LONG TERM ADAPTATION SCENARIOS

TOGETHER DEVELOPING ADAPTATION RESPONSES FOR FUTURE CLIMATES

FOOD SECURITY

environmental affairs
Department:
Environmental Affairs
REPUBLIC OF SOUTH AFRICA

giz
On behalf of:
Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
of the Federal Republic of Germany

SANBI
Biodiversity for Life

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LONG-TERM ADAPTATION SCENARIOS
FLAGSHIP RESEARCH PROGRAMME (LTAS)

CLIMATE CHANGE ADAPTATION PERSPECTIVES ON FOOD SECURITY IN SOUTH AFRICA

LTAS Phase II, Technical Report (no. 5 of 7)

The project is part of the International Climate Initiative (ICI), which is supported by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF MAPS

LIST OF ABBREVIATIONS

ACCESS	Australian Community Climate and Earth System Simulator
BFAP	Bureau for Food and Agricultural Policy
CCAM	Conformal-cubic atmospheric model
CF	Carbon dioxide fertilisation
CMIP5	Coupled Models Intercomparison Project Phase 5
CSIR	Council for Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organization (Australia)
DAS	Directorate of Agricultural Statistics
DSSAT	Decision Support System for Agrotechnology Transfer
FAO	Food and Agriculture Organization of the United Nations
FAPRI	Food and Agricultural Policy Research Institute
GAM	Generalised additive model
GCM	General circulation models
GHG	Greenhouse gas
IES	Income and expenditure survey
IFPRI	International Food Policy Research Institute
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
IPCC AR4	Intergovernmental Panel on Climate Change Fourth Assessment Report
IPCC AR5	Intergovernmental Panel on Climate Change Fifth Assessment Report
IPCC	Intergovernmental Panel on Climate Change
LTAS	Long-term Adaptation Scenarios
MAP	Mean annual precipitation
MPI	Max Planck Institute for Meteorology
NAMC	National Agricultural Marketing Council
NCAR	National Centre for Atmospheric Research (USA)
NDP	National Development Plan
NoCF	No carbon dioxide fertilisation
NPC	National Planning Commission
OECD	Organisation for Economic Co-operation and Development
PDF	Probability density function
RCP	Representative concentration pathway
SAFEX	South African Futures Exchange
SAGIS	South African Grain Information Service
SANBI	South African National Biodiversity Institute
SAWS	South African Weather Service
SRES	Special Report on Emissions Scenarios (IPCC)
StatsSA	Statistics South Africa
UCS	Union of Concerned Scientists
WMS	water management system

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Over the past decade, the BFAP has become a valuable resource for government, agribusiness and farmers by providing analyses of future policy and market scenarios and measuring their impact on farm and firm profitability. The BFAP is a network linking individuals from multi-disciplinary backgrounds to a coordinated research system that informs decision making within the food system. The core analytical team consists of independent analysts and researchers who are affiliated with the Department of Agricultural Economics, Extension and Rural Development at the University of Pretoria, the Department of Agricultural Economics at Stellenbosch University, and the Directorate of Agricultural Economics at the Provincial Department of Agriculture, Western Cape. The BFAP acknowledges and appreciates the tremendous insight of numerous industry specialists over the past decade.

REPORT OVERVIEW

This report develops preliminary high-level messages on the socioeconomic and food security impacts of climate change in South Africa, including the consideration of impacts on South African consumers and employment in the agricultural sector, and implications for adaptation. The messages are preliminary because they are based on modelled impacts on only the two main staple cereal crops (maize and wheat) under a limited set of downscaled LTAS climate scenarios.

The first objective of this study was to translate the selected climate scenarios into maize and wheat production and price effects. To do this, the impacts on staple crop production of four downscaled climate models were incorporated into an econometric, recursive partial equilibrium model of the South African agricultural sector. Within this model, rainfall, both in terms of the total during the production season and its timing, represents one of a number of variables that have an impact on the eventual results of total area planted, total production and commodity price changes. These results were compared to a baseline scenario generated from historical rainfall data. This study therefore provides an economic perspective on the LTAS climate scenario impacts that crop modelling approaches alone are unable to do, for example, by simulating how producers choose to respond to climate change in terms of area planted, and the resultant impact on the equilibrium of demand and supply in maize and wheat markets.

The second objective of this study was to incorporate these results into a consumer impact analysis in order to evaluate the price effects of the respective climate scenarios on poor households. Three approaches were followed in this analysis: The first was the "BFAP poor person's index", the second was the StatsSA income and expenditure based analysis, and the third was the balanced food plate approach.

The third objective of this study was to evaluate the impact of these possible climate futures on agricultural employment. This was achieved through incorporating the results into the BFAP employment model. Collectively these results are interpreted in terms of their food security impacts, both in terms of supply and access. This is translated into adaptation and mitigation recommendations, policy recommendations and future research requirements.

Chapter 1 (Introduction) provides a literature review of comparable research and links with LTAS Phase 1, specifically the LTAS Phase 1 report (no. 3 of 6) on agriculture and forestry.

Chapter 2 (Methodology and Data) delivers an overview of the respective methodologies used in the study, and of the data used within the relevant models.

Chapter 3 (Crop Model Results) provides the results of the partial equilibrium modelling in terms of the changes in the area planted, total production, trade and price of maize and wheat due to the respective climate scenarios.

Chapter 4 (Consumer Impact Study) presents the results of the consumer impact study.

Chapter 5 (Employment Impacts) provides the results of the possible agricultural employment impacts of the respective climate scenarios.

Chapter 6 to 8 (Food Security and Messages) conclude with a discussion of the food security impacts, mitigation and adaptation responses, policy recommendations and future research requirements.

EXECUTIVE SUMMARY

There have been numerous studies on the effects of potential climate change on crop suitability and productivity from a southern African and South African perspective, but these studies do not provide an integrated perspective on how the agricultural and food system could be affected under various climate change scenarios from an economic and social perspective. There is therefore a key need to translate the respective climate scenarios into economic impacts using a locally relevant understanding of food access (price) and of food security. One critical component of such an understanding is the impact on the decision to produce, which also affects agricultural employment. This study aims to fill this gap through a stochastic partial equilibrium modelling approach in order to provide high-level messages on the impact of climate change on South African maize and wheat production towards 2030, and the broader socioeconomic implications.

The Bureau for Food and Agricultural Policy (BFAP) sector model was used to evaluate the impacts under drier LTAS climate scenarios. This sector model can best be described as an econometric, recursive partial equilibrium model of the South African agricultural sector, which presently covers 52 commodities. The results obtained were analysed further from a consumer impact and employment perspective. The objective of this study was to provide high-level messages on the potential impact of climate change on food security and employment under a set of assumptions in order to translate these into policy recommendations that will enable adaptation and mitigation. This study has a strong element of foresighting and, in order to achieve these objectives, a combination of modelling tools was applied. When undertaking foresighting analyses, it is useful to consider the future stochastic range of key fundamental variables and not only to focus on the deterministic projections. It is far more important to explore the possible ranges of key variables and how climate change potentially could have an impact on the maize and wheat industries.

For this study, the actual rainfall data for the period 1950 to 2000 was modelled in order to provide a real-world baseline for 2000 to 2050 to which the results obtained from the inclusion of the precipitation data from the four general circulation models (GCMs) selected could be compared. An analysis of the results from the respective climate models, incorporated into the BFAP model, showed a high correlation before 2030 with a significant divergence only occurring thereafter. In other words, it is apparent that for most of the scenarios the effects on precipitation are apparent only towards the end of the simulation period. Therefore, in order to analyse the potential economic impacts of climate on the South African maize and wheat industries, the precipitation data projected for the period 2034 to 2050 was introduced into the BFAP sector model for each of the scenarios, which were then compared to the base case.

The BFAP sector model generates absolute and percentage shocks to illustrate the relative deviations from the base. The implication can be described best as the effect of more than 20 years of climate change on the current context. It also became clear that only one of the four climate models showed a significant rainfall change after the data were summarised according to national maize and wheat production regions, both in terms of total precipitation and its timing. This underscores the importance of spatial downscaling of national average rainfall changes and timing, and emphasises the need to consider these in much more detail in future studies.

An overview of the fundamental trends within the base precipitation scenario (namely without climate change) is essential for a correct interpretation of the modelled results of the respective climate scenarios. Under the base scenario, South Africa is anticipated to remain a net exporter of white and yellow maize, with domestic supply exceeding demand, and a net importer of wheat, with net imports growing beyond 50% of consumption. Maize prices, therefore, are expected to remain at export parity levels, whilst wheat prices will remain at import parity levels. Within this scenario the total area under field crop production is anticipated to remain relatively stable towards 2030, at around the current level of approximately 4.7 million hectares. However, the allocation of crops within this area is projected to change, most notably with a decline projected in the area planted to white maize from 1.5 million hectares to 1.1 million hectares, and the doubling of the area planted to soybean from around 500 000 ha to more than one million hectares. This shift is the result of the expected continuation of the upward trend in maize yields, whilst the demand for white maize is expected to remain flat due to continued shifts in consumer preferences in favour of bread. The area planted to yellow maize is anticipated to show a small increase, whilst the area under sunflower production is expected to remain flat. The area planted to wheat is expected to decline slightly in favour of an increase in canola production. Wheat imports, therefore, are expected to increase given the growing demand and stagnant supply. Given this context one can evaluate the modelling results of the respective climate models.

For the purpose of this study the data for each climate scenario (monthly precipitation per quaternary catchment) were isolated according to the respective production regions, and the months within the relevant growing period were isolated for inclusion in the model. One of the most interesting findings was that the climate model with the smallest expected decline in mean annual precipitation (MAP), the warmer/drier Max Planck Institute for Meteorology (MPI 4.5) model, had the greatest impact on the maize and wheat production regions, again emphasising the challenge of inferring national impacts from nationally averaged projected climate change.

The BFAP model with the MPI 4.5 model data showed a decline in rainfall during the summer months in the maize producing areas that resulted in a projected decrease in maize yields. White maize yields for example, are anticipated to decline by 1.1 t/ha on average over the outlook period, resulting in a drop in total production of approximately 1.6 million tons per annum and an increase in the white maize price of 16%. Given this increased price environment farmers opt to increase white maize production expanding the area planted. This does not result in an absolute increase in the area planted but rather in a smaller decline (about 200 000 hectares) than was forecast in the base scenario.

Conversely the MPI 4.5 climate model forecast an increase in annual precipitation during the summer months in the summer wheat producing areas (mostly the Free State) that results in a projected yield increase of more than 1 t/ha. This increase in yield does not result in an increase in the area planted to wheat due to the greater relative profitability of maize production for the reasons discussed above. In the winter wheat producing areas (the Western Cape) the results projected by the model show a small decline in precipitation during the winter months resulting in a decline in yield. Collectively these changes result in a projected decline in total wheat production of just over 100 000 tons per annum relative to the base. This does not result in a change in domestic prices, however, since wheat prices are at import parity price levels and are expected to remain there given the fact that close to 50% of wheat consumed in 2013 was imported.

The warmer/drier MPI 4.5 climate scenario results illustrate a number of key principles.

1. The greatest change in MAP does not necessarily equate to the greatest adverse effect, in this study the opposite is true.

2. The timing and locality of rainfall is the deciding factor for eventual area planted and yield.

3. A decline in yield could result in an increased area planted in response to higher prices.

4. Relative prices/profitability matter – farmers in the BFAP model chose to allocate land to maize production,

regardless of forecast increase in wheat yields due to the higher forecast relative profitability of maize production.

One should therefore be mindful of the fact that farmers, as rational economic decision makers, are not confronted with a simple once-off produce/don't produce decision, but rather face multiple decisions over time on expanding, contracting or shifting production to other crops given prevailing prices and climate risk.

This study evaluated the price impacts of the respective climate scenarios on (mostly poor) consumers using three instruments – the BFAP poor person's index, a staple food expenditure-based analysis, and a balanced daily food plate model. At present, maize porridge and brown bread contribute 73.5% of the costs of a five-item low-income weighted food plate. In terms of bread, all the climate scenarios showed no deviation from the base because each of the scenarios, like the base, tracks the world price throughout. In terms of white maize meal, the MPI 4.5 scenario showed a small deviation from the base. The significance of this deviation decreases over time due to a declining trend in white maize consumption per household in favour of bread. It has to be stated, however, that the anticipated increase in the price of white maize based on the MPI 4.5 scenario is the highest increase in the food basket, which is anticipated to increase significantly in price towards 2030. The BFAP poor person's index almost doubles in price by 2025. From a food security perspective this brings the affordability of a balanced food basket prominently to the fore. From a supply perspective, farmers have the ability to increase production in response to high prices. In terms of wheat, the country has been and will continue to be a major importer. Food security therefore is not a question of supply but rather of access, both in terms of financial means or own supplementary production.

The maize and wheat industries are not major employers and are also not regarded as having significant growth potential - together they employed less than 7% of the agricultural labour force in 2013. For the period 2014 to 2025, employment in the maize industry is expected to decline by 2% relative to the base scenario, whereas the least favourable MPI 4.5 scenario delivers the smallest decline (-1.1%). This is partly due to the smaller contraction in the area planted in response to the increase in the maize price relative to the base case. This reduction does not necessarily equate to a decline in absolute employment due to the transfer of area (and labour) to the production of other crops – within the base scenario the area under soybean production is expected to increase from 500 000 to one million hectares. The converse is true in the wheat industry, with the greatest expected decline (-2.2%) in the MPI 4.5 scenario, which is twice the decline in the base scenario.

The challenges faced as a result of climate change do not act on producers in isolation, but rather interact with the multiple stresses to which producers are exposed. It is therefore useful to consider how climate change adaptation responses could be integrated with existing best practices that have evolved to cope with these multiple stresses, including improving the overall efficiency and competitiveness of the production system. Such an approach could focus specifically on responses that benefit producers at multiple scales of production, from smallholder through to large-scale commercial agriculture. Examples include improved transport infrastructure, improvements in irrigation efficiency and water management, continued field trials in partnership between producers, commercial entities and the public sector, public research spending and public information collection and sharing.

It also has to be emphasised that farmers are already adapting to climate change. The reduction in the area under wheat production serves as a good example. Farmers have opted to decrease the area planted by more than half, partly in response to price decreases, but also in order to decrease exposure to climate risk. Farmers are also continually conducting formal and informal field trials in order to identify the varieties best suited to each locality. A supportive response from the public sector would not replace these initiatives, but rather expand and integrate the results of these respective trials. Greater cooperation between producers, seed companies and the state will assist in improving the focus of public research and the quality of extension services provided, particularly to small-scale farmers close to the areas where the trials are conducted. There is clearly an opportunity for government to explore the role of the state in providing an overarching climate change adaptation framework, and associated capacity and support for all agricultural producers.

This study shows that the area under irrigation could be expanded through new investments in storage capacity. Significant gains are possible, however, within existing systems by reducing distribution losses, adopting more efficient irrigation systems, and improving the management of existing irrigation systems. This has the potential to add a further 282 000 ha to the area under irrigated production, simply by using the available water more efficiently. The maintenance of and improvements to existing irrigation systems therefore are imperative. Incentives for the upgrading of existing systems to more efficient alternatives, for example, flood to drip irrigation, would be beneficial, especially if incentivised by the state; alternatively, the amount of water available to consumers could be regulated in order to encourage investments in more efficient systems.

South Africa has been a net importer of wheat since the early 1990s, but the country has also experienced significant increases in high-value agricultural exports since that time. According to the MPI 4.5 climate scenario, wheat imports are expected to increase by around 100 000 tons due to a decline in production and an increase in consumer demand for wheat. Therefore increasingly larger amounts of wheat will have to be moved between sources of supply or the respective ports, and sources of demand. A cost-efficient transport system is imperative in order to ensure the provision of this staple at the lowest possible cost. An improvement in port, road and especially rail infrastructure therefore is of utmost importance. Such infrastructure would also improve the competitiveness of agricultural exports, particularly fruit and wine. These exports currently are significant earners of foreign exchange and will continue to enable the country to afford the substantial and growing primary food imports. They will have to be expanded in future in order to maintain a positive agricultural trade balance and to avoid the negative effects of exchange deficits. Higher export earnings could also benefit from the improvement of SADC regional road and rail networks in order to enable more cost-efficient trade. Zimbabwe is currently one of South Africa's biggest trade partners. Fruit and wine exports to the SADC countries are expected to continue to grow, whilst Zambia, for example, could serve as an important trade partner for wheat.

This study has provided an essential first perspective, but it is a limited one. Maize and wheat are components of a bigger production system in which producers are continuously adjusting the allocation of their resources in order to maximise their return on labour and capital. A study that follows an integrated approach with a much larger number of commodities and the full range of climate scenarios is needed to build a full picture of risks to South Africa's food system. The expected trend in expanded soybean and canola production is a good example of shifts not reflected in this study. An integrated approach would be possible by extending this study to include all 52 commodities in the BFAP sector model and extending the current 10-year outlook. The biophysical ability of the BFAP model requires improvement by inclusion of temperature and carbon fertilisation effects. The development and improvement of biophysical models for horticultural crops and livestock also needs attention. In conjunction with this the models need to be disaggregated to regional and sub-regional levels in order to deliver more localised policy messages.

The inclusion of horticultural crops, together with the development of improved biophysical modelling tools, is particularly important in the South African context due to the higher sensitivity of these crops to climate vulnerability, their importance as foreign exchange earners and as a major source of agricultural employment. One of the major goals of future development, such as the National Planning Commission's National Development Plan (NDP), is job creation and the NPC suggests supporting labour-intensive "winners" in order to expand production (NPC 2011). The crops identified are all horticultural and include pecan nuts, avocados, mangos and table grapes. The plan assigns low employment potential to the wheat and maize industries because of their low growth potential and non-labour-intensive mode of production.

The NDP also highlights the importance of increased agricultural productivity through expanded irrigation based on infrastructure investments in new dams, the reduction of distribution losses, increased usage efficiency and improved water scheme management. The impact of climate change on existing and proposed storage capacity is therefore highly relevant for optimal policy development.

In addition, the plan highlights the importance of creating livelihoods through small-scale agriculture, which could be at greater risk from the impacts of climate change. Further research on how the responsiveness to change of these producers could be increased is important, because at present they have limited capacity to adopt new technology and practices when compared to their commercial counterparts.

Finally, research on how the distribution of agricultural commodities can be improved is essential, given the need to reduce pollution, increase trade competitiveness through increased transport efficiency, and provide food to the consumer at the lowest possible price. The impact of improvements to the existing rail and road network are particularly important future research themes.

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1. INTRODUCTION

Numerous studies have been conducted on the potential effects of climate change on agricultural production in South and southern Africa, particularly in the maize and wheat industries. These studies typically present the results of various model frameworks that simulate the impact of climate change on crop productivity (yield) and changes in crop suitability. These studies, though insightful, only provide a partial perspective because they do not provide insights into the economic and social impacts of these changes in production and their suitability over time. Such an integrated approach is essential for evaluating the food security impacts of climate change because food security is not only limited to physical access to the product through own or local production, but also includes access to the product in monetary (price) terms. This study aims to fill this gap through a partial equilibrium modelling approach in order to provide high-level messages on the impact of climate change on maize and wheat production in South Africa.

The International Food Policy Research Institute (IFPRI) has conducted some of the most comprehensive regional and global studies on the possible impacts of climate change on agricultural production and food security. A study by Nelson et al. (2009) developed possible world food security scenarios towards 2050. These were generated through their International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), which allows for biophysical effects through integration with the Decision Support System for Agrotechnology Transfer (DSSAT) crop-simulation model. For climate data they rely on modelling results from the National Centre for Atmospheric Research (NCAR, USA) and the Commonwealth Scientific and Industrial Research Organization (CSIRO, Australia), which assume the A2 scenario of the Intergovernmental Panel on Climate Change's Fourth Assessment Report (IPCC AR4). These models forecast a warmer climate (higher temperatures) towards 2050, with an increase in both evaporation and total precipitation. The extent of the expected increases in precipitation show a wide disparity, however, with the NCAR model forecasting an average increase of about 10%, compared to the CSIRO's 2%.

The results of Nelson et al. (2009) on sub-Saharan Africa and developing countries are presented in **Table 1** - split according to the inclusion (CF) or exclusion (NoCF) of carbon fertilisation effects. From a sub-Saharan perspective the expected impact on dryland maize production is a decline of between 0.8 and 4.6%, whereas irrigated production shows an increase of between 0.3 and 0.8%. The impact on wheat production is more pronounced, with an expected decline of between 11.2 to 21.9% in dryland production, whereas irrigated production shows an expected increase of between 0.7 and 9.7%. A similar study by Ringler et al. (2010) also concludes that dryland wheat production will be affected most showing an expected decline of just over 20%. An important observation from the table below is that the inclusion of carbon fertilisation delivers a more favourable result in terms of expected decline or increase throughout. This suggests that studies that disregard carbon fertilisation effects generally overstate the impact of climate change on maize and wheat production.

The Nelson et al. 2010 study extended the earlier study to include price effects and the results are presented in **Table 2**. This table shows the expected changes in maize, rice and wheat prices under non-mitigating and perfect mitigation scenarios. In these two scenarios three possible futures are imagined assuming the future as an extension of the current base, or an optimistic or pessimistic future. The pessimistic future assumes a greater increase in population and a lower income growth rate. Collectively, these results show a clear break in the trend of declining commodity prices. Interestingly, maize prices are expected to be affected most in the non-mitigating pessimistic scenario, with an expected increase of just over 100% towards 2050.

Table 1: Yield effects (% change from 2000 to 2050) by crop and management system

Commodity	Region	NoCF[1]		CF[2]	
		CSIRO	NCAR	CSIRO	NCAR
Maize, irrigated	Sub-Saharan Africa	0.3	0.6	0.5	0.8
	Developing countries	-2	-2.8	-1.4	-2.1
Maize, rain fed	Sub-Saharan Africa	-2.4	-4.6	-0.8	-2.7
	Developing countries	0.2	-2.9	2.6	-0.8
Wheat, irrigated	Sub-Saharan Africa	0.7	1.4	7.3	9.7
	Developing countries	-28.3	-34.3	-20.8	-27.2
Wheat, rain fed	Sub-Saharan Africa	-19.3	-21.9	-11.2	-15.9
	Developing countries	-1.4	-1.1	9.3	8.5

Source: Nelson et al. (2009)

Note: 1. Excluding higher atmospheric concentrations of CO_2.
2. Including higher atmospheric concentrations of CO_2.

Table 2: Price outcomes of the overall scenarios

Scenarios	Maize	Rice	Wheat	Maize	Rice	Wheat
	% price change, 2010 mean to 2050 mean			% price change, 2010 mean to 2050 mean with perfect mitigation		
Baseline	100.7	54.8	54.2	32.2	19.8	23.1
Optimistic	87.3	31.2	43.5	33.1	18.4	23.4
Pessimistic	106.3	78.1	58.8	34.1	19.5	24.4

Source: Nelson et al. (2010)

Note: The percentage increase for the scenarios is the mean across the results for the four climate scenarios, CSIRo and MIRoC GCMs with the IPCC's Special Report on Emissions Scenarios (SRES) A1B and B1 greenhouse gas (GHG) forcings.

All of the studies cited above had a sub-Saharan or global focus, but studies have been conducted on South Africa as well. Hachigonta et al. (2013) applied the same modelling framework as Nelson et al. (2010), but assumed the IPCC's A1B scenario towards 2050. In terms of South African maize production, the Hachigonta et al. study projects a decrease in area planted and an increase in average production of between 1.9 and 2.7 tons/hectare, which results in an increase in total production of 0.3 to 2.8 million tons. Three of the four models project significant productivity increases in the North West Province, currently one of the biggest maize-producing areas but with a low average yield. In the Free State Province, some areas currently growing maize are projected not to be able to do so, whilst other areas will see the opposite happening. The suitability of maize production in the Eastern Cape is also expected to increase in general. For wheat, the models forecast large areas of increased yields in the Free State and Mpumalanga provinces, whilst yields could come under threat in the Western Cape due to decreased annual precipitation. The results on the increased wheat yields, especially in Mpumalanga, are somewhat suspect, given that very little wheat is grown in this area, partly due to its disease-prone climate and to rain during harvest time.

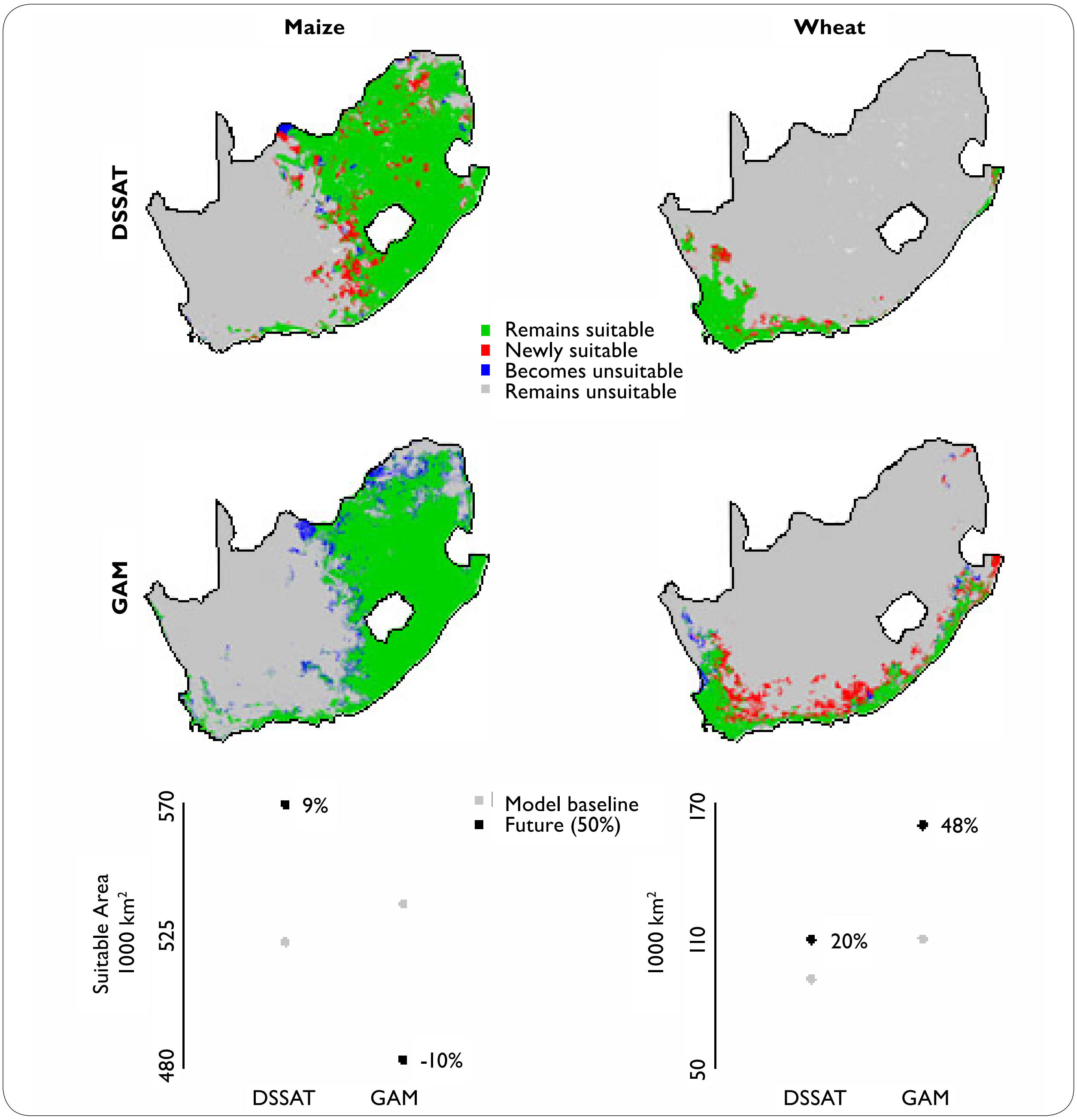
Estes et al. (2013) applied both mechanistic (DSSAT, as used above) and empirical (generalised additive models (GAM)) models to project the climate change impacts on the potential spatial distribution (suitability) and productivity of maize and spring wheat in South Africa under 18 downscaled climate scenarios (nine models run under two emissions scenarios) towards 2055. Both the mechanistic and empirical models project that the current core maize production areas will remain suitable towards 2055, but not equally so. The DSSAT model projected a 9% gain, primarily along the south-western boundary (north-western Free State) of the baseline, while the GAM model showed a 10% loss, concentrated along the northern and western boundaries (see **Map 1**).

Both models show an expansion in the area suitable for wheat production, with the GAM and DSSAT models projecting an increase of 48 and 20% respectively. The DSSAT model showed an expansion of the suitable area into the interior from the northwest and southeast of the current growing region, whereas GAM showed gains into the interior along the entire length of its baseline suitability region (see **Map 1**). In terms of productivity projected by the models for maize and wheat, the GAM model projected a change of -3.6% and 6.2% respectively, compared to the 6.5% and 15.2% respectively predicted by the DSSAT model.

The first phase of the LTAS project included a technical report (No. 3) that provided insights into the biophysical effects of climate change on agricultural and forestry production. In terms of productivity changes, this report showed an expected change in dryland maize yield of between -25 and 10% in a non-mitigation scenario, and a change of between -10 and 5% if CO_2 would stabilise at 450 ppm. In terms of wheat and sunflower production, the results are mostly similar (DEA, 2013).

A number of general observations can be made for the above regardless of the high degree of variation in results:

1. From a sub-Saharan African perspective, maize yields are expected to be affected minimally if compared to the expected declines in wheat yields.
2. The inclusion of CO_2 fertilisation has a positive impact through smaller declines or increases.
3. Irrigated crop production shows an increase in productivity.
4. The results on South African maize suitability vary from negative to positive, whereas wheat suitability is expected to increase moderately or significantly.



Map 1: The change in areas suitable for maize and spring wheat production in 2055

Source: Estes et al. (2013)

Note: Projected by both the Decision Support System for Agrotechnology Transfer (DSSAT) model and the Generalised Additive Model (GAM) under the median agreement criterion (at least 9/18 simulations agree regarding future suitability). Plots along the bottom row show the per cent change in suitable area (given in km2 relative to each model's simulated baseline suitability.

2. METHODOLOGY

This study explores impacts on only the two main staple cereal crops (maize and wheat) under a limited set of downscaled LTAS climate scenarios. These crops were selected because they are of national relevance. The BFAP sector model is used to evaluate the effect of climate scenarios on the price, trade and production effects of these key staple crops. It is envisaged that impacts on other commodities will be investigated at a later stage. These results, in turn, are incorporated into the BFAP consumer models in order to evaluate the effect of the possible price changes, especially on poorer households in South Africa. The data will also be incorporated into the BFAP employment model in order to explore the employment effects of the scenarios on employment in the maize and wheat industries.

2.1. The sector model

Section 3 presents the results obtained through the BFAP sector model. This model was first used in 2003 and can be described as an econometric, recursive partial equilibrium model of the South African agricultural sector. The model presently covers 52 commodities. Within each sector, the components of supply and demand are estimated and equilibrium is established based on balance sheet principles, where demand equals supply at the national level. The model is solved within a closed system of equations, where grains are linked to livestock through feed, implying that a shock in the livestock sector is transmitted to grains and oilseeds and vice versa. The model is linked to global markets through the Food and Agricultural Policy Research Institute (FAPRI) in America, as well as the Aglink-Cosimo modelling system used for the annual Organisation for Economic Cooperation and Development and Food and Agricultural Organization of the United Nations (OECD–FAO) agricultural outlook. **Figure 1** presents a diagram of the BFAP modelling system in which weather has been captured as an external driver of the BFAP sector model.

The BFAP sector model does not incorporate a biophysical model (such as the DSSAT model) as such, but incorporates biophysical elements, specifically the locality and timing of precipitation. In the model rainfall has an impact on producers' decisions to plant and eventually on the yield achieved during the season. For the purpose of this study it is assumed that temperature effects are offset by CO_2 fertilisation effects. Therefore the impacts of temperature changes and CO_2 fertilisation effects are omitted. Given the results of Nelson et al. (2010) discussed in section 1, one can argue that this is a realistic, if not conservative, assumption. Nelson et al. showed net positive effects on both wheat and maize yield if CO_2 fertilisation effects were included.

The BFAP sector model includes macroeconomic data from various international modelling organisations. Data from these organisations are currently forecast up to 2023 (typical 10-year outlook), and in some cases up to 2030. From a visual analysis of long-run stochastic modelling projections it is evident that they are not meaningful over the very long run because the projections will simply flatline, becoming non-stochastic, after the establishment of equilibrium. The trend will be unchanged thereafter (essentially a straight line) until a new, exogenous shock is introduced into the model. Given the above, the BFAP sector model is not extended beyond 2030, partly due to the unavailability of data and the resulting simple continuation of the trend thereafter.

2.2. Consumer impact study

Section 4 presents the results of the consumer impact study. In this study the retail prices for maize meal and bread generated through the BFAP retail price transmission models will serve as the main input for the analysis. The potential impact of maize and wheat price changes due to climate change, especially on poorer households in South Africa, will be investigated using multiple approaches.

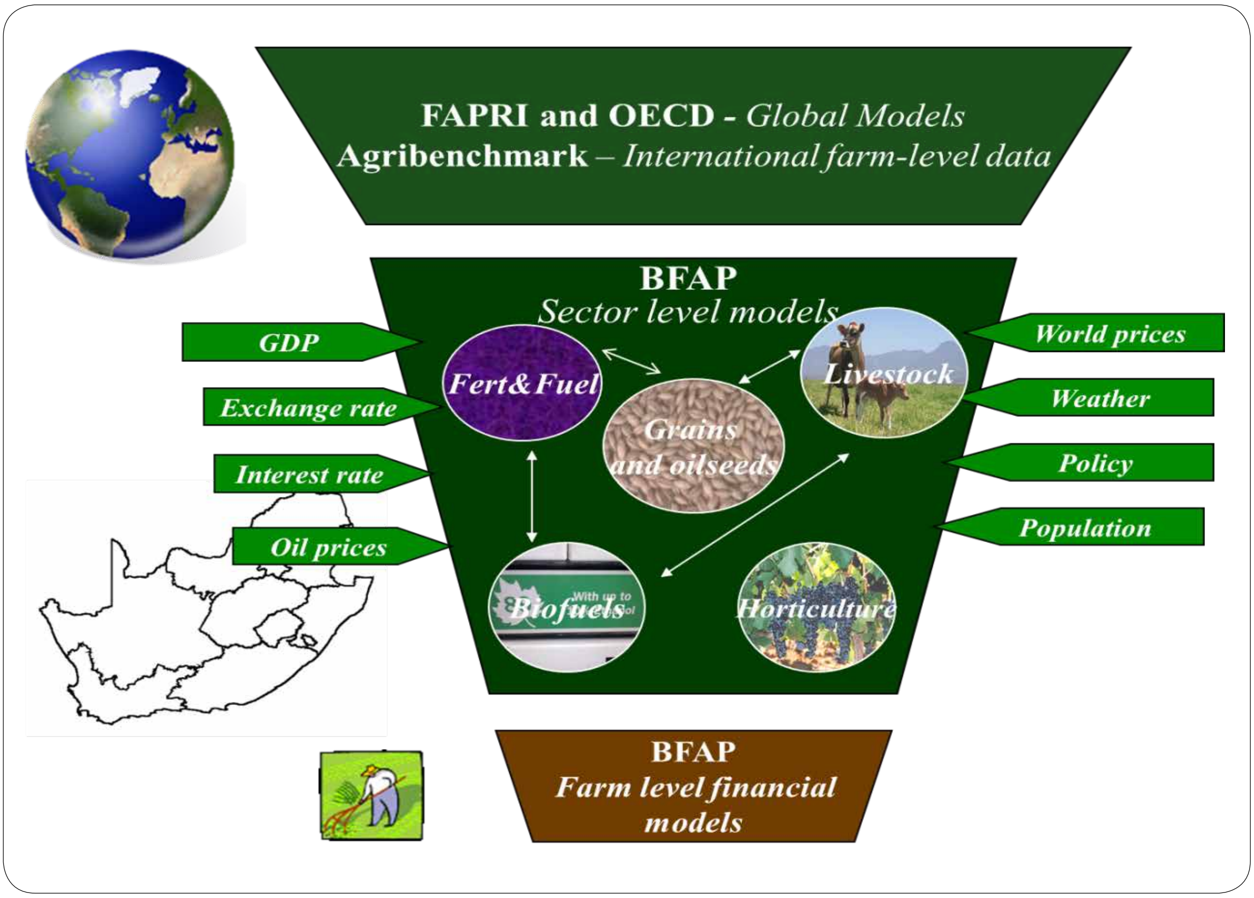


Figure 1: The BFAP modelling system

Approach 1: The BFAP poor person's index

The BFAP poor person's index (**Table 3**) was developed based on poor South African consumers' typical portion sizes of the five most widely consumed food items in the country: maize porridge, brown bread, sugar, tea and full cream milk (*Nel & Steyn 2002; Oldewage-Theron et al. 2005; Steyn et al. 2000*). The term "most widely consumed" means that these food items are consumed by the largest share of South African adults according to the National Food Consumption Survey and other similar studies among poor South African consumers. The BFAP poor person's index was calculated based on the typical weightings of (cooked) daily portions of these food items consumed by very poor consumers (as obtained from the various nutritional studies mentioned above), in order to calculate the cost of a typical daily food plate for the poor. This index is usually calculated based on the official food price database used by the National Agricultural Marketing Council (NAMC) for food price monitoring activities. For this exercise, the projected prices for brown bread and maize meal will be inserted into the model to investigate the potential impact on poor households' basic food expenditure.

Table 3: Composition of the BFAP poor person's index

Category	Products
Bread & cereals	Maize porridge (532g cooked portion)
	Brown bread (150g portion)
Dairy	Full cream milk (56g portion)
Sugary foods	White sugar (22g portion)
Hot beverages	Tea (2.5g dry tea portion)

Approach 2: Staple food expenditure-based analysis

A model of the staple food consumption patterns of households from different socioeconomic groups in South Africa will be developed, using the average expenditure of the ten income deciles in South Africa on main staple food commodities as a departure point (StatsSA, 2012). The projected prices for bread and maize meal will then be inserted into this model to estimate:

- The potential additional expenditure on these staple foods if consumption quantities remain the same at higher price levels.
- The potentially reduced energy intake if staple food budgets remain unchanged but the retail prices of bread and maize meal increase.

Approach 3: A balanced daily food plate model

The BFAP has been working with nutritionists to compile examples of balanced daily food plates, adhering to both the requirements of adequate energy intake and micronutrient composition. The projected prices for bread and maize meal will then be inserted into this balanced daily food plate model to estimate:

- The potential additional expenditure on these staple foods if consumption quantities remain the same at higher price levels.
- The potentially reduced energy intake within this daily food plate if food budgets remain unchanged but retail prices of bread and maize meal increase.

Developing future scenarios for a change in household characteristics, such as food expenditure patterns, class mobility and other factors, falls beyond the scope of this study. Hence, the current characteristics will be applied in order to generate the impact of future maize meal and bread prices in the analyses described above. The assumption therefore is that households will have the same characteristics 20 years into the future as is the case presently.

2.3. Climate Data

LTAS Phase I developed a consensus view on the range of plausible climate scenarios for three time periods for South Africa at national and sub-national scales under a range of global emissions scenarios. The time periods considered were 2015 to 2035 (centred on ~ 2025, so-called short term), in addition to the previously followed approach of exploring climate change over several decades into the future centred on ~ 2050 (medium term) and ~ 2090 (long term).

These scenarios were developed through local and international climate modelling expertise using both statistical and dynamic downscaling methodologies based on outputs from IPCC AR4 (A2 and B1 emissions scenarios) and IPCC AR5 representative concentration pathways (RCP) with radiative forcing of 8.5 and 4.5 Wm-2. These represent an unmitigated future energy pathway (unconstrained, A2 and RCP 8.5) and a mitigated future energy pathway (constrained, B1 and RCP 4.5, or emissions scenarios equivalent to CO2 levels stabilising between 450 and 500 ppm).

South Africa's climate future up to 2050 and beyond can be described by using four fundamental climate scenarios at national scale, with different degrees of change and likelihood that capture the impacts of global mitigation and the passage of time.

1. Warmer (< 3°C above 1961–2000) and wetter, with a greater frequency of extreme rainfall events.
2. Warmer (< 3°C above 1961–2000) and drier, with an increase in the frequency of drought events and somewhat greater frequency of extreme rainfall events.
3. Hotter (> 3°C above 1961–2000) and wetter, with a substantially greater frequency of extreme rainfall events.
4. Hotter (> 3°C above 1961–2000) and drier, with a substantial increase in the frequency of drought events and a greater frequency of extreme rainfall events.

The effect of strong international mitigation responses would be to reduce the likelihood of scenarios 3 and 4. It was not possible to evaluate the effect of all the respective climate models using the BFAP model during the time frame of LTAs Phase 2, due to the amount of work required to prepare the data for analysis. Therefore the decision was made to conduct a preliminary test of the effect of four climate models representing a range of rainfall changes at national level. A subset of scenarios was selected from those available to explore the vulnerability of wheat and maize production and its effect on the food system.

Table 4: LTAS scenario representative models (2040–2050), with calculated percentage average rainfall changes

LTAS scenario	Model	Average change in MAP (%)
Warmer/moderately drier	ACCESS RCP 4.5	- 3.3%
Warmer/drier	MPI RCP 4.5	- 1.1%
Hotter/moderately drier	ACCESS RCP 8.5	- 4.3%
Hotter/drier	MPI RCP 8.5	- 14%

Source: Aurecon (2014)
Note: Australian Community Climate and Earth System Simulator (ACCESS); representative concentration pathway (RCP); Max Planck Institute for Meteorology (MPI)

In light of the above, the four Council for Scientific and Industrial Research (CSIR) Coupled Models Intercomparison Project Phase 5 (CMIP5) climate models in **Table 4** were selected and the results were incorporated into the BFAP sector model in order to evaluate the possible price and production impacts of each of these possible climate futures. The warmer models incorporate the assumptions of the RCP 4.5 climate futures, whilst the hotter scenarios assume the RCP 8.5 futures. Both of the moderately drier scenarios are the result of the Australian Community Climate and Earth System Simulator (ACCESS) global climate model, whilst the drier scenarios are the result of the MPI global model.

These models delivered actual monthly precipitation, dynamically downscaled through the conformal-cubic atmospheric model (CCAM) into quaternary catchments. These quaternary catchments, in turn, were aggregated into secondary catchments by averaging the quaternaries that constitute each of the secondary catchments. The resulting secondary catchments were then grouped according to production areas and months of interest specified by the BFAP sector model. With the wheat model, for example, both the winter (Western Cape) and summer (Free State) production areas were compared with the calculated secondary catchments. The relevant catchments within each of these production areas were then identified, the precipitation data of the relevant months was isolated, totalled per production area and then included in the model.

As stated above, this model can only provide meaningful econometric results up to 2030 due to the fact that forecast data on the determining factors (dependent variables) of the model, other than precipitation in this case, is only available up to this date. The problem, however, is that an analysis of the precipitation data of the respective models, grouped in accordance with the BFAP model, shows a high correlation before 2030 and only shows a significant divergence thereafter. In other words, it is apparent that, for some of the scenarios, the effects on precipitation increase towards the end of the period (2050). Therefore, in order to analyse the potential economic impacts of climate on the South African maize and wheat industries, the precipitation data projected for the period 2034 to 2050 is introduced into the BFAP sector model for each of the scenarios, which are then compared to a base case. The BFAP sector model generates absolute and percentage shocks to illustrate the relative deviations from the base. The implications can best be described *as the effect of more than 20 years of climate change on the current context*.

It was decided to use actual historic precipitation data as a base to compare the modelling results of the respective scenarios with. Rainfall for the period 1950 to 2000 was used for this purpose, and this data was also aggregated to secondary catchments and allocated to the relevant production areas, as explained above, and included in the model. The modelling results of this data hence serve as a real-world stochastic base to which the other results can be compared.

3. CLIMATE CHANGE IMPACTS ON PRODUCTION AND PRICES

3.1. Developing the LTAS Base 2030 projections

Various approaches and modelling techniques can be applied in the world of foresighting and developing future outcomes of agricultural markets. The methodology that BFAP has developed links scenario thinking techniques to a set of empirical models at global, national and farm level. The starting point for the empirical impact analysis is first to set a benchmark from which potential deviations can be measured. For BFAP, this benchmark is the most basic projections that are simulated in the BFAP sector model and are referred to as deterministic baseline projections. As discussed in **Section 2.1** of this report, the BFAP sector model is a recursive partial equilibrium model. The model takes the interaction between various industries, like livestock, grains and oilseeds, into consideration and projects the future equilibrium between demand and supply for a range of agricultural markets subject to a set of assumptions.

Traditionally, the BFAP baseline projections provide a 10-year outlook on commodity markets, but this baseline was extended to 2030 for the purpose of this study. In other words, a future scenario is simulated for the next 17 years grounded in a series of assumptions about the general economy, agricultural policies and technological change. The typical macroeconomic assumptions that are used to generate the baseline are presented in **Table 5**. The outlook for international maize and wheat prices was generated by FAPRI at the University of Missouri in February 2014. These macroeconomic projections were extended to 2030.

Since the BFAP sector model also takes future rainfall into consideration when projecting the area planted and the yield for a specific crop, a further critical driver that has to be incorporated is the future expectations of rainfall. In this type of modelling exercise it is assumed traditionally that normal rainfall conditions will prevail and, in the BFAP's baseline analysis, normal rainfall is taken as the average rainfall received over the past thirty years from the South African Weather Service's (SAWS's) database. One can anticipate that the deterministic outlook is far less volatile than will actually be the case. In order to simulate any alternative outcome and to illustrate the impact of volatile weather conditions, the model is simulated stochastically, where the variability of precipitation in the past is projected into the future.

Table 5: Macroeconomic baseline assumptions

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Crude oil Persian Gulf: (USD/barrel)	101.0	95.5	100.9	105.4	109.8	114.3	117.7	121.0	124.4	127.8
SA population (millions)	51.2	51.4	51.7	51.9	52.1	52.3	52.6	52.8	53.0	53.3
Exchange rate (R/USD)	11.00	10.83	11.20	11.56	11.97	12.40	12.84	13.30	13.77	14.26
Yellow maize, US No. 2 FOB ($/ton)	231	215	216	218	221	224	223	222	221	218
Wheat, US HRW No. 2 FOB ($/ton)	287	251	242	244	249	256	258	257	256	257

Source: FAPRI (2014)
Note: FOB – free on board; HRW No.2 – US Hard Red Winter

For the purpose of this study, a different approach was followed, with the LTAS base precipitation being used in the model to develop a benchmark to which the modelling results of the respective scenarios can be compared. It was decided to use actual historic precipitation data as the base. For this purpose rainfall for the period 1950 to 2000 was used, aggregated to secondary catchments and allocated to the relevant production areas as explained in section 2 of this report. The modelling results of this data serve as a real-world stochastic base to which the other results can be compared.

Figure 2 compares the normal rainfall assumption applied in the BFAP approach to the LTAS base approach used for this study. From the figure it is clear that the LTAS base already has significant variation in the projected future rainfall.

Grounded on these key assumptions of macroeconomic drivers and the LTAS base precipitation, the agricultural outlook for the period 2014 to 2030 was generated in the BFAP sector model. A proper understanding of the fundamental trends projected under the base precipitation is required before any comparison under alternative climate scenarios can be undertaken.

Figure 3 presents a summary of the hectares planted under the main field crops. In the base case, the total area devoted to the main field crops is anticipated to remain relatively stable compared to the current levels of around 4.7 million hectares. It is interesting to note that in the late 1970s the total area covered by these crops was close to seven million hectares. Therefore, a major shift away from dryland farming has already taken place. A detailed discussion of why this shift has occurred falls beyond the scope of this report, but in short the subsidised production environment previously maintained by the marketing boards and the department of agriculture led to the expansion of field crop production into marginal areas.

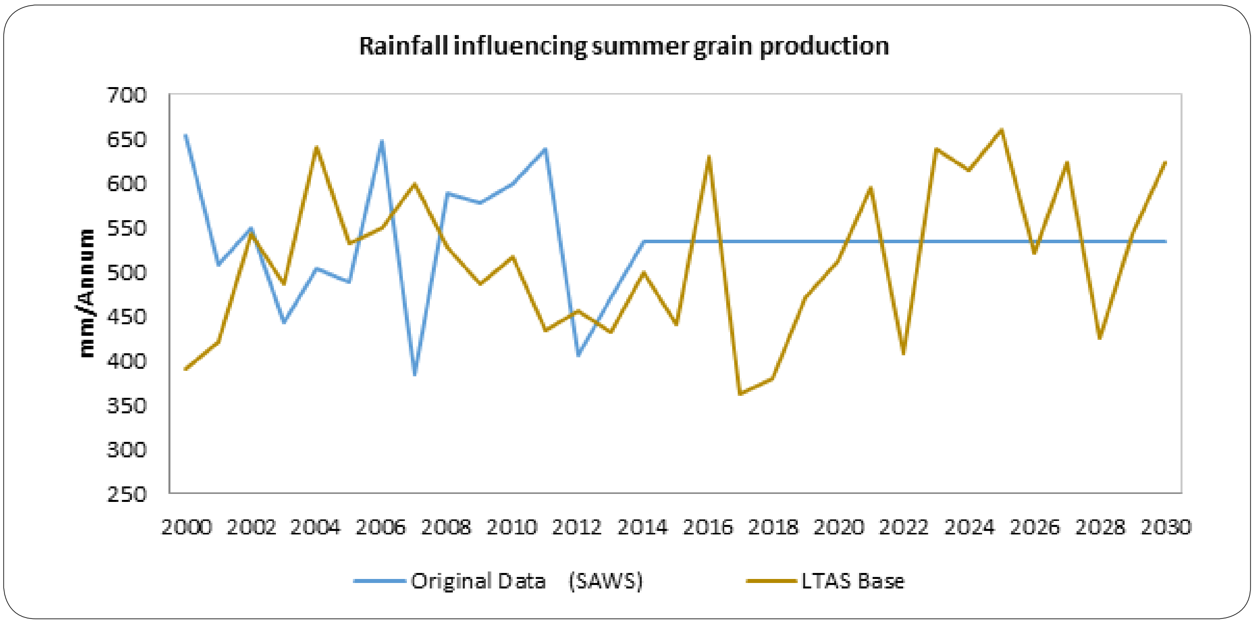


Figure 2: Rainfall for maize production, historical and forecast

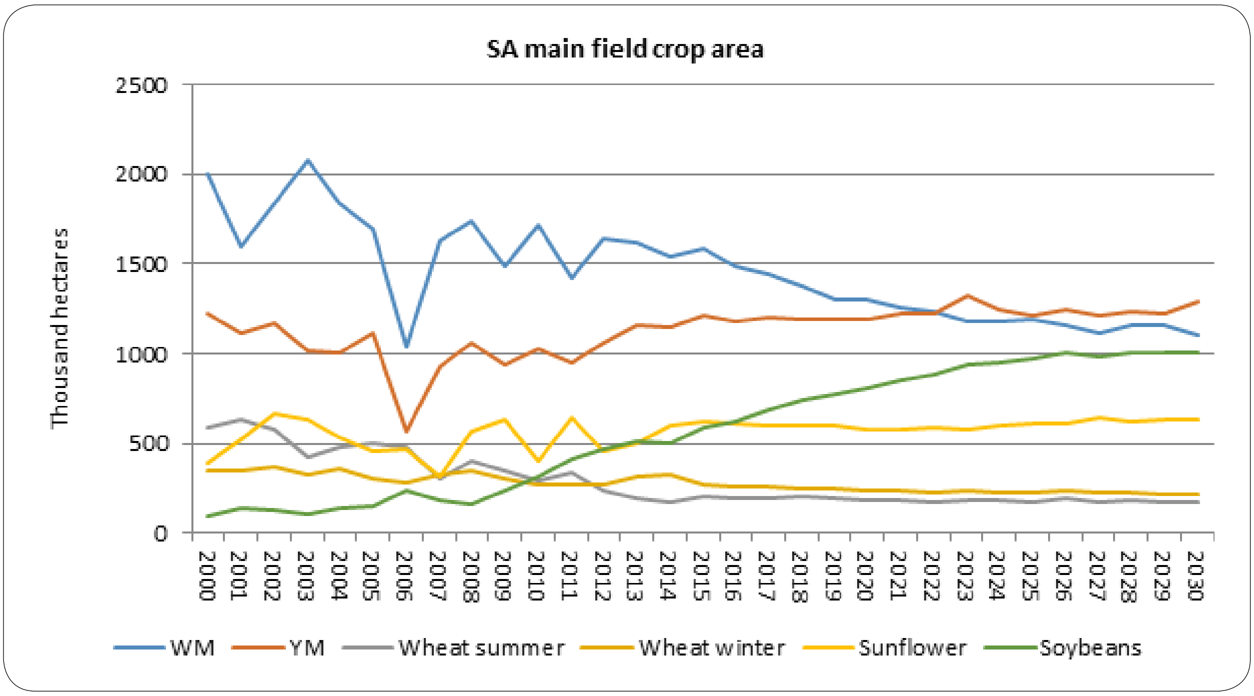


Figure 3: SA main field crop area

However, despite the stable outlook for the total field crop area, there are a number of dynamic shifts taking place in the various types of field crops. A definite shift is occurring over the outlook period, with the white maize area declining from 1.5 million hectares to 1.1 million hectares and the soybean area doubling from around 500 000 ha to more than one million hectares. Farmers will plant more yellow maize and the area under sunflower is expected to remain relatively constant. In short, the oilseed area is anticipated to expand at the cost of grains.

The amount of dryland wheat planted in the Free State and parts of Limpopo and the North West provinces has declined drastically, from levels close to one million hectares in the late 1990s, shortly after the abolition of the marketing boards, to less than 200 000 ha in 2013. Basic economic principles have been the key driver behind this dramatic shift, with the profitability of maize, and lately of soybeans, outstripping that of wheat, mainly due to the introduction of new genetically modified seed varieties boosting the yields of maize and soybeans at a rapid rate. A further driver behind the shift in the area is the increased level of risk aversion of farmers in the deregulated marketing environment, with wheat yields in these areas more exposed to climatic risks such as late frost or rain that is not received in time. In recent years, excessive precipitation during harvest in November and December has increased crop losses and decreased the quality of wheat delivered. In other words, farmers are already adapting in order to mitigate their risk due to climate variability and volatile markets.

Although the area under dryland wheat production in the Western Cape Province has also gradually declined over the past decade, the shift has not been nearly as dramatic, with the area stabilising around 300 000 ha. However, over the baseline period it is anticipated that some land in this production region will be lost to rotation production practices with canola. Significant strides have been made in recent years in improving canola yields and the introduction of genetically modified canola will bring significant relief compared to the significant weed pressure experienced by wheat farmers.

The long-term cropping patterns portrayed in **Figure 3** are simulated based on the dynamic interaction between demand and supply, which basically determines the equilibrium pricing conditions. Equilibrium pricing conditions drive the impact of exogenous shocks on commodity markets. The focus in this research falls on maize and wheat, which experience significantly different equilibrium pricing conditions. Even within the maize market there is a difference in the way that yellow and white maize prices, for example, relate to international prices. In short, under free-market conditions, domestic prices tend to trade closer to export parity when local supply exceeds local demand by a significant margin and there is a tradable surplus. If, however, there is a shortfall in the local market and local demand can only be met by imports, the domestic price tends to trade at import parity. Therefore, in a free market, local prices are expected to trade between import and export parity based on local supply and demand dynamics. **Figure 4** presents the projected levels of white maize production, consumption and yield under the LTAS base precipitation data. Despite varying yields over time, there is a strong upward trend in national yields that is offsetting the decline in the area under production presented in **Figure 3**, and a surplus of white maize will be produced over the outlook period. Another important trend to pick up from the white maize market is that of the domestic consumption of white maize, which is expected to remain flat as people move to higher income levels, where the general shift is from maize meal to bread and rice.

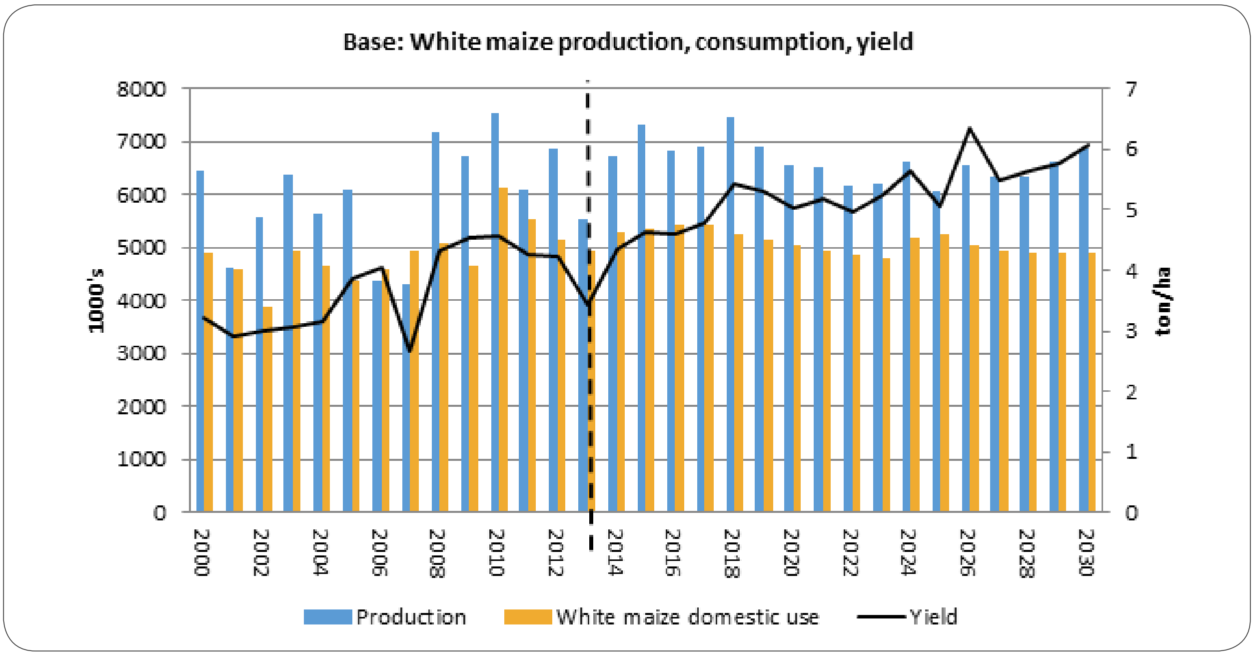


Figure 4: Base: White maize production, consumption and yield

The corresponding price and trade space for white maize is presented in **Figure 5**. Local white maize prices (red line) are expected to gradually ease away from export parity (yellow line) levels, and the level of exports will decline until prices are high enough to induce a shift back into the white maize area. This correction takes place in 2026, when the level of production rises significantly. This effect clearly illustrates the advantage of a partial equilibrium model to capture the dynamics between supply and demand.

In the case of yellow maize (**Figure 6**), the balance between demand and supply is significantly tighter, with the demand for yellow maize increasing rapidly in the feed market on the back of larger livestock production, mainly poultry. Despite a strong growth in yields, the supply of yellow maize is barely able to keep up with demand in most years and by 2025 a shock occurs, with significantly higher prices boosting the area under production, after which it returns to a long-run equilibrium.

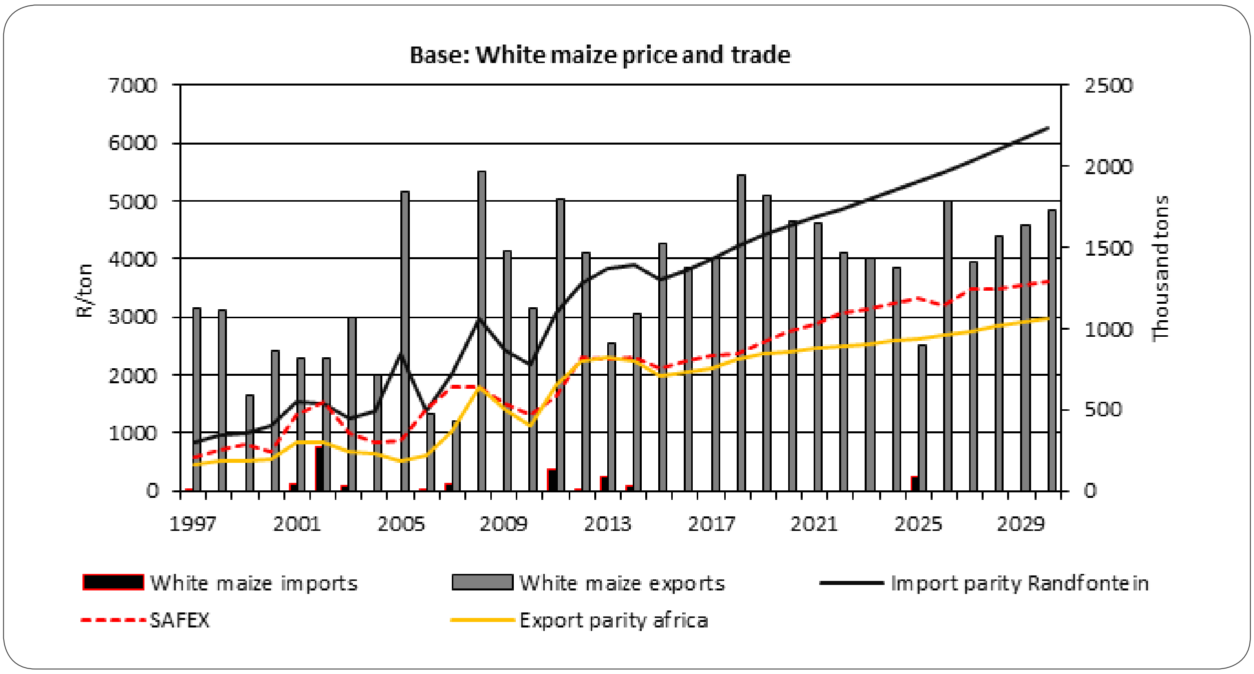


Figure 5: Base: White maize price and trade space

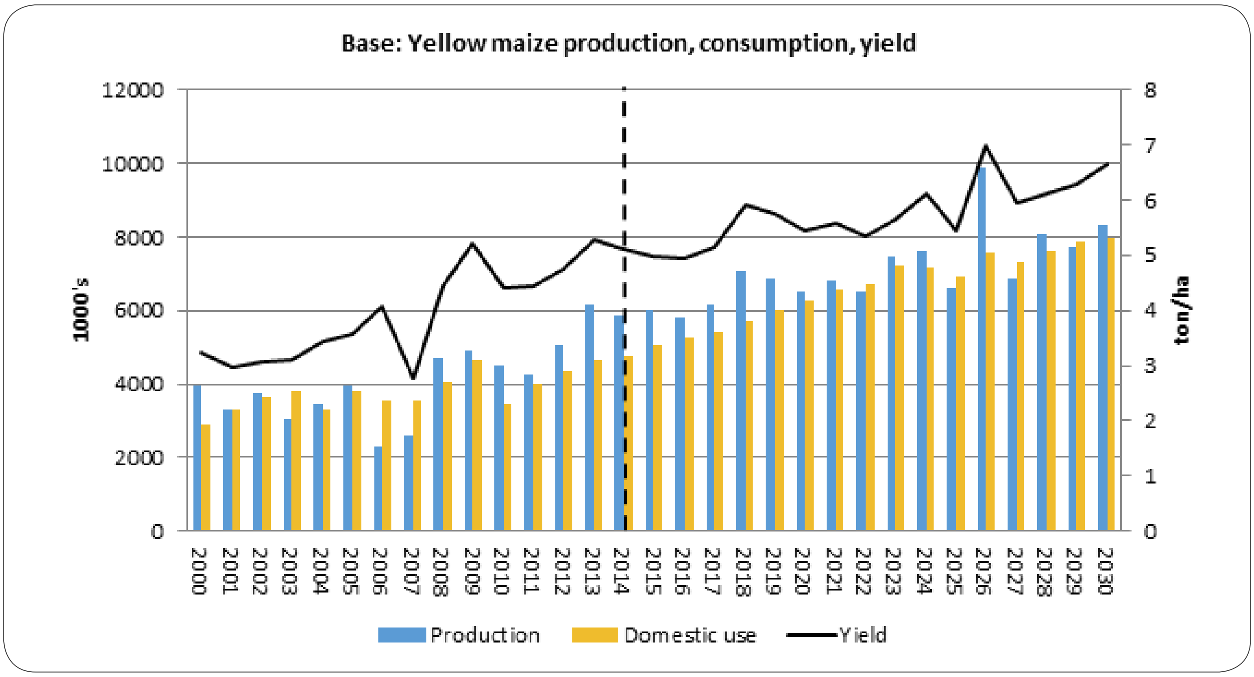


Figure 6: Base: Yellow maize production, consumption and yield

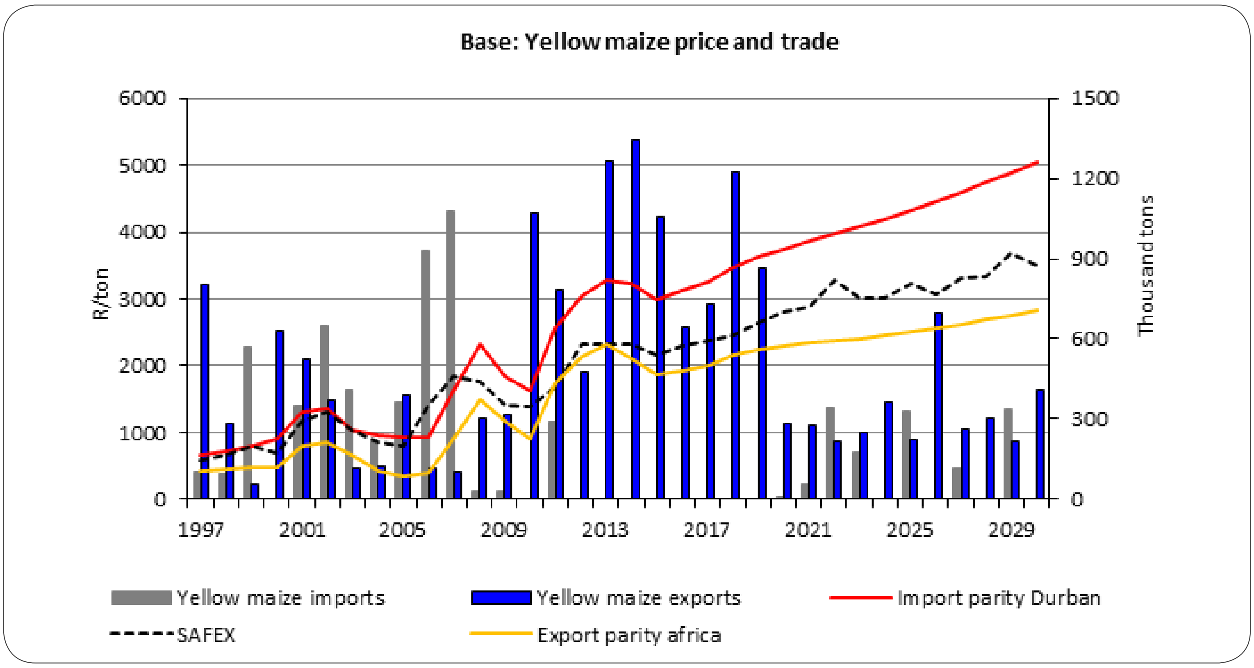


Figure 7: Base: Yellow maize price and trade space

Figure 7 presents the corresponding price and trade space for yellow maize. Due to the lower yields projected over the period 2018 to 2021 (induced by lower precipitation in the LTAS base), the level of yellow maize exports plummets and the local market responds with more volatility in the market compared to white maize. Naturally, yellow maize can be substituted with white maize at a slight price premium in the feed market, and therefore the level of correlation between these two markets will remain high.

In contrast to the situation relating to white and yellow maize, SA is a net importer of wheat and the level of wheat imports is expected to rise, with consumption reaching more than four million tons by 2030 and the level of production fluctuating around 1.7 million tons. The majority of wheat consumed locally will be imported. The general rise in per capita income and the rate of urbanisation triggers strong growth in the demand for bread, rice and potatoes. The historic trend in summer yields presented in **Figure 8** is misleading, because the relative share of irrigated wheat has increased rapidly as the dryland hectares have dwindled, which is the reason for the sharp rise in yields. Over the outlook period, average yields will continue to increase, the dryland area will be consolidated further and a larger share of the total area of wheat planted in the summer rainfall region will be under irrigation.

Wheat yields in the winter rainfall region (Western Cape) have been exceptional since 2010, with above-normal climatic conditions boosting average yields for the total region above 3 t/ha in 2012. Yields declined in 2013, due to slightly less rain. Over the outlook period, yields in the winter rainfall area are expected to increase marginally. The reason for much lower yields in the outlying years is simply the lower projected precipitation levels under the LTAS base case. The main drivers behind the increasing trend in yields are better rotational cropping patterns and the exclusion of marginal soils. In total, the Western Cape is expected to lose almost 70 000 ha of wheat over the baseline. Fifty thousand hectares will be picked up by canola, and the remaining hectares will go for grazing purposes.

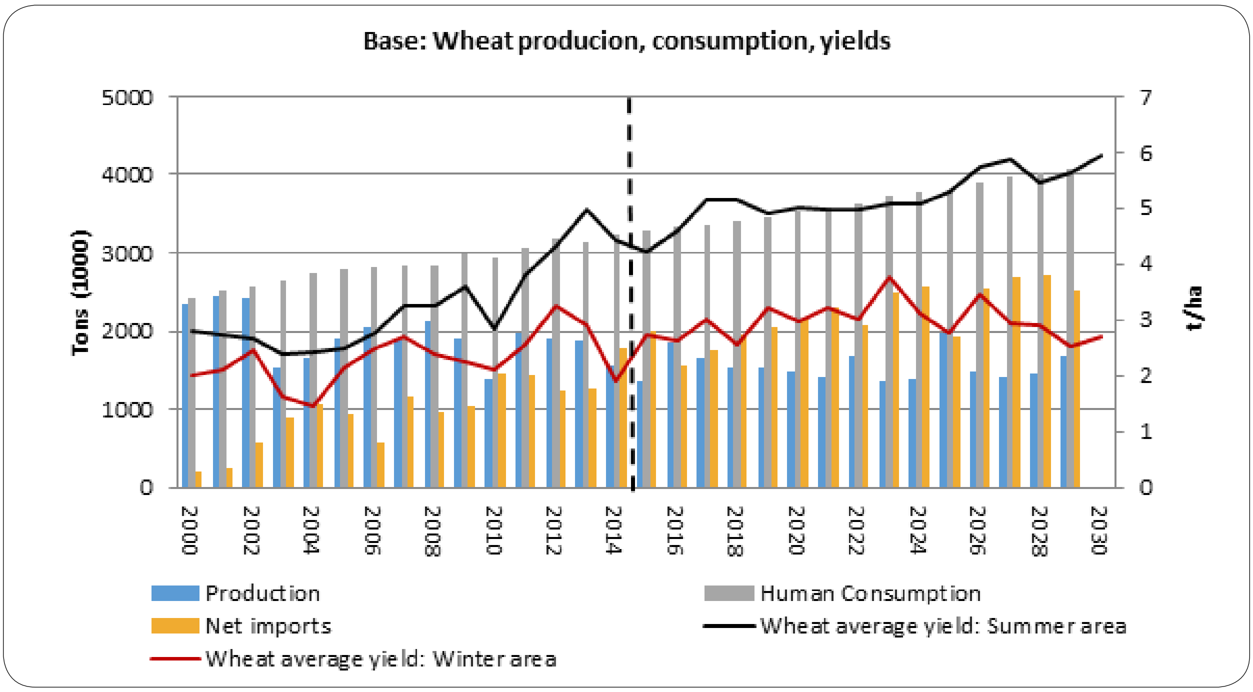


Figure 8: Base: Wheat production, consumption and yield

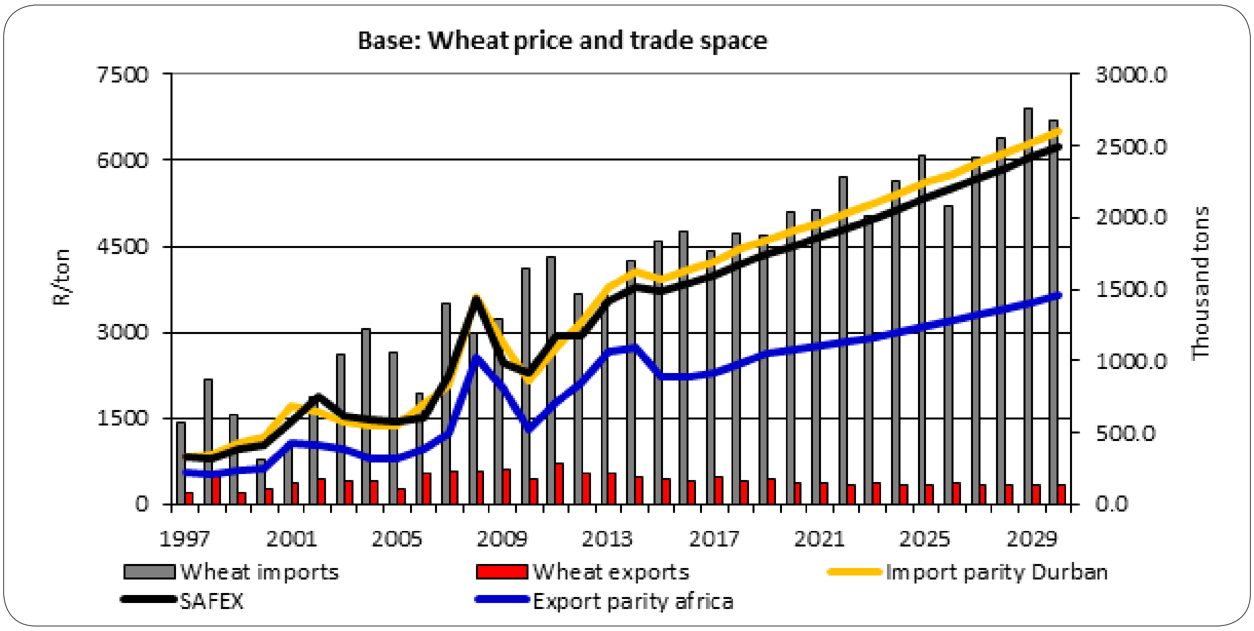


Figure 9: Base: Wheat price and trade space

The price and trade space for the South African wheat market are presented in **Figure 9**. As can be expected, the domestic wheat price follows import parity price levels and will continue to do so in future unless there is a major shift in trade policies that influences the equilibrium pricing conditions. In fact, BFAP estimates show that the level of price transmission from international to local market prices equals 92%. Hence, no local supply or demand shock will have any major impact on the price of wheat. The market will simply adjust the level of imports, depending on the expected shortfall.

The wheat import parity price continues to increase along a linear trend. This is due to the projected global wheat price (**Table 5**) generated by FAPRI. The import parity price in rand terms increases as the rand depreciates over time.

Case Study 1: Maize

Figure 10 presents South Africa maize production in terms of area planted and average yield, expressed as a five-year moving average to better illustrate the trend. The figure clearly shows a decline in the area planted since 1988, from its highest level of close to five million hectares in the mid-1980s to a low of less than three million hectares in the mid-2000s, a reduction of about 40%. Average yield increased from an average of around 1.5 tons/ha in the 1970s and 1980s, to the current level of around 4 tons/ha. Average yield shows a similar but opposite trend to that of the decline in the area planted, starting to increase at a relatively slow rate from 1988 and then accelerating in the mid-1990s.

The reduction in the area planted since 1988 is mainly the result of the deregulation of maize marketing through the abolition of the fixed-price, single-channel marketing scheme. This resulted in the reduction of the domestic maize price to export parity levels, which in turn lowered the profitability of marginal land in production to such an extent that it was made unprofitable to produce on (Vink & Kirsten, 2000). Maize price increases, especially during the late 1980s and early 1990s, were driven by this trend of the removal of marginal land from production, mainly in the more arid western production regions.

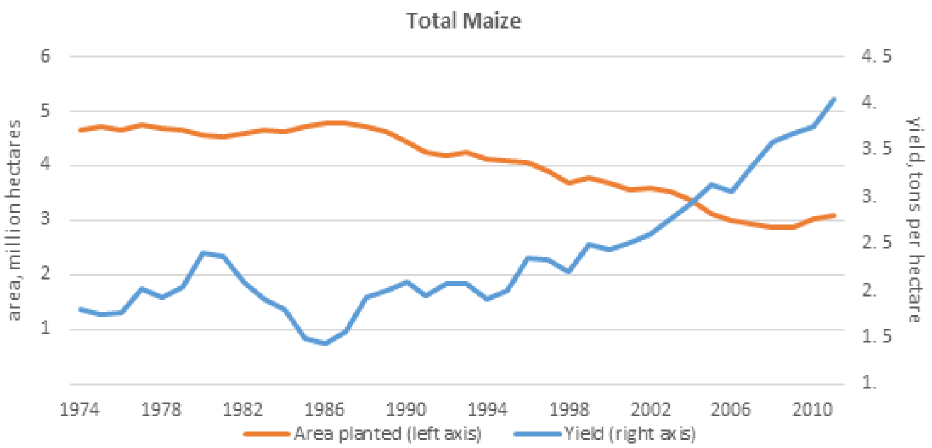


Figure 10: South African maize: area planted and yield (five-year moving averages)
Source: DAS (2013)

Another reason for the major shift in the summer production area, where almost all maize is grown, is the emergence of soybeans as a significant crop. Production of this crop has grown from a negligible 22 000 hectares in 1975 to 470 000 hectares in 2012. This exceeds the 452 000 hectares under sunflower production in the same year (2012). The area used for production of this crop has remained at around this level since the late 1980s.

Given the above one can conclude that more than one million hectares (two million minus 0.5 million under soybean) of land previously under maize production have been converted to planted pastures, natural grazing or lost to mining activity since the late 1980s. A significant percentage of this land, even though marginal, could be reintroduced to maize production given increased rainfall in the western production regions or an increase in the maize price due to domestic shortages.

3.2. Comparing the LTAS scenarios to the base

3.2.1. Maize

Given the comprehensive discussion of the fundamental maize and wheat trends under the base case, alternative scenarios with altering precipitation levels can now be introduced into the BFAP sector model and compared to the baseline. It is meaningful, however, to view the data presented in **Table 4** graphically in order to gain a better understanding of the impact of these scenarios. Unlike the data presented in **Table 4**, **Figure 11** does not represent national MAPs, but rather the relevant rainfall data extracted from the national monthly quaternary data set for the respective maize-production regions. From this figure it is evident that there is only one scenario in which future precipitation levels differ significantly from the base case, namely the MPI 4.5 scenario. It is important to note that this scenario showed the lowest decline in national MAP. This highlights the fact that both the timing and locality of rainfall are more important than national mean annual precipitation rates. Hence, for the purpose of further discussions, only the modelling results of this scenario will be presented.

The various scenarios were introduced into the BFAP sector model in order to generate the potential impact of the different precipitation levels on maize and wheat markets. **Figure 12** shows that white maize yields are anticipated to decline by 1.1 t/ha on average over the outlook period, resulting in a drop in total production of approximately 1.6 million tons per annum and an increase in white maize prices of 16% (**Figure 13**). Similarly, yellow maize production will decline by approximately 900 000

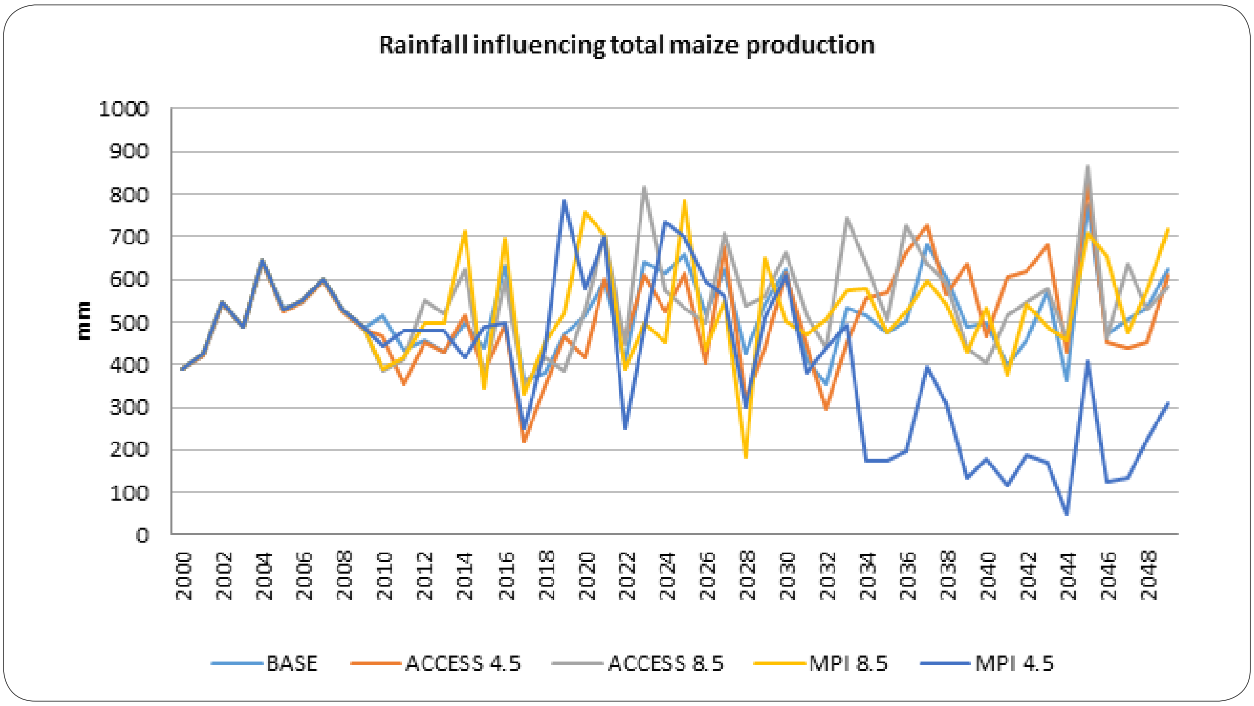


Figure 11: Precipitation influencing maize production – base versus alternative scenarios

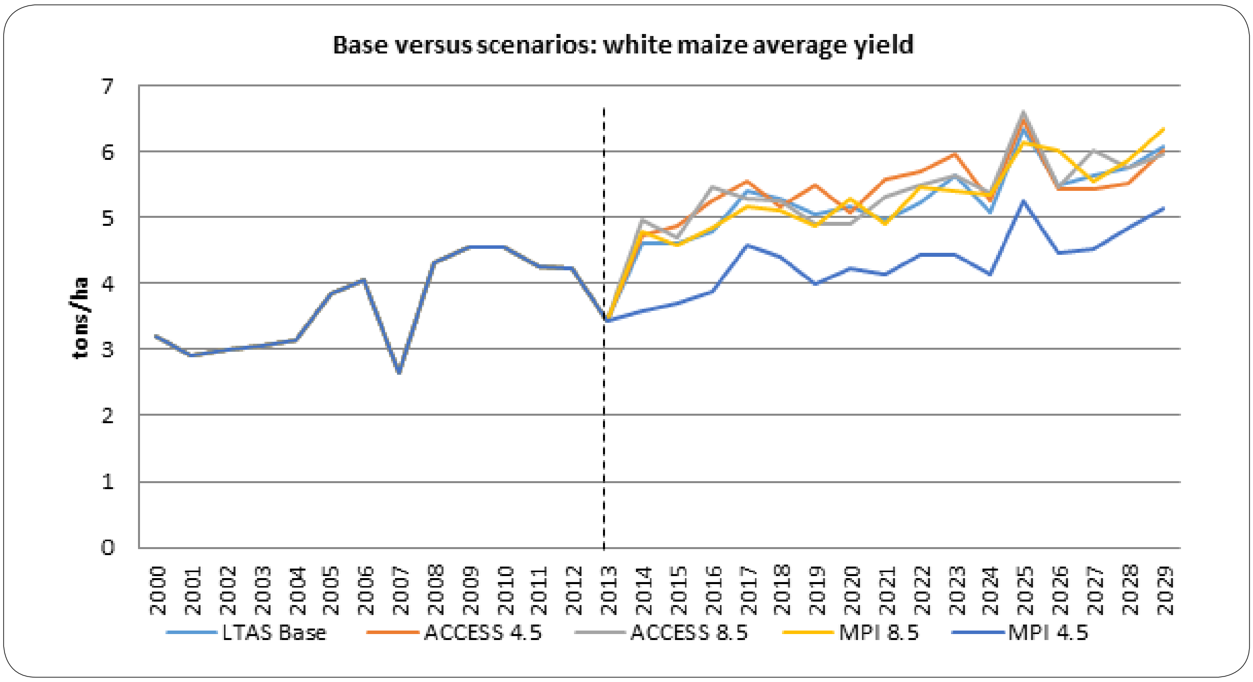


Figure 12: Base versus scenarios: white maize average yield

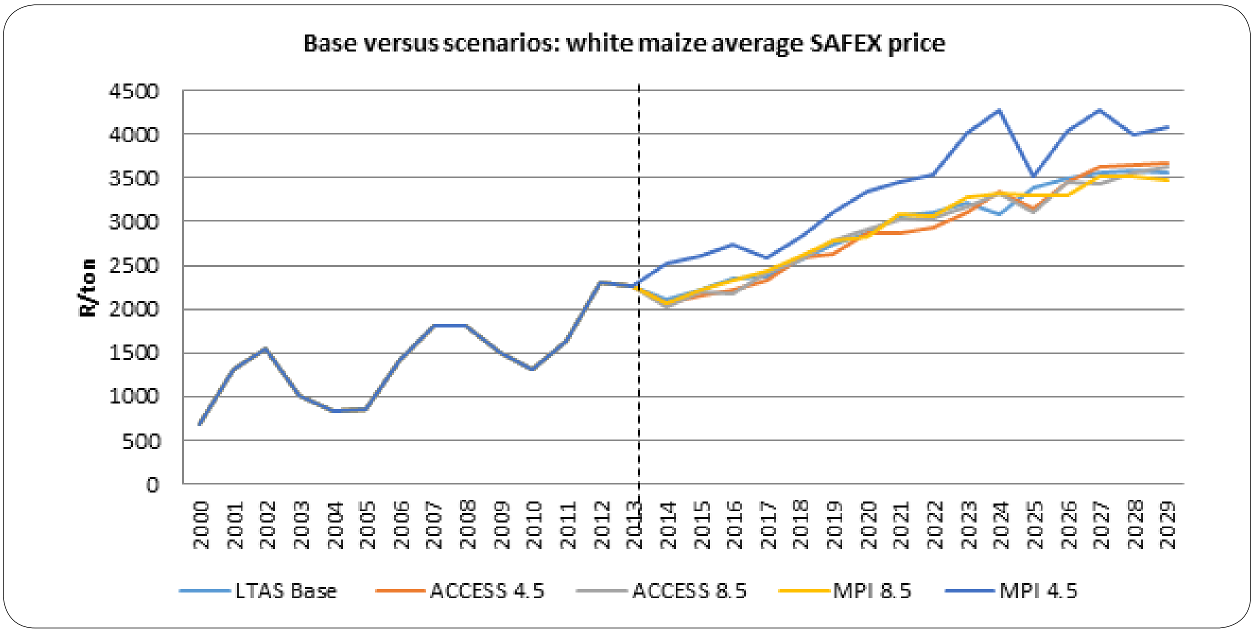


Figure 13: Base versus scenarios: white maize average South African Futures Exchange (SAFEX) prices

tons per annum. Under this scenario, South African maize exports will drop by more than one million tons, which implies that the pressure of funding the foreign account deficit will increasingly fall on other agricultural export products like wine and fruits.

The interesting part of this scenario is that the area under maize production is expected to increase by more than 200 000 ha. This shift in hectares comes from the drop in yields, which is more than offset by the increase in prices, resulting in an increase in net revenue; consequently, farmers are expanding the hectares under maize production. This is typical for a market in which supply faces an inelastic demand and the equilibrium pricing conditions determine that local supply and demand dynamics drive prices.

When undertaking foresighting analyses, it is useful to consider the future stochastic range of key fundamental variables, and not to fixate on the deterministic projections as presented in the graphs above. It is in any case highly unlikely that the actual number in future will exactly match the projected deterministic number. It is far more important to explore the possible ranges of variables.

For this exercise, BFAP applies stochastic modelling techniques that can assist in generating a plausible range of outcomes given the set of assumptions. **Figure 14** and **Figure 15** compare the base case stochastic results to the stochastic results simulated under the MPI 4.5 scenario. Apart from significantly lower precipitation levels under MPI 4.5, the range of rainfall that can be received is significantly wider under the MPI 4.5 scenario compared to the base case. This increases the climatic risks significantly.

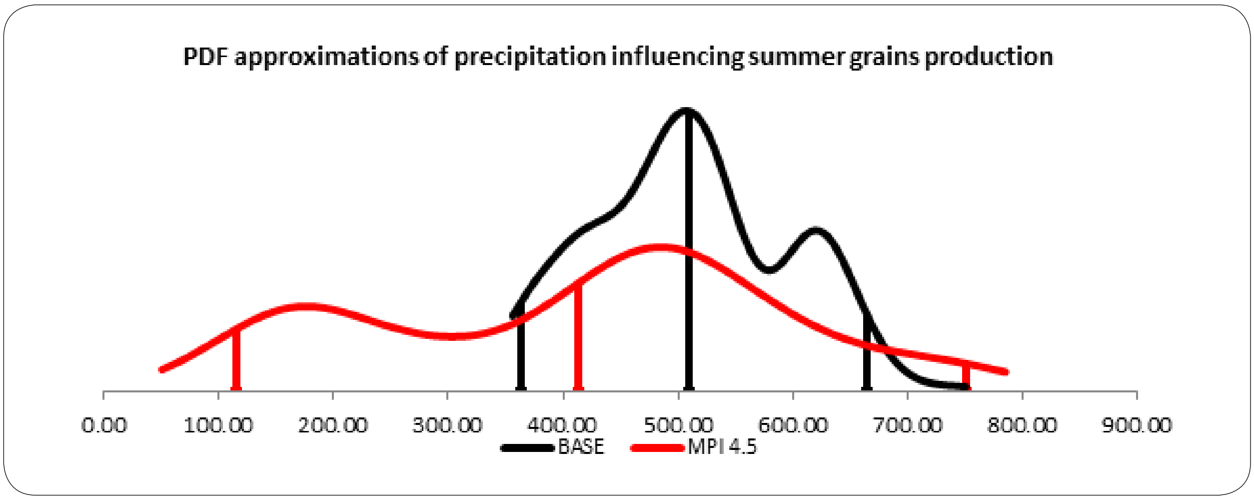


Figure 14: Stochastic precipitation – base versus MPI 4.5
Note: PDF – probability density function

Based on the distribution for future precipitation, the distribution of plausible maize prices is significantly higher under MPI 4.5 than under the base case. **Figure 15** illustrates that, compared to an average white maize price of around R3000/t under the base case, the most likely white maize price can increase to levels around R3700/t under the MPI 4.5 scenario.

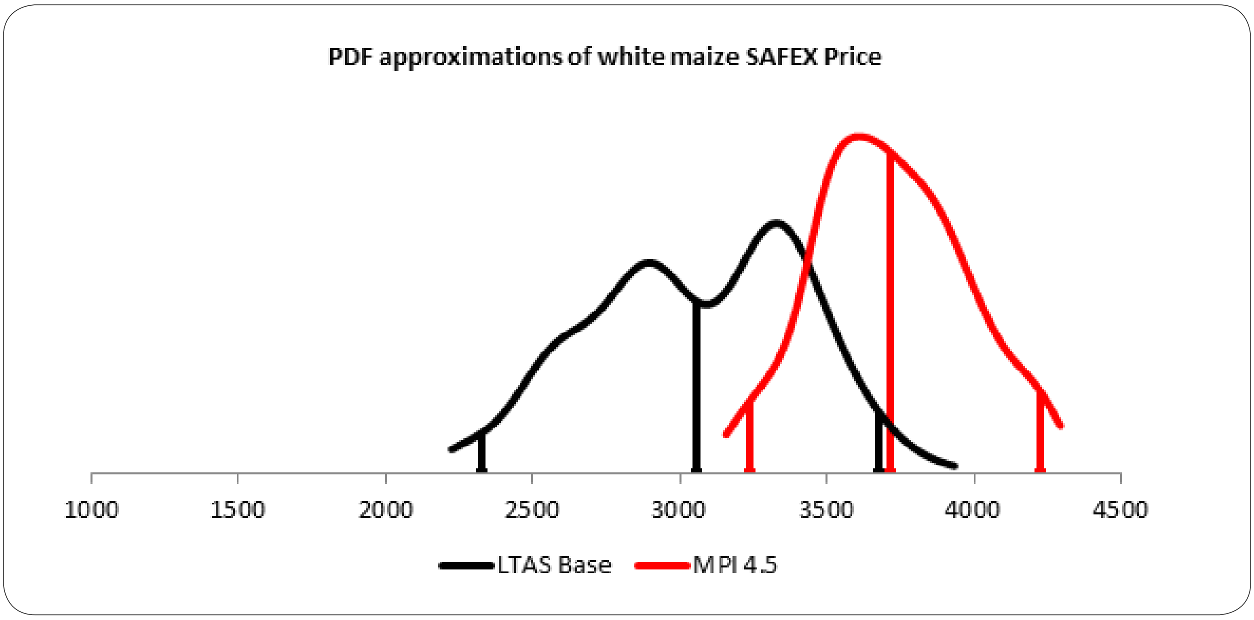


Figure 15: Stochastic white maize price – base versus MPI 4.5

Case Study 2: Wheat

Figure 16 shows South African wheat production and domestic use patterns for the period 1994 to 2013. From this figure it is clear that the domestic demand has exceeded the domestic supply; in 2013, for example, 40% of the domestic demand was imported. The decline in production is due to a significant decrease in the area planted in the Free State in response to greater profitability for summer crop production as opposed to winter wheat, and a the comparatively higher climate risk with wheat production. The price of wheat in South Africa will therefore be equal to the import parity price (world price plus transport cost to SA), unless domestic production exceeds domestic demand. As indicated in **Section 1**, Estes et al. (2013) concluded that the area suitable for wheat production could expand between 20% and 48%, depending on the biophysical model used. The models showed a possible productivity increase of between 6.5% and 15.2%. These changes have the potential to increase domestic supply sufficiently to move South Africa towards net exporter status. If this is not possible, however, the discussion relating to wheat moves to one of the size of imports, the area under production and the yield, because the local price will simply be equal to the world price plus transport.

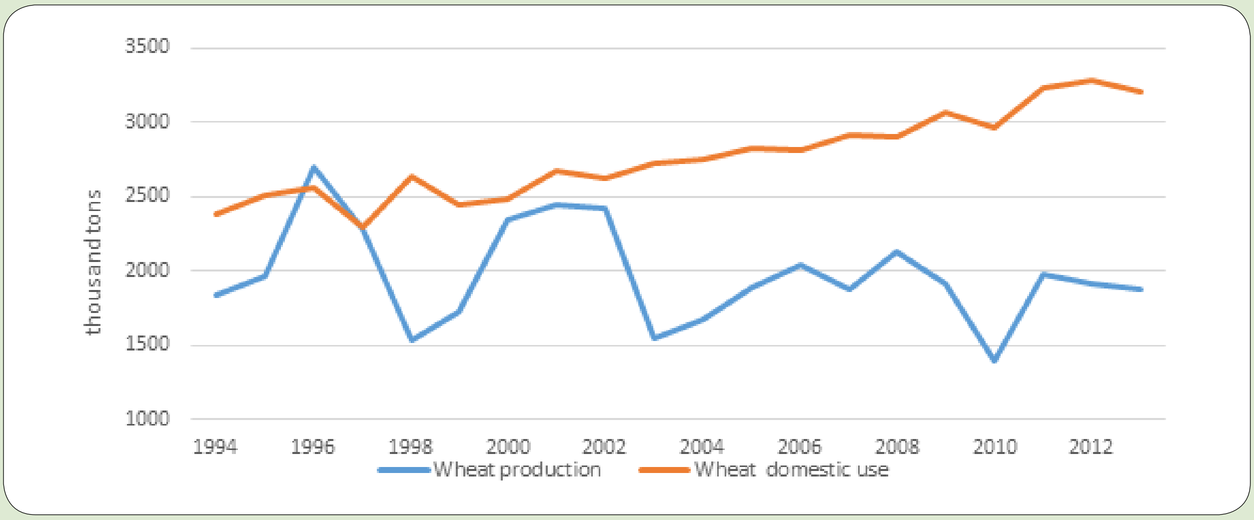


Figure 16: South African wheat production and domestic use

Source: DAS (2013); SAGIS (2014)

3.2.2. *Wheat*

The impact of alternative future precipitation levels on the wheat market is significantly different from the impact on the maize market. The BFAP sector model makes a distinction between the summer and winter rainfall wheat production areas, with the former mainly represented by the Free State and the latter the Western Cape. In the case of the winter rainfall area, the precipitation under scenario MPI 4.5 is lower than the base and the other scenarios tested. The reduction is not as dramatic as was the case with maize in the MPI 4.5 scenario. **Figure 17** presents the future precipitation levels under the LTAS base case and the scenarios that will influence the production of wheat in the winter rainfall region.

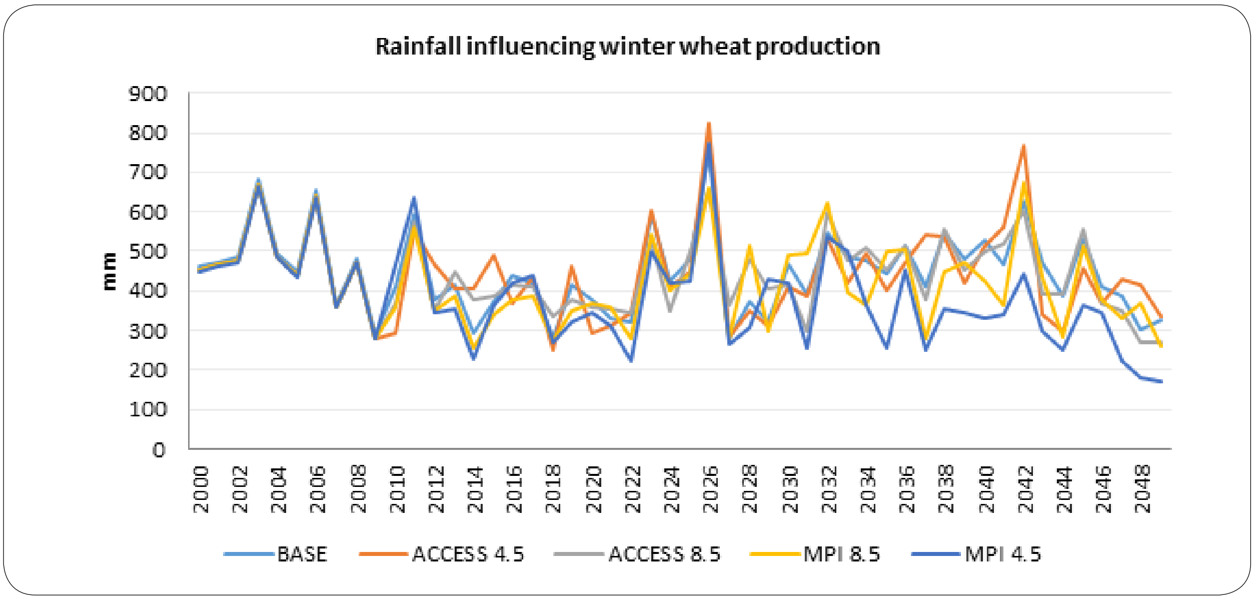


Figure 17: Precipitation influencing wheat production in the winter rainfall region

For the precipitation levels influencing the production levels of wheat in the summer rainfall area (mainly Free State), the exact opposite is expected, with much higher winter precipitation levels projected under the MPI 4.5 scenario compared to the base and other scenarios (**Figure 18**).

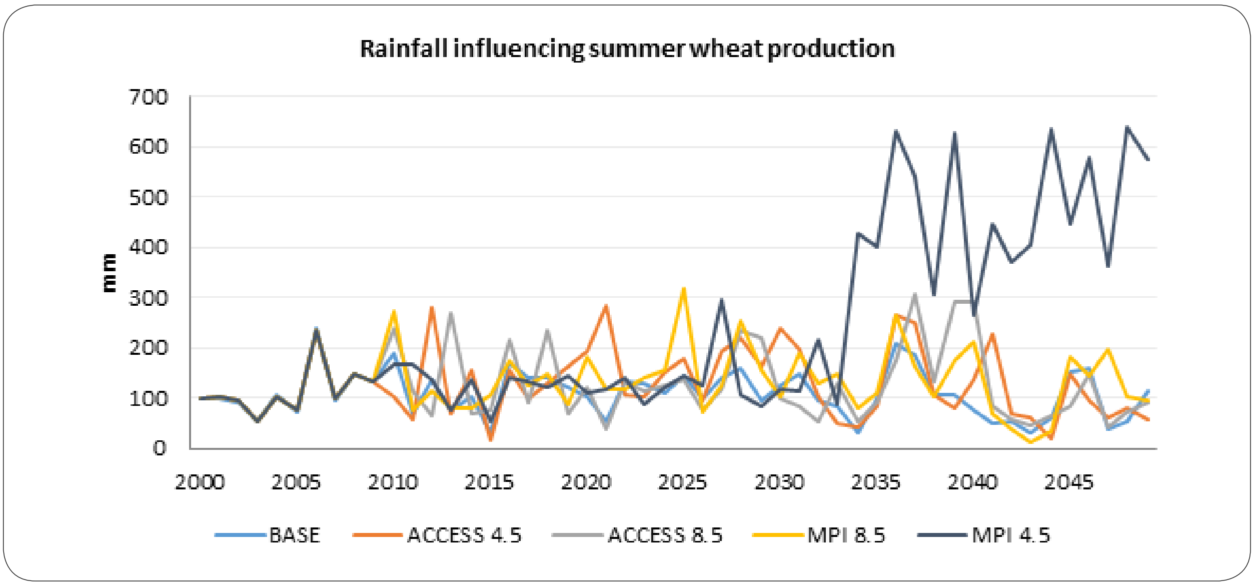


Figure 18: Precipitation influencing wheat production in the summer rainfall region

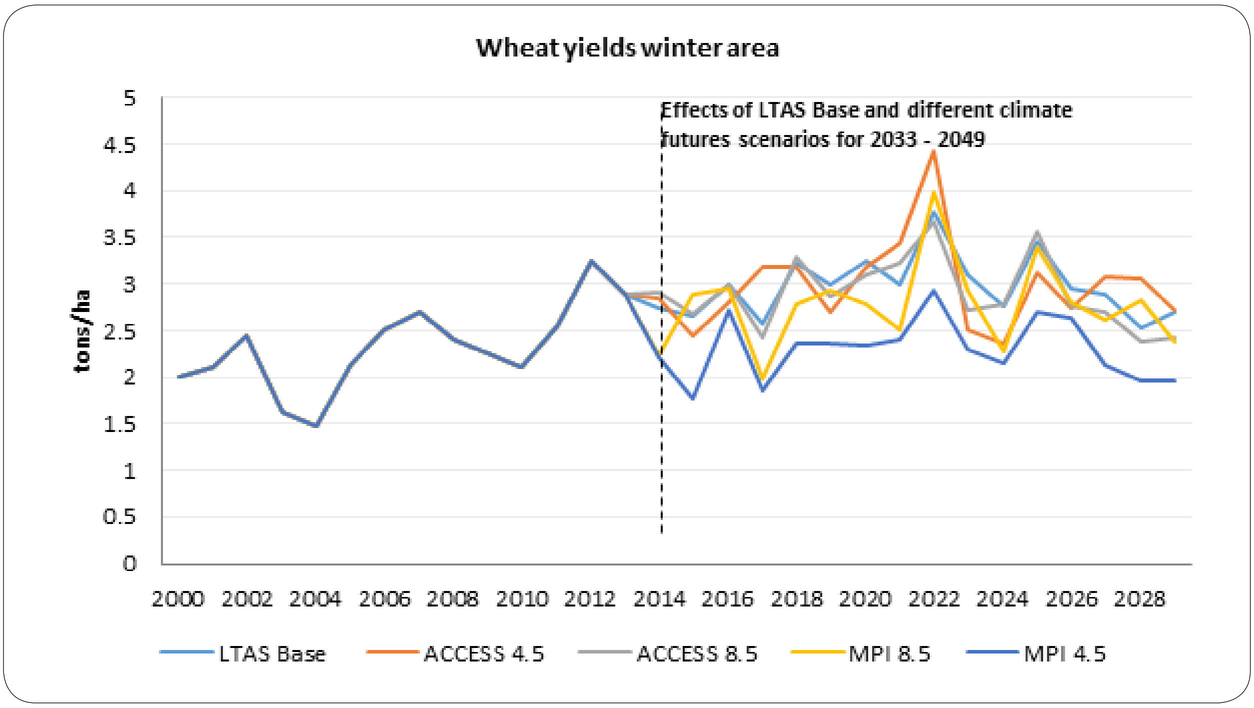


Figure 19: Wheat yields in the winter rainfall region

Therefore, although less rainfall is projected under MPI 4.5 in the months influencing maize production (December, January, February), the rainfall is expected to increase in the winter months (July, August, September), which will have a positive effect on winter wheat yields in the summer rainfall area.

The consequent impacts on wheat yields in the winter and summer rainfall areas are portrayed in **Figure 19** and **Figure 20**. Whereas winter wheat yields are projected to decline by approximately 600 kg/ha on average over the outlook period, wheat yields in the summer area (mainly the Free State) will rise by slightly more than 1 t/ha.

There is, however, a lot more interaction in the background of the simulation than just the impact on wheat yields, since wheat prices will not be affected by a change in production levels. As already discussed, South Africa is a net importer of wheat and, under a scenario of lower or higher production levels, the level of wheat imports will simply be adjusted and local wheat prices will continue trading at import parity levels. In other words, lower yields will not be offset by higher prices and vice versa, as is the case with maize. A further fact complicating results in the wheat simulation is the substitution happening between maize and wheat in the summer rainfall area. Despite the different seasons, farmers still have to decide between maize or wheat production in the dryland areas and the sharp rise in maize prices under the MPI 4.5 scenario sees the maize area expanding due to higher profitability at the expense of dryland wheat production. This implies that the average wheat yields in the summer rainfall area will increase even further because the share of irrigated wheat increases as part of the total area. Overall, South African wheat production is set to decline

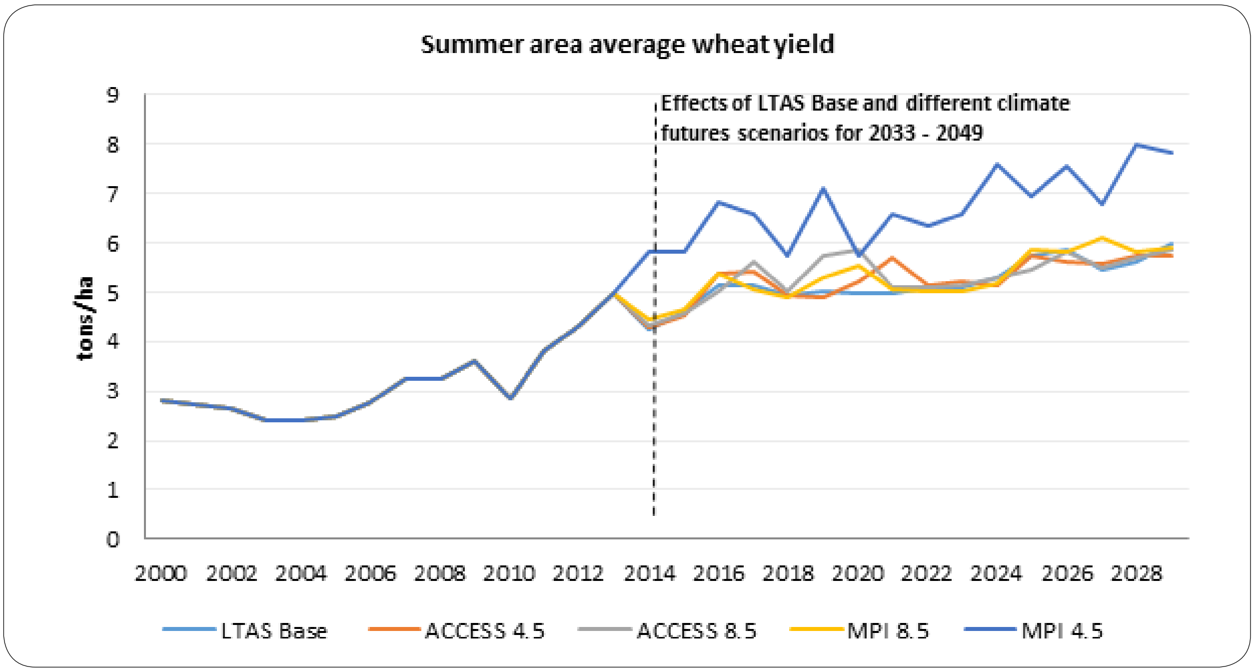


Figure 20: Wheat yields in the summer rainfall region

by just over 100 000 tons per annum over the outlook period compared to the base case.

Lastly, it is interesting to compare the simulation results of an economically based model with the typical output of biophysical models. Estes et al. (2013) (see **Section 1**) concluded that, under certain climate change scenarios, the area suitable for wheat production could expand between 20% and 48%, and show a possible productivity increase of between 6.5% and 15.2%. The BFAP sector model attempts to replicate the typical producer's supply response, and simulates the interaction between various commodities in the local market and also the link between local and global markets.

4. CONSUMER IMPACT STUDY

The objective of this section is to model the effect of maize and wheat price changes due to climate change on (mainly) poorer households in South Africa. Retail prices for maize meal and bread generated through the BFAP sector models and retail price transmission models will serve as the main input for this analysis. The potential impact of maize and wheat price changes due to climate change on (mainly) poorer households in South Africa was investigated using multiple approaches.

4.1 Approach 1: The BFAP poor person's index

In 2013, the average cost of the five-item food plate that forms the basis of the BFAP poor person's index amounted to R4.41, calculated from official food prices monitored by Statistics South Africa (**Table 6**). The dominance of maize porridge and brown bread is clearly evident, with a 73.5% contribution of costs to this portion-weighted, five-item food plate.

The maize meal and bread prices projected through the BFAP sector model for the base scenario and climate change scenario MPI 4.5 were inserted into the BFAP poor person's index model while keeping prices for milk, tea and sugar constant at 2013 prices. As stated above, the MPI 4.5 scenario was the only one used due to the fact that it showed a significant deviation from the base scenario. All the other climate scenarios show a limited deviation from the base.

Table 6: Poor person's food basket cost and composition

	Average 2013 portion cost	Average 2013 share contribution to total cost
Cooked maize porridge (532g)	R 1.27	28.8%
Bread (150g)	R 1.97	44.7%
Full cream milk (56g)	R 0.63	14.3%
Tea (2.5g)	R 0.33	7.5%
White sugar (22g)	R 0.21	4.8%
TOTAL COST	R 4.41	

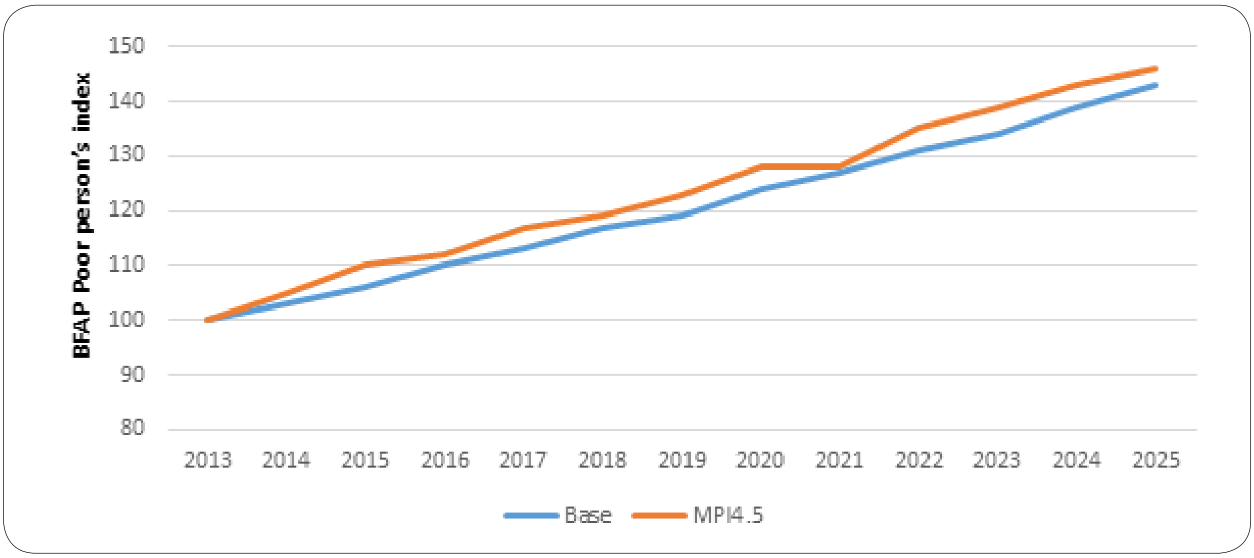


Figure 21: The BFAP poor person's index – projected results

Figure 21 shows the estimated BFAP poor person's indexes for the base and MPI 4.5 climate change scenario. From this figure it is evident that the MPI 4.5 climate scenario results in an increase in the index above the base scenario, but this increase is not spectacular – varying between 1.2 and 3.5% each year. Detailed results are shown in Annexure A. Climate change effects aside, it is important to note that the cost of the calculated poor person's food basked is expected to almost double over the next ten years.

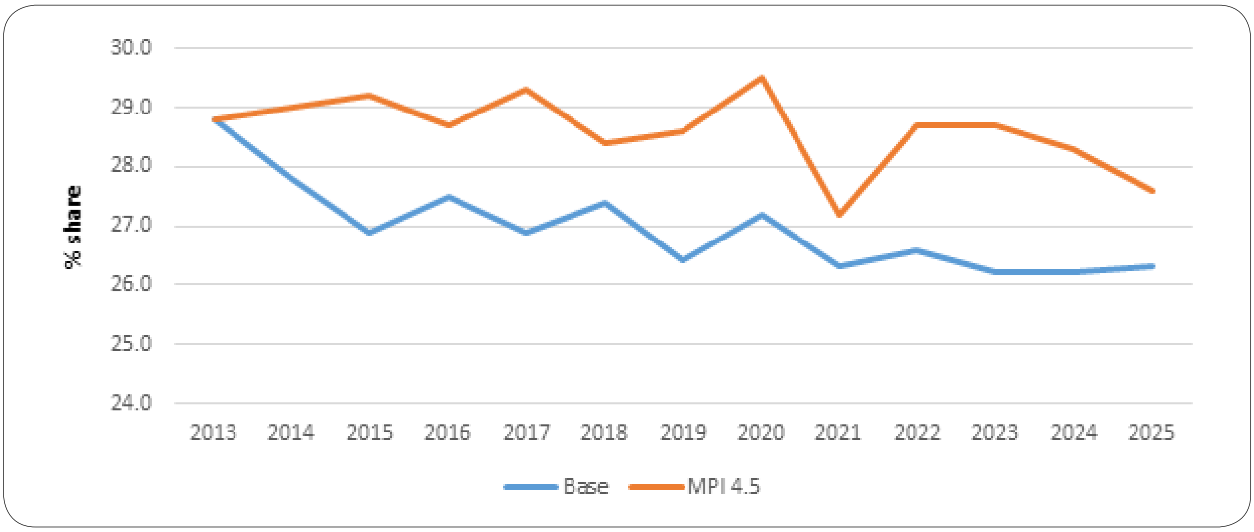


Figure 22: Cost share contributions of maize meal within the weighted five- item food plate

Figure 22 shows a comparison between the base and the climate change scenario index in terms of the contribution of maize meal to the cost of the portion-weighted, five-item food plate. This clearly shows a declining trend in both the base and MPI 4.5 scenario, with the cost share decreasing from 28.8% in 2013 to 26.3% in 2025 for the base scenario, and to 27.6% for the MPI 4.5 scenario. This declining trend is the result of a projected decline in maize meal consumption in favour of an increase in bread consumption. This is reflected in the projected increase in the cost share of brown bread, from 44.7% in 2013 to 55.2% and 54.2% for the base and MPI 4.5 scenarios respectively. For detailed results see **Annexure C**. The implication of this conclusion from a climate perspective is that, whilst the cost of a poor person's food basket will increase in the future, this group will be less exposed due to a lower preference in the future for maize meal, a commodity that is expected to see an increase in price towards import party under the MPI 4.5 scenario, whereas the wheat price is already at import parity and will continue to track this in the future.

4.2 Approach 2: Staple food expenditure pattern-based analysis

An alternative model of the maize meal and bread consumption patterns of households that considers different socioeconomic groups in South Africa has been developed by BFAP. This model uses the average expenditure of the ten income deciles in South Africa on main staple food commodities (according to StatsSA 2012a) as the point of departure. Note that within this analysis it was not necessary to evaluate bread, because the retail price projections for bread in terms of the base and the climate change scenarios do not differ, as shown in **Section 3**.

4.2.1 *Implications for annual household food expenditure*

The annual quantity of maize meal purchased by each of the ten income deciles (each representing 10% of the South African population) was calculated by dividing annual household maize meal expenditure by average retail prices for 2010. These consumption quantities were then multiplied by the maximum projected maize meal retail prices for the base and climate change scenarios to obtain the potential increased expenditure levels at the higher projected prices. The calculated expenditure values were reworked to a per-month basis and expressed as a share of households' 2010 income levels (according to StatsSA 2012a), as well as households' projected future income (increased according to BFAP projections for real disposable income in 2025). The analysis clearly indicates the following (see **Annexure C** for more details):

- The minimal impact of the projected maize meal price changes due to climate change, as the potential additional expenditure on maize meal varies between R2.21 and R11.86 per household per month and represents a very small share of the income of households across income deciles (varying from 0.0% to 1.1% of projected 2025 household income levels).
- The impact is more prominent among the poorest 50% of the population, where the potential additional expenditure on maize meal could be up to 1.1% of projected 2025 household income levels.

4.2.2 *Energy intake implications of a constrained food budget*

The annual household expenditure values on maize meal for 2010 for each of the ten income deciles (each representing 10% of the South African population) were divided by the maximum projected maize meal retail prices for the base and climate change scenario to obtain the maize meal quantity that households could possibly afford at the higher projected prices. These maize meal quantities were then translated into energy values for maize meal based on official South African food composition tables and compared on the basis of energy contribution per household member per day (using official household size data from StatsSA (2012a).

The analysis clearly indicates the following when comparing the energy intake impact of climate change to the base projections:

- The minimal impact of the projected maize meal price changes due to climate change as the reduced energy intake varies between 15 and 83 kJ per household member per day (compared to a recommended daily adult energy intake level of about 8 800 kJ according to the FAO, in other words less than 1%).
- The impact is more prominent among the poorest 50% of the population, where the reduced energy intake could be in the range of 68 kJ to 83 kJ per household member per day.

Even though total maize meal expenditure within the various income deciles will probably increase towards 2025 as the disposable income of households increases, this analysis provides a good 'worst-case' analysis in terms of energy intake impacts.

4.3 Conclusion

According to the base analysis and the climate change scenario, the projected retail prices for bread showed no deviation, as the wheat price remains at import parity levels. Thus, from a consumer impact perspective, the climate change scenario should not have a significant impact.

For maize meal the potential impact of climate change on consumers from a staple food perspective is somewhat more prominent, even though the impacts are expected to be minimal compared to the base scenario projections.

5. CLIMATE CHANGE IMPACTS ON AGRICULTURAL EMPLOYMENT

The BFAP employment matrix (**Figure 23**) (BFAP 2011) provides an employment overview of various agricultural industries by mapping the relative level of dependence on labour in conjunction with the current growth rates or the potential to expand in the future. Impact multipliers, which provide the scale on the x-axis, are only illustrated for on-farm activities and do not include the up- and downstream multipliers. The most labour-intensive commodities with the highest growth potential are grouped in quadrant number two, whilst the opposite is true for the commodities in quadrant number four.

Given the matrix, it is clear that grains and oilseed crops are not likely to act as the big drivers in agricultural employment. These commodities also represent a relatively small percentage of total agricultural employment, with the total maize and wheat sectors employing less than 7% of the total agricultural labour force in 2010 (own calculations).

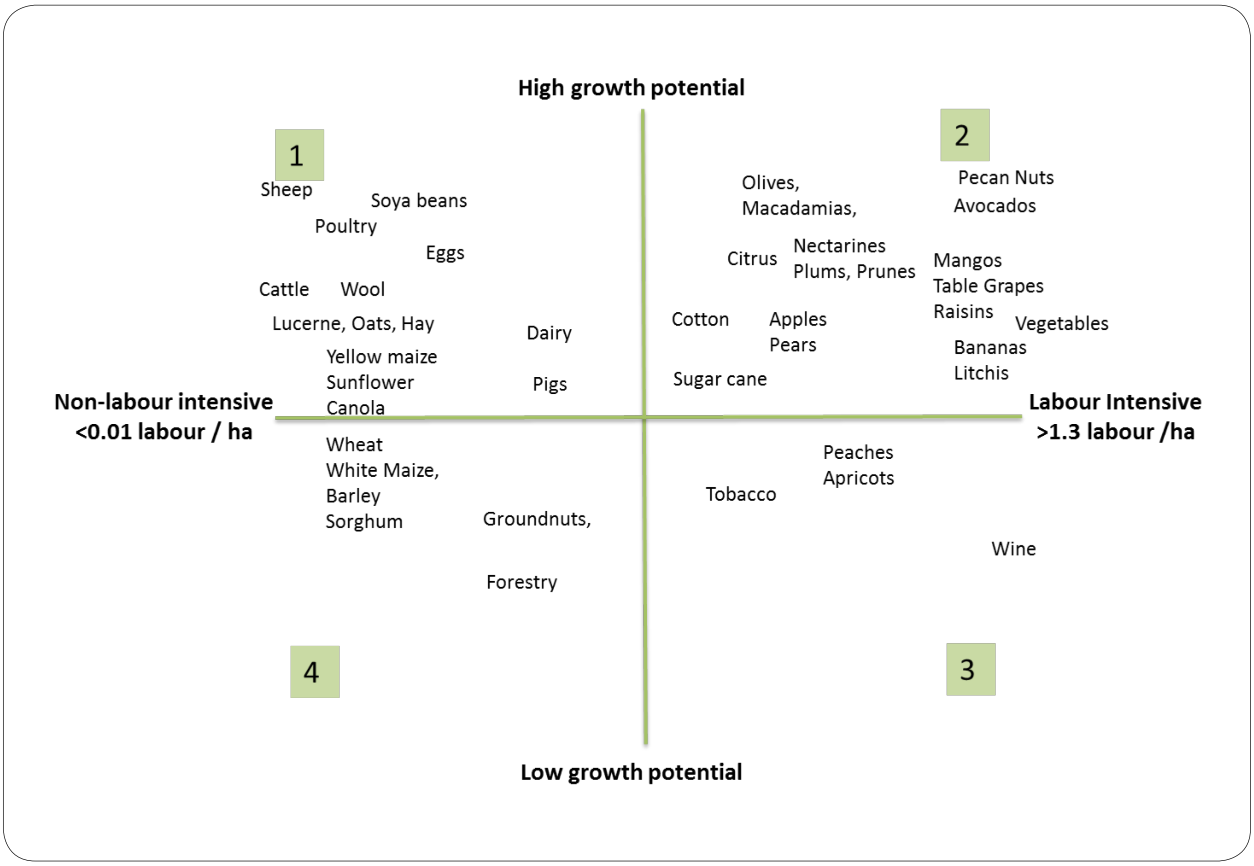


Figure 23: The BFAP employment matrix

Source: BFAP (2011)

The effects of climate change on the amount of maize and wheat hectares planted was used in the BFAP agricultural employment model and the results are presented in **Figure 24** and **Figure 25** below. These results have to be interpreted with care due to the fact that a reduction or increase in employment does not automatically equate to a reduction in total employment, due to the fact that hectares could be moved to the production of alternative crops. Some of the hectares removed from maize production, for example, could be moved to the production of soybeans or sorghum. An analysis of the entire cash crop industry would therefore provide a more complete indication of employment trends.

Again, the largest impacts were calculated under the MPI 4.5 scenario, with up to 20% variations in employment, both negative and positive. As explained in the above section, the assumption will have to be made that these hectares are not replaced by another commodity.

For maize production the results show the greatest expected decrease (-2.3%) in employment with the MPI 8.5 scenario whereas the most adverse scenario (MPI 4.5) shows the smallest decline (-1.1%) due to the expansion of the area planted in response to the increase in price. Conversely, the MPI 4.5 scenario shows double (-2.2%) the decline in employment for wheat production (**Table 7**).

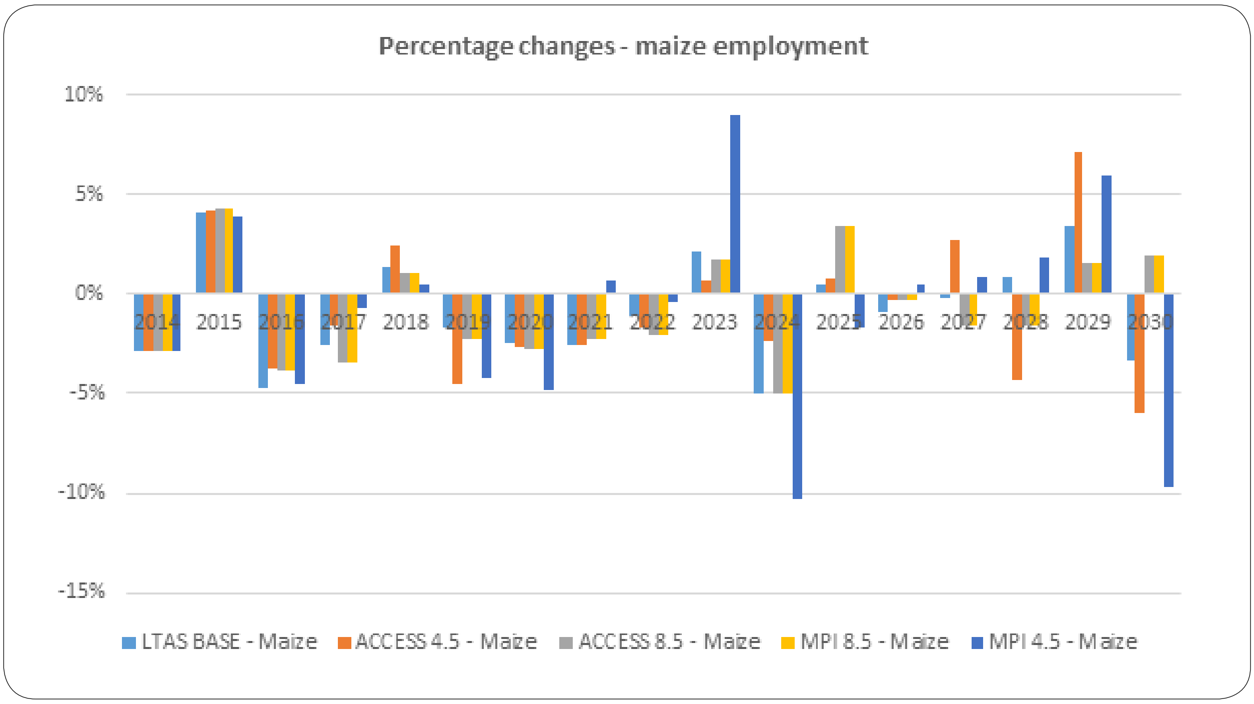


Figure 24: Percentage changes – maize employment

Source: Own calculations

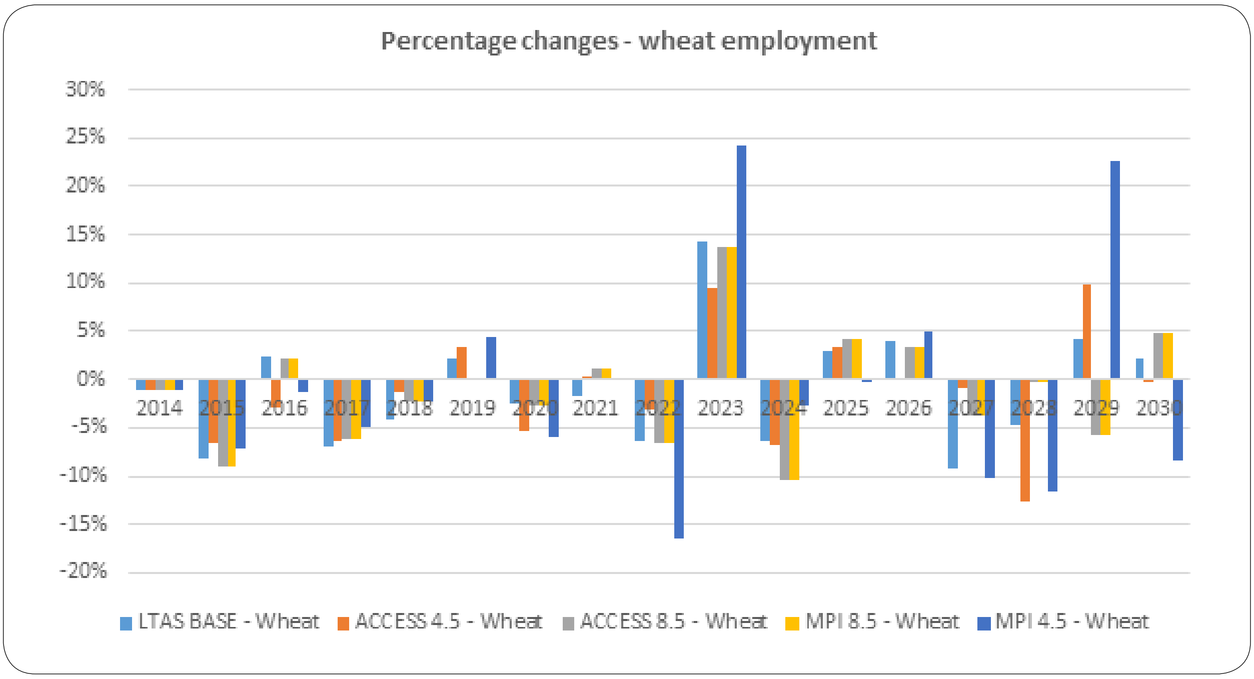


Figure 25: Percentage changes – wheat employment

Source: Own calculations

Table 7: Compounded annual growth rates in employment

		Compounded annual growth rate 2014–2025
Maize	LTAS base	-2.0%
	ACCESS 4.5	-1.8%
	ACCESS 8.5	-2.1%
	MPI 8.5	-2.3%
	MPI 4.5	-1.1%
Wheat	LTAS base	-1.1%
	ACCESS 4.5	-1.0%
	ACCESS 8.5	-1.1%
	MPI 8.5	-1.2%
	MPI 4.5	-2.2%

6. FOOD SECURITY AND ADAPTATION RESPONSES

This extract, from the DEA's LTAS report on the *Climate Change Implications for the Agriculture and Forestry Sectors*, provides an excellent introduction to this section:

> *It has to be emphasised that climate and climate change issues are superimposed upon the multiple other challenges, problems and stressors that the South African agriculture sector already faces (e.g. globalisation, urbanisation, environmental degradation, disease outbreaks, market uncertainties, higher fuel and machinery costs, policies concerning water, veld burning, overgrazing and land redistribution, and slow responses from authorities). Together these affect future planning strategies. However, up to a point, farming communities already cope with, and adapt to, a variable climate (DEA 2013, 42).*

This paragraph has significant implications for any mitigation or adaptation strategy by making it clear that i) climate change does not have an impact on famers in isolation and ii) farmers are adapting to climate change already. The adaptation to climate change by farmers therefore is a dynamic and continuous process.

6.1 Small-scale agriculture and food security

Rural households rely on multiple livelihood strategies that are derived from agriculture, wages earned as labourers and social grants. In 2010, only 1.5% of households (216 000) indicated that they earned an income from the sale of farm products and services (**Table 8**). Far more households indicated that they earned an income through salaries (62.3%), grants (44.9%) and remittances (16.4%) from able-bodied household members who work in urban areas. Therefore, the number of households that earn an income from agricultural production does not portray the full reality.

Table 8: Household sources of income, 2010

Income source	Households (thousands)	%
Salaries/wages	8 918	62.3
Income from a business	1 818	12.7
Remittances	2 346	16.4
Pensions	458	3.2
Grants	6 428	44.9
Sales of farm products and services	216	1.5
Other, e.g. rental income, interest	362	2.5
No income	113	0.8
	14 304	144.4

Source: Stats SA (2012b)

Table 9 shows that close on 1.6 million South African households engaged in some of form of agricultural activity in 2010. About 19% engaged solely in livestock production (predominantly on communal lands), whilst close on 1.3 million households engaged in some form of crop production, mostly on small plots, with 83.9% indicating that they produced on an area smaller than 0.5 ha.

When asked why they produce, 86.8% indicated that they did so for an extra source of food, whilst 5.3% indicated that it serves as a main source of food, 4.5% indicated that it serves as an additional source of income, and less than 1% indicated it was a primary source of income (see **Figure 26**). Just under 94% of respondents indicated that they did not sell agricultural produce.

Table 9: South African households' access to agricultural land, 2010

Agricultural activity	Households	% in category	% share in total
Crop production land size (ha)			
Less than 0.5	1 073 888	83.8	67.7
0.5 – 1	146 476	11.4	9.2
1 – 2	47 402	3.7	3.0
2 – 5	11 271	0.9	0.7
5 – 10	1 481	0.1	0.1
10 – 20	246	0.0	0.0
Sub-total	**1 280 764**	**100.0**	**80.8**
Grazing			
Communal grazing (livestock)	304 919	100.0	19.2
Total	**1 585 683**		**100.0**

Source: Stats SA (2012b) compiled by Pienaar (2013)

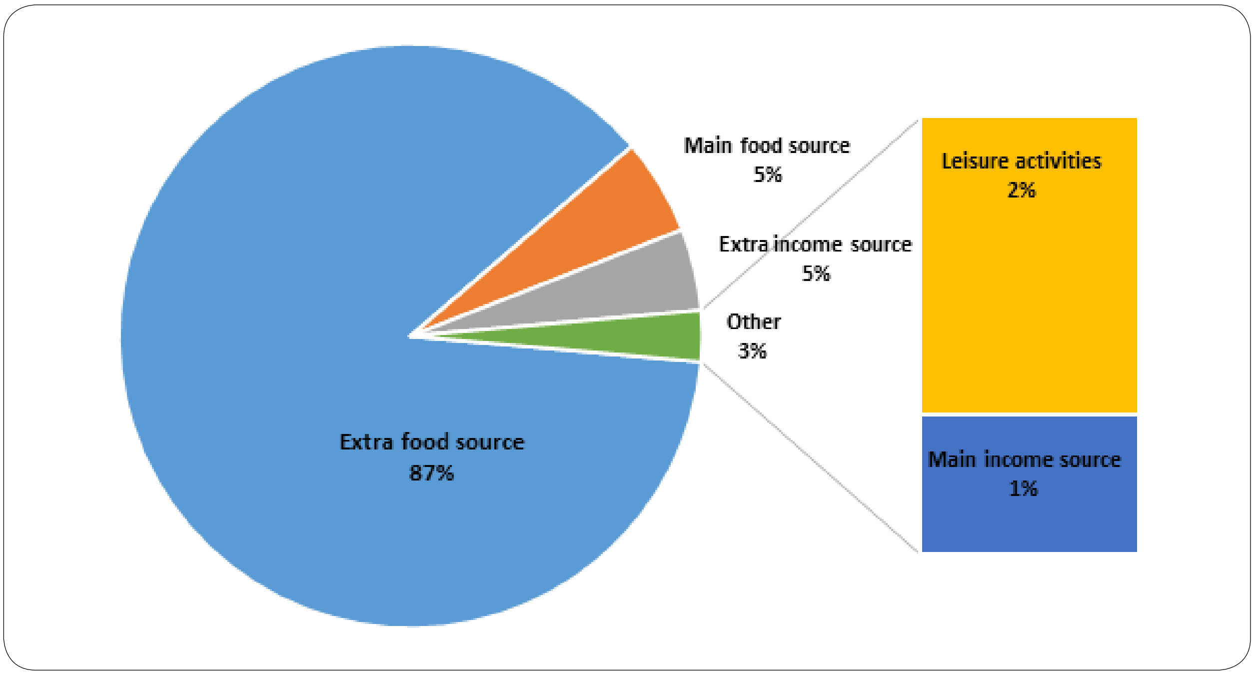


Figure 26: Reason for engaging in agriculture
Source: Stats SA (2012b) compiled by Pienaar (2013)

Aliber (2009) showed that, since 2000, there has been a strong movement away from agricultural production as a primary source of food and income toward agriculture as an additional source of food and, to a lesser extent, as a source of income. This shift can be attributed partly to the expansion of social grants, which seem to have replaced agricultural production as the primary rural livelihood asset/safety net. The study also showed that agricultural production was practised mainly by women over the age of 50, which explains the fact that most households engage in agricultural production as an extra source of food. All able-bodied persons therefore chose to seek urban employment.

One of the main adaptation responses to climate change is migration. Research in Africa in recent decades has shown that populations in rural areas have adopted strategies to cope with recurring drought that incorporate migration. In Western Sudan, for example, male household members have often migrated to Khartoum in search of wage labour in times when low rainfall hinders agricultural production (Afolayan & Adelekan 1998). In the dryland production areas of Ethiopia, families migrate during times of drought after other measures such as reducing food consumption and selling off possessions have been exhausted (Meze-Hausken 2000). This was also the case during the large-scale famines of the 1980s, when a considerable number of households in northern Ethiopia migrated to the cities (Ezra 2001). A study in Burkina Faso, however, showed that land degradation had a greater influence on migration behaviour than episodic climate-related events (Henry et al. 2004).

From a small scale/subsistence perspective, agricultural activity in South Africa therefore does not serve as a primary source of subsistence, but rather as a livelihood asset/safety net for the rural poor when other income sources fall away (Tregurtha et al. 2009) or as a supplement to existing means. Given this, a mass migration from rural to urban areas is not expected due to the fact that most able-bodied persons are already seeking employment beyond small-scale agricultural production. A reduction in the productivity of small-scale farmers will have the biggest impact on the ability of households to supplement their consumption basket with additional food production. This possible reduction will have to be mitigated through an expansion of existing grants, more remittances, and other sources in order to enable additional food purchases. From a crop-production perspective, these households could also be supported through the development of irrigation infrastructure and extension tailored towards conservation and climate-smart production systems. The removal of supplementary food production in rural areas will put existing and often inadequate transport infrastructure under increased pressure. It is therefore essential that rural road infrastructure is improved in order to ensure the delivery of food to rural areas at the lowest possible cost. This improved infrastructure will also connect small-scale producers to markets, which could increase their income earned from agricultural production.

6.2 Continual adaptation and technology

Case study 2 and figure 3 illustrate that farmers are continually adapting to climate change through changing where and what the produce. Case study 2 has shown that farmers in the traditional wheat-growing areas of the Free State Province have reduced production due to factors affecting profitability and risk. Farmers and seed companies are continuously testing current and new seed varieties through formal and informal field trials in order to ensure that the best-suited varieties are identified for each locality. These trials enable the identification of the best suited variety for the specific region or farm, given the unique and possibly changing attributes of rainfall, temperature, daylight length, and other relevant factors.

Significant progress has been made by seed companies with improved hybrid varieties. One example is the development of drought-resistant genetically modified maize varieties, such as the registration of DroughtGuard® technology by Monsanto in the USA in December 2011. The company claims a five bushel per acre (approximately 300 kg/ha) advantage over other drought-tolerant varieties (Monsanto 2014). These innovations have not been very well received everywhere, however, with the Union of Concerned Scientists (UCS) claiming that it "… provides only modest results in only moderate drought conditions" (Gillam 2012).

Farmers are also employing other adaptation/mitigation strategies in order to reduce their production risk. These include planting varieties with a shorter growing period, delaying the start of planting according to rainfall, investing in more machinery in order to shorten planting time, collecting rainwater by digging furrows near plants, and increased use of irrigation (Benhin 2006). Small-scale crop farmers are being encouraged by farmers' industry organisations like AgriSA to adopt improved farm management practices, especially in terms of the timing of planting and tillage practices. Farmers, both small-scale and commercial, are increasingly adopting conservation tillage practices due to the advantages of reduced soil moisture losses, weed control, reduced erosion and increased general soil health, and climate-smart agriculture approaches are being advocated by the Department of Agriculture, Forestry and Fisheries (DAFF).

6.3 Irrigation

Irrigation is one of the central themes when considering climate change, agriculture and adaptation. At present, the agricultural sector consumes 60% of the available water for irrigation (Blignaut et al. 2009).

Map 2 shows the various South African water management areas as presented in the National Water Resource Strategy 2004. According to this report, water management areas 4, 5, 7 and 11 are already overusing the available water, mainly due to significant industrial and residential use in these areas. Excess water is currently available in water management areas 6, 12, 15 (all on the eastern seaboard) and 13 (upper Orange) (DWA 2004). It is estimated that an additional area of 90 000 ha could be added to the irrigated area without an investment in additional storage capacity, and more than 300 000 hectares potentially could be added through investments in additional capacity (BFAP 2011). Note that all management areas with available water do not include major urban settlements or industrial areas, and thus a large percentage of the water could be used for agricultural production.

A major source of additional water, especially relevant within the context of a drying climate, is that of possible efficiency gains. The technical efficiency of different types of irrigation differs significantly

- flood irrigation achieves 55 to 65% efficiency, compared to 75 to 85% for sprinkler irrigation and 85 to 95% for micro-irrigation systems. The prevalence of each of these in South Africa is shown in **Table 10**, which shows that a total of just over 1.6 million hectares were irrigated in 2007, with the largest percentage irrigated through sprinkler systems. The switch to micro-irrigation systems has been slow

- taking almost two decades to increase from 11.8% to 21.8% (Backeberg & Reinders 2009).

Map 2: **South African water management areas**
Source: DWA (2004)

Table 10: Agricultural irrigation: Area and method

Year	Area (ha)	Irrigation method (%)		
		Flood	Sprinkler	Micro/Drip
1990	1 290 132	33	54	11.8
2007	1 675 882	14.5	54.9	21.8

Source: Backeberg & Reinders (2009)

It can be assumed that the remaining area under flood irrigation could be converted to alternative systems given sufficient incentives to do so, preferably micro and drip irrigation for horticultural products, and centre pivots for grains and oilseeds. The use of drip irrigation should also be encouraged with future expansion. An additional source of efficiency gains is possible through the improved maintenance and upgrading of existing infrastructure, especially channels, and the implementation of a water management system (WMS). The implementation of WMSs in the Loskop (Mpumalanga) and Orange-Riet (Northern Cape) rivers reduced losses by up to 50%. Participation in the FruitLook programme, aimed at increasing crop yield whilst reducing water usage, will also result in increased water availability. The conversion to more efficient modes of irrigation and the implementation of a national WMS could result in expansion of the area under irrigation by an additional 282 000 hectares (BFAP 2011), given current water availability levels.

6.4 Expansion of area planted

South Africa currently uses about 13 million hectares of agricultural land for field crop and horticultural production, while total land cultivation was as high as 16.2 million hectares in the 1980s. The reduction in area is due to the removal of marginal land from production after the removal of agricultural price support schemes from the late 1980s to late 1990s. Fields were removed from production due to unsuitable gradients, unfavourable soil properties and low rainfall. At present the amount of arable land is estimated at 15 million hectares, including some land previously cultivated and underused land in former homeland areas. Some of the land previously cultivated could be reintroduced into production given an increase in real net revenue per hectare. This is confirmed by the BFAP sector model, which indicates an increase in the area planted under maize of more than 200 000 ha under the MPI 4.5 scenario. The decline in yields due to lower precipitation is offset by an increase in market prices due to lower production levels, resulting in net revenue increases and farmers therefore expanding the area under production. According to the BFAP sector model, the total area under the main grain and oilseeds is projected to find its long-run equilibrium at around 4.2 million hectares by 2020, compared to 4.4 million hectares in 2014 and 6.7 million hectares in 1980.

7. HIGH-LEVEL MESSAGES AND RECOMMENDATIONS

This study has investigated the effects of the respective climate change scenarios identified in the LTAS Phase I project on the South African maize and wheat industries from an economic, food security and employment perspective for the period 2014 to 2030. This was achieved by including precipitation data, generated from various climate models that best suit each of the LTAS Phase I scenarios, in the BFAP sector model.

One of the main themes of this study was that climate change effects cannot be viewed in isolation or as a deviation from the current status quo, but should be viewed in the context of existing and continuing trends within the respective industries. White maize serves as a good example, as expected growth in demand is flat or declining, whilst total production is expected to increase due to advances in hybrid seed technology, production techniques and other factors. This puts the price of white maize under pressure due to a production surplus (therefore priced at export parity levels), to which farmers respond by allocating the area currently under white maize production to the production of other crops or by removing it from production altogether. Within the worst, warmer/drier (MPI 4.5) scenario, average white maize yield is expected to decrease by more than one tonne per hectare. This increases prices relative to the base, which in turn results in a smaller decline in area planted compared to the base. The yellow maize area under production is expected to show a small increase, whilst yields show a yearly increase and prices remain at export parity levels. The area under wheat production is expected to show a small decrease in favour of the production of alternative crops, mainly canola, and the removal of production in high-risk areas such as the Free State province. Wheat imports are expected to continue to increase due to the combination of decreasing production and increasing demand.

As stated in **Section 6.2**, the challenges faced due to climate change do not act on producers in isolation, but interact with multiple stresses to which producers are exposed. **Any adaptation strategy therefore should be guided by an economically integrated view, and not based solely on the biophysical impacts on the crop yield itself. It is also useful to integrate climate change responses with existing best practices that have evolved under current multiple stresses, including improving the overall efficiency of the production system, and focusing on approaches that benefit both smallholder and commercial agriculture.** Examples include improved transport infrastructure, improvements in irrigation efficiency and water management, continued field trials in partnership between producers, commercial entities and the public sector, public research spending, and public information collection and sharing.

It also has to be reiterated that farmers are already adapting to climate change. The observed historical reduction in the area under wheat production is a good example. Farmers have opted to decrease the area planted by more than half, partly in response to price decreases and other drivers but also in order to decrease exposure to climate risk, such as too low rainfall or rainfall during harvest. Farmers are also continually doing field trials, mostly in partnership with seed companies or input suppliers, in order to identify the best suited varieties for their locality. Farmers also experiment with various fertilisation, pesticide and herbicide strategies and cultivation practices in order to maximise yield and return on investment. Commercial farmers also do not rely solely on public extension officers, but obtain support from various qualified individuals employed by input suppliers to support farmers. The role of the state is equally important, particularly in providing extension services to small-scale producers and financing public research; greater co-operation between farmers, seed companies and the state will assist in improving the focus of public research and the quality of the extension services provided, particularly for small-scale farmers in close proximity to these trials. **There is an opportunity**

for government to explore the role of the state in providing an overarching climate change adaptation framework and associated capacity and support for all agricultural producers. This undertaking, however, should follow an integrated approach aimed at increasing the efficiency and competitiveness of the entire food system.

This study has shown that the area under irrigation could be expanded through new investments in storage capacity. Significant gains are possible, however, within existing systems through decreasing distribution losses, adopting more efficient irrigation systems, and improving the management of existing irrigation systems. This has the potential to add an additional 282 000 hectares to the area under irrigation, simply by using the available water. Therefore it is imperative to maintain and improve existing irrigation systems. **Incentives for upgrading existing systems to more efficient alternatives, for example from flood to drip irrigation, should be provided by the state; alternatively, the amount of water available to consumers should be regulated in order to warrant investments in more efficient systems.**

South Africa has been a net importer of wheat since the early 1990s and, according to the MPI 4.5 climate scenario, wheat imports are expected to increase substantially due to a decline in production and an increase in consumer demand for wheat. Increasingly larger amounts of wheat therefore will have to be moved between sources of supply or the respective ports and sources of demand. **A cost and carbon efficient transport system therefore is imperative in order to ensure the provision of this staple at the lowest possible cost. Improvements in port, rail and road infrastructure is of the utmost importance, especially an improvement in railways. This infrastructure will also improve the competitiveness of agricultural exports, particularly of fruit and wine.** Currently, these exports are significant earners of foreign exchange and will continue to support the affordability of the substantial and growing primary foodstuff imports. Exports of these products will have to be expanded in future in order to maintain a positive agricultural trade balance and avoid the negative effects of exchange deficits. This will require, in addition, the improvement of the SADC regional road and rail networks in order to enable more cost-efficient trade. Zimbabwe is currently one of South Africa's biggest trade partners. Fruit and wine exports to the SADC region are expected to continue to grow, whilst Zambia, for example, could become an important trade partner for wheat.

8. FUTURE RESEARCH NEEDS WITH LINKS TO FUTURE ADAPTATION WORK AND MODELLING CAPACITY

This study has provided a more holistic perspective on the possible impact of climate change on the South African maize and wheat industry. The results produced clearly illustrate that climate change impacts cannot be viewed simply in terms of changes in the suitability of production, yield and eventually total production, but are more usefully viewed in the context of existing trends and producers' responses to changes in price. Producers, as enterprising individuals, will allocate their available land to the production of specific crops or livestock in accordance with expected profitability and perceived production risk. The current trend in expanded soybean and canola production serves as a good example of such a shift in the allocation of land away from maize and wheat production. Therefore it is essential that the total production system is modelled and not only two crops. This was not possible in this study due to the limited funding available. The processing of climate data, the extension of the BFAP sector model beyond the usual 10-year outlook, and the consideration of various scenarios is a time-consuming operation. Efforts should also be made to disaggregate results to the regional and sub-regional level.

The BFAP sector model is well suited to providing this perspective as it includes 52 commodities at present. The expansion of each of the 50 remaining commodities (excluding maize and wheat) beyond the current 10-year outlook will be a significant undertaking. In addition, the biophysical modelling capability for all 52 commodities including maize and wheat will have to be improved to enhance the ability to reflect the impact of climate shocks. At present the grain and oilseed models incorporate rainfall timing and locality, but the inclusion of carbon fertilisation and temperature effects is an essential improvement that is required. The modelling of climate change effects on the livestock industry will also have to be improved. This would involve extending modelling of the effect of heat stress on growth, milk and wool production.

Research on the impact of climate change on horticultural production is severely lacking. One can argue that horticultural products, such as apples for example, are more vulnerable to climate change than maize due to their greater sensitivity to changes in temperature. Increased winter temperatures beyond a specific threshold could result in significant yield decreases and even crop failures. Temperature is also an important determinant of wine quality. In the South African context horticultural and wine production are particularly important from a food security perspective due to their role in ensuring that primary foodstuffs, mainly wheat and rice, can be imported at the lowest price possible. The growth in fruit and wine exports since the late 1990s has offset the cost of increased imports of wheat, rice and various animal feeds, thereby ensuring that the sector maintains a positive agricultural trade balance. Under a scenario of expected increases in wheat imports, the potential adverse impacts on horticultural and wine exports will result in a negative trade balance, which in turn would result in depreciation of the rand. Such depreciation will result in increases in the price of both imported and domestically produced foodstuffs with a negative impact on household food access.

Given the above, research on the climate vulnerability of the South African horticultural and wine industries is urgently needed. This should also include the development and/or improvement of biodynamic modelling techniques which should be integrated with existing sector models, such as the BFAP model, in order to improve the model's ability to account for climate change effects. Studies on the current state of these industries' competitiveness, and how it could be improved, should also be undertaken from a food security perspective.

Research on how the distribution of agricultural commodities can be improved is essential, given the need to reduce pollution and the expected increase in trade in these commodities. This would ensure greater global competitiveness and the provision of food to the consumer at the lowest possible price. The impact of improvements to the existing rail and road network has to be investigated in order to inform policy.

The National Development Plan (NPC 2011) identifies the creation of an integrated and inclusive rural economy as the primary role of the agricultural sector and highlights the importance of the sector in creating employment. One of the plan's suggestions is creating employment through supporting labour-intensive "winners" in order to expand production. The crops identified consist mainly of horticultural crops, including pecan nuts, avocados, mangos, table grapes, apples, pears and other produce as shown in **Figure 23**. The plan assigns a low level of importance to the maize and wheat industries due to their low growth potential and labour intensity. This highlights the importance of future research on the impact of climate change on horticultural production, the development of improved biophysical models and of integrated sector modelling approaches, due to the higher climate sensitivity of horticulture and its importance as a foreign exchange earner, a contributor to food security and a provider and potential creator of employment.

The plan also highlights the importance of increased agricultural productivity based on expanding irrigation through infrastructure investments in new dams, the reduction of distribution losses, increased usage efficiency and improved water scheme management. The impact of climate change on existing and proposed storage capacity will have to be researched in order to produce optimal policy recommendations. The plan also highlights the importance of the creation of livelihoods through small-scale agriculture. Research on how the responsiveness to change of these producers could be increased is important because, at present, they are not at the forefront of the adoption of new technology and practices when compared to their commercial counterparts.

9. CONCLUSIONS

This study aimed to provide an integrated perspective on how the agricultural and food systems could be affected under various climate change scenarios from an economic and social perspective. A stochastic, partial equilibrium modelling approach was used to provide preliminary high-level messages on the impact of climate change on South African maize and wheat production towards 2030, and the broader socioeconomic implications. In addressing only wheat and maize the study does not provide a fully integrated picture of risks to food security, but it provides useful insights into potential impacts especially by exploring price impacts of selected climate scenarios on (mostly poor) consumers, and possible impacts on employment in the sector.

Under a base climate scenario (current climate projected to 2030), South Africa remains a net exporter of white and yellow maize and a net importer of wheat, with net imports growing beyond 50% of consumption. Maize prices remain at export parity levels, while wheat prices remain at import parity levels. The total area under field crop production remains stable towards 2030 (about 4.7 million hectares), but crop allocations are projected to change, with a decline in the area planted to white maize (1.5 million hectares to 1.1 million hectares), and a doubling of the area under soybean (500 000 ha to > 1 million hectares). This is due to the expected upward trend in maize yields but stable demand due to the continued shift in consumer preference in favour of bread. Yellow maize plantings show a small increase, while sunflower production is expected to remain flat. Wheat plantings are expected to decline slightly in favour of an increase in canola production. Wheat imports are projected to increase given the growing demand and stagnant supply.

Under a drying scenario in maize producing areas, white maize yields are anticipated to decline by 1.1 t/ha on average over the outlook period, resulting in a drop in total production of approximately 1.6 million tons per annum and a 16% increase in white maize prices. Producers would increase white maize production by expanding the area planted by around 200 000 hectares, almost compensating for the yield declines relative to the base scenario. The climate scenario with the smallest expected decline in national mean annual precipitation had the greatest impact on the maize and wheat production regions due to the local pattern of rainfall change, emphasising the importance of local rainfall projections for projecting socioeconomic impacts for this sector.

In the summer rainfall wheat producing areas (mostly the Free State Province), the same climate scenario projected increased annual precipitation during the winter months resulting in a projected yield increase of more than 1 t/ha for winter wheat. This increase in yield does not result in an increase in the area planted, however, due to the greater relative profitability of maize production. In the winter rainfall wheat producing areas (Western Cape Province) the same climate scenario model showed a small decline in precipitation during the winter months that resulted in a yield decline. Together, these changes result in a projected decline in total wheat production of just over 100 000 tons per annum relative to the base climate scenario. This did not result in a change in domestic prices, however, since wheat prices are at import parity price levels and are expected to remain there.

Overall, the following main messages emerge:

1. The greatest change in rainfall nationally does not necessarily equate to the greatest adverse effect in the agriculture sector.
2. The timing and locality of rainfall, together with price signals, are the deciding factor for eventual area planted and yield.
3. A decline in yield could result in an increased area planted in response to higher prices.
4. Relative prices and profitability matter – producers chose to allocate land to maize production, regardless of the forecast increase in wheat yields,

due to the higher forecast relative profitability of maize production.

Producers are not confronted with a simple once-off produce/don't produce decision, but rather face multiple decisions over time on expanding, contracting or shifting production to other crops given prevailing prices and climate risk.

Price impacts of the respective climate scenarios on (mostly poor) consumers were evaluated through the use of three instruments – the BFAP poor person's index, a staple food expenditure-based analysis, and a balanced daily food plate model. Currently, maize porridge and brown bread contribute 73.5% of the costs of a five-item low-income weighted food plate. For bread, none of the climate scenarios showed a deviation from the base because the wheat price remains at import parity regardless of the level of domestic production. For white maize meal, the drying scenario showed a small deviation from the base. However, the significance of this deviation decreased over time due to a declining trend in white maize consumption per household in favour of bread. Importantly, the anticipated increase in the price of white maize due to the drying scenario comes on top of a significant increase in the price of the food basket towards 2030, with the BFAP poor person's index almost doubling in price towards 2025. From a food security perspective this suggests possible sensitivities in the affordability of a balanced food basket given adverse climate conditions. From a supply perspective, producers have the ability to increase production in response to high prices. The country is and will continue to be a major wheat importer. Food security therefore is not a question of supply, but rather of access in terms of financial means and/or own supplementary production.

For the period 2014 to 2025, employment in the maize industry is expected to decline by 2% for the base scenario, whereas the drying climate scenario delivered the smallest decline (-1.1%). This is in part due to the smaller contraction in the area planted in response to the increase in the maize price relative to the base case. This reduction does not necessarily equate to a decline in absolute employment due to the transfer of the area formerly under maize (and the labour) to the production of other crops. In the base scenario the area under soybean production is expected to increase from 500 000 to 1 million hectares. The converse is true in the wheat industry, with the greatest expected decline (-2.2%) in the drying climate scenario, twice that of the base scenario.

Overall, climate change challenges do not act on producers in isolation, but rather interact with the multiple stresses to which producers are exposed. It is therefore useful to consider how climate change adaptation responses could be integrated with existing best practices that have evolved to cope with these multiple stresses, including improving the overall efficiency and competitiveness of the production system. Such an approach could focus specifically on responses that benefit producers at multiple scales of production, from smallholder through to large-scale commercial agriculture.

Significant gains in production under limited water supply are possible within existing systems by reducing distribution losses, adopting more efficient irrigation systems, and making improvements in the management of existing irrigation systems. Water use efficiency increases have the potential to add a further 282 000 hectares to the area under irrigated production. Maintenance of, and improvements to, existing irrigation systems are critical to reduce production risks. Incentives for the upgrading of existing systems to more efficient alternatives, for example flood to drip irrigation would be beneficial; alternatively, the amount of water available to consumers could be regulated in order to encourage investments in more efficient systems.

The exports of high value agricultural products could be expanded in future in order to maintain a positive agricultural trade balance and to avoid the negative effects of exchange deficits. Higher export earnings could also benefit from improvement of the SADC regional road and rail networks in order to enable more cost-efficient trade. Zimbabwe is currently one of South Africa's biggest trade partners. Fruit and wine exports to the SADC region are expected to continue to grow, whilst Zambia, for example, could serve as an important trade partner for wheat. However, further study of a larger range of commodities under a broader range of climate scenarios would be useful to assess the relative costs and benefits of such a response.

Finally, further research on how the responsiveness to change of small-scale agricultural producers could be increased is important, because these producers are currently limited in their capacity to adopt new technology and practices when compared to their commercial counterparts.

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ANNEXES

Appendix A: Water Abstraction per country and per sector

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Base: Total cost of five items (index, with 2013 = 100)	100	103	106	110	113	117	119	124	127	131	134	139	143
Scenario MPI 4.5: Total cost of five items (index, with 2013 = 100)	100	105	110	112	117	119	123	128	128	135	139	143	146
Percentage increase	0.0%	1.7%	3.3%	1.8%	3.4%	1.4%	3.1%	3.2%	1.2%	3.0%	3.5%	2.9%	1.9%

Annexure B: The BFAP poor person's index – Projected results based on the cost share contributions of maize meal and bread within the portion-weighted, five-item food plate

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
							%						
Base: Maize as share of total cost	28.8	27.8	26.9	27.5	26.9	27.4	26.4	27.2	26.3	26.6	26.2	26.2	26.3
Scenario MPI 4.5: Maize as share of total cost	28.8	29.0	29.2	28.7	29.3	28.4	28.6	29.5	27.2	28.7	28.7	28.3	27.6
Base: Brown bread as share of total cost	44.7	46.5	48.5	48.5	49.6	50.0	51.4	51.5	52.7	53.1	54.1	54.7	55.2
Scenario MPI 4.5: Brown bread as share of total cost	44.7	45.8	46.7	47.7	48.0	49.3	49.8	49.9	52.1	51.6	52.2	53.1	54.2

Appendix C: The potential additional expenditure on maize meal and bread if consumption quantities remain the same (2010) at higher price levels

	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
1. Maize meal expenditure in 2010 (R/hh/year)	R 614	R 893	R 947	R 969	R 914	R 751	R 658	R 553	R 341	R 180
2. Estimated maize meal expenditure at projected BASE price max level (R/hh/year)	R 1 255	R 1 824	R 1 936	R 1 980	R 1 869	R 1 536	R 1 344	R 1 130	R 698	R 368
3. Estimated maize meal expenditure at projected CLIMATE CHANGE SCENARIO price max level (R/hh/year)	R 1 345	R 1 955	R 2 076	R 2 122	R 2 003	R 1 646	R 1 441	R 1 211	R 748	R 395
Difference (scenario less base) (R/hh/year) [(3) less (2)]	R 90	R 131	R 139	R 142	R 134	R 110	R 97	R 81	R 50	R 26
Difference (scenario less base) (R/hh/month)	R 7.52	R 10.93	R 11.60	R 11.86	R 11.20	R 9.20	R 8.05	R 6.77	R 4.18	R 2.21
Difference as share of 2010 income levels	1.9%	1.0%	0.7%	0.5%	0.4%	0.2%	0.1%	0.1%	0.0%	0.0%
Difference as share of projected 2025 income levels	1.1%	0.6%	0.4%	0.3%	0.2%	0.1%	0.1%	0.0%	0.0%	0.0%

Appendix D: The potentially reduced energy intake if staple food budgets remain unchanged at 2010 levels, but retail prices of bread and maize meal increase as per projections

	ID 1	ID 2	ID 3	ID 4	ID 5	ID 6	ID 7	ID 8	ID 9	ID 10
1. Energy value contribution of maize meal in 2010 (kJ per household member per day)	2 446	2 515	2 350	2 477	2 066	1 734	1 535	1 308	822	447
2. Energy contribution of maize meal according to maximum projected "base" price (kJ per household member per day)	1 197	1 231	1 150	1 212	1 011	848	751	640	402	219
3. Energy contribution of maize meal according to maximum projected "climate change scenario" price (kJ per household member per day)	1 116	1 148	1 073	1 130	943	791	701	597	375	204
Difference (kJ/household member/day) [(3) less (2)]	- 80	- 83	- 77	- 81	- 68	- 57	- 50	- 43	- 27	- 15

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