. (2018). Climate Change and Avocado Production: A Case Study of the Limpopo Province of South Africa. (Unpublished Masters dissertation). University of Pretoria.

Rojas-Downing, M.M., Nejadhashemi, A.P., Harrigan, S., Woznicki, S.A.(2017). Climate change and livestock: Impacts, adaptation, and mitigation. Climate Risk Management, 16:145–163. http://dx.doi.org/10.1016/j.crm.2017.02.001

Rust, J.M., Rust, T. (2013). Climate change and livestock production: A review with emphasis on Africa. *South African Journal of Animal Science,* 43 (3):255-267. http://dx.doi.org/10.4314/sajas.v43i3.3.

Schulze, R (ed.) 2016. Handbook on adaptation to climate change for farmers, officials and others in the agricultural sector of South Africa. Department of Agriculture, Forestry and Fisheries. https://www.nda.agric.za/doaDev/sideMenu/forestry/docs/Booklet%201%20Agric%20Setting%20Scene.pdf

Sikhipa, N. 2019a. Successful Study Groups for Smallholder Farmers: Vhembe District: Limpopo Province, South Africa. Presentation delivered at the Subtrop Transformation Summit '19, Ingwenyama Conference & Sports Resort, White River, South Africa, 19 June.

Sikhipha, N. 2019b. Assistant director, Limpopo Department of Agriculture and Rural Development. Personal communication, Thohoyando, 29 July.

Sirohi, S., Michaelowa, A. (2007). Sufferer and cause: Indian livestock and climate change. *Climatic Change*, 85:285–298. DOI 10.1007/s10584-007-9241-8

Tegegn, A., Assefa, A., Adene, F. (2018). The Impacts of Climate Change on Livestock Production and Productivity in Ethiopia. *Ethiopian Institute of Agricultural Research,* Adama, Ethiopia.

Thomas, D.S.G., Twyman, C., Osbahr, H., Hewitson, B. (2007). Adaptation to climate change and variability: farmer responses to intra-seasonal precipitation trends in South Africa. Climatic Change 83, 301–322. https://doi.org/10.1007/s10584-006-9205-4

Thornton, P.K., Loboguerrero, A.M., Campbell, B.M., Kavikumar, K.S., Mercado, L., Shackleton, S. (Unpublished). Rural livelihoods, food security and rural transformation under climate change.

Thornton, P.K., Steeg, J., Notenbaert, A., Herrero, M. 2009. The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. *Agricultural Systems* 101: 113–127. doi:10.1016/j.agsy.2009.05.002

UNFCCC, 2014. Technologies for Adaptation in the Agriculture Sector. Technology Executive Committee, UNFCCC. https://unfccc.int/ttclear/misc_/StaticFiles/gnwoerk_static/TEC_column_L/544babb207e344b88bdd9fec11e6337f/bcc4dc66c35340a08fce34f057e0a1ed.pdf

Van Averbeke W and Mohamed, SS (2006). Smallholder farming styles and development policy in South Africa: The case of Dzindi Irrigation Scheme. *Agrekon,* 45(2): 136-157

Vermeulen, S.J., Aggarwal, P.K. , Ainslie, A., Angelone, C., Campbell, B.M., Challinor, A.J., Hansen, J.W., Ingram, J.S.I., Jarvis, A., Kristjanson, P., Lau, C., Nelson, G.C., Thornton, P.K., Wollenberg, E. (2012) Options for support to agriculture and food security under climate change. Environmental Science & Policy, 15(1):136-144. https://doi.org/10.1016/j.envsci.2011.09.003

Vetter, S., Goodall, V.L., Alcock,R. (Unpublished). Effect of drought on communal livestock farmers in Msinga, KwaZulu-Natal.

VinPro (2019). South African Wine Harvest Report 2019. http://vinpro.co.za/wp-content/uploads/2019/05/SA-WINE-HARVEST-REPORT-2019_6May2019.pdf

Western Cape Department of Environmental Affairs and Development Planning. (2014). Western Cape Climate Change Response Strategy.

https://www.westerncape.gov.za/text/2015/march/western_cape_climate_change_response_strategy_2014.pdf

Western Cape Government. (2016). A Status Quo Review of Climate Change and the Agriculture Sector of the Western Cape Province. https://www.greenagri.org.za/assets/documents-/SmartAgri/Briefs-/Smart-Agri-Status-Quo-Review-2016.pdf

Wolski, P., Jack, C., Conradie, S., Hall, A., Hewitson, B., New, M. (2018). Attributing 2015-2017 drought in Western Cape, South Africa. EGU General Assembly Conference Abstracts. https://ui.adsabs.harvard.edu/abs/2018EGUGA..2013705W/abstract

Zwane, E.M. (2019) Impact of climate change on primary agriculture, water sources and food security in Western Cape, South Africa*, Jàmbá: Journal of Disaster Risk Studies* 11(1), 562. https://doi.org/10.4102/ jamba.v11i1.562