International Institute for Applied Systems Analysis
IIASA www.iiasa.ac.at

Address: IIASA, Schlossplatz 1, A-2361 Laxenburg, Austria
Email: repository@iiasa.ac.at **Telephone:** +43 (0)2236 807 342

Report

South African agriculture towards 2030/50

Günther Fischer (fisher@iiasa.ac.at)

Sylvia Tramberend (sylvia.tramberend@iiasa.ac.at)

March 2019

Approved by

Simon Langan, Director Water Program

IIASA Contract No. 16-118

This research presents results of a sub-task of a larger project on Sub-Saharan Africa, funded by the Worldwide Wildlife Fund (WWF) South Africa, under the service contract ZA5403 on 'Sustainable Aviation Biofuel Feedstock Potential in Sub-Saharan Africa'.

ZVR 524808900

Table of Contents

Abstract

South Africa is a major producer and exporter of agricultural products. The diversified agricultural sector produces a wide variety of agricultural commodities based on both large-scale commercial farming and small-scale family farms. However, pockets of food insecurity persist with more than 10 % of households experiencing hunger. A growing and more affluent population will require a further increase in agricultural production. We present scenario model projections for the South African agricultural sector in accordance with the projections of the study “World agriculture towards 2030/2050” by the Food and Agricultural Organization of the United Nations. Until the 2050s, depending on scenario, South Africa’s current population of 55 million will grow by another 10 to 17 million people. At the same time average per capita income will increase by 150 to 200 % resulting in shifts in dietary patterns in favour of vegetables, fruits and livestock products. Between 2000 and 2050, meat consumption and food use of milk will increase by a factor of 2.2 to 2.5, while other commodities double or less than double. Increases in domestic production can account for most of the increasing food consumption. This is achieved by a combination of increases in cropping intensity, yields per hectare and smaller increases in areas equipped for irrigation. Cropping intensity increases from 50 % in 2000 to 60 % in 2050, i.e. the average fallow periods in crop rotation cycles will decrease. Yield, in terms of crop output per harvested area, will increase at an aggregate level by some 40-45 %. Changes in physical cropland depend on the scenario used. Mainly because of population numbers, for two scenarios the 14 million hectare arable land in 2000 decreases to between 13.6 and 13.1 million hectares. One scenario, which assumes higher population growth up to 73 million by 2050, result in some 300 thousand hectares cropland increase. Due to growing competition for already constrained water availability in many regions, total water withdrawals allocated to agriculture are expected to decrease over time. Therefore the sustained growth depends on careful use and integrated planning of water for irrigation. At an aggregate country level, by 2050, average food energy supply will increase by 16 % up to 3000 kcal per capita per day. The fraction of animal protein in total protein will increase from one fourth in 2000 to more than one third by 2050. Despite adequate and promising levels of future food supply, poverty can lead to parts of the population lacking access to food. At the same time, urban low income populations are prone to overweight and obesity. Food security plans should address strategies for the distribution of adequate and high-nutrient food, alongside environmental concerns focused on the conservation of the productive land in South Africa.

Acknowledgments

This research presents results of a sub-task of a larger sub-Saharan Africa project funded by the Worldwide Wildlife Fund (WWF) South Africa under the ZA5403 service contract on 'Sustainable Aviation Biofuel Feedstock Potential in Sub-Saharan Africa'. Tjasa Bole-Rentel (WWF South Africa) supported the extension of the Sub-Saharan Africa study with a more detailed analysis for South Africa. We thank Tatjana von Bormann (WWF South Africa) and anonymous reviewers from South Africa's Bureau for Food and Agricultural Policy (BFAP) for valuable comments and suggestions.

About the authors

Günther Fischer is a senior researcher (Water Program) in land use systems of the Food and Water thematic area at IIASA. He also holds the position of adjunct professor in the Department of Geography at the University of Maryland, USA. His main fields of research are mathematical modelling of ecological-economic systems, econometrics, optimization, applied multi-criteria decision analysis, integrated systems and policy analysis, spatial agro-ecosystems modelling, and climate change impacts and adaptation. He participated in the development of IIASA's world food systems model and was a key contributor to several major food and agricultural studies: On welfare implications of trade liberalization in agriculture; on poverty and hunger; on biofuels and food security; on the climate-water-food-energy-ecosystem nexus; and on climate change and world agriculture. He is collaborating with the United Nations Food and Agriculture Organization (FAO) on the development, implementation and application of the Agro-Ecological Zones (AEZ) methodology to a global assessment and several regional and national resource appraisals in Africa, Asia and Europe. (Contact: fisher@iiasa.ac.at)

Sylvia Tramberend is a research scientist (Water Program) working on IIASA's interdisciplinary and policy oriented research as a land use systems and GIS expert in the Food and Water thematic area. Her key research interests and main responsibilities include scenario development, identifying solution pathways until the 2050's in the food-water-energy-environment nexus and sustainable consumption in a globalized world, and studying linkages between the biophysical and socio-economic domain. Her responsibilities have included the development of large spatial databases serving the modelling and analysis needs in the areas of food-environment-bioenergy-water linkages, food-system analysis, land use and water scenarios and environmental transition. In the development of the FAO/IIASA Global Agro-Ecological Resources Assessment, she managed the integration of the large spatial input databases and analysis needs in the areas of global and selected higher resolution (Sub-Saharan Africa, China, Europe, Brazil) regional food-water-bioenergy-environment linkages, land use and water scenarios, food-system analysis and environmental transition.
(Contact: sylvia.tramberend@iiasa.ac.at)

List of Figures

List of Tables

List of Boxes

1. Introduction

The perceived limits to producing food for a growing and more affluent population have been a source of debate and preoccupations across the world. The decades until 2050 are critical. The majority of population projections expect global population to peak in the2050s and thereafter remain stable or start to decline (Samir and Lutz, 2017). The Food and Agriculture Organization of the United Nations (FAO) has published in its 'World Agriculture towards 2030/2050' (Alexandratos and Bruinsma, 2012) long-term projections on the additional agricultural produce required to supply demand for a larger population with higher income. FAO's assessment is based on country-level analysis. However, results were presented by major global regions including Sub-Saharan Africa as one region.

Unlike most of Sub-Saharan Africa, South Africa includes highly productive large-scale commercial farming. Agricultural economy is highly diversified including the production of all major grains (except rice), oilseed, fruits, sugar, citrus, wine and most vegetables. Livestock production includes cattle, dairy, hogs, sheep, and a well-developed poultry and egg industry. In 2016, the agricultural sector contributed about 12% to South Africa's total export earnings. More than one fifth of total agriculture export value generated in Sub-Saharan Africa is due to exports from South Africa alone (FAOSTAT, 2018).

The analysis presented here has been commissioned by the World Wildlife Fund of South Africa to provide input for a study on "Agro-food Systems: Facts and Futures. How South Africa can produce 50% more by 2050" (Bormann, 2019). The aim of this study is to calculate a scaled down version of the FAO regional projections presented in "World Agriculture towards 2030/2050" for the case of South Africa. The methodology for these projections aligns with the FAO global study by using FAO development trends of changes in agricultural productivity and major consumption patterns for South Africa. Since the future is uncertain, we use a scenario approach to explore different but all plausible development paths. Using population and GDP projections for defined development scenarios, we update the FAO's per capita consumption for major commodity groups to take into account the availability of more recent data.

The following section describes key features of South Africa's current agricultural sector and production system. The third section introduces the approach and applied economic modelling framework, the development scenario narratives and assumptions. Agricultural sector development trends resulting from population growth and dietary changes due to wealthier consumers are described in section 4. The final section presents conclusions.

2. Current agricultural sector

2.1 Socio-economic role of agriculture

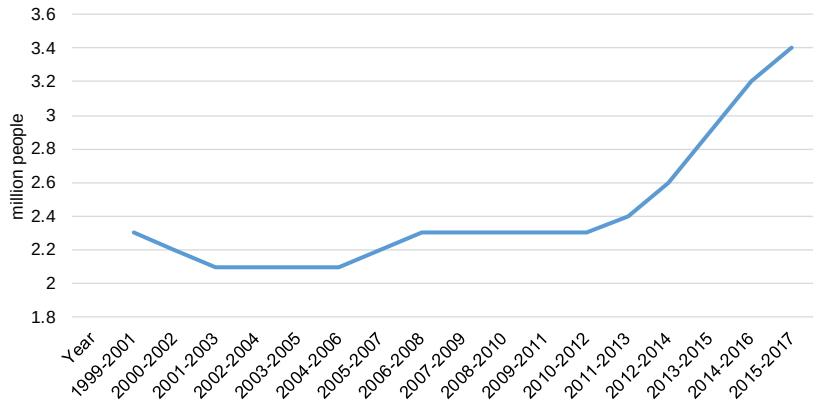
South Africa has shifted from a primary and secondary sector economy in the mid-twentieth century to an economy driven primarily by the tertiary sector in the present day, which accounts for an estimated 69% of GDP (value for 2016 according to World Bank Development Indicators). The contribution of agriculture, forestry and fisheries to total value added was only 2 % to 2.7 % between 2005 and 2016. Despite its relatively small share of the total GDP, primary agriculture is an important sector in the South African economy.

Agriculture remains a significant provider of employment, especially in the rural areas, and a major earner of foreign exchange (DAFF, 2017). Nevertheless, in the past two decades direct employment in agriculture has decreased from almost 2 million in 2000 to an estimated 885 thousand people in

2017 (ILOSTAT, 2017). Employment in agriculture accounts for some 5.4 % of total labour force, compared to 27 % in industry and 71 % in the service sector.

The latest "Poverty Trends in South Africa" report shows that, more than half of South Africans were classified as poor in 2015. Despite a general decline in poverty between 2006 and 2011, poverty levels rose in 2015 (STAT-SA, 2017). The increasing trend in poverty apparently has propagated into the number of people undernourished. In South Africa, more than 2 million people are undernourished with an increasing trend in the past years. For 2015-2017, FAO estimates some 3.4 million people being undernourished (Figure 1).

Figure 1. Number of people undernourished, South Africa, 1999 to 2017



Source: FAOSTAT Country indicators, http://www.fao.org/faostat/en/#country/202

The climate-related shock of a prolonged drought affecting large parts of South Africa between 2015 and 2017 and its adverse impact on the agricultural sector has likely contributed to the recent reversal of trend in food security indicators. From 13 March to 13 June 2018 the government of South Africa has declared a 'national state of disaster' in an effort to deal with the country's drought crisis.

According to South Africa's annual General Household Survey, in 2016, more than one fifth (22 %) of households had inadequate or severely inadequate access to food (STATS-SA, 2017a). Moreover, 12 % of households and 13 % of individuals experienced hunger.

South African agriculture is of a highly dualistic nature where a developed commercial sector coexists with large numbers of subsistence (communal) smallholder farmers (Sandrey and Vink, 2009). Smallholder agriculture is still dominant in rural areas where at least 70% of the country's poorest households dwell (Tshuma, 2014). Land reform also lies at the heart of dealing with the increasing levels of inequality in a dualistic agricultural system in South Africa (BFAP, 2018). Land reform in South Africa focuses on restitution, land tenure reform and land redistribution. It is the subject of intense debate and its implementation is still uncertain.

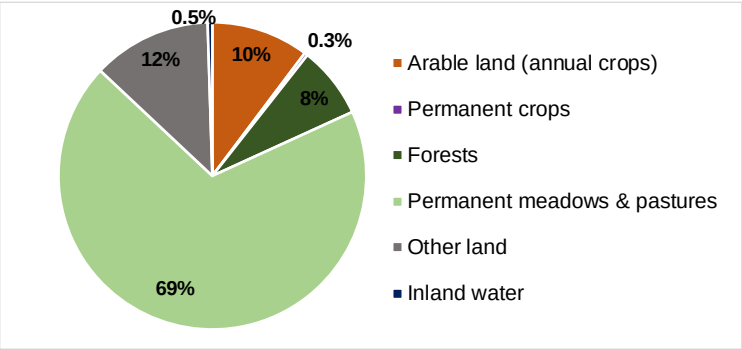
2.2 Land use and harvested areas

The dominant land cover in South Africa is grassland (84 Mha), followed by cropland cultivated for annual crops (12.5 Mha) and perennials (0.4 Mha). Forests cover 9.2 Mha and inland waters 0.6 Mha (FAOSTAT, 2018). The remaining category 'other land' includes built-up areas and sparsely vegetated or barren land (Figure 2).

Farmland includes cropland for the production of annual crops and perennials and grassland in use for browsing livestock. Compared to area statistics for cropland, grassland extents actually used for agriculture is more uncertain. BFAP (2018) reports a total of 78 Mha of farm land under freehold (i.e.

in full private ownership) and 18 Mha farm land under traditional tenure. Thus farm land accounts for almost 80% of South Africa's total land (122 Mha). As the western half of the country, with the exception of the region north of Cape Town, is semi-arid or arid, nationally classified farm land obviously this includes large stretches of grassland with a low productivity.

Figure 2. Major land use categories in South Africa, 2013-15



Source: FAOSTAT

South Africa's current 12.9 Mha cropland is used for the production of food, animal feed and some industrial crops (Table 1). Harvested areas amount to just over half or 7 Mha of the country's cropland. The relatively low cropping intensity (i.e. the ratio of harvested areas and cultivated cropland) of 0.54 may suggest extensive crop rotation schemes including regular fallow periods. It may however also be a result of the large

Table 1. Harvested areas and key crops, South Africa, 2014-16

Area extents in 1000 hectares			
Harvested areas			Key commodities (Area)
Cereals	3182	46 %	Maize (2429); Wheat (489)
Fodder crops*	1585	23 %	
Oil crops	1345	19 %	Sunflower (631); Soybean (564);
Fruits, vegetables, nuts, spices	439	6 %	Grapes (123)
Sugarcane	259	4 %	
Roots & Pulses	157	2 %	Potatoes (64); Beans (51)
Fibre, stimulants	12	0.2 %	Tobacco (5)
Total harvested areas	6979	100 %	
Cropping intensity	0.54		

* Values for 2011 includes Alfalfa, mixes of grasses and legumes for forage and silage.

Source: FAOSTAT

Almost half of total harvested areas is used for the production of cereals (maize and wheat), followed by dedicated fodder crops (alfalfa and other annual grasses), and oil crops (sunflower, soybean). It should be noted that the land use classes captured in the Southern African Land Cover Map produced for South Africa in 2013-14 (SALC1314) report somewhat higher extents of cultivated[1] areas amounting to 13.9 Mha (GEOTERRAIMAGE, 2015) reported in Table 5.1 of (Niekerk et al., 2018).

[1] In FAO cultivated land refers to the sum of arable land (for annual crops) and agricultural land for permanent crops (e.g. fruits, grapes, oil plam).

Agriculture is the largest water user accounting for 63 % (9.7 km^3/year) of human water withdrawals, followed by municipal (27 %) and industrial (10 %) water withdrawal. The majority of agricultural water (9.3 km^3/year) is used for irrigation, mainly large-scale commercial schemes. In 2012, 1.6 Mha cropland were equipped for irrigation (i.e. with irrigation infrastructure), of which 55 % were sprinkler irrigation, 23 % surface irrigation and 22 % localized irrigation systems. A variety of crops is irrigated including fruits, grapes, maize, wheat, and vegetables (Table 2).

Using various remotely sensed Earth observation and diverse geographical information systems techniques, South Africa's Water Research Commission reports the land surface that was actively irrigated during 2014/15 amounting to a total of 1.3 Mha. Irrigation occurs throughout the country. More than half of irrigated areas are concentrated in three provinces: Western Cape (0.27 Mha), Limpopo (0.22 Mha) and KwaZulu-Natal (0.18 Mha) (Niekerk et al., 2018).

Table 2. Harvested area on cropland equipped for irrigation, South Africa, 2008-12

Harvested irrigated crop area [1000 ha]			
Annual crops		**Permanent crops**	
Maize	231	Citrus	67
Wheat	217	Other fruits	238
Leguminous crops	143	Other permanent crops	251
Vegetables	136		
Sugarcane	90		
Fodder	83	TOTAL Annual & permanent crops	1665
Other annual crops[1]	209		

1 includes e.g. cotton, potatoes, tobacco, other cereals;

Source: FAO (2016). AQUASTAT Main Database

2.3 Crop and livestock sector commodity balances

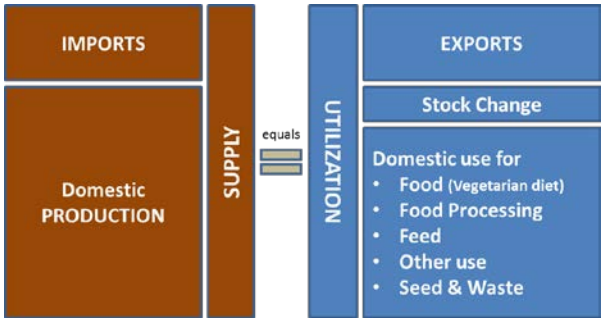
The FAO supply and utilization accounts (SUA) provide a comprehensive summary of production, trade and utilization of agricultural commodities (Box 1). The database structure is designed to cover each country's entire agricultural sector. Over 200 different primary and processed crop and livestock commodities are linked by a consistent commodity tree structure and balanced annually for each country. Intermediate or processed commodities may be included in a particular SUA commodity in their primary equivalent. For example, the SUA commodity wheat includes in its account of imports not only the import of primary wheat, but also all imported wheat products converted into primary wheat equivalent. Table 3 and 4 show the most recent SUA accounts for key crops in South Africa.

South Africa is a major producer and net importer of wheat and wheat products. Production accounts for about 60 % of domestic supply and the majority (96 %) is consumed as food. The supply of maize and maize products originates from domestic production, some 20% of production is exported. Approximately half of maize consumption is used for food, the other half mainly for as feed for raising domestic livestock herds. The variety 'white maize[2]' is used for food as an integral part of local diets, commonly prepared as a traditional porridge (locally knows as "pap"). Unlike other parts of the world, in South Africa the 'yellow maize[3]' variety is exclusively used for livestock feed. Rice, another important food crop, originates from imports only.

[2] Outside southern Africa, white maize is grown in significant quantities only in Mexico and the United States. It requires more favorable climatic conditions than yellow maize, is generally considered a food crop, and mostly produced for local markets.
[3] Yellow maize constitutes the bulk of world production and international trade. Large quantities are used as animal feed and has a wide range of industrial applications, including production of ethanol.

Box 1. Supply Utilization Accounts (SUA)

The FAO Supply Utilization Account annual time series data balance supply with use of agricultural commodities. The Figure in this box depicts the individual items in the SUA accounting system. The total quantity of agricultural commodities produced in a country, that is, domestic production added to the total quantity imported and adjusted to any change in stocks that may have occurred since the beginning of the reference period, gives the supply available during that period. The utilization side distinguishes between the quantities exported, food supplies available for human consumption (food), fed to livestock (feed), put to manufacture for food use (processing), other uses (other use), used for seed production (seed), losses during storage and transportation (waste), and changes in stocks (stock change).



Items in the FAO Supply Utilization Accounts

Table 3. Supply and utilization of cereals, South Africa, 2011-13

1000 tons primary equivalents	**CEREALS**[1]	of which	**Wheat & products**	**Maize & products**	**Rice** (Milled Equivalent)
Supply and trade					
Production	13882		1930	11430	2
Import	5098		1720	134	1173
Export	2865		276	2332	89
Net imports	2233		1444	-2198	1084
Stock variation[2]	579		-83	1150	-203
Domestic Supply[3]	16694		3290	10383	883
Used for:					
Food	10729		3152	5236	882
Feed	4811		37	4677	0
Processing	597		0	44	1
Seed, losses	558		101	425	0

1 Cereals include wheat, maize, barley, millet, oats, rye, sorghum**: 2** positive number indicates 'From Stock', a negative number 'To Stock'. **3** Domestic Supply = Production + Imports – Exports + Stock changes including consideration of stock changes, which are not shown here;
Source: FAOSTAT

South Africa is a major producer and net exporter of fruits and wine. More than half of fruits or 3.4 Mt are produced for export markets. Some 1.5 Mt of fruits are for domestic food use and the remainder (mainly grapes) is processed into higher value products (e.g. wine). Almost half of the wine produced in the country is for export markets. South Africa is also a major producer of sugar, produced from domestic sugar cane production. Though some sugar is imported, the country is a net

exporter. Domestic food use of sugar (raw equivalent) has increased by 40 % from 1.3 Mt in the beginning of the 1990s to 1.8 Mt in 2013.

Table 4. Supply and utilization of sugar, fruits and wine, South Africa, 2011-13

In 1000 tons primary equivalents	**Sugar[1]**	**Fruits**	**Wine**
Supply and trade			
Production	2073	6437	1043
Import	389	491	3
Export	526	3402	464
Net imports	-138	-2911	-461
Stock variation	-112	19	-26
Domestic Supply	1823	3581	556
Used for:			
Food	1779	1542	405
Feed	0	0	0
Processing	45	1470[2]	151
Seed, losses	0	202	0

1 Sugar (raw equivalent), Domestic sugar production is derived from processing of 17 million tons of sugar cane;
2 including 1359 thousand tons of grapes used for food processing

Source: FAOSTAT

In the livestock sector, South Africa is a major producer and practically self-sufficient in meat, milk and eggs. The exception is poultry meat, where almost one fifth (18% or 331 thousand tons) is supplied by net imports (Table 5).

Table 5. Production and net imports of livestock products for human food, South Africa, 2011-13

1000 tons	**Poultry meat**	**Bovine meat**	**Pig meat**	**Other meat[1] & edible offal**	**Milk**	**Eggs**
Supply and trade						
Production	1494	834	206	459	3293	519
Net imports	331	1	30	60	143	-5
Domestic food use	1825	827	235	476	3137	386[2]

1 Mainly mutton and goat; **2** Losses and used for breeding are not shown here.

Source: FAOSTAT

In the non-food sector, the country produces some 181 thousand tons hides, skins and wool, of which about half (97 thousand tons) is exported.

Aquatic products are of local importance. In 2011-13, total production was 620 thousand tons, of which 404 and 170 thousand tons were pelagic and demersal fish catches respectively. Fish products are extensively traded (179 thousand tons imports and 370 thousand tons exports).

3 Development scenarios

3.1 Approach and economic modelling framework

The FAO study “World agriculture towards 2030/2050: the 2012 revision” (Alexandratos and Bruinsma, 2012) provides a comprehensive summary of the magnitudes and trajectories of major food and agriculture variables until 2050. The analysis compiles key drivers of food demand, trade and agricultural productivity growth for individual countries and projects how the agricultural production and food consumption may develop until 2050. Results are presented by major world region and for some variables for selected large economies.

Here we present a scaled down and updated version of the FAO study for South Africa using IIASA’s World Food System (WFS) model to simulate food demand under alternative socio-economic development scenarios, to investigate impacts on production, cropland use and food price development. Several applications of the WFS to international agricultural policy analysis, trade liberalization, climate-change vulnerability, and to the food vs. fuel debate have been published (Fischer et al., 2009, Fischer et al., 2005, Fischer et al., 2002, Fischer et al., 2019, Prieler et al., 2013).

The WFS is an applied general equilibrium model. Simply put, its framework comprises of a series of linked national and regional agricultural economic models. In these models, national food and agricultural components are seen as embedded in national economies, which in turn interact with each other through international trade. Although the WFS focuses on agriculture, non-agricultural economic activities are also represented in the model so that the essential dynamics across sectors among capital, labour, and land are captured.

The WFS consists of 35 national and/or regional geographical components globally with individual models linked by means of a world market, i.e. an international linkage mechanism. For the purpose of this study, South Africa has been implemented as a separate regional market. Each individual country or region model covers the whole economy of the respective geographical area. Within each country/region, the model considers three groups of actors: producers (supply), consumers (demand); government (market interventions). The model takes into account the budget constraints of each group. It is assumed that the actors in the system are rational and allocate their income to maximize their objectives subject to financial constraints.

In this representation of the national and global commodity markets, international clearing prices are computed to equalize global demand with supply. Whatever is produced will be demanded, either for human consumption, feed, or industrial use. Alternatively, it can be exported or put into storage. Working in annual time steps, the system is balanced simultaneously for all countries in each time period. Production in the next year is based on changes in agricultural resources (land, labor, capital stock) and realized prices in the current one, making the WFS a recursively dynamic model.

For the purpose of international linkage, production, consumption, and trade are aggregated to nine agricultural sectors and one non-agricultural sector. All physical and financial accounts are balanced and mutually consistent: the production, consumption, and financial ones at the national level, and the trade and financial flows at the global level.

For South Africa, we use the country-level FAO study development trends of changes in agricultural productivity (yield growth, changes in cropping intensity) and per capita consumption (per major commodity group) in response to income growth and update them with population and GDP projections for the development scenarios described in the following sections. In line with the FAO study, the projections presented here do not separate fisheries products.

3.2 Scenario narratives

Scenarios provide a method to explore different possible development pathways against the background of uncertain futures. They help to understand long-term consequences of near-term decisions and therefore form an essential part of sustainability research. South Africa's agricultural sector is closely linked to socio-economic development trends. Amongst others, they determine different diets and demand patterns for agricultural products. Together with management priorities and technology, shifts in food demand may result in different patterns of land and water resource use.

This study integrates into the widely applied new parallel process (Moss et al., 2010) developed by the International Panel on Climate Change for the 5th Assessment Report. It is characterized by a Scenario Matrix Architecture (Van Vuuren et al., 2014) including the Shared Socio-economic Pathways (SSPs) and Representative Concentration Pathways (RCPs) (Van Vuuren et al., 2011). The SSPs were developed in an extensive consultation process to provide a set of alternative plausible trajectories of future societal development (O'Neill et al., 2017). Among others, the SSPs include a quantification of demographic and economic development. This study analyses two (Box 2) of the five[4] SSP scenarios.

The Scenario 'Sustainability - Taking the green road' (SSP1) is of the five portrayed futures the only possible pathway that can most likely achieve the recently agreed Sustainable Development Goals (UN, 2015). The 'Middle of the Road' Scenario (SSP2) largely assumes business-as-usual trends, uses a medium population growth, generates economic and food security improvements in all regions, but cannot achieve agreed climate targets. SSP2 is most closely related to the assumptions for population and economic growth in the above cited FAO "World agriculture 2030/50" study.

3.3 Scenario assumptions

Population has been increasing in South Africa from 13.6 million 1950 to 45.7 million in 2000. Since 2000, the average annual growth has been about 600 thousand people. According to South Africa statistics, the most recent population estimate is 56.5 million people residing in the country in 2017 (STATS-SA, 2017b).

Different institutions provide population projections. The dynamic nature of population growth requires regular updates for these projections. The FAO "World agriculture 2030/50" study (Alexandratos and Bruinsma, 2012) used the 'medium variant' projections of the United Nations published in the early 2010s. The UN updates its projections on an annual basis for three variants (low, medium, high).

The quantified drivers of the Shared Socio-economic Pathways, available in the SSP database (IIASA, 2016), provide population and urbanization projections for each SSP, developed by the International Institute for Applied Systems Analysis (IIASA-WIC) and the National Centre for Atmospheric Research (NCAR). For GDP, three alternative interpretations of the SSPs by the teams from the Organization for Economic Co-operation and Development (OECD), the International Institute for Applied Systems Analysis (IIASA) and the Potsdam Institute for Climate Impact Research (PIK) have been developed and included in the SSP database. The GDP projections are based on harmonized assumptions for the interpretation of the SSP storylines in terms of the main drivers of economic growth. They differ however with respect to the employed methodology and outcomes.

[4] The other three scenarios include SSP3 (Regional rivalry – A rocky road), SSP4 (Inequality – A road divided); SSP5 (Fossil-fueled development – Taking the highway)

Box 2. Scenario narratives for two Shared Socio-Economic Pathways (SSPs)

Adapted from adapted from (O'Neill et al., 2017).

SSP1 is a sustainability scenario ("*Sustainability – Taking the green road*") where the world shifts gradually, but pervasively, toward a more sustainable path, emphasising more inclusive development that respects perceived environmental boundaries. Increasing evidence of and accounting for the social, cultural, and economic costs of environmental degradation and inequality drive this shift. Rapid technological progress facilitates the reduction of resource intensity and fossil-fuel dependency. Consumption is oriented toward low material growth and lower resource and energy intensity. Low-income countries grow more rapidly, inequality between and within economies falls, and technology spreads. Educational and health investments accelerate the demographic transition, leading to a relatively low population. The world has an open trade economy, associated with increasingly effective and persistent cooperation and collaboration of local, national, and international organizations and institutions. For scenario implementation, these general tendencies of development in the SSP1 storyline were interpreted to have the following specific agriculture/irrigation related implications:

- Improved agricultural productivity through more rapid reduction (compared to reference technological assumptions on yields) of prevailing yield gaps toward environmentally sustainable and advanced technology yield levels
- Progressive elimination of barriers and distortions in international trade of agricultural products
- Progress towards effective land use regulation especially for preventing deforestation caused by expansion of cropland
- Enforcement of legally protected conservation areas
- Large improvements of irrigation water use efficiency where possible
- Reliable water infrastructure and water supply
- Substantial improvements in food security globally, including the low-income countries in Sub-Saharan Africa.

SSP2 is a continuation of current trends scenario (*"Middle of the road"*), where the world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns. Development and income growth proceeds unevenly, with some countries making relatively good progress while others fall short of expectations. Most economies are politically stable. Globally connected markets function imperfectly. Global and national institutions work toward but make slow progress in achieving sustainable development goals. Fossil-fuel dependency decreases slowly. Global population growth is moderate and levels off in the second half of the century as a consequence of completion of the demographic transition. However, education investments are not high enough to accelerate the transition to low fertility rates in low-income countries and to rapidly slow population growth. For food system scenario implementation this means continuation of past agricultural growth paths and policies, continued (albeit decreasing over time) protection of national agricultural sectors, and further environmental damages caused by agriculture, and includes:

- Progress of agricultural productivity in developing countries as portrayed in FAO perspective study "World Agriculture: Towards 2030/2050" (Alexandratos and Bruinsma, 2012)
- Increasing per capita consumption of livestock products with growing per capita incomes
- Barriers and distortions in international trade of agricultural products are reduced only slowly
- Some improvements of water use efficiency, but only limited advances in low-income countries
- Gradual reduction of food insecurity due to trickle down of economic development
- Food and water insecurity remain as problems in some areas of low-income countries
- Insufficient measures and protection to prevent deforestation due to cropland expansion in developing country regions

A key element of harmonization was to use population and education data from the IIASA-WIC contribution to the SSP framework (Chateau et al., 2012). This study uses the OECD GDP projections[5] that are harmonized with the IIASA-WIC (version 1[6]) (Samir and Lutz, 2017) population projections.

Table 6 summarizes population and GDP growth, two key exogenous variables used in the scenario simulations for South Africa. In the scenarios SSP1 (Sustainability) and SSP2 (Middle of the Road) population increases by 40% between 2000 and 2050. By 2050, SSP1 population projections are similar to the current UN 'low variant' projections (UN, 2017). During the same period GDP increases six-fold in SSP1 and five-fold in SSP2.

Table 6. South Africa socio-economic drivers 2000-2050, by scenario

	2000	**2015**	**2030**	**2050**	Change 2000-2050
Scenario SSP1 (Sustainability)					
Population (million)	44.7	51.6	58.5	62.3	+ 39 %
GDP PPP (in U$ 2005, billion)	336	570	1087	2075	+ 517 %
Scenario SSP2 (Middle of the Road)					
Population	44.7	51.7	58.6	63.0	+ 41 %
GDP PPP	336	571	1024	1736	+ 416 %
Sensitivity variant SSP2b					
Population (UN 2017 revision, Medium variant)	45.7	55.1	64.4	72.7	+ 59 %
GDP PPP, same as SSP2	336	571	1024	1736	+ 416 %

Source: SSP Database Version 1.1 and UN population projections (UN 2017 revision)

Because of the underestimation of current population in South Africa in the SSP version 1.1 projections (51.7 million in SSP and 55.1 million in the latest UN revision), we define a sensitivity variant of the SSP2 scenario. It applies the most recent 'medium variant' UN population projections (UN, 2017) and is henceforth termed 'SSP2b'. In this scenario, by 2050, total population amounts to 73 million that is an increase of 59 % compared to 2000 and 32 % compared to 2015. For economic growth SSP2b assumes the same GDP development as SSP2. In all scenarios population growth is declining over time.

In addition to socio-economic development trends, the modelling system requires specific assumptions for food and agriculture. Table 7 summarizes the characteristics of the two development pathways and the main assumptions used in the implementation of the scenario simulations with regard to food and agriculture. The sustainability scenario SSP1 achieves land productivity improvements exceeding those in SSP2 (and SSP2b). These assumptions were implemented regarding crop yield increases, changes in cropping intensity (i.e, multi-cropping), and concerning the share of irrigated land in total cropland.

[5] The SSP consortium suggests using the OECD projections as 'illustrative' case in an effort to foster comparison across different model applications.

[6] The IIASA-WIC version population data were made available as of 2011.

Table 7. Overview on assumptions for food and agriculture scenario simulations

Variable	**SSP1 - Sustainability**	**SSP2 – Middle of the Road; SSP2b**
Yield growth	Higher than medium	Medium
Irrigation share	Slightly increasing irrigation share	Approximately maintaining current irrigation share
Trade liberalization	Full liberalization by 2040	Incomplete & slow path toward liberalization
Land use changes	Strong regulation	Some regulation
Protected areas	Fully enforced	Incomplete enforcement

4. Results and discussion

Population growth and dietary changes due to wealthier consumers are leading to increased per capita and total food consumption. Depending on agricultural commodity, prices and policies related to trade liberalization and land use regulations, changes in demand result in domestic production increases and changing trade patterns. The World Food System model simulates demand and responding domestic production patterns by over 15 agricultural commodity groups (Table 8).

Table 8. Commodity groups reported in the World Food System

Main group	Sub-group	Utilization[1]		
		Food	Feed	Other use
Cereals	Wheat	X	X	
	Rice	X		
	Coarse grain (includes maize)	X	X	x
Oil crops	Vegetable oil	X		X
	Oilseed cakes	x	X	
Other food	Sugar	X	x	X
	Fruits	X		
	Roots, Pulses and vegetables	X	X	
	Coffee	X		
	Cocoa and tea	X		
Non-food	Cotton			X
	Other industrial crops			X
Livestock	Meat, beef and mutton	X		x
	Pig meat	X		x
	Poultry meat and eggs	X		x
	Milk	X	X	

1 Large X indicates major utilization, a small x refers to minor quantities of utilization

4.1 Growing consumption of agricultural products

Population increases combined with economic development result in additional food consumption. Table 9 summarizes for one scenario (SSP2, Middle of the Road), the extent of changes in human consumption separately for different agricultural commodity groups. Over time, per capita food consumption increases for all commodities except sugar and coarse grains (maize). However, the majority of staple food remains coarse grain. By 2050, in this scenario, each South African is

estimated to consume 121 kg/capita coarse grain, compared to 65 kg wheat and 17 kg rice. Vegetable oils for food are projected to increase from 12 kg/capita in 2000 to 17 kg/capita in 2050.

In all scenarios, between 2000 and 2050, feed use will roughly double (80 to 90% for maize and 110-130 % for oilseed cakes) as more feed is needed for livestock due to increased demand for livestock products (see also section 4.3). Livestock-based food use more than doubles for beef (including mutton) and increases by a factor of 3 for pig meat. On a per capita basis, consumption increases between 2000 and 2050 from 16.6 to 25.1 kg for beef and from 2.7 to 6.0 kg for pig meat. Protein consumption from the poultry sector (meat and eggs) more than doubles over the 50-year period. Likewise, milk consumption increases from 51 kg/capita to 80 kg/capita.

Increases in the non-food sector are primarily due to expanding use of vegetable oil for industrial products of the oleo-chemical industry (biodiesel, soap, detergents).

Table 9. Increases in human consumption, 2000-2050, South Africa, Scenario SSP2

	Unit	2000	2030	2050	Change 2000-50
Food, Vegetarian products					
Wheat	1000 mt	2714	3697	4087	51%
Rice	1000 mt	564	934	1048	86%
Coarse grain	1000 mt	5408	7285	7623	41%
Roots, pulses, vegetables	Volume*	512	719	863	69%
Sugar	1000 mt (raw equ.)	1435	1752	1886	31%
Vegetable oil	1000 mt	555	946	1082	95%
Fruits	Volume*	469	733	913	95%
Coffee	1000 mt	17	37	50	195%
Cacao, tea	Volume*	26	46	59	129%
Food, Livestock products					
Beef, Mutton	1000 mt	742	1395	1583	113%
Pig meat	1000 mt	122	299	377	209%
Poultry met & eggs	1000 mt protein	136	305	365	167%
Milk	1000 mt	2289	4273	5037	120%
Non-food use					
Vegetable oil	1000 mt	262	640	841	221%
Cotton & other non-food	Volume*	81	85	88	9%

* Volume index. Aggregate commodity groups where individual commodities differ significantly in terms of physical volume (e.g. apples, potatoes, and vegetables) are aggregated to a volume index calculated as the sum of original unit (tons) times a relative weight factor (here we use the Geary-Khamis international prices for the agricultural sector published by the FAO).

Source: Scenario implementation and simulations using IIASA World Food System model.

4.2 Increases in domestic production

Agricultural produce supply for rising consumption is mainly met by increases in domestic production. Production increases are to the largest extent due to intensification measures including higher yields (tons per hectare harvested area) and increases in cropping intensity (i.e. the ratio of harvest area and cropland extent).

Table 10 summarizes development trends in harvested areas, cropland use and cropping intensity. In South Africa, crop rotation schemes include fallow periods for soil fertility management. Over time,

cropping intensity increases from 47 % in 2000 to 61 % in 2050. In other words, there is a reduction of aggregate fallow periods.

Table 10. Cropland, harvested areas and cropping intensity from 2000 to 2050

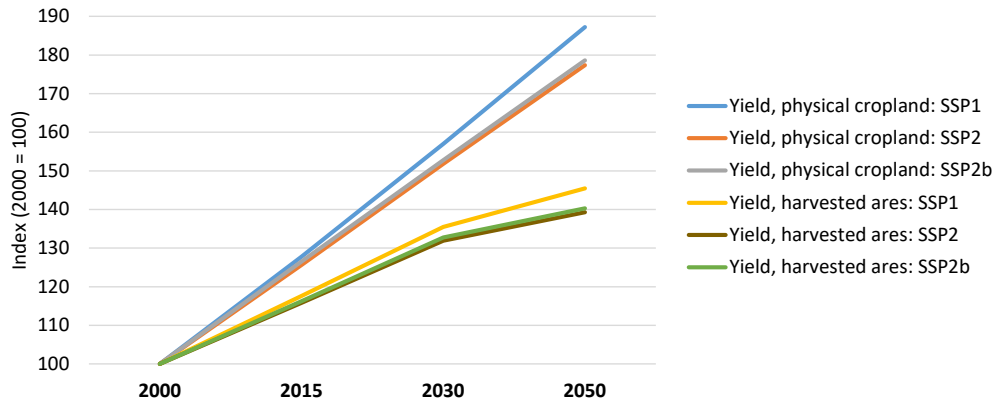
Scenario / Variable (1000 ha)	2000	2015	2030	2050	Change 2000-2050	
Scenario SSP1 (Sustainability)						
Cropland	14,000	13,650	13,300	13,137	-863	- 6 %
Cropland, equipped for irrigation	1,499	1,527	1,556	1,584	85	6 %
Harvested areas	6,649	7,041	7,319	8,028	1,380	21 %
Cropping intensity	47.5%	51.6%	55.0%	61.1%	14	29 %
Scenario SSP2 (Middle of the Road)						
Cropland	14,000	13,850	13,700	13,678	-322	- 2 %
Cropland, equipped for irrigation	1,499	1,547	1,596	1,641	142	9 %
Harvested areas	6,649	7,136	7,489	8,271	1,622	24 %
Cropping intensity	47.5%	51.5%	54.7%	60.5%	13	27 %
Sensitivity variant SSP2b						
Cropland	14,000	14,066	14,131	14,309	309	2 %
Cropland, equipped for irrigation	1,499	1,572	1,646	1,716	218	14%
Harvested areas	6,649	7,269	7,725	8,652	2,003	30 %
Cropping intensity	47.5%	51.7%	54.7%	60.5%	13	27 %

Source: Scenario implementation and simulations using IIASA World Food System model.

At an aggregate level, yields per physical cropland almost double (Figure 3). They are highest for the SSP1 (Sustainability) scenario where by 2050 yields are 87% above the level of 2000. Nearly 85 % of this increase can be attributed to rising yields per harvested area; the remainder is due to increasing cropping intensity. Thus, the production per unit of the physical cropland acreage increases and the fallow times are reduced.

Cropland equipped for irrigation increases somewhat, by some 6 – 14 %, depending on the scenario, an additional factor in the intensification process (Table 10). It should be noted that agricultural water use is not expected to increase due to demands from competing sectors (urban, industry) in the context of already scarce water resources in many parts of the country.

Figure 3. Productivity increases 2000-2050, per scenario



Source: Scenario implementation and simulations using IIASA World Food System model.

4.3 Supply, utilization and trade

In addition to significant increases in domestic production, for some commodities trade plays an important role. Table 11 summarizes for each scenario, development trends of supply and utilization for cereals and other food crops from 2000 to 2050.

Table 11. Supply and utilization of cereals and other food, South Africa, by Scenario, 2000-2050

a) Scenario SSP1 (Sustainability)

	CEREALS[1] (1000 mt)				**Other Food[2]** (volume)			
	2000	**2030**	**2050**	2000-50	**2000**	**2030**	**2050**	2000-50
Production	11,764	18,008	19,995	70%	2,074	3,096	3,651	76%
Human use	8,686	11,930	12,644	46%	1,383	2,073	2,526	83%
Feed	3,704	5,750	6,763	83%	116	196	233	101%
Seed	136	190	210	55%	7	13	17	157%
Waste	403	529	587	46%	91	133	158	74%
Other use	173	251	251	45%	96	260	330	243%
Total use[3]	13,102	18,649	20,454	56%	1,692	2,676	3,264	93%
Net export	-1,338	-641	-459	-66%	382	420	387	1%
SSR[4]	90	97	98	9%	123	116	112	-9%

b) Scenario SSP2 (Middle of the Road)

	CEREALS[1] (1000 mt)				**Other Food[2]** (volume)			
	2000	**2030**	**2050**	2000-50	**2000**	**2030**	**2050**	2000-50
Production	11,764	18,011	20,073	71%	2,074	3,091	3,619	74%
Human use	8,686	11,916	12,758	47%	1,383	2,065	2,475	79%
Feed	3,704	5,704	6,671	80%	116	195	229	98%
Seed	136	194	216	59%	7	13	18	164%
Waste	403	529	589	46%	91	133	157	72%
Other use	173	250	250	44%	96	258	326	240%
Total use[3]	13,102	18,594	20,484	56%	1,692	2,664	3,205	89%
Net export	-1,338	-582	-411	-69%	382	427	414	8%
SSR[4]	90	97	98	9%	123	116	113	-8%

c) Scenario SSP2b (Middle of the Road, using UN 2017 population projections)

	CEREALS[1] (1000 mt)				**Other Food[2]** (volume)			
	2000	**2030**	**2050**	2000-50	**2000**	**2030**	**2050**	2000-50
Production	11,764	18,541	20,954	78%	2,074	3,218	3,826	84%
Human use	8,686	13,037	14,643	69%	1,383	2,254	2,803	103%
Feed	3,704	5,906	7,041	90%	116	201	242	109%
Seed	136	200	226	67%	7	14	19	176%
Waste	403	545	614	52%	91	139	166	82%
Other use	173	250	250	44%	96	258	326	240%
Total use[3]	13,102	19,939	22,774	74%	1,692	2,866	3,556	110%
Net export	-1,338	-1,398	-1,820	36%	382	353	270	-29%
SSR[4]	90	93	92	2%	123	112	108	-12%

1 Cereals include wheat, maize, other coarse grains, rice; **2** Other Food includes roots, pulses and vegetables, coffee, tea and cacao. It is reported in physical volumes as an aggregate of tons multiplied by international prices in U$ of the 1970s; **3** Total use: Total domestic use is the sum of human food use, feed, seed, water, and other use; **4** Self-sufficiency ratio (Ratio of Production and Total domestic use)

Source: Scenario implementation and simulations using IIASA World Food System model.

Cereal production increases by 70 to 80 % and is used mainly for food and feed. Some cereals are also used to produce non-food commodities. Considering the aggregate of all cereals, South Africa's total production almost equals total consumption.

Concerning trade and self-sufficiency depends on the individual commodity in the aggregate cereal group[7]. While South Africa is a net importer of wheat and rice, the country is a net exporter of coarse grains (mainly maize). The size of the trade balance depends on the scenario, but over time the trade balances for all cereal increase.

South Africa's vegetable oil production is insufficient to meet demand (Table 12). About half of the total use is based on net imports. All scenarios project a further increase in net imports. Vegetable oil is used for human food and other non-food industrial uses. In the coming decades, there is a relative increase in the non-food use of vegetable oils, in particular in the Middle of the Road scenario SSP2 and its variant SSP2b.

Oilseed meals provide protein feed for raising domestic livestock herds. Today about half of supply stems from net imports. Over time, with the expansion of oilseed production imports decrease and South Africa becomes by 2050 about 90 % self-sufficient in the oilseed meal market.

Table 12. Supply and utilization of oilseed products, South Africa, by Scenario, 2000-2050

Scenario		SSP1	SSP1		SSP2	SSP2		SSP2b	SSP2b	
	2000	**2030**	**2050**	Change 2000-50	**2030**	**2050**	Change 2000-50	**2030**	**2050**	Change 2000-50
Vegetable oil (1000 mt)										
Production	434	678	1,137	162%	676	1,131	161%	692	1,172	170%
Human use	555	954	1,095	97%	946	1,082	95%	1,027	1,226	121%
Feed	1	2	3		2	3		2	3	
Seed, Waste	18	30	49	202%	30	49	211%	31	51	222%
Other use	262	645	850	225%	641	841	221%	641	841	221%
Total use	836	1,632	1,997	139%	1,619	1,975	136%	1,701	2,120	154%
Net export	-402	-953	-860	114%	-943	-844	110%	-1,008	-948	136%
SSR (%)	52	42	57	10%	42	57	10%	41	55	6%
Oilseed meals (1000 mt protein)										
Production	161	372	761	372%	372	760	371%	373	763	373%
Human use	20	34	39	97%	34	39	95%	37	44	121%
Feed	353	667	790	124%	662	780	121%	685	823	133%
Seed, Waste	7	15	29		15	30		15	30	
Other use										
Total use	380	717	858	126%	711	848	123%	738	896	136%
Net export	-218	-344	-98	-55%	-339	-88	-60%	-365	-134	-39%
SSR (%)	42	52	89	109%	52	90	11%	51	85	100%

Source: Scenario implementation and simulations using IIASA World Food System model.

Livestock consumption increases significantly until the 2050s in all scenarios due to a continuation of population growth and improved diets (Table 13). Between 2000 and 2050 human consumption for milk, beef, and mutton more than doubles. It roughly triples for pig meat and poultry and eggs, with the highest increases in Scenario 2b.

[7] Results are available but not shown in Table 11.

For beef and mutton, South Africa is projected to remain almost self-sufficient. Demand is met by increasing domestic production. In the case of pig meat, poultry meat and eggs, increasing domestic production is as well the key factor for meeting demand. This is supplemented by somewhat growing net imports. The same holds for dairy products. As expected the strongest decrease in self-sufficiency occurs in Scenario 2b, where population grows to over 70 million.

Table 13. Production, trade and use of livestock products, South Africa, by Scenario, 2000-2050

Scenario		SSP1	SSP1		SSP2	SSP2		SSP2b	SSP2b	
	2000	2030	2050	Change 2000-50	2030	2050	Change 2000-50	2030	2050	Change 2000-50
Beef & mutton (1000 mt)										
Production	701	1283	1497	114%	1,276	1,487	112%	1,326	1,580	125%
Human use	742	1411	1604	116%	1,395	1,583	113%	1,507	1,787	141%
Seed, Waste	0	0	0							
Other use	6	8	8		8	8		8	8	
Net export	-46	-136	-115		-127	-104		-190	-215	
SSR (%)	94	90	93		91	93		87	88	
Pig meat (1000 mt)										
Production	113	211	268	138%	209	263	133%	216	277	146%
Human use	122	304	392	221%	299	377	209%	320	418	242%
Seed, Waste	0	0	0		0	0		0	0	
Other use	0	0	0		0	0		0	0	
Net export	-9	-93	-124		-90	-114		-104	-141	
SSR (%)	92	69	68		70	70		68	66	
Poultry and eggs (1000 mt protein)										
Production	135	287	345	155%	284	340	152%	295	359	166%
Human use	136	310	375	175%	305	365	167%	328	407	198%
Seed, Waste	8	13	15		13	15		13	15	
Other use	0	0	0		0	0		0	0	
Net export	-9	-36	-45		-33	-39		-46	-63	
SSR (%)	94	89	88		89	90		86	85	
Milk (1000 mt)										
Production	2,655	4,483	5,339	101%	4,460	5,290	99%	4,621	5,583	110%
Human use	2,289	4,321	5,139	125%	4,273	5,037	120%	4,619	5,668	148%
Feed	319	464	553	73%	460	545	71%	476	576	81%
Seed, Waste	13	21	24		20	24		21	25	
Other use	0	0	0		0	0		0	0	
Net export	35	-322	-378		-293	-316		-495	-686	
SSR (%)	101	93	93		94	94		90	89	

Source: Scenario implementation and simulations using IIASA World Food System model.

4.4 Food security indicators

Over time, average food energy supply across the country increases by about 16% from 2830 kcal/capita/day in 2000 to around 3300 kcal/capita/day by 2050 (Table 14). Protein intake improves by 20-25 %, depending on scenario, from 80 g/capita/day to more than 90 g/capita/day in 2050. This is mainly due to higher livestock consumption patterns. To put into perspective, South Africa's average protein intake is close to levels in Northern America and Europe.

However, the protein supply of animal origin is significantly lower compared to that in the developed world. According to FAOSTAT indicator data on food security, the protein supply of animal origin in the years 2011-2013 was more than 50 g protein/capita/day for the vast majority of industrialized countries. Regardless, food protein supply and its animal component in South Africa is higher compared to most countries of Sub-Saharan Africa.

For comparison, the current international Recommended Dietary Allowance (RDA) for total protein is 0.8 g per kg of body weight, regardless of age (FNB, 2005, WHO, 2007). This suggests a recommended intake of between 40 g and 70 g for adults.

Table 14. Per capita food energy and protein supply, South Africa, by Scenario, 2000-2050

	FOOD ENERGY (Kcal/cap/day)				FOOD PROTEIN (g protein/cap/day)			
	2000	**2030**	**2050**	Change 2000-2050	**2000**	**2030**	**2050**	Change 2000-2050
SSP1 (Sustainability)								
Cereals	1665	1755	1746	5 %	55	57	57	4%
Other Food	858	959	1029	20 %	4	5	6	37%
Livestock	313	494	551	76 %	21	33	37	76%
Total	2836	3208	3327	17 %	80	95	99	25%
SSP2 (Middle of the Road)								
Cereals	1665	1749	1741	5%	55	56	57	4%
Other Food	858	954	1011	18%	4	5	5	19%
Livestock	313	486	533	70%	21	27	32	56%
Total	2836	3190	3285	16%	80	87	94	19%
SSP2b (Middle of the Road + UN population growth)								
Cereals	1630	1738	1731	6%	54	55	57	6%
Other Food	840	948	999	19%	4	5	5	20%
Livestock	306	476	518	69%	20	26	32	56%
Total	2776	3163	3247	17%	78	86	93	20%

Source: Scenario implementation and simulations using IIASA World Food System model.

The Sustainable Development Goal 2, Target 2.2, calls for an end to “all forms of malnutrition” by 2030, as does the UN Decade of Action on Nutrition. Malnutrition ranges from severe undernutrition to obesity. As shown in Table 14, at the aggregate level South Africa can supply adequate and nutritious food supply. However, the results for the aggregate “average” consumer, as shown in Table 14, may conceal potential inequalities across the country.

At the same time, the prevalence of obesity has increased. South Africa follows a global trend in rapidly rising body mass index, overweight and obesity. This also applies to low and middle income countries of Sub-Saharan Africa, especially in urban settings (Biadgilign et al., 2017). South Africa is experiencing dramatic increases in population mean BMI within a relatively short time period between 2008 to 2015, particularly among female school-aged children, adolescents and young adults. In only six years (between 2002 and 2008) adolescent obesity rates have doubled in South Africa (Sartorius et al., 2017).

Hence, in addition to adequate aggregate food supplies also major efforts to improve distribution and access to food as well as education and information campaigns to prevent malnutrition from obesity will be needed.

4.5 Scope and limitations

This study was commissioned by the World Wildlife Fund of South Africa with the aim of downscaling regional results of the FAO global assessment ‘World Agriculture towards 2030/50’ to the national

scale of South Africa. This study could not address important additional questions that are relevant for the future development of the South African agricultural sector.

Climate change impacts on the water cycle and potential impacts on agricultural production should be further explored. Variability and seasonal shifts in precipitation patterns together with increasing temperatures will require targeted climate adaptation response strategies of the agricultural sector. Agricultural water use is one sector competing for scarce water resources next to increasing claims from the domestic and industrial sector. Water scenario analysis can support the objective of achieving water security in the context of competing human demands while safeguarding environment flows for sustaining freshwater ecosystems. Future trajectories of South Africa's agricultural sector are critically dependent on the envisioned land reform policies. Uncertainties relate to the implementation of the land reform policies, which aim to increase the contribution of smallholder farmers to food security and rural employment.

5. Conclusions

Although South Africa's population growth will slow down compared to the last decades, further growth of population and income will continue to increase food demand until the 2050s. Depending on scenario, another 10 to 17 million people will need food while average per capita income will increase by 150 to 200 %. Rising wealth likely leads to dietary changes towards diversification and a higher share of livestock products.

As in other countries, shifts in dietary patterns will reduce the relative importance of staples in direct food consumption like cereals, roots, and pulses, in favor of vegetables, fruits, and livestock products. Between 2000 and 2050, meat consumption will increase by a factor 2.3 to 2.5 (depending on scenario) and similarly the food use of milk by a factor 2.2 to 2.5. During the same period, consumption of wheat, rice, coarse grain, sugar and other food (roots, pulses, vegetables, fruits) doubles or less than doubles.

Increases in domestic production can account for most of the increasing food consumption. This is achieved by a combination of increases in cropping intensity (i.e. the ratio of harvested areas and extent of cropland), in yields per hectare and in irrigation share, i.e. the ratio of area equipped for irrigation. Cropping intensity increases from less than 50 % in 2000 to 60 % in 2050. In other words, the average fallow periods in crop rotation cycles decrease. Areas equipped for irrigation increase slightly between 2000 and 2050, from 1.5 to 1.6 million hectares. Yields, in terms of crop output per harvested hectare, will increase for all commodities, at an aggregate level by some 40-45 % between 2000 and 2050. In combination with the increased cropping intensity, the projected average output per hectare of cropland increases during 2000 to 2050 by 80 – 90 % depending on scenario.

South African agriculture is subject to significant water availability restrictions in many regions due to increased competition with other water use sectors. Urban growth and industrial demand are growing faster and contribute more to national GDP compared to the agricultural sector. Hence, the share of total water withdrawals allocated to agriculture will decrease over time. The Department of Agriculture, Forestry and Fisheries recognizes this in the recently developed 'Irrigation Strategy for South Africa' (DAFF, 2015). Key response strategies to serious constraints on the availability of water for agriculture include integrated planning across different governmental departments and the development of a national center of knowledge and information on irrigated agriculture.

Changes in physical cropland (i.e. arable land) depend on scenario. In two scenarios, the 14 million hectares arable land in 2000 decrease by 2050 to 13.6 and 13.1 million hectares in the SSP2 (Middle of the Road) and SSP1 (Sustainability) scenario respectively. Arable land increases by some 300

thousand hectares only for Scenario SSP2b, which assumes a higher population growth up to 73 million people by 2050 compared to 63 million in SSP2.

In the coming decades, South Africa can make further progress in raising food consumption levels. At an aggregate country level, year 2050 average food energy supply will increase by some 16 % compared to 2000, up to some 3300 kcal per capita per day. Food protein supply will increase more, namely by 20 to 25 % to more than 90 g protein per capita per day. The fraction of animal protein in total protein consumption increases from one fourth in 2000 to more than one third by 2050. This will further narrow the gap with diets in the most developed countries.

Despite adequate and promising levels of future food supply, poverty can lead to parts of the population lacking adequate access to food. At the same time, it has been shown that urban low income populations are prone to overweight and obesity. To this end, South Africa is working towards the implementation of a 'National Food and Nutrition Security Plan'. Food security plans should address strategies for the distribution of adequate and high-nutrient food, alongside environmental concerns focused on the conservation of the productive land in South Africa.

The scenario analysis in this study portrays possible futures of food and agriculture development in South Africa. Assuming moderate demographic change, quite rapid economic growth and effective technological development, the agriculture sector is able to meet the growing food demand of a larger, even more urbanized and wealthier South African society in 2050. Nevertheless, success is not guaranteed and will require comprehensive strategies for managing land and water use as well as research and investments to sustain yield growth. Perhaps the greatest risks for achieving scenario outcomes are due to impacts of climate change, environmental degradation and over-exploitations, as well as possible failure to achieve inclusive growth and avoid social conflict.

References

ALEXANDRATOS, N. & BRUINSMA, J. 2012. World agriculture towards 2030/2050: the 2012 revision. Rome: Food and Agriculture Organization of the United Nations (FAO).

BFAP 2018. Agricultural Outlook 2018 - 2027. Pretoria, South Africa: The Bureau for Food and Agricultural Policy (BFAP).

BIADGILIGN, S., MGUTSHINI, T., HAILE, D., GEBREMICHAEL, B., MOGES, Y. & TILAHUN, K. 2017. Epidemiology of obesity and overweight in sub-Saharan Africa: a protocol for a systematic review and meta-analysis. *BMJ open,* 7**,** e017666.

BORMANN, T. V. 2019. Agri-food Systems: Facts and Futures. How South Africa can produce 50% more by 2050. Cape Town, South Africa: WWF South Africa.

CHATEAU, J., DELLINK, R., LANZI, E. & MAGNÉ, B. Long-term economic growth and environmental pressure: reference scenarios for future global projections. draft presented at the OECD EPOC/WPCID meeting in September, 2012.

DAFF 2015. Irrigation Strategy for South Africa. Pretoria: Department Agriculture, Forestry and Fisheries (DAFF); Republic of South Africa.

DAFF 2017. Economic Review of the South African Agriculture. *In:* DEPARTMENT OF AGRICULTURE, F. F. D. (ed.). Pretoria: Department of Agriculture, Forestry & Fisheries. Republic of South Africa.

FAOSTAT 2018. FAOSTAT Online Database. *In:* DATA, F. A. A. (ed.). Rome: The Food and Agriculture Organization of the United Nations (FAO).

FISCHER, G., HYZSNYIK, E., PRIELER, S., SHAH, M. & VAN VELTHUIZEN, H. 2009. Biofuels and Food Security *In:* IIASA, O. S. P. B. T. (ed.). Vienna: OPEC Fund for International Development (OFID).

FISCHER, G., SHAH, M., TUBIELLO, F. N. & VAN VELHUIZEN, H. 2005. Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990–2080. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 360**,** 2067-2083.

FISCHER, G., SHAH, M. M. & VAN VELTHUIZEN, H. 2002. Climate change and agricultural vulnerability.

FISCHER, G., TRAMBEREND, S., VAN VELHUIZEN, H., BOLE-RENTEL, T. & REELER, J. 2019. Sustainable Aviation Biofuel Feedstock Potential in Sub-Saharan Africa. A systems analysis investigation into the current and future potential for biofuel feedstock production. *WWF Report.*

FNB 2005. Dietary Reference Intakes for Energy, Carbohydrate, Fibre, Fat, Fatty Acids, Cholesterol, Protein and Amino Acids (Macronutrients). *The National Academies Press.* Washingotn, DC, USA: Food and Nutrition Board (FNB) of the Institute of Medicine.

GEOTERRAIMAGE 2015. 2013-2014 South AFrican National Land-Cover Dataset. Data user Report and MetaData. . Pretoria.

IIASA 2016. The Shared Socioeconomic Pathways (SSP) Scenario Database - Version 1.1. International Insitute for Applied Systems Analysis (IIASA), Energy Program.

ILOSTAT 2017. Employment by sector. *In:* (ILO), I. L. O. (ed.) *International Labour Statistics Database.*

MOSS, R. H., EDMONDS, J. A., HIBBARD, K. A., MANNING, M. R., ROSE, S. K., VAN VUUREN, D. P., CARTER, T. R., EMORI, S., KAINUMA, M. & KRAM, T. 2010. The next generation of scenarios for climate change research and assessment. *Nature,* 463**,** 747-756.

NIEKERK, V. A., JARMAIN, C., GOUDRIAAN, R., MULLER, S., FERREIRA, F., MÜNCH, Z., PAUW, T., STEPHENSON, G. & GIBSON, L. 2018. AN EARTH OBSERVATION APPROACH TOWARDS MAPPING IRRIGATED AREAS AND QUANTIFYING WATER USE BY IRRIGATED CROPS IN SOUTH AFRICA. Report to the Water Research commission and the Department of Agriculture, Forestry and Fisheries. *Report No. TT 745/17.* Gezina: Water Research Commission (WRC) South Africa.

O'NEILL, B. C., KRIEGLER, E., EBI, K. L., KEMP-BENEDICT, E., RIAHI, K., ROTHMAN, D. S., VAN RUIJVEN, B. J., VAN VUUREN, D. P., BIRKMANN, J. & KOK, K. 2017. The roads ahead: narratives for shared socioeconomic pathways describing world futures in the 21st century. *Global Environmental Change,* 42**,** 169-180.

PRIELER, S., FISCHER, G. & VAN VELTHUIZEN, H. 2013. Land and the food–fuel competition: insights from modeling. *Wiley Interdisciplinary Reviews: Energy and Environment,* 2**,** 199-217.

SAMIR, K. & LUTZ, W. 2017. The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100. *Global Environmental Change,* 42**,** 181-192.
SANDREY, R. & VINK, N. 2009. Deregulation, trade reform and innovation in the South African agriculture sector. *OECD Journal: General Papers,* 2008**,** 219-255.
SARTORIUS, B., SARTORIUS, K., TAYLOR, M., AAGAARD-HANSEN, J., DUKHI, N., DAY, C., NDLOVU, N., SLOTOW, R. & HOFMAN, K. 2017. Rapidly increasing body mass index among children, adolescents and young adults in a transitioning population, South Africa, 2008–15. *International journal of epidemiology*.
STAT-SA 2017. Poverty Trends in South Africa. An examination of absolute poverty between 2006 and 2015. *Report No. 03-10-06.* Pretoria: Statistics South Africa.
STATS-SA 2017a. General Household Survey 2016. *In:* AFRICA, S. S. (ed.) *Statistical Release P0318.* Pretoria.
STATS-SA 2017b. Mid-year population estimates. *Statistical release P0302.* Pretoria: Statistics South Africa.
TSHUMA, M. 2014. Understanding the small-scale agricultural sector as a precondition for promoting rural development in South Africa. *African Journal of Agricultural Research,* 9**,** 2409-2418.
UN 2015. Transforming our world: The 2030 agenda for sustainable development. United Nations.
UN 2017. *World population prospects: the 2017 revision,* New York.
VAN VUUREN, D. P., EDMONDS, J., KAINUMA, M., RIAHI, K., THOMSON, A., HIBBARD, K., HURTT, G. C., KRAM, T., KREY, V. & LAMARQUE, J.-F. 2011. The representative concentration pathways: an overview. *Climatic change,* 109**,** 5.
VAN VUUREN, D. P., KRIEGLER, E., O'NEILL, B. C., EBI, K. L., RIAHI, K., CARTER, T. R., EDMONDS, J., HALLEGATTE, S., KRAM, T. & MATHUR, R. 2014. A new scenario framework for climate change research: scenario matrix architecture. *Climatic Change,* 122**,** 373-386.
WHO 2007. Dietary Reference Intakes for Energy, Carbohydrate, Fibre, Fat, Fatty Acids, Cholesterol, Protein and Amino Acids (Macronutrients). *WHO Technical Report Series 935.* Geneva, Switzerland: World Health Organisation (WHO).