FORECAST ESTIMATES OF PROTEIN FOR ANIMALS IN SOUTH AFRICA

BY WILLEM DE JAGER

Submitted in partial fulfilment of the requirements for the degree

MASTER OF SCIENCE IN AGRICULTURAL ECONOMICS

In the

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DECLARATION

I, Willem de Jager, hereby declare that this dissertation submitted by me for the degree of Master of Science (M.Sc. Agric) in the Department of Agricultural Economics, Faculty of Natural and Agricultural Sciences, at the University of the Free State, is my own independent work and has not been submitted by me to any other university.

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ABSTRACT

Forecast estimates of protein for animals in South Africa

by

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Abstract

Across the globe, the world population is rising at a drastic rate, higher income opportunities in urban areas attract more people to cities, and coupled therewith is the higher income that these people have at their disposal. Higher income streams increase the demand for protein-rich and high-value foods. Furthermore, humans are faced with the huge challenge of producing the same amount of food that was produced in the last 8 000 years, but only in the next 40 years.

South Africa is currently experiencing the same challenges and there is an important drive to supply the human demand for animal-source protein and to reach self-sufficiency in protein supply. Critical linkages exist between the human demand for animal-source protein, the number of animals to be slaughtered to supply this demand, and the animal feeds required to feed the animals. South Africa requires a decision support tool to aid decision making, to provide accurate and relevant results, and to measure self-sufficiency in protein supply.

Various researchers have examined these linkages globally and in South Africa. In this study, dynamic data generated by the BFAP model is integrated into the APR model. Thereafter, the APR_OPT model is able to determine least-cost animal feeds to satisfy the nutrient requirements of all animal categories. This study aims to quantify, manage, and forecast the linkages between these industries. The specific objectives are to replicate and update the APR model, to generate and forecast baseline results for the period 2015 to 2024 with integrated BFAP data, and to simulate shocks on the specific linkages using an external shock analysis on the supply and demand side of the APR_OPT model.

Three external shocks are simulated in the study. Firstly, the effect of the introduction of a new raw material into the animal feed industry. Secondly, the effect of increased imports of animal-source

protein is simulated. Thirdly, the shock of the 2015/2016 drought on the specific linkages, animal feed cost, and demand for imports of raw materials.

Animal feed consumption is expected to increase with an average of 2.54% annually to 14.63 million tonnes by 2024. Total protein usage for animal feeds is expected to increase from 1.98 million tonnes in 2015 to 2.806 million tonnes by 2024, with a 4.63% average increase per year. South Africa's self-sufficiency in protein supply for animal feeds is expected to increase from 60% in 2015 to 79% by 2024.

Sorghum distillers dried grains with solubles (S-DDGS) are fully absorbed into the animal feed industry at 100% of the yellow maize price. The biggest consumer of S-DDGS is dairy cattle. The implementation of the African Growth and Opportunity Act (AGOA) is expected to decrease the demand for broiler feed, as well as the demand for imported raw materials. The 2015/2016 drought caused an average 52% increase in animal feed costs across all rations. Total imports of raw materials for animal usage are expected to increase from 573 525 tonnes in a normal 2016 year to 2.78 million tonnes in the drought shock year.

The APR_OPT model poses, in this study, a huge variety of beneficial abilities that are able to aid decision making and quantify the linkages between the industries.

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LIST OF ABBREVIATIONS

ABARE	Australian Bureau of Agricultural and Resource Economics
ADG	Average Daily Gain
AFMA	Animal Feed Manufacturers' Association
AGOA	African Growth and Opportunity Act
AID	Apparent Ileal Digestibility
APR	Agricultural Products Requirements
APR_OPT	Agricultural Products Requirements Optimizing model
BFAP	Bureau for Food and Agricultural Policy
CAST	Council for Agricultural Science and Technology
CEC	Crop Estimates Committee
DAFF	Department of Agriculture, Forestry and Fisheries
DDGS	Distillers dried grains with solubles
EU	European Union
FAO	Food and Agriculture Organization
FAPRI	Food and Agricultural Policy Research Institute
FCR	Feed Conversion Ratio
FPU	Food Production Unit
GAMS	General Algebraic Modelling System
GDP	Gross Domestic Product
IFIF	International Feed Industry Federation
IFPRI	International Food Policy Research Institute
IIASA	International Institute for Applied Systems Analysis
ILRI	International Livestock Research Institute
IMF	International Monetary Fund
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
LP	Linear Programming
LSM	Living Standards Measure
NDF	Neutral Detergent Fibre
NLP	Non-linear Programming
OECD	Organization for Economic Cooperation and Development
PRF	Protein Research Foundation
RMAA	Red Meat Abattoir Association
RUP	Rumen Undegradable Protein
SAFA	South African Feedlot Association
SAFEX	South African Futures Exchange
SAPA	South African Poultry Association
SAPPO	South African Pork Producers' Organisation

S-DDGS	Sorghum Distillers dried grains with solubles
SID	Standard Ileal Digestibility
Stats SA	Statistics South Africa
TMR	Total Mixed Ration
USA	United States of America

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

At the annual Rio+20 food security conference, Polman and Servitje (2012) stated, “Imagine all the food mankind has produced over the past 8 000 years. Now consider that we need to produce that same amount again — but in just the next 40 years if we are to feed our growing and hungry world.”

The global population was estimated at 7.2 billion people in 2014; 83% of which were living in less developed countries, while 17% inhabited more developed countries (Population Reference Bureau, 2014). The global urbanisation rate is increasing, amounting to 53% of the global population living in urban areas (Population Reference Bureau, 2014:1). Statistics South Africa (Stats SA) estimated the South African population for mid-2014 at 54 million (Stats SA, 2014:3), and it is projected to increase to 64 million over the next 35 years (Population Reference Bureau, 2014). The South African urbanised share of the population is 62% (Stats SA, 2014). The large debate, however, is how to feed the projected 9.7 billion people by 2050 and what this rapidly growing population will demand.

A global transition is taking place where people are urbanising, mainly driven by higher incomes and better living standards (Council for Agricultural Science and Technology (CAST), 2013:12). Class mobility is a reality in South Africa, where consumers move to higher Living Standards Measure (LSM) groups due to economic growth and socioeconomic empowerment (The Bureau for Food and Agricultural Policy (BFAP), 2014:94). Furthermore, the average household income has substantially increased from R6 215 per month in 2005/2006 to R9 962 in 2010/2011 (Stats SA, 2011). An urbanised population with more income at their disposal demand high-value products. CAST (2013:2) stated that there is a positive correlation between the demand for livestock products (milk, meat, and eggs) and per capita income. A continued global demand increase in high-protein diets and consumers seeking convenient natural protein strengthen the abovementioned statement (BFAP, 2014:98). Thus, unless a major change occurs in the consumers’ diet preference, livestock products will be in great demand over the next 35 years (CAST, 2013:2). Livestock protein will play an invaluable role in ensuring future nutrition and food security across the globe (Smith, Sones, Grace, MacMillan, Tarawali & Herrero, 2013).

Animal-source foods are nutrient-dense and provide the most affordable source of essential dietary nutrients. It contains high-quality protein and bio-available micronutrients which are critical for developing children and pregnant and lactating women (Food and Agriculture Organization (FAO), 2011:8; Drenowski, 2011). Animal protein provides one-third of the protein consumed in the human diet (Bradford, 1999:95; FAO, 2011:8). CAST (1997) and the FAO (2011:8) reported that food originating from animals provide a brilliant source of essential amino acids and vitamins, including vitamin A, thiamine, riboflavin, niacin, and B_{12}. It also includes iron, calcium, and zinc. Murphy and

Allen (1996) proved that both the physical and mental development of children was strongly and positively related to the amount of animal protein included in their daily diet.

The main sources of animal protein are regarded as chicken, pork, beef, mutton, eggs, and milk and dairy products. The FAO (2014:52) reported that there has been a 1.1% growth in global meat production since 2013, generating 311.6 million tonnes globally. The global demand for livestock products remains stable, driven by emerging regions showing an increase in income growth, as well as growing and more urbanised populations (BFAP, 2014:52). Therefore, the Organisation for Economic Cooperation and Development (OECD)-FAO (2014) projected a global expansion of the meat industry in the coming years. Poultry is regarded as the cheapest, most accessible meat, free of cultural barriers, and which will account for 50% of the meat consumed over the next decade. Pork accounts for 29%, beef for 16%, and sheep for 6% (OECD-FAO, 2014).

The BFAP (2014:55) projected that domestically there will be continued growth in meat consumption over the next decade, driven mainly by an increase in income growth. The choice between various meat types is driven by consumer preference. In South Africa, chicken meat dominates the meat industry due to being the most affordable meat type. Chicken meat is projected to increase by 34% over the next decade, and will account for 73% of additional meat consumed by 2023 (BFAP, 2014:55). An expansion of 41% is projected for pork consumption; however, pork will only account for 10% of additional meat consumed. The demand for beef and mutton will increase 20% and 15% respectively by 2023 (BFAP, 2014:56). The increasing demand for animal-source foods are linked to a necessary increase in the production of cereals and oilseeds to provide in the nutritional requirements of the animals. Cereals, oilseeds, and other feedstuffs represent an indirect nutrient source, initially converted to animal protein before human consumption (CAST, 2013:4).

Animal feed is formulated using a combination of cereals, oilseeds, by-products, and other feedstuffs to formulate rations for animals according to the animals' nutritional requirements (Briedenhann, 2001). Ruminants, including cattle, sheep and goats, can digest high-cellulose plant materials through bacterial fermentation and are able to convert the solar energy stored in fibrous feeds growing on grassland into meat, milk, and wool (Van Soest, 1994). In contradiction to ruminants, bacterial fermentation is non-existent in monogastric animals and they are therefore unable to digest fibrous plant materials. Significant quantities of cereals are fed to monogastric animals to drive production (CAST, 2013:5). The animal feed industry is the main manufacturer of animal rations formulated specifically to meet the animals' nutrient requirements and to drive production.

The 28 200 feed mills globally produce approximately 963 million tonnes of feed annually (Alltech, 2014:4). Ruminant animals and pigs consumed 196 million and 243 million tonnes of animal feed produced globally respectively, while poultry consumed 444 million tonnes of feed globally (Alltech, 2014:5). South Africa produced 11.38 million tonnes of feed during the 2013/2014 season (Animal Feed Manufacturers' Association (AFMA), 2014:44; Alltech, 2014). According to AFMA (2014:44), ruminants, including sheep and beef and dairy cattle, consume 47% of the total tonnage produced locally, where chickens (layers and broilers) account for 40% of the consumption of the tonnage produced. The South African agricultural industry is required to adjust the supply of commodities according to human demand for livestock products and accommodate the major shortage of essential raw materials (Briedenhann, 2001:1). Quantifying the raw material usage in animal feed rations is of critical importance for adapting to shifts in the global and domestic demand for animal-source foods.

The main cereals used in animal feeds are maize, wheat, barley, sorghum, and oats, while the plant protein sources are soya beans, sunflower seeds, cotton meal, and canola meal (Wilkinson, 2011). In South Africa, 1.2 million tonnes of soya oilcake is consumed by the animal feed industry. South African production provides 50% of the consumption, while the other half is imported (AFMA, 2014:5). The BFAP (2014:45) projected that soya oilcake consumption will rise to 1.8 million tonnes over the next decade, while the biggest part of the local consumption coming from local supply is due to increased crushing capacity. Current domestic consumption of sunflower oilcake is 400 000 tonnes, and is projected to increase to 550 000 tonnes during the next decade (BFAP, 2014:47). Local sunflower production is expected to remain constant, while imports will provide for the shortage (AFMA, 2014:5). Humans, animals, and raw materials are all interconnected with one another. A constant flow of protein between these factors is visible.

1.2 PROBLEM STATEMENT AND MOTIVATION

In 35 years' time, 9.7 million people will inhabit the earth. Simultaneously, urbanisation rates are increasing; driven by the high income standards in urban areas. Two mega trends are highlighted here: The global population is growing, and people have higher income at their disposal.

A rising global population with richer consumers will be the main demand drivers for high-value products and food. The BFAP (2014:98) stated that the nutrient protein is increasingly recognised as a "good ingredient" and that people are moving to high-protein diets. Animal protein provides 40% of all dietary protein consumed globally, while in Africa it amounts to 24% (FAO, 2013). Globally, a rise in income is positively correlated with calorie consumption, and furthermore, there has been a shift from grains to animal-protein sources (CAST, 2013:8). Thus, it is clear that livestock protein will be the greatest supplier of high-quality foods and protein, currently and over the next 35 years. The livestock and animal feed sectors, which are supplementary sectors to the meat sector, will therefore also show significant growth.

A change in the human demand for animal-source foods will affect a change in the number of animals supplied. Furthermore, an increased demand for livestock products will affect a higher supply of raw materials to feed the animals. Adapting and adjusting supply and demand according to these changes are vital. The interactions between these industries are evident and need to be managed and quantified concerning a shock or change in one of the other industries.

There is currently limited accurate information available on the raw material usage in South Africa. AFMA (2014) provided accurate information on the raw materials used by AFMA members, but it only covers 60% of the animal feed manufacturing industry. South Africa requires a decision support tool that takes into account the interactions between human demand, animals, and raw material supply.

The decision support tool will play a role in forecasting protein demand and the amount of raw materials required for animal feed. It will support decisions on which raw materials will be in high demand, quantities of imported raw materials required to supply local shortages, and the effects of a new raw material introduced into the animal feed industry.

The model will enable South Africa to simulate the following:

- The effects the human demand side will have on the production of livestock, and furthermore the effect on quantities of animal feed products.
- The shocks and effects of import tariffs on livestock protein can be simulated to estimate quantities of animal feeds required locally. Thus, this model will give policy makers the power to model the effects of their decisions on the closely linked human, livestock, and animal feed industries.
- The model will provide industry leaders the ability to simulate shocks on the livestock sector and the effects thereof.
- The entry and effect of a new raw material into the animal feed industry.
- How different raw materials will substitute one another in situations of price increases.

1.3 AIM AND OBJECTIVES

The **aim** of the study is to effectively quantify, manage, and forecast the interactions between the human demand for livestock protein, the number of animals required to supply the meat demanded, and the raw material requirements of the animal feed industry. Technical industry data, nutritional requirements, and animal performance data will be used to formulate animal feed requirements.

The aim of the study will be achieved through the following sub-objectives:

Sub-objective 1: *Replicate and update the APR model to quantify protein interactions*

- Firstly, determine the human demand for livestock protein by using per capita consumption and population estimates.
- Secondly, once that figure has been determined, estimate the number of animals required to be fed to satisfy humans’ animal-source protein demand.
- Thirdly, replicate the APR model to create an Agricultural Products Requirements Optimizing (APR_OPT) model. Use the APR_OPT model to balance and formulate least-cost animal feed rations and aggregate the amount of raw materials required to do so. The new APR_OPT model will also allocate raw materials from supply to demand points in South Africa. Rations are formulated using technical industry data, nutrient requirements of animals, and the cost and availability of raw materials.

Sub-objective 2: *Forecast and quantify the protein interactions from 2015 to 2024*

- Incorporate dynamic data from the BFAP model into the decision support tool to accurately forecast human demand.
- Dynamic raw material prices and quantities will also be incorporated to formulate animal rations.
- Dynamic data are required to effectively quantify the interactions between human demand, livestock, and raw materials.

Sub-objective 3: *External shock analyses*

The third sub-objective is devoted to simulate ad hoc external shocks in the different industries. The following external shocks on the APR_OPT model to be simulated

1. The effect of sorghum distillers dried grains solubles (S-DDGS) on the animal feed industry.
2. The AGOA trade agreement changes and implementation thereof.
3. The 2015/2016 Drought shock.

1.4 CHAPTER OUTLINE

The scene and scope for the study were set in the commencement of this chapter. The importance of the interaction between human demand, livestock, and raw material supply was explained. The aims and objectives were provided thereafter.

Chapter 2 provides a comprehensive literature review of the relevance of the animal feed industry, the livestock industry, and the meat industry – locally and internationally. The linkages between these industries are discussed.

Chapter 3 discusses the methodology used to obtain the results and achieve the objectives. The incorporation of different methodologies is illustrated and explained. The data sets used for the methodology to achieve relevant results are also explained. Methodology used by other authors to obtain similar results is described.

Chapter 4 is a summary of the results obtained from the methodology. Following these results, are results obtained from the incorporated model. Thereafter, a summary of results obtained from the external shock simulation will be discussed.

Chapter 5 concludes the study and makes recommendations in the view of assisting policy makers and farmers in decision making in South Africa.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

Chapter 2 will provide a complete overview of the latest consumer trends, as well as the meat, livestock, and animal feed industries both globally and in South Africa. This chapter will also provide the reader with a clear understanding of how these industries are linked and how interactions take place between the industries. Thereafter, literature will be provided on similar studies conducted and methodologies utilised globally and in South Africa.

2.2 CONSUMER TRENDS

Global and domestic consumers will be analysed in this section; focusing mainly on what type of food products consumers spend money on. The key drivers for substitution between products will be highlighted. The consumption trends across different income groups will also be emphasised.

2.2.1 Global consumer trends

The demand for animal-source foods remains firm around the globe, driven primarily by emerging countries with rapid income growth, as well as an increasing and more urbanised world population (BFAP, 2014:53). The emerging and rapidly growing economies of Africa and Asia are expected to account for the greatest increase in consumption (OECD-FAO, 2014:30), while North America and Europe have reached saturation levels in terms of food consumption. Rising income and increased urbanisation rates cause a transition in diets and lifestyle habits among consumers.

A major challenge for the global food systems is the significant increase in global consumer demand for animal-source protein and dairy products (Godfray, Beddington, Crute, Haddad, Lawrence, Muir, Pretty, Robinson, Thomas & Toulmin, 2010:816). This occurrence has caused the global numbers of sheep, cattle, and goats to increase 1.5 times over the past 50 years; pigs with 2.5 times, and chicken numbers increased 4.5-fold (Godfray *et al.,* 2010:816). Increased consumer wealth is the greatest attribute to this transition in diets and the increase in global animal-source protein demand. The big meat demand is largely driven by China and India (Godfray *et al.,* 2010:816).

Hume (2014) reported that the human diet consists mainly of cereals, but changes in consumer preferences, eating habits, income growth, and urbanisation have caused a transition to diets that contain higher levels of protein, fats, and sugars. Higher levels of income cause consumers to increase protein intake relative to starches (OECD-FAO, 2014:31). Consumers want to spend money on convenient, high-value products that suit their healthy and fast-paced lifestyles.

Protein is enriched into products, with the dairy category being the main beneficiary (Food Stuff SA, 2013b). Related to rising incomes is consumers' interest in convenient, healthy products which are enriched with protein and vitamins. Consumers are seeking natural protein in convenient products which are recognised by the consumer. This enables the consumer to include higher levels of protein into their diets using recognisable products (Food Stuff SA, 2013b). As consumers shift away from carbohydrates, the demand for conveniently packaged high-protein products will increase in the future (Food Stuff SA, 2013a). The demand for animal-source foods will increase during the next decade.

Poultry dominates the growth in world meat consumption as it remains the most affordable and accessible protein source for poorer consumers. Pork will account for 30% of meat consumed over the next decade, followed by 15% beef and 6% mutton (OECD-FAO, 2014:32). Dairy products show considerable growth of 1.9% per year for cheese and butter, and 1.2% per year for milk powder (OECD-FAO, 2014:33).

2.2.2 South African consumer trends

The demographics and characteristics of the South African consumer have changed over the past ten years. Stats SA (2010:40) stated that 67% of households were located in urban areas, and a rising standard of income in urban areas will further increase the urbanisation rate.

The average household income per month increased from R6 215 in 2005/2006 to R9 962 in 2010/2011 (Stats SA, 2005; Stats SA, 2010). The rising income indicated among consumers causes the occurrence of class mobility to take place (BFAP, 2013:73). This trend takes place when consumers move to higher Living Standard Measure (LSM) groups, triggered by economic growth and empowering people in the socioeconomic environment (BFAP, 2013:73; BFAP, 2014). When examining the average South African consumer, expenditure patterns should also be closely observed.

According to the Income and Expenditure Survey conducted by Stats SA (2010:68), food and non-alcoholic beverages account for 12.8% of total consumer expenditure. Furthermore, animal-source foods (meat, fish, eggs, and dairy products) represent 37% of the money spent on food and non-alcoholic beverages. Closely examining the expenditure patterns, expenditure on foods and non-alcoholic beverages increased for poorer and lower middle-class consumers, while the contribution of the upper-middle class and wealthy consumers towards food decreased over the period between 2005 and 2010 (Stats SA, 2005:76; Stats SA, 2010:68; BFAP, 2014:100).

As evident from Table 2.1, the poor segment of consumers made a significant contribution of expenditure towards poultry meat, the middle segment of consumers showed an expenditure increase on processed pork (polonies and Vienna sausages), while the wealthy segment of consumers dominated the expenditure on mutton (BFAP, 2014:104).

Table 2.1: Patterns of the South African consumer

Segment	Decline in contribution	Increase in contribution
Poor	Pork, mutton, beef sausage	Poultry, processed pork, beef
Middle	Mutton, beef sausage	Pork, processed pork, poultry, beef
Wealthy	Poultry, beef, processed pork, pork	Mutton, beef sausage

Source: Stats SA (2005); Stats SA (2010); BFAP (2014)

From studying expenditure on meat types, it is clear that income growth is the main driver of increased meat consumption, while consumer preference and relative meat prices drive the choice of meat type (BFAP, 2014:55). The relative prices of protein sources drive the choices between them, as Hedley (2014) stated that chicken producers decreased the volumes of chicken produced, while consumers were switching to more affordable proteins, including polony, Vienna sausages, boiled eggs, pilchards, and corned beef. The canned protein market in South Africa also showed considerable growth in 2012, mostly dominated by canned fish (BMI, 2014).

2.3 THE MEAT INDUSTRY

This section will provide a complete overview of the global and South African meat industries. Meat sectors have grown considerably over the past years as a result of the continued growing demand for meat. This section will describe all the meat sectors and the quantities of animals slaughtered, as well as highlighting the difference between commercial and developing production.

2.3.1 The global meat industry

Animal products supply 12.9% of the calories consumed worldwide, and even more importantly, contribute 27.9% of global protein consumption (FAO, 2009:13). During the past 13 years (2000 – 2013), world production of pork, beef, chicken, and mutton showed particularly good growth. Global meat production in 2014 was estimated at 311.6 million tonnes – an increase of 3 million tonnes or 1.1% from the previous year (FAO, 2014:8). Global meat trade in 2013 amounted to 30.9 million tonnes and was expected to increase by a further 2.3% in 2014 to 31.6 million tonnes. Poultry is the highest livestock product traded at 43%, followed by bovine, porcine, and ovine meat.

China is the biggest role player in the global pig meat sector, being responsible for 50% of all pig meat activity worldwide (ABSA, 2015:82). China produces 51.44% of the global production, followed by the European Union (EU) (20.14%), and the United States of America (USA) (9.33%). Pig meat showed a 31% increase in growth over the 13-year period, producing 113 million tonnes in 2013 (Table 2.2). Brazil and China have been rapidly expanding the countries' pig industries (FAO, 2009:14).

Dairy cattle numbers increased with 3.7% from 243 million head in 2005 to 252 million head in 2014 (ABSA, 2015:78). Beef cattle, however, decreased from 218 million head in 2005 to 204 million head in 2014. The USA is the biggest producer of beef in the world, accounting for 11.8 million tonnes, or

19% of the world production. The USA is followed by Brazil’s 16.85%, the EU with 12.88%, and China with 9.8% (ABSA, 2015:78). The production of beef increased steadily from 2000 to 2013, with a 14% growth and the production of 64 million tonnes (Table 2.2).

The USA is the biggest global producer of broilers (20.2%), followed by China (14.9%), Brazil (14.85%), and the EU (11.7%) (ABSA, 2015:85). Chicken production increased with 64% over the period, with a production of 96 million tonnes. In India, poultry products account for 50% of per capita livestock protein consumption, compared to 22% in 1985 (Pica-Ciamarra & Otte, 2009).

Sheep numbers increased with 0.49% from 2013 to 2014, estimated at 1 180 million head of sheep. China reigns as the country with the biggest sheep herds (187 million sheep) in the world, followed by the EU, Australia, and India. The production of sheep meat steadily increased to a production of 8.5 million tonnes in 2013, increasing with 10% from 2000.

Table 2.2: Global changes in the total livestock production sector

Meat type	Animals slaughtered (million head)		Production (tonnes)		
	2000	2013	2000	2013	% growth
Pig	1 103.86	1 451.86	86 035 889	113 034 814	31%
Beef cattle	271.74	298.80	56 066 473	63 983 529	14%
Chicken	40 570.76	61 171.97	58 697 029	96 121 163	64%
Sheep	492.77	536.74	7 790 565	8 589 257	10%

Source: FAO (2009); FAO (2012)

In 2013, Africa produced 16.542 million tonnes of meat, imported 2.8 million tonnes, exported 139 000 tonnes, and deriving utilisation of 19.252 million tonnes. The total production for 2014 was forecasted at 16.731 million tonnes (FAO, 2014:111). South Africa produced 16.8% of Africa’s total meat production, as the biggest meat producer in Africa. A closer look at the South African industry is necessary for better understanding.

2.3.2 The South African meat industry

Large-scale commercial producers co-exist with small-scale communal producers; between them herding 13.9 million head of cattle (Department of Agriculture, Forestry and Fisheries (DAFF), 2014:57). Cattle in the commercial sector amounted to 8.22 million, while developing farmers herded 5.68 million head of cattle. Dairy cattle, consisting of cows over two years and heifers, represent 10% of the commercial cattle stock (DAFF, 2014:57).

Commercial sheep stock decreased with 38.8% from 29.7 million in 1990 to 21.58 million in 2013 (DAFF, 2014:61). Sheep numbers in the developing areas amounted to 3.3 million. Goat stocks amounted to 2 million in 2013. Total pig numbers were 1.57 million in 2013, which produced 214 400 tonnes of pork (DAFF, 2014:60).

The broiler industry showed considerable growth over the past ten years. From 2005 to 2008, a 28% growth rate was shown in the industry. During the period 2009 to 2012, the growth in the industry slowed down to a rate of 7.7% (South African Poultry Association (SAPA), 2012a:37). In 2013, 1.045 billion broilers were slaughtered, while the broiler breeder flock amounted to 292 000 hens. The number of laying hens was estimated at 24.528 million in 2013 – 509 000 less than in 2012.

According to the South African Pork Producers' Organisation (SAPPO) (2015), 230 farmers own 110 400 commercial sows used for intensive pig production. South Africa has 153 registered pig abattoirs which slaughter 2.7 million pigs annually (SAPPO, 2015; DAFF, 2014:60).

The commercial cattle feedlot sector is a well-established industry in South Africa. Meat Trade News Daily (2011) reported that there were a total of 60 commercial feedlots in the country, with a potential annual throughput of 1.5 million animals. According to the South African Feedlot Association (SAFA) (2015), the commercial feedlots are responsible for 75% of all beef produced in South Africa, with a one-time standing capacity of approximately 420 000 head of cattle. The commercial feedlots are responsible for slaughtering 2.2 million animals per year. The total local production of beef and veal amounts to 855 000 tonnes, with 51 000 tonnes being imported (DAFF, 2014:58). According to the DAFF (2014:62), 7.5 million sheep, lambs, and goats were slaughtered at abattoirs during 2013, which produced 180 000 tonnes of meat. The imports amounted to 7 000 tonnes. The Red Meat Abattoir Association (RMAA) (2013:37-38) reported that there were 460 active abattoirs that slaughtered 2.5 million cattle, 5.1 million sheep, and 2.6 million pigs in 2013.

The literature detailing consumer trends and the meat industry, globally and locally, highlights the importance of the interaction between the increasing human demand for animal-source protein and the quantity of animals that need to be fed and slaughtered to supply that demand. In the South African meat industry, it is important to recognise the influence of imported animal-source protein to supply in the local shortage, as it has a direct effect on the quantity of animals that need to be slaughtered.

2.4 THE LIVESTOCK INDUSTRY

This section will provide a complete overview of both the global and South African livestock industries. Important figures that will be examined in these industries are the gross value of the livestock industry compared to other industries such as field crops and horticulture, as well as the gross value that each animal category contributes to the livestock industry. The aim of this section is to emphasise the importance of the livestock industry globally and in South Africa, and to highlight the main animal categories which contribute to the sector.

2.4.1 The global livestock industry

The global agricultural sector added 3.09% to the world economy in 2012 (FAO, 2012). The contribution of the agricultural sector decreased over the last decade up to 2012 with 17.42% (FAO, 2012). In Table 2.3 the gross production value of the global agricultural sector is estimated at US$3 840 875 million, with crops contributing 68% of the value and livestock the remaining 32%.

Table 2.3: Gross production value of global agriculture in 2012 (1US$ = R8.21)

Production	Gross production value (million US$)	Percentage of total
Crops	2 614 606	68%
Livestock	1 226 269	32%
Total	**3 840 875**	**100%**

Source: FAO (2012)

When investigating the livestock products' contribution to the global agricultural gross production value, it is clear from Table 2.4 that pig meat dominates the contribution to the global agricultural gross production value with 25%, followed closely by dairy products (22%) and poultry (18%).

Table 2.4: Global gross production value of each product in 2012 (1US$ = R8.21)

Product	Gross production value (million US$)	Percentage of total
Beef	172 294	14%
Poultry meat	226 360	18%
Pig meat	309 569	25%
Sheep meat	32 311	3%
Goat meat	18 030	1%
Other meat products	8 333	1%
Eggs	135 885	11%
Dairy products	270 505	22%
Other milk products	45 159	4%
Wool	7 823	1%
Total	**1 226 269**	**100%**

Source: Adapted data from FAO (2012)

The gross production value of African agriculture amounted to US$319 757 million (1US$ = R8.21) in 2012, with crops contributing 79.3% and livestock products 20.7% of the total gross production value (FAO, 2012). Cattle meat, fresh milk, chicken meat, and sheep meat were the biggest contributors to the African livestock industry (FAO, 2012). Nigeria has the biggest agricultural gross production value of US$94 275 million, while South Africa was ranked third with a gross production value of US$22 800 million in 2012 (FAO, 2012).

2.4.2 The South African livestock industry

The FAO (2012) stated that the agricultural sector added 2.32% to the Gross Domestic Product (GDP) in South Africa during 2013. The South African agricultural sector is divided into animal products, horticulture, and field crops categories. The contribution of these categories is shown in Table 2.5.

Table 2.5 indicates the gross value of agricultural production for the period 2012/2013. It is clear from Table 2.5 that animal products dominate the agricultural production in South Africa, contributing R84 610.80 million to agricultural production, which is 46% of the total production (DAFF, 2014:75).

Table 2.5: Gross value of agricultural production in South Africa (2012/2013)

Production	Gross value (R million)	Percentage of total
Field crops	51 783.00	28%
Horticulture crops	46 481.50	25%
Animal products	84 610.80	46%
Total	**182 875.30**	**100%**

Source: Adapted from DAFF (2014:75)

Table 2.6 shows the contribution of various categories of animals to the gross value of animal products. The poultry industry is the biggest contributor to the gross value, contributing 47.17% of the total production in 2012/2013. Beef was the second largest contributor, with dairy products ranked third in contribution. The gross value of the agricultural production showed a significant growth of beyond 50% in only five years' time. The poultry industry recorded the biggest growth (67.96%) over the five-year period.

Table 2.6: Gross value of animal category products produced in South Africa

Product	Gross value (R million) (2007/08)	Gross value (R million) (2012/13)	% of total animal production (2007/2008)	% of total animal production (2012/2013)	% change
Poultry (layers & broilers)	23 763 210	39 912 555	43.75%	47.17%	67.96%
Sheep & goats (wool, mohair, karakul pelts & meat)	4 503 673	6 980 987	8.29%	8.25%	55.01%
Beef	11 592 663	18 564 921	21.34%	21.94%	60.14%
Dairy products	9 232 004	11 645 023	17.00%	13.76%	26.14%
Pigs	2 482 760	3 721 337	4.57%	4.40%	49.89%
Ostriches (feathers & products)	370 270	276 255	0.68%	0.33%	-25.39%
Other animal products	2 374 452	3 509 675	4.37%	4.15%	47.81%
Total	54 319 032	84 610 753	100%	100.00%	55.77%

Source: Adapted from DAFF (2014:76)

According to the DAFF (2014:2), the poultry meat industry made the largest contribution to the total gross value of agricultural production in 2014. The poultry meat industry contributed 15.5%, followed by maize with 12.5%, and cattle and calves slaughtered with 11.4%.

The livestock industry section aimed to highlight the major animal categories that serve as a source to supply the human demand for animal-source protein. Globally, pork is in the highest demand, while in

South Africa, broiler meat is the highest in demand. The importance thereof is that the respective animal categories are the biggest consumers of animal feed, both globally and locally.

2.5 THE ANIMAL FEED INDUSTRY

In the process of estimating the amount of animal feed required to satisfy the nutritional requirements of animals, it is important to understand the livestock sector and the number of animals that need to be fed. The following section will give the reader a better understanding of the global and South African animal feed industries, the size of these industries, and the feeds needed to be mixed for various animal categories.

2.5.1 The global animal feed industry

The International Feed Industry Federation (IFIF) represents over 80% of the global animal feed producers and is reckoned as an essential partner in the food chain that ensures safe, sustainable, and nutritious food. According to the IFIF (2013), the demand for livestock products will continue to increase throughout the next decades as the demand for animal protein is expected to increase with 1.7% per year over the next 40 years (IFIF, 2013:5). The IFIF (2013:8) stated that the global feed industry continues to expand in volume and value to supply the demands of a fast-growing global population, urbanisation, and growing consumer purchasing power. More than 130 countries produce and sell manufactured animal feed products, employing more than 250 000 skilled workers, managers, technicians, and professionals.

The global animal feed industry had a business value of $460 billion in 2014 and produced 980 million tonnes (Figure 2.1) in 31 043 feed mills around the globe (Alltech, 2015). Global feed tonnage increased from 960 million tonnes in 2013 to 980 million tonnes in 2014, accounting for a 2% growth in the industry (Alltech, 2015:2).

China is the biggest animal feed producer globally, producing 183 million tonnes in more than 9 500 feed mills. China, however, showed a 4% decline from the 2013 estimates, mainly caused by an outbreak of avian flu that dampened consumer demand, and a slowly developing hog market. India was the biggest grower in 2014, showing a 10% increase from 2013 to 29.4 million tonnes due to good weather conditions and continued improvements in technology and farming methods (Alltech, 2015:4). The USA is in the second place with 172 million tonnes produced in 6 718 feed mills, and Brazil ranked in third place, with 1 698 feed mills producing 66 million tonnes of animal feed (Alltech, 2015:4).

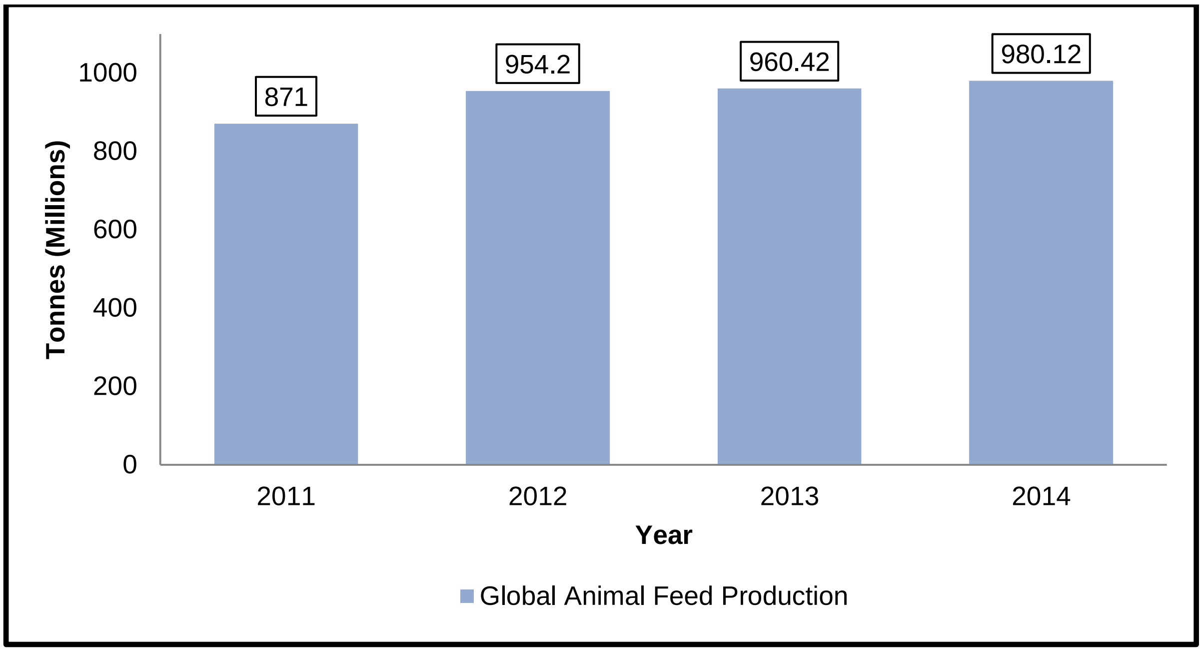


Figure 2.1: Global animal feed production from 2011 to 2014
Source: Alltech (2015)

According to Alltech (2015:5), poultry held its position as the industry leader with 45% of the animal feed market at 439 million tonnes (Figure 2.2). Pigs and pets showed the biggest growth percentage from 2013 with a 5.3% and 5% increase respectively. The pig industry has a market share of 26% at 256 million tonnes, while ruminants are responsible for 20% (196 million tonnes) of global animal feed production (Alltech, 2015:5).

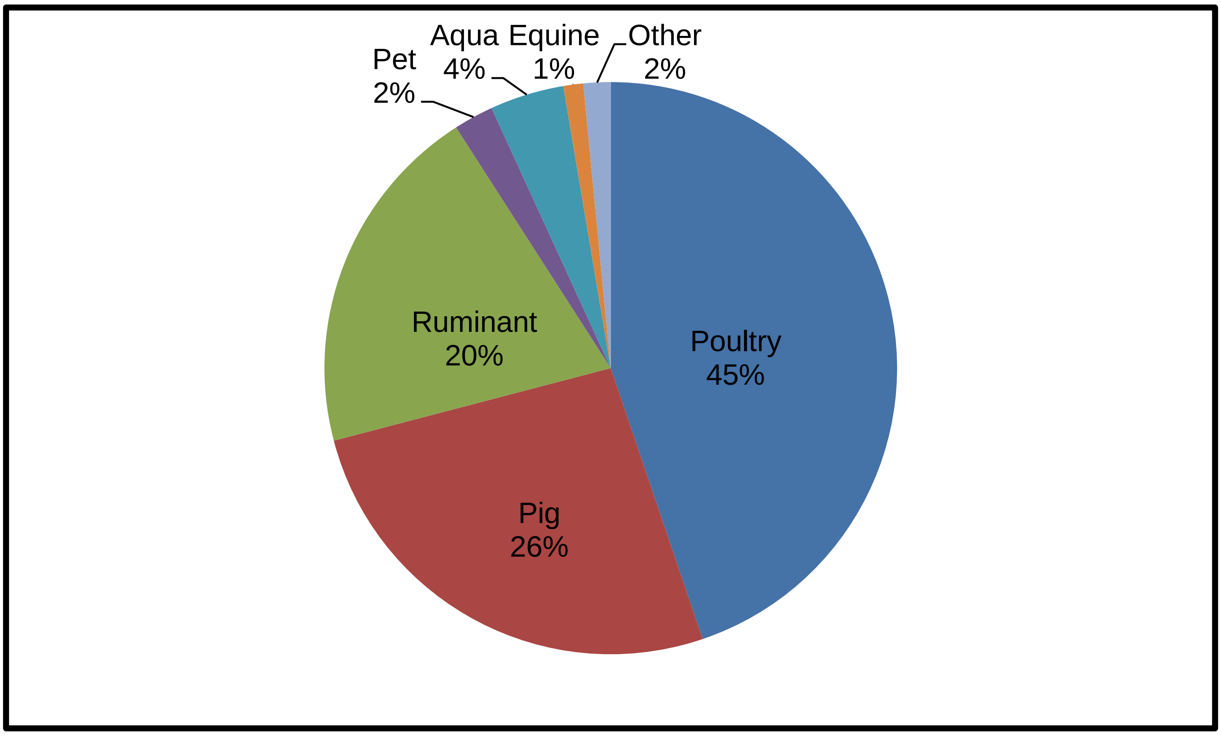


Figure 2.2: Feed production per category for 2014
Source: Alltech (2015)

According to Alltech (2015:4), Africa has a total of 1 150 feed mills that produce 34.57 million tonnes of feed. South Africa is ranked 23rd amongst the 130 commercial feed producing countries and is the largest feed producing country in Africa. South Africa produces 11.38 million tonnes of feed and contributes 33% of the total feed produced in Africa.

2.5.2 The South African animal feed industry

Production in the formal animal feed industry, consisting of the AFMA, gradually increased from 1935. During the 1997/1998 period, production stood at 3.9 million tonnes. This production showed significant growth over the years, with a production of 4.7 million tonnes in 2006/2007 and a gross turnover value of R8.3 billion (AFMA, 2008). During the 2012/2013 period, production was estimated at 11.13 million tonnes of feed with a national gross turnover value of national animal feed production of R48 billion per annum.

Table 2.7 indicates historical AFMA sales and national production of animal feeds. The AFMA's animal feed sales increased with 50% over the ten-year period, while national production of animal feeds increased with 34% over the last decade (AFMA, 2014).

Table 2.7: Historical AFMA sales and national production of animal feeds

Year	AFMA feed sales (tonnes)	% growth	National production (tonnes)	% growth
2005/2006	4 462 088	-	8 687 216	-
2006/2007	4 687 097	5.04%	9 125 052	5.04%
2007/2008	5 158 786	10.06%	9 590 598	5.10%
2008/2009	5 262 693	2.01%	9 783 369	2.01%
2009/2010	5 498 297	4.48%	10 791 257	10.30%
2010/2011	5 750 578	4.59%	10 655 028	-1.26%
2011/2012	6 143 576	6.83%	11 086 124	4.05%
2012/2013	6 176 151	0.53%	11 146 238	0.54%
2013/2014	6 431 328	4.13%	11 380 587	2.10%
2014/2015	6 688 581	4.00%	11 619 579	2.10%

Source: AFMA (2005-2015)

Accurate statistics regarding animal feed sales are kept by the AFMA. The formal industry represents only an estimated 60% of the entire animal feed industry (Table 2.8). The rest is produced by the informal industry. During the 2013/2014 period, the total amount of produced animal feed was estimated at 11.381 million tonnes. From Table 2.8 it is clear that the poultry sector dominates the demand for animal feed with 40%, followed by beef cattle and sheep (28.98%), and dairy (18.08%).

Table 2.8: AFMA feeds shown as percentage of national feeds for 2013/2014

Feed type	AFMA feeds plus feeds derived from concentrates (Tonnes)	National feed production (Tonnes)	AFMA feed as % of national production	Feed type as % of national production
Dairy	1 039 420	2 057 619	50.52%	18.08%
Beef & sheep	1 191 537	3 297 788	36.13%	28.98%
Pigs	290 618	855 539	33.97%	7.52%
Layers	954 980	1 223 333	78.06%	10.75%
Broilers	3 280 052	3 364 156	97.50%	29.56%
Dogs	34 932	318 206	10.98%	2.80%
Horses	22 799	132 100	17.26%	1.16%
Ostriches	11 177	127 553	8.76%	1.12%
Aquaculture	4 293	4 293	100.00%	0.04%
Total	**6 829 808**	**11 380 587**	**60.01%**	**100.00%**

Source: Adapted from AFMA (2014)

The change in consumer trends to higher-protein diets has caused an increased demand for livestock products. Livestock and animal feed production is demand-driven by the human population. The number of animals that need to be fed is derived from the human demand for livestock products, from which the amount of animal feed is determined.

The background provided is to emphasise the relationships between industries and how these industries interact with one another. Over the years, the importance of these interactions between the industries has created a growing need for producers in both animal feed and livestock industries to better understand the relationship between them. Changes in the industries, and even more importantly, the impact that these changes may cause in the industries, are very critical in competitive markets and for food security. It is necessary to look at various studies and models to evaluate different methods and approaches to quantify these linkages.

2.6 SIMILAR STUDIES

This section focuses on research projects that are similar or related to this specific study. The most important literature is mentioned and discussed in this section in terms of international as well as local research projects. The APR model is explained in detail as it is one of the most important models that accurately estimate raw material consumption and the interaction of protein sources.

2.6.1 International

Many studies have been conducted over the years to model animal feed demands and the usage of various raw materials in the feeds. The two models that are very similar to this current study is the global International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) and the Regional Feed Demand and Allocation model developed for the Australian industry. These two models and the results generated by these models will be discussed in the sections that follow.

2.6.1.1 The IMPACT

This model was developed by the International Food Policy Research Institute (IFPRI) as a tool to address the lack of long-term vision and consensus of policy makers and researchers in making vital decisions regarding sufficient food supply for a fast-growing global population, reducing poverty, and protecting natural resources (Rosegrant & IMPACT Team, 2012:1).

The IMPACT examines linkages between the production of vital food commodities, food demand, and security at local level, considering changes from different future scenarios. The focus of the IMPACT is on regional issues, commodity-level analyses, and interdisciplinary, scenario-based work future food supply and demand (Rosegrant & IMPACT Team*,* 2012:1). The basic methodology comprises equations that generate data for baseline analyses, as well as scenario analyses for global food demand and supply, trade, income, and population.

The food methodology covers 115 geopolitical areas and 126 hydrological basins, therefore creating 281 food production units (FPUs) at intersections of the two layers. All regions are linked with trade and the IMPACT determines supply and demand and commodity prices within each region (Rosegrant & IMPACT Team*,* 2012:4). The model includes 45 internationally traded commodities, which cover categories of grains, legumes, roots and tubers, fruit and vegetables, and oilseeds either produced on dry land and/or under irrigation. Livestock commodities are grouped under beef, milk, lamb, eggs, poultry, and pork (Rosegrant & IMPACT Team, 2012).

Market-clearing assumptions are made for commodities and prices are defined as endogenous, while income and population growth are exogenous.

Since the development of the IMPACT in the early 1990's, many improvements have been made in terms of the amount of crops and livestock included, but very little improvements have been made regarding animal production and feed demand. Recently, scientists of the International Livestock Research Institute (ILRI) and the International Institute for Applied Systems Analysis (IIASA) made great developments to the IMPACT to simulate animal production of and the demand for feed (Msangi, Enahoro, Herrero, Magnan, Havlik, Notenbaert & Nelgen*,* 2014:369).

The demand for feed required for animal production within the model responds to changes in the quantity of livestock produced and the prices of feeds. The model also contains fixed feed conversion and efficiency improvement factors. The new improvements also account for distinction between ruminant and non-ruminant diets.

The results generated by the model include total production of different livestock categories, numbers of livestock heads produced, and the amount of feed demanded for the baseline projections. Scenario analyses and industry shocks are integrated into the model and results are obtained for the year 2020 and 2030 (Msangi *et al*., 2014:372). Global prices for main commodities are also shown by the model.

The results shown for the improved livestock IMPACT by Msangi *et al.* (2014:372) stated that the production of beef and mutton in China is expected to show a significant increase by 2030, while

Brazil will show the biggest production estimates for 2030 of beef and mutton. India shows the highest dynamics in the production of milk products and overshadows the likes of China, Brazil, and the USA. Msangi *et al.* (2014:374) stated in the model's results that the overall demand for grassland biomass, for more extensive livestock production systems, as well as marketed animal feeds, will increase until the year 2030. The demand, however, for grassland biomass shows the biggest demand increase, with China as the leader. The demand for animal feeds has very little effect on the increase.

The global IMPACT simulates world feed consumption derived from an increase in production of livestock animals worldwide. This model, however, does not specifically focus on raw materials required for feed rations to feed different animals according to nutritional requirements. The Regional Feed Demand and Allocation model looks more specifically at the raw materials used in various animal feed rations and has a more detailed approach.

2.6.1.2 The Regional Feed Demand and Allocation model

The model was developed by Hafi and Andrews (1997) for the Australian Bureau of Agricultural and Resource Economics (ABARE). It is a mathematically programmed model which combines feed mixing and market components to determine the regional usage of all feed ingredients, regional prices, regional trade, and imports and exports from various countries. The model is specifically designed for Australia, where the main transport infrastructure, grain handling, and storage have been specially designed and located for handling products for the export market.

In 2000, the model was further refined to simulate external shocks on the supply and demand side of the model that included seasonal droughts, higher availability of feed wheat, and an increased growth in the number of cattle in feedlots (Hafi & Rodriguez, 2000).

The analysis takes the different nutritional requirements of various livestock categories into account to determine the feed demand of the animals (Hafi & Andrews, 1997). The Australian livestock industry was then divided into 12 livestock categories, which were grouped into six aggregate groups, namely poultry broilers, poultry layers, pigs, dairy, feedlot cattle, and other. Table 2 shows the six industry groups, as well as the industries analysed under the industry groups.

Table 2.9: Australian livestock industries analysed

Industry groups	Industry under analysis
Poultry broilers	Broilers – starter
	Broilers – finisher
Poultry layers	Layers – pullets
	Layers/breeders
Pigs	Weaners
	Growers/finishers
	Breeders
Dairy	Dairy
Feedlot cattle	Feedlot cattle
Other	Live sheep exports
	Grazing ruminant supplement
	Other, including horses

Source: Adapted from Hafi and Andrews (1997); Brennan and Singh (2000:11)

Nutritional characteristics are linked to each feed ingredient, and 43 different ingredients are used to mix rations to satisfy the minimum requirements of each industry under analysis, which ensures sufficient growth and maintenance of livestock, with the main objective of minimising the total cost of feed rations (Hafi & Andrews, 1997). Feed ingredients are either produced locally or imported from other countries.

Livestock numbers and output generated from the livestock industries are fixed throughout the study and prices are unresponsive within the analysis framework. The amount of animal feed rations needed to feed each animal type is also fixed for every industry. Specifications included in the Feed Demand model are:

a) Minimum nutritional requirements;
b) Upper bounds on ingredients; and
c) Limits on supply availability.

The prices of the feed ingredients are determined through supply and demand projections. Hafi and Rodriguez (2000) generated the data on total production of livestock products and allocated demand and supply elasticities to each industry. Elasticities are medium-term (three to five years) and are based on livestock product markets and as derived from various studies.

Hafi and Connell (2003) made further refinements to the model and simulated three "what-if" cases in the study, which included the introduction of waxy sorghum into the animal feed industry, the higher availability of feed barley, and a decrease in transportation cost. The study projected that the demand for main feed ingredients in the domestic market was expected to increase with 18% during the period 2003/2004 until 2007/2008. Cattle proved the leader in feed ingredient consumption, with an increase of 29% over the five-year period, followed by the pig, broiler, and dairy industries (Hafi & Connell, 2003:32). All three “what-if” cases generated positive results in proving cheaper rations and in the process increasing the competitiveness of the animal feed and livestock industries in Australia.

2.6.2 Local

Three dominant protein demand studies have been conducted locally. The BFAP model is dynamic and sectoral in determining linkages between different commodities and determining price and availability under various levels of consumption. The Nieuwoudt/McGuigan model is an integrated study that operates from the starting point of determining protein demand by humans and then deriving the protein feed demand thereof. The APR model estimates animal protein demanded by humans, derives the total number of animals required to satisfy human demand, and estimates the amount of raw materials needed to feed the animals according to their specific nutritional requirements, as well as the raw materials’ prices and availability.

These models are fully explained in the sections that follow.

2.6.2.1 Nieuwoudt/McGuigan model

This model is applied to estimate the demand for protein in South Africa. The model is also used to estimate future demands for protein animal feeds (McGuigan, 2001:2). The livestock demand for protein meal determines the overall demand for protein meal. The demand growth for livestock models is mainly driven by population growth and real per capita income growth. According to McGuigan (2001:2), the growth in supply is mainly driven by technological advances and producing on previously non-productive lands. McGuigan (2001:3) stated that the model to project future supply and demand is based on past production trends. By using estimated price elasticities of supply and demand, the model can calculate consumption and equilibrium prices.

Before the Nieuwoudt/McGuigan model was developed, Nieuwoudt (1998a:130) created a mathematical projection model that would consider structural changes that can occur in major demand components in South Africa during the following decades. In the model, final product demand projections are made for pork, mutton, broiler meat, eggs, fresh milk, milk powder, and cheese. The main reasons that would cause structural adjustments in the demand for food are:

a) different population growth rates;
b) different population groups;
c) changes in income elasticities; and
d) urbanisation (Nieuwoudt 1998a:130).

Nieuwoudt (1998a:130) projected the production and consumption of these animal-protein sources and derived the demand for protein feed thereof.

Nieuwoudt (1998b:143) improved the previous model by following a procedure of initially estimating the consumption of livestock products and then deriving the consumption of animal feed from the consumption of livestock products. The livestock supply was included in the model, where the projected increase in consumption of final animal products was used to derive the projected protein consumption of these animals (Nieuwoudt 1998b:144).

Calculating the future demand index for livestock protein

McGuigan (2001:58) calculated the demand index for broilers, beef, pork, lamb, eggs, and dairy:

$Index_{py}$ = 100 * (DDF/CON)

Where:

$Index_{py}$ is the future demand of product *p* in year *y*.

Total consumption for the base year

$$CON = \sum_{pj} P_{pj} * C_{pj} \qquad \ldots\ldots (1)$$

Where:

p = beef, mutton, pork, poultry meat, eggs, fresh milk, milk powder, and cheese
j = urban blacks, rural blacks, Asians, coloureds, whites
P = population numbers
C = per capita consumption figures

Written out as:

CON = BUP * BUC + BRP * BRC + AP *AC + CP * CC + WP * WC.

Population numbers for urban blacks, rural blacks, Asian, coloureds and whites are indexed as BUP, BRP, AP, CP, and WP respectively.

The per capita consumption figures for product *p* are indexed as BUC, BRC, AC, CC, and WC for urban blacks, rural blacks, Asians, coloureds and whites respectively.

Projecting future protein livestock demand

Assuming constant prices, DDF_p is the projected future demand for product *p* in year *y* and calculated as follows (McGuigan, 2001:58):

$$\begin{aligned} DDF_p = {} & [((1 + BUI)^n - 1) * BUE + 1)) * (1 + BUPg)^n * BUC] + \\ & [((1 + BRI)^n - 1) * BRE + 1)) * (1 + BRPg)^n * BRC] + \\ & [((1 + AI)^n - 1) * AE + 1)) * (1 + APg)^n * AC] + \\ & [((1 + CI)^n - 1) * CE + 1)) * (1 + CPg)^n * CC] + \\ & [((1 + WI)^n - 1) * WE + 1)) * (1 + WPg)^n * WC] \ldots\ldots (2) \end{aligned}$$

- BUI, BRI, AI, CI, and WI are the projected per capita growth rates for urban blacks, rural blacks, Asians, coloureds, and whites respectively.
- BUE, BRE, AE, CE, and WE are the income elasticities of urban blacks, rural blacks, Asians, coloureds, and whites respectively.
- BUPg, BRPg, APg, CPg, and WPg are the population growth rates for urban blacks, rural blacks, Asians, coloureds, and whites respectively.
- *n* is the number of years from the base year to the projected year.

According to McGuigan (2001:62), the sectors that use protein feed most intensively are pork, broilers, and layers. McGuigan (2001:62) stated that broilers, layers, and pork can be seen as factory-type products and technological improvements in the species can cause the supply function to shift downwards. If the technological improvement trends in the broiler industry continue, broilers with 452 grams of breast meat will be produced in 26 days by the year 2020 (McGuigan, 2001:64).

Calculating technology index

McGuigan (2001:64) composed a function which predicts the required feeding days until slaughter weight for a broiler. The function is used to calculate a technology index that will be able to estimate the future effects of technology. It is described as follows:

$TI_{By} = (1 + tgr_B)^n$…………………………………………………………………….. (3)

Where:

TI_{By}= broiler production's technological index in year *y*

tgr_B= compound growth rate for broiler production resulting from genetic change

n = number of years from base year to year *y*

The abovementioned is only an example for broilers.

Future livestock protein consumption

To project the future consumption of livestock products, a price index for intensively produced products (broiler, pork, eggs, and dairy) is estimated using the following equation (McGuigan, 2001:67):

$PI_{py} = TI_{py} * IPI_y$………………………………………………………………………(4)

Where:

PI_{py} = price index for product *p* in year *y*

TI_{py}= technology index for product *p* in year *y*

IPI_y = international protein price index (can be independently estimated)

Consumption effected by projected prices

How consumption is affected by projected prices is calculated as follows (McGuigan, 2001:68):

$FCon_p = (1 + (PE_p * (PI_p - 100) / 100)) * DDF_p$ ………………………………………… (5)

$FCon_p$ = future consumption of product *p* in year *y*

PE_p = price elasticity of demand for products *p*

DDF_p = demand index for product *p*

As explained by McGuigan (2001:69), to project the future protein consumption for South Africa, the consumption indexes calculated (5) for intense feeding is multiplied by the base usage.

McGuigan and Nieuwoudt (2002) projected the South African consumption of livestock products until 2020 and derived the protein feed usage thereof. The results the model generated, assuming constant international prices and base population growth, were that forecasted usage of protein feed and meals would increase with 0.29 million tonnes (1.06%) under low-income growth, and with 0.72 million tonnes (2.30%) under high-income growth (McGuigan & Nieuwoudt, 2002:13).

Three scenarios are simulated by the model, namely the effect of tariff elimination, population growth with the possible effect of HIV/Aids, and improved feed conversion ratios (FCRs) showed by intensive livestock production systems.

During 2002, tariffs protected the South African livestock industry. The elimination of tariffs would cause livestock imports to increase relative to local production of animal products. McGuigan and Nieuwoudt (2002:15) stated that if a 40% tariff would be eliminated, the local usage of protein feeds would decrease with 9% and 12% respectively for low-income and high-income growth. The worst case HIV/Aids scenario under low-income growth forecasted protein consumption at 1.4 million tonnes by 2020. The poultry and pork industry with improved FCRs was expected to reduce protein consumption by 11% and 12% for low-income and high-income growth respectively (McGuigan & Nieuwoudt, 2002:16-17).

The Nieuwoudt/McGuigan model emphasises protein feed demand by animals, but does not specifically mix rations for animals according to nutrient requirements, least-cost, and raw material price and availability. The APR model takes a detailed approach to mixing least-cost animal rations to satisfy the minimum nutrient requirements of animals, takes into consideration the per capita consumption of each livestock product by the population, and allocates feed ingredients to different regions in South Africa.

2.6.2.2 The Agricultural Product Requirements (APR) model

The APR model was developed by Briedenhann (2001) to calculate the demand for animal products and to estimate the number of animals that need to be nourished. The model also takes into account the nutrient requirements of the animals, as well as the feed needed for consumption to satisfy these demands. Performance criteria are also taken into account (Briedenhann, 2001:13). Linear Programming (LP) is used to formulate feed rations utilising the most cost-effective use of raw materials.

The prices of available local and international raw materials are taken into account, where the local availability of raw materials determines the amount of imported raw materials (Briedenhann, 2001:13). The demand for animals (per species) is determined by using population figures and then determining the number of animals which need to be fed to satisfy the demand of the population.

The country is divided into three regions by the model, namely:

a) Cape;
b) Interior; and
c) KwaZulu-Natal

The model makes the assumption that the animal feed is supplied from the same area in which the animals are fed, and Bekker (2000, in Briedenhann, 2001:14) verified this assumption by stating that industry delivery only takes place within a 138-km radius from the mill.

Substitution between types of raw materials can be determined by numerous other parameters. The parameters to fulfil the requirements are (Briedenhann, 2001:12):

a) Prices and components of raw materials;
b) Animal distribution; and
c) Raw material distribution and availability.

Calculating the demand for animal feed

Section one described the calculations made to determine the demand for animal feeds from the per capita consumption of animal products, making use of data that measure animal performance. The total feed demanded is broken down into numerous sub-categories (Figure 2.3), such as local animal product demand, animals required to satisfy the population's demand, and the feed demand per region (Briedenhann, 2001:15).

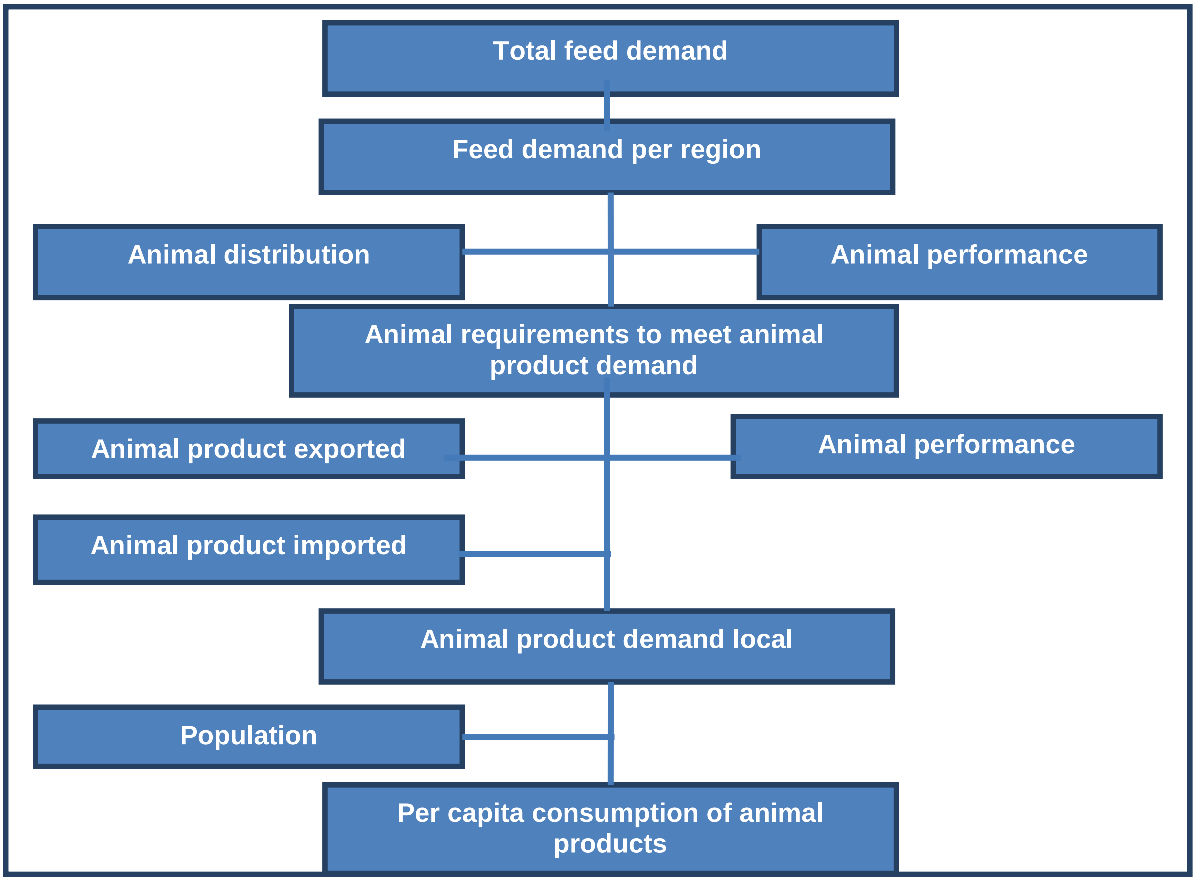


Figure 2.3: The model interrelationship for calculating animal feed
Source: Briedenhann (2001:15)

Calculating the total raw material requirements

Section two describes how the animal feed demand is satisfied using LP and the prices and availability of raw materials to determine raw material requirements. Briedenhann (2001:14) stated that the total feed demand is calculated using the demand generated by the livestock industry, as well as animals that are fed for non-consumption purposes, for example horses and pets. In Figure 2.4, main categories are further divided into sub-categories, and some even into sub-sub-categories.

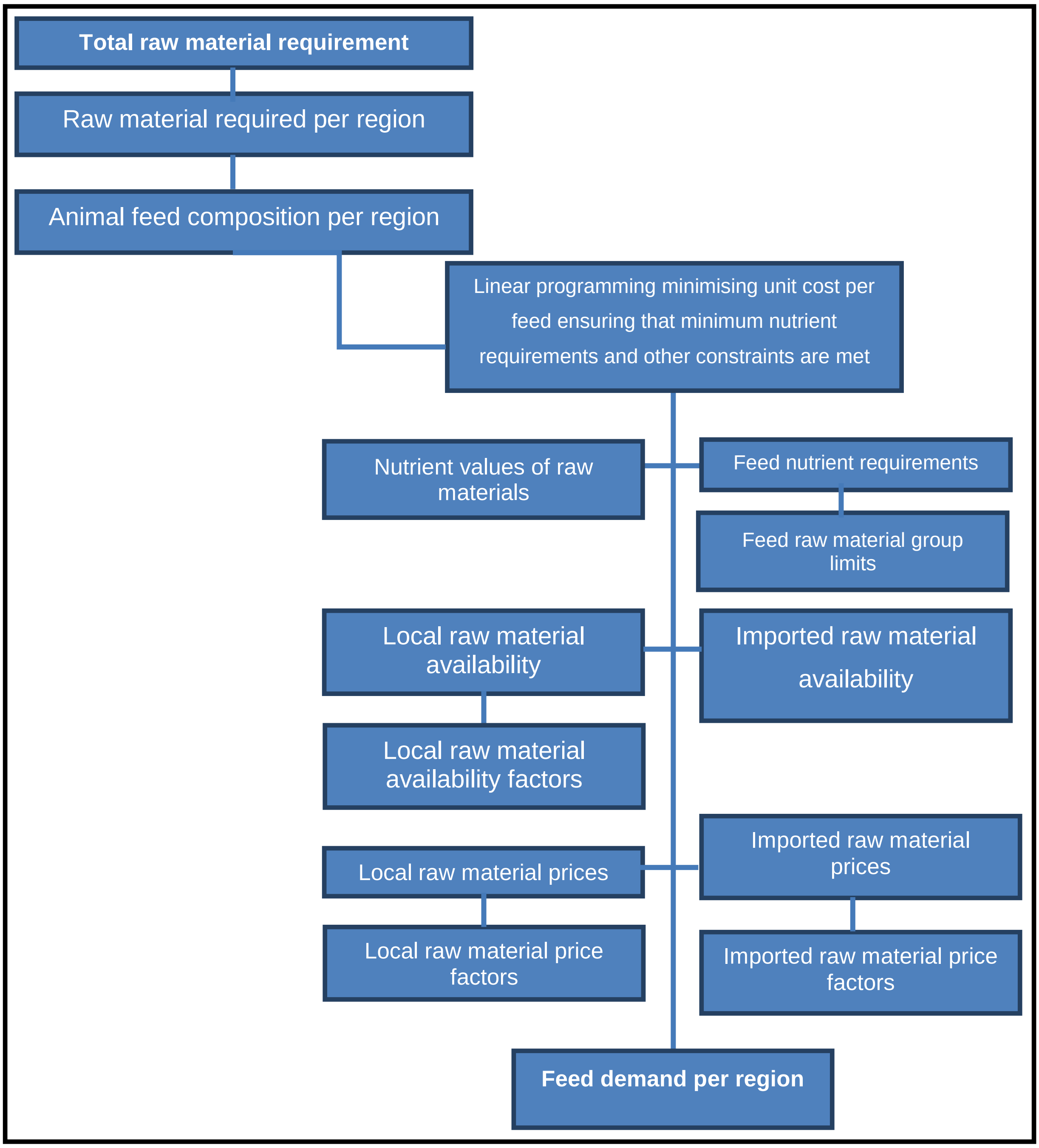


Figure 2.4: Illustration of the model interrelationship for calculating raw material demand
Source: Briedenhann (2001:16)

Calculation of animal feed

Different parameters were included in the calculations to accommodate forecasted changes in human demand for products and future animal performance (Briedenhann, 2001:23). The example below shows how animal feed is determined for broilers.

Parameters for broiler feed consumption

A	Per capita broiler meat consumption (kg)
B	Population size (million)
C	Total broiler meat consumption (tonnes)
D	Imported broiler meat (tonnes)
E	Exported broiler meat (tonnes)
F	Local broiler meat production (tonnes)
G	Average slaughter weight (kg)
H	Average slaughter-out (%)
I	Average broiler weight after slaughter (kg)
J	Total number of broilers slaughtered per annum (million)
K	Total broiler weight (tonnes)
L	FCR
M	Total broiler feed consumption (tonnes)

Calculation of broiler feed consumption

$C = A * B$

$F = C – D + E$

$J = F/(G * H)$

$K = (J * G)$

$M = (K * L)$

Calculation of broiler feed type quantities

Pre-starter	0.06 * L
Starter	0.24 * L
Grower	0.29 * L
Finisher	0.26 * L
Post-finisher	0.15 * L

In 2000, the base year of the APR model, a total of 7.6 million tonnes of animal feeds were mixed, with broilers (2.3 million tonnes) accounting for the most feed amongst the different feed types, cattle and sheep (1.6 million tonnes) in the second place, and dairy (1.5 million tonnes) using the third most feed in the country. Total animal feed consumption for 2010 was forecasted at 8.5 million tonnes, and 9.4 million tonnes for 2020 (Briedenhann, 2001:50).

Various scenarios are also simulated through the APR model, generating results for a high, medium, and low population growth rate, the usage of fish meal in relation to soybean meal prices, the maximum usage of sunflowers in animal diets (to assess crushing capacity), and the effect of genetic improvement on feed consumption.

Under a high population growth rate (1.6%), the total amount of animal feed required for 2015 and 2020 was forecasted at 10.3 million tonnes and 11.5 million tonnes respectively. Yellow maize required for 2015 and 2020 amounted to 5.3 million tonnes and 6.1 million tonnes respectively for a high population growth rate (Briedenhann, 2001:61). The effect of genetic improvement on feed consumption in broilers means that the required slaughter weight of an animal is achieved in a shorter time. Without genetic improvement, the amount of feed required for broilers in 2020 is estimated at 2.88 million tonnes, while the amount decreases to 2.2 million tonnes with genetic improvement.

The APR supplements the Nieuwoudt/McGuigan model for predicting the demand for livestock products. Much emphasis is placed on animal requirements for raw materials, as it is a major driving force for determining raw material requirements. The model accounts for the nutrient content of each raw material. Raw materials are allocated in South Africa according to the demand thereof, which is influenced by price and availability.

2.6.2.3 The BFAP sector model

The BFAP sector model is a dynamic system compiled with econometric equations, and has the ability to model linkages between different commodities (Meyer, Strauss & Funke, 2008:330). In 2003, Meyer and Westhoff developed and operationalised the first version of the South African grain, livestock, and dairy model (Meyer & Kirsten, 2005). Meyer *et al.* (2008) classified the BFAP model as a large-scale multi-sector commodity level simulation model.

This partial equilibrium model of the South African agricultural sector currently includes 52 commodities categorised under five groups; namely cereals, oilseeds, livestock and dairy, horticulture and viticulture, and other (Table 2.10). Important supply and demand components are identified for each commodity. Thereafter, equilibrium in each market is established using a balance sheet principle where demand equals supply (BFAP, 2014). The closed system of equations then solves the model through various linkages between different commodities. To explain the linkages, the linkage between the livestock sector, grains used in animal feeds, and grains utilised in the biofuel industry is considered. This linkage implies that a shock in the livestock and biofuel industries will be transferred through to the grain industry and vice versa (BFAP, 2015).

Table 2.10: Products used in the BFAP commodity model

Cereals	Oilseeds	Livestock and dairy	Horticulture and viticulture	Other
White maize	Sunflowers	Chicken	Wine (9 varieties)	Petrol
Yellow maize	Sunflower oils	Beef	Table grapes	Diesel
Wheat	Sunflower cake	Sheep meat	Apples	Biodiesel
Sorghum	Soya beans	Pork	Pears	Bioethanol
Barley	Soya bean oil	Wool	Potatoes	Bioethanol gel
	Soya cake	Eggs	Sugarcane	DDGS
	Canola	Dairy – Milk	Sugar	Fertiliser
		Dairy – Cheese	Oranges	Machinery
		Dairy – Butter	Soft citrus	
		Dairy – WMP	Grapefruit	
		Dairy – SMP	Lemon	

Source: BFAP (2015)

A number of critical assumptions need to be made for baseline projections. Assumptions on the outlook of macro-economic conditions are based on a combination of projections developed by the World Bank and the International Monetary Fund (IMF). Critical assumptions, globally and locally, are then captured within the BFAP sector model, thereafter the outlook for all commodities takes place in a closed system of equations (BFAP, 2014:8). The baseline represents a benchmark of what events may occur under a certain set of assumptions, but does not establish a forecast (BFAP, 2014:8). The linkages and inputs of the integrated BFAP approach are illustrated in Figure 2.5.

The Food and Agricultural Policy Research Institute (FAPRI) global commodity model is linked to the BFAP model, and generates global baseline projections for commodity markets (Figure 2.5) The FAPRI model consists of a set of dynamic, multi-commodity, multi-market, econometric, non-spatial, partial-equilibrium models that represent approximately 40 commodities in more than 60 countries (Meyers, Westhoff, Fabiosa & Hayes, 2010:7). The model generates results that consider the production, consumption, and prices of various commodities. For more important commodities like maize, the price is determined using the equilibrium condition where global supply must equal global demand (Meyers *et al.,* 2010:5).

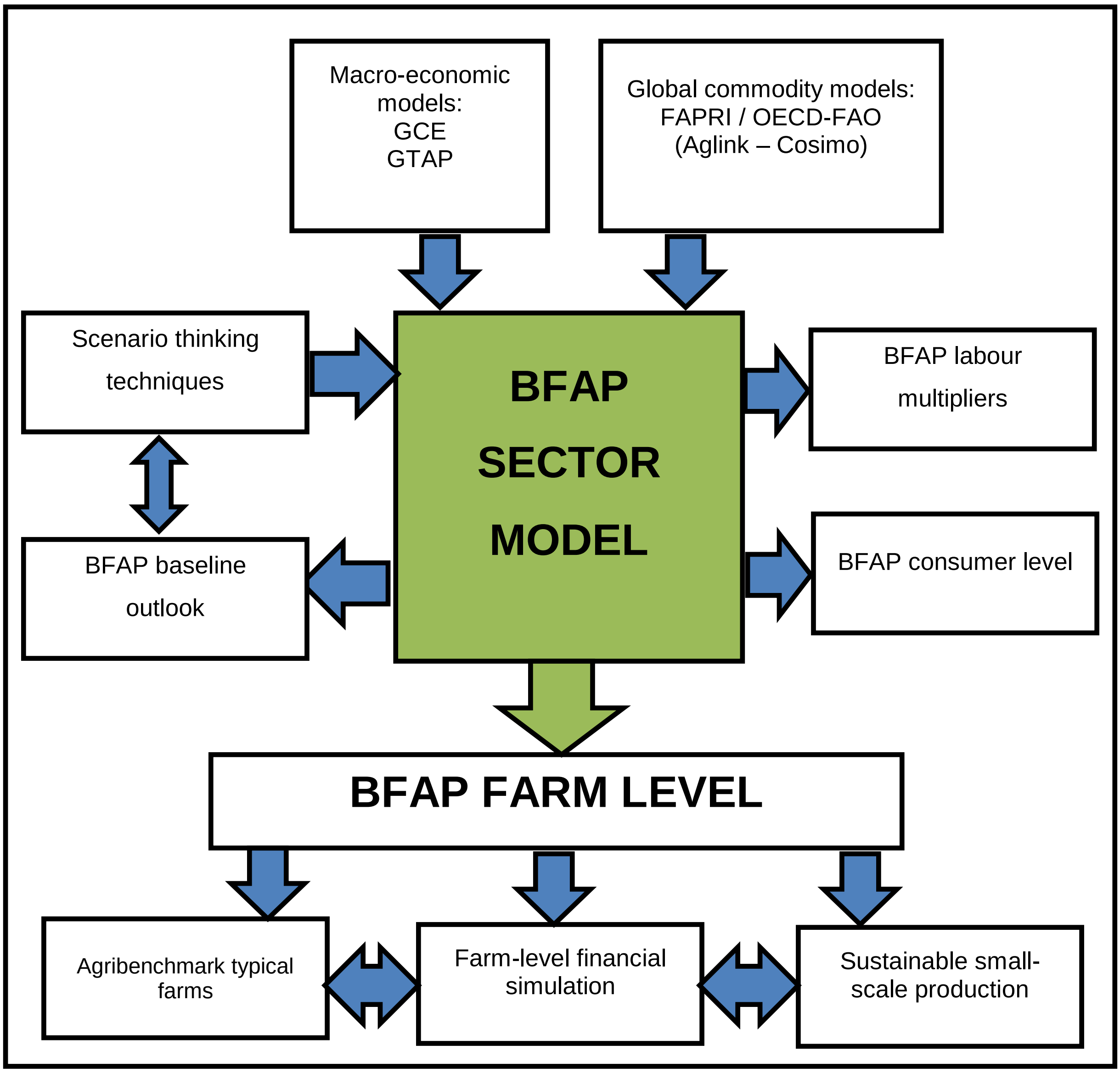


Figure 2.5: The BFAP integrated approach
Source: BFAP (2015)

The BFAP sector model is a dynamic model, whereas the APR model is static in nature. Table 2.1 indicated recent trends of the South African consumer market, where the middle-class consumer is becoming richer, showing class mobility (moving to a higher LSM group), and moving to more processed animal-protein products.

The results generated by the BFAP (2014:56) regarding a forecast of South African meat consumption until 2023 are as follows: beef consumption showed a 20% increase, chicken a 34% increase, pork is forecasted to increase with 41%, and the consumption of eggs is expected to rise with 27% by 2023. The South African dairy industry continued to grow as the demand for milk products increased throughout the last decade, and with easing feed prices during 2014, the industry is forecasted to expand with 30% during the next decade (BFAP, 2014:65).

The focus of the BFAP model is mainly on modelling cross-commodity linkages, but it focuses very little on the protein demanded by animals and more specific and different diets. The

Nieuwoudt/McGuigan model focuses on the protein feed demands of animals derived from animal product consumption from the human side.

2.7 CHAPTER SUMMARY

The chapter took a "funnel" approach in all the sections to give the reader a complete understanding of all the trends, markets, and industries, both globally and in South Africa. From the consumer trends, it is clear that the demand for livestock is on a tremendous increase as consumers are becoming wealthier and populations are increasingly attracted to cities.

The meat, livestock, and animal feed industries are closely linked to one another. The importance of every industry was explained in terms of size and value. Each industry was narrowed down, from global to Africa and then further to South Africa.

Evident vital linkages were shown between humans' meat demand and livestock and animal feed industries. Consumer demand for meat drives the quantity of livestock required to satisfy human demand, thereafter animal feeds are formulated to feed the animals required for satisfying the human demand.

The IMPACT focuses on global shocks and the effects of such shocks on commodities globally, while the Regional Feed Demand and Allocation model narrows down the focus to regional supply, demand, and allocation of feed and raw materials. The latter model has similar principles as the APR model, where it takes into account the nutritional requirements of animals, technical animal performance data, and raw material availability and costs. The model, however, is insufficient with regards to the human demand side of animal protein, which is the main driver of meat supply and animal feed required.

The BFAP model simulates and models various shocks on commodities and the cross-commodity linkages shown in South Africa in a general equilibrium model. The model has a wide focus, and does not narrow down its focus to regional feed demand and the allocation of raw materials to animals.

The Nieuwoudt/McGuigan model is more specific in modelling protein raw material sources as well as animal-source protein for human consumption. In this model, humans' meat demand drives the demand for protein raw materials. The model does not account for the nutritional requirements of animals, and neglects the mixing of least-cost animal feed rations.

The APR model focuses on the linkages between the human side and livestock and animal feed industries. The model is specific in mixing animal feed rations according to animals' nutritional requirements and raw material costs and availability. It has the ability to allocate raw materials throughout South Africa and to estimate raw material usage. The shortcoming this model displays is the integrated dynamic approach of modelling the human demand side together with the livestock and animal feed sectors. However, it is important to note that the dynamic BFAP model possesses this characteristic and is able to supplement the APR model with regards to this subject.

CHAPTER 3: METHODOLOGY AND DATA USED

3.1 INTRODUCTION

Chapter 3 aims to satisfy the aims and objectives of the study by using the APR model and the BFAP sector model described in Chapter 2. A description of the APR_OPT model is also given in Chapter 3. The APR_OPT model, a LP model, is developed specifically for the problem at hand and uses the exact data of the APR model. Chapter 3 is divided into two sections. The first section focuses on the benchmarking year and the structure it takes. LP principles and the methodology used to replicate and improve the APR model are described. The second part of Chapter 3 shifts the focus to the future forecasting of protein usage. This section describes the BFAP data and how the data will be integrated into the APR_OPT model.

3.2 LINEAR PROGRAMMING INTRODUCTION

The year 2015 is used as the benchmarking year, as ready and accurate data for 2015 are available for usage. In this section, the benchmarking structure is explained in full, to give the reader an adequate background of LP principles used to solve the problem. Furthermore, a simple feed mix least-cost problem is discussed. Thereafter, the model structure is described.

3.2.1 Linear programming concepts

LP is described by Kaiser and Messer (2011:2) as a category of mathematical programming models and can be categorised into two classes of models: LP models and non-linear programming (NLP) models. In this chapter, the focus will fall on the LP model, which has proven to be a successful problem-solving approach in quantitative methods. The main goal of LP problems is to determine the optimum solution for a problem, being either the minimisation or maximisation of the objective function (defining the objective of the function), such as maximum profit or minimum costs. The objective function is always subject to a set of linear constraints which define the limits of the problem (Kaiser & Messer, 2011:3; Briedenhann, 2001).

The main purpose of LP models is to assist and aid people and/or organisations in the important daily decisions to be made. Therefore, LP models can be defined as decision models assisting people in the decision-making process, unlocking a powerful quantitative tool to improve managerial and policy decision making (Kaiser & Messer, 2011:3).

Over the years, LP models have proven to be a good general purpose technique for finding optimal solutions. LP models have the ability to find fast and reliable solutions over a widespread range of problem sizes and applications. LP is applied to a wide range of problems, including (Kaiser & Messer, 2011:4):

- The Diet problem – The problem comprises finding a least-cost diet solution for a specific person given food prices subject in fulfilling the nutritional needs of a person. The solution would be the least-cost combination of foods to be purchased by the person.
- The Carbon Abatement problem – Firms are forced by legislation to reduce carbon emissions. The carbon abatement problem entails the least-cost methods to be used by a firm to successfully reduce carbon emissions to the mandated level. The solution would provide the best combinations of methods to reduce emissions.
- The Product Mix problem – The product mix problem is used to determine the mix of products or combination of outputs to be sold, subject to limited resources, to maximise profit, potential of farm, gross revenue, and cash flow.
- The Portfolio problem – This problem comprises finding alternative prospects for a fixed amount of resources (for example a maize harvest) to minimise the risk associated with it or to maximise profit. A maize farmer can either sell the maize directly after harvest, store the maize and wait for a price increase, or hedge the harvest on SAFEX to minimise risk.
- The Transportation problem – The problem is how to transport different products from a supply point (farm) to a demand point (market, silos) in the least-cost transportation way.
- The Allocation problem – An allocation problem is solved by allocating a scarce resource (money) to different projects, given that the different projects achieve the desired outcomes with the allocated money.
- Capital Budgeting problem – This problem is explained by how to invest capital (money, machinery, and stock), which is a scarce resource, into alternative projects, albeit monetary investments, or the allocation of man-made aids (machinery) to production in projects.

All of the abovementioned problems have four general properties that form an integral part of LP, namely (Kaiser & Messer, 2011:4):

1. Each model has an **objective function** which has to be optimised, either through optimisation or maximisation.
2. The problem contains **constraints and limitations** which restrict the activities carried out by the objective function.
3. Equations are in **linear** form.
4. The **decision variables** of the model are generally **non-negative** in nature.

The Diet problem determines the least-cost diet for a person considering food prices and subject to daily nutritional requirements. The optimal solution would be the least-cost diet for a person, given the combination of foods the individual should buy. This problem directly applies to feedlots, farmers, and animal feed factories which aim to produce a diet to feed livestock using a least-cost ration with a combination of raw materials. The Feed Mix problem designed for least-cost ration formulation is one of the simplest and most straightforward LP to express and solve.

3.2.2 The Feed Mix problem

Waugh (1951) was the first person to apply LP to the livestock feed formulation problem and it has become a widely used LP application. In LP, the contribution that each nutrient makes to the finished diet is linear and additive. McCarl and Spreen (1997) described the problem as composing a diet with minimum costs from available raw materials while satisfying the nutritional characteristics of the animals within certain bounds.

The main objective of formulating animal feed is profit maximisation with limited resources in supply, but the objective can also be formulating least-cost (cost minimisation) rations with available raw materials.

Stachiw (2000) provided a basic example of a simple LP problem with only two raw materials. In Table 3.1 the nutrient content each raw material contains is shown in units, as well as the cost of each raw material.

Table 3.1: Nutrient composition and cost of soybeans and maize

Raw material	Protein	Fat	Starch	Cost
Soybeans (X_1)	4	1	0	2
Maize (X_2)	3	2	1	3

Source: Stachiw (2000)

The animals have certain nutritional requirements that the nutrients of the two raw materials should satisfy. Table 3.2 shows that the animal requires a minimum of 12 units of protein, two units of starch, and a maximum of eight units of fat.

Table 3.2: Animal nutritional requirements

Nutrient	Inequality	Amount
Protein	≥	12
Fat	≤	8
Starch	≥	2

Source: Stachiw (2000)

Every raw material should be non-negative, meaning that the quantity used should be equal to zero or more.

Objective function:

Minimise $2X_1 + 3X_2$

Subject to: $X_2 \geq 2$

$4X_1 + 3X_2 \geq 12$

$X_1 + 2X_2 \leq 8$

Where: $X_1, X_2 \geq 0$

The problem is then graphically explained by plotting each of the constraints to generate Figure 3.1. Initially, the feasible solution is estimated, and then the feasible region of the graph is determined, given the constraints and limits (Kaiser & Messer, 2011:14).

Solution points are points on the graph that simultaneously satisfy all constraints. In Figure 3.1, points A, B, and C satisfy all the constraints and are known as the solution points. The red shaded region in the figure is named the feasible region, while point B proves to be the optimal least-cost solution for the problem (Kaiser & Messer, 2011:17; Stachiw, 2000).

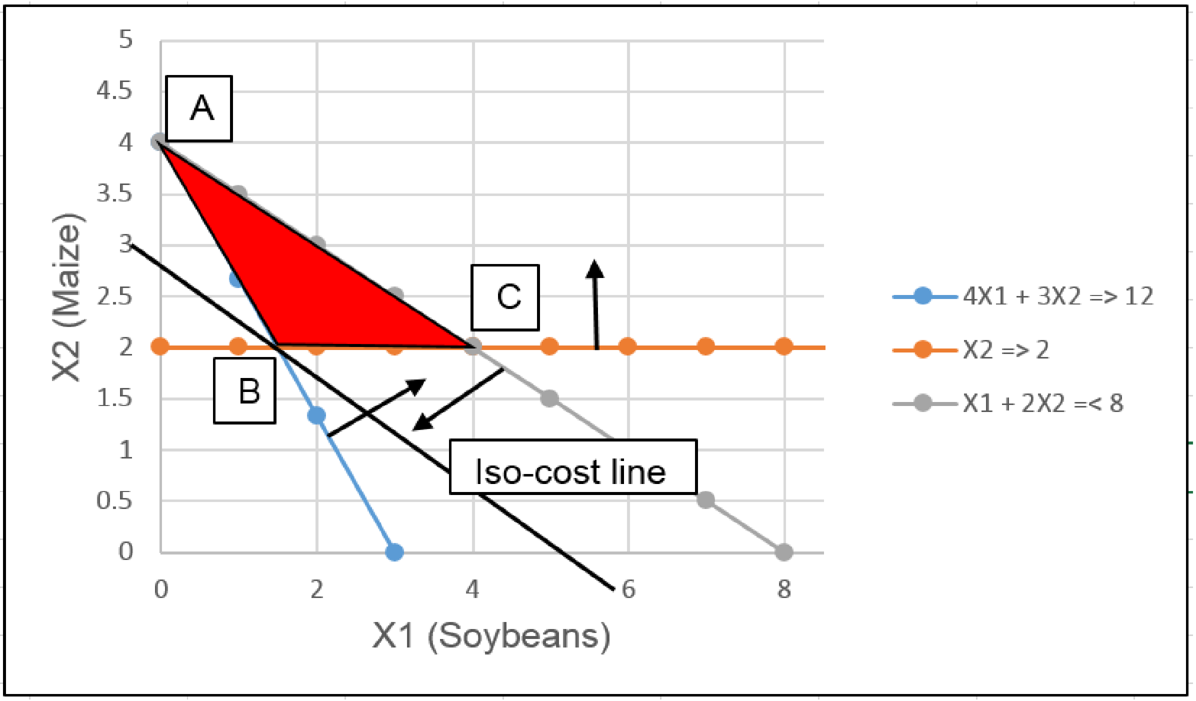


Figure 3.1: An example of a graphically explained LP problem
Source: Adapted from Stachiw (2000)

The abovementioned example is, however, a very simple example used in the beginning of all LP. The linear problem attempting to be solved in this study is far more complex. It has multiple raw materials which are limited in supply, and different rations to be mixed for various animal categories according to the nutritional requirements of each animal in every life cycle stage. Sklan and Dariel (1993) proposed and used the mixed-integer LP technique. This is a computerised method that uses software such as the General Algebraic Modelling System (GAMS) (Brooke, Kendrick, Meeraus & Raman, 1998).

To fully understand the Feed Mix problem, a more complex example of animal feed formulation will be given. McCarl and Spreen (1997) formulated the basic model as follows: Indexes are used to define certain sets in the model. Index (i) will represent the nutritional requirements (protein, energy, fat, fibre, etc.) of the animals in the problem, which should fall between specific constraints (lower and upper bounds). Index (j) is defined as the available raw materials which can be used to formulate the ration. Then, a variable (F_j) is defined, which represents the amount of each raw material used in the ration formulation. The problem includes four constraints, namely:

1. Minimum nutritional requirements (lower bound);
2. Maximum nutritional requirements (upper bound);
3. Volume to be mixed of the diet; and
4. Non-negativity constraint.

Parameters are required to state the nutritional value of each raw material, as well as parameters which describe the minimum and maximum nutrient requirements in the diet. Therefore, let a_{ij} be the quantity of a nutrient (i^{th}) present in one unit of raw material (j^{th}). The upper and lower bounds are defined as UL_i and LL_i , as the maximum and minimum amounts (Equations 3.1 and 3.2) of the i^{th} nutrient in the ration (McCarl & Spreen, 1997). By summing the nutrients generated from each raw material ($a_{ij}F_j$), the constraints require the summed amount to be less than UL_i and should exceed $LL_{i.}$

The resulting constraints read as follows:

$$\sum_j \boldsymbol{a_{ij} F_j} \geq \boldsymbol{LL_i} \quad (3.1)$$

$$\sum_j \boldsymbol{a_{ij} F_j} \leq \boldsymbol{UL_i} \quad (3.2)$$

The third constraint required is the volume of the rations needed to be mixed (Equation 3.3). An assumption is made that the weight of the formulated feed is similar to that of the raw materials.

$$\sum_j \boldsymbol{F_j} = \mathbf{1} \quad (3.3)$$

The final piece of the problem is defining an objective function (Equation 3.4) that involves a parameter for raw material cost (c_j) and an equation which sums the total ration cost across all the raw materials used (McCarl & Spreen, 1997).

$$\sum_j \boldsymbol{c_j F_j} \quad (3.4)$$

The Feed Mix problem is formulated as follows:

Minimise $\sum_j c_j F_j$

Subject to $\sum_j a_{ij} F_j \geq LL_i \; for\ all\ i$

$\sum_j a_{ij} F_j \leq UL_i \; for\ all\ i$

$\sum_j F_j = 1$

$F_j \geq 0 \quad for\ all\ j$

This is an example of a cost minimisation problem, which aims to formulate a least-cost animal feed according to the limitations in resources, as well as minimum nutrient requirements (McCarl & Spreen, 1997).

The benchmark structure of the model is explained in the following section. The new model is built on the same foundation as the Feed Mix model explained by McCarl and Spreen (1997) and follows the same basic principles.

3.3 BENCHMARK MODEL DESCRIPTION

The Benchmark model is formulated on input data from the year 2015. The first part of the model works on 2015 input data to generate benchmark results. The model is divided into two main sections, namely:

1. Determining the animal feed demand through using per capita consumption of livestock produce, population figures, and animal performance data (Figure 2.3); and
2. Using LP to determine quantities of raw material requirements, considering animal feed demand and raw material prices and availability (Figure 2.4).

Both of these main sections are explained in the following separate sections.

3.3.1 Calculating animal feed demand

This section includes all the categories that must be taken into consideration when determining the amount of animal feed required satisfying all animal categories' needs.

3.3.1.1 Animal feed demand

The demand for animal feed is mainly influenced by the per capita consumption of certain livestock meat types and the population. When taking imports and exports of meat into consideration, the model can calculate the amount of local meat required to be produced. Using final slaughter weights of animals and slaughter-out percentages, the number of animals to be slaughtered can be determined. Thereafter, using animal performance data (FCRs), the model determines the amount of animal feed required.

Thus, the model can determine animal feed demand by ways of two methods:

1. Deriving animal feed demand from per capita consumption and population estimates; and
2. Deriving animal feed demand through the number of livestock and animal slaughtering.

3.3.1.2 Animal feed consumption

The performance data of animals that are slaughtered are entered into the model. To determine the amount of animal feed, the average required weight of the animal at slaughter is multiplied by the FCR. The consumption of breeding animals – in the case of broilers, layers, ostriches, and pigs – that are required to restock slaughtered animals is determined through performance and general daily feed intake.

The feed consumed by non-slaughter animals (horses and pets) are determined by using feed consumption relative to body mass and activities during the day.

3.3.1.3 Animal performance data

The genetic improvements of animals play a critical role in animal feed demand. With improved genetics, animals are able to reach target weights earlier and consume less feed. These factors are considered in the calculations of determining animal feed demand.

In the forecasting section, predicted changes in animal performance data will be incorporated into the calculation to see the effects thereof.

3.3.1.4 Factors affecting raw animal feed demand

Certain human factors can directly influence the demand for animal feed and the derived raw material requirements of animals.

These factors include:

- Population size;
- Per capita consumption of animal-source protein; and
- Population growth.

3.3.1.5 Calculation of animal feed demand

This section explains the determination of animal feed demand, and the calculations used to derive it. The quantities of required feeds are determined and the animal feeds are then divided into different feed quantities. Figure 3.2 illustrates the main animal categories presented in the APR_OPT model. Each main animal category is further sub-divided into different animal types. Different animal types are then further divided into animal rations, which are specifically formulated to satisfy nutritional requirements for animals either in a specific life stage or precisely for the activity the animal performs.

The calculation is obtained from the APR model designed and developed by Briedenhann (2001). The APR model works on similar principles to estimate animal feed demand.

These calculations are all done on Microsoft Excel© 1997-2003 spreadsheets and are easy to change and access.

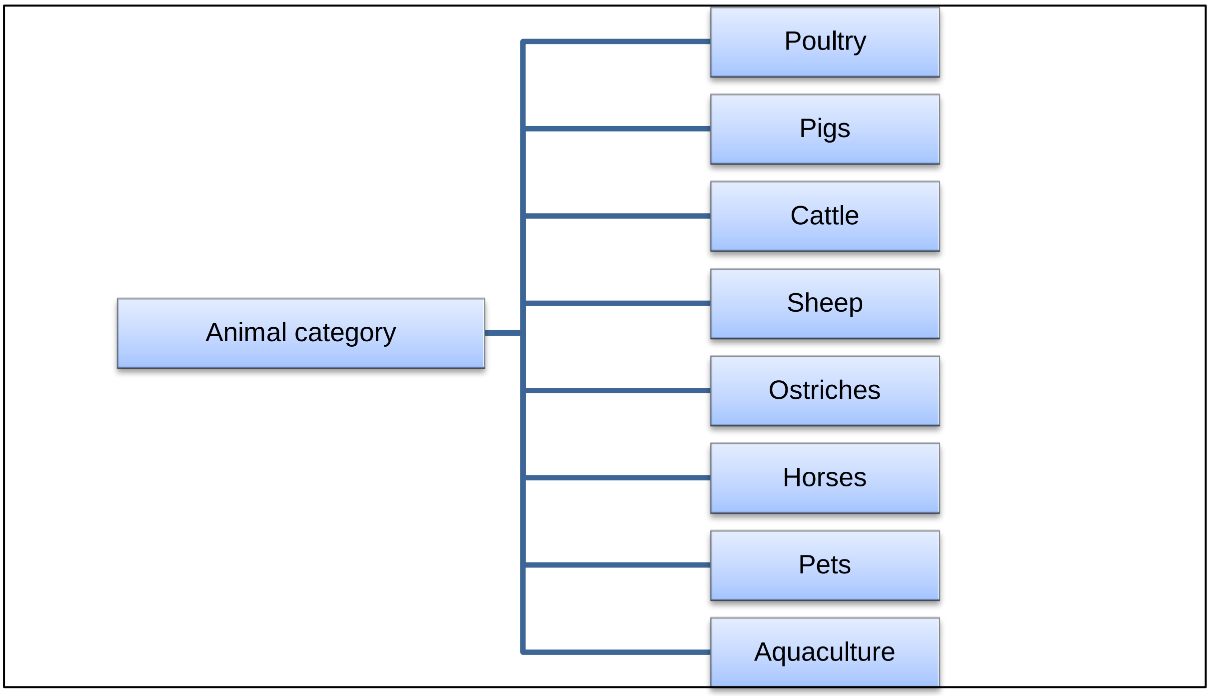


Figure 3.2: Graphical display of the main animal categories
Source: Adapted from Briedenhann (2001)

*	=	Multiplied
/	=	Divided

3.3.1.5.1 Poultry

Figure 3.3 shows the organisational chart of poultry. Poultry is referred to as the main animal category, with broilers and layers as the sub-divisions of poultry. Standard and breeder are referred to as the animal type and the sub-set below that as the different rations considered in the APR_OPT model.

Kleyn (2012) stated that the choice between diets during stages in the production process is regarded as very important, and can impact technical efficiency and the profitability of the operation. As broilers grow, their demand for energy increases relative to protein requirements (Kleyn, 2012). Thus, phase feeding implies feeding birds a nutritionally phase-formulated feed during the bird's production cycle.

The same applies to layers – different rations cater for the changing nutritional requirements of the birds.

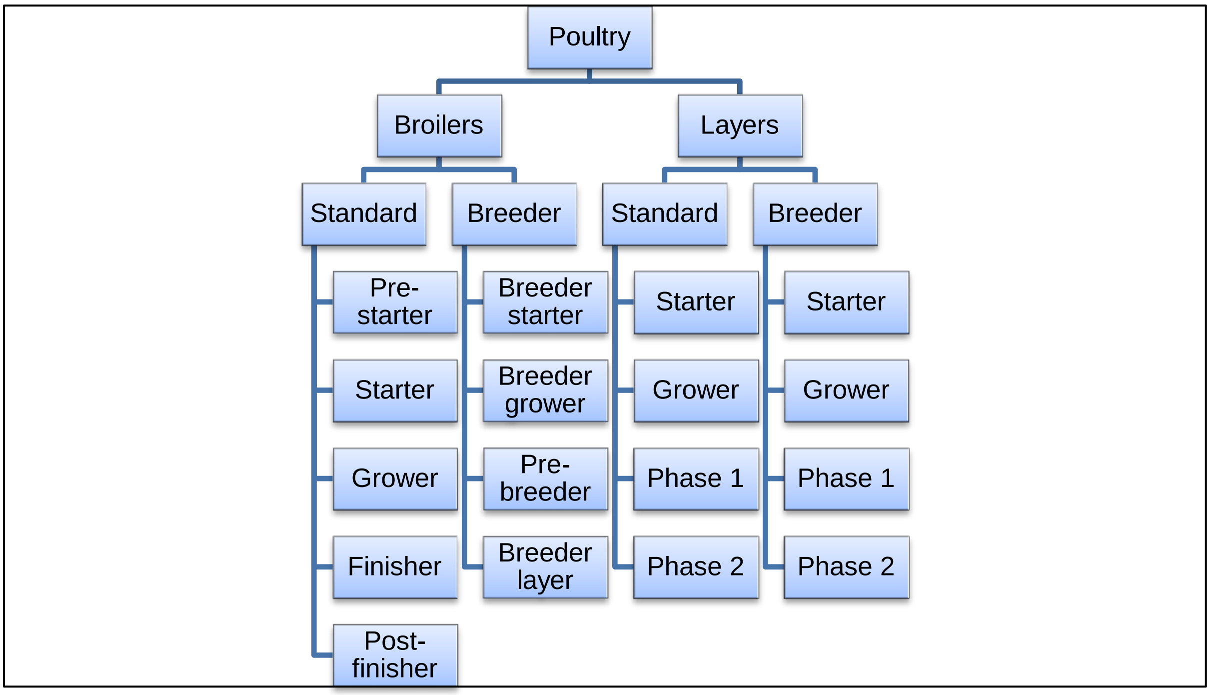


Figure 3.3: Poultry and the different rations considered in the model
Source: Adapted from Briedenhann (2001)

Table 3.3 indicates the factors taken into consideration when determining the animal feed demand of standard broilers. Per capita consumption of chicken meat and population size are the main determinants of the animal feed required. Animal performance data in terms of FCR are included to accurately estimate feed demand.

Table 3.3: Broiler standard feed consumption factors

Index	Factors	Units
A	Per capita broiler consumption	kg
B	Population size	People
C	Total broiler meat consumption	kg
D	Imported broiler meat	kg
E	Exported broiler meat	kg
F	Local broiler meat production	kg
G	Average slaughter weight	kg
H	Average slaughter out	%
I	Broiler weight after slaughter	kg
J	Broilers slaughtered per annum	Chickens
K	Total broiler weight	kg
L	FCR	ratio
M	Total broiler feed consumption	kg

Source: Briedenhann (2001)

Calculation of broiler standard feed consumption

C = A * B

F = C - D + E

J = F / (G * H)

K = J * G

M = K * L

Calculation of broiler standard ration types

1. Pre-starter 0.06 * M
2. Starter 0.24 * M
3. Grower 0.29 * M
4. Finisher 0.26 * M
5. Post-finisher 0.15 * M

Table 3.4 shows the factors taken into consideration to estimate the feed demand of broiler breeders. In Index A, the number of chickens slaughtered under standard broilers is incorporated into the calculations to determine the number of breeding hens required to replenish the slaughtered broilers.

Table 3.4: Broiler breeder feed consumption factors

Index	Factors	Units
A	Broilers slaughtered per annum (J under broiler standard)	Chickens
B	Egg production per hen housed	Eggs
C	Culling age of hens	Weeks
D	Egg production per hen per year	Eggs
E	Rejected eggs	%
F	Hatchability	%
G	Chicks per hen per year	Chickens
H	Mortality to point of lay	%
I	Total number of breeding hens required	Chickens
J	Average feed consumption per hen	kg/day
K	Total feed consumption of laying hens	kg
L	Feed consumption of rearing birds	kg
M	Total feed consumption of rearing birds	ton
O	Laying cycle	Weeks
P	Days per week	Days
Q	Rearing period	Weeks
R	Total broiler breeder feed consumption	kg

Source: Briedenhann (2001)

Calculation of broiler breeder feed consumption

I = [(A / G) * (1 - H)]

G = D * (F - E)

K = I * J

M = I * L

Calculation of broiler breeder ration types

1. Breeder rearing ration types

Breeder starter	0.19 * M
Breeder grower	0.55 * M
Breeder pre-layer	0.26 * M

2. Breeder layer ration types

Breeder layer	K

Table 3.5 presents the standard layer feed consumption factors. Once again, feed demand is driven by the human demand for eggs. Technical parameters are included in the calculation for a more complete and accurate calculation of feed demand.

Table 3.5: Layer standard feed consumption factors

Index	Factors	Units
A	Per capita egg consumption	kg
B	Population size	People
C	Total egg consumption	kg
D	Imported eggs	kg
E	Exported eggs	kg
F	Local egg production	kg
G	Average egg weight	kg
H	Egg production average (eggs/hen/cycle)	Eggs
I	Egg production per hen per year	kg
J	Culling age of hens	Weeks
K	Total number of eggs produced locally	kg
L	Total number of hens	Hens
M	Average feed consumption of hens (kg/hen/day)	kg
N	Total feed consumption of laying hens	kg
O	Feed consumption of rearing birds	kg/bird
P	Total feed consumption of rearing birds	kg
Q	Weeks in lay	Weeks
R	Days in week	Days
S	Rearing period	Weeks
T	Rearing consumption	kg
U	Total layer standard feed consumption	kg

Source: Briedenhann (2001)

Calculation of layer standard feed consumption

C	=	A * B
F	=	C - D + E
K	=	F / G
I	=	[H / (J - S)] * Q
L	=	K / I
N	=	L * M
P	=	L * O

Calculation of layer standard ration type quantities

1. Layer rearing feed rations

Layer starter	0.18 * P
Layer grower	0.82 * P

2. Laying hens feed rations

Phase 1	0.40 * N
Phase 2	0.60 * N

Table 3.6 shows the factors taken into consideration when determining the feed demand of layer breeders. Index A is linked to standard layers and is used to determine the number of layer breeder hens required to replace the aged standard layer hens.

Table 3.6: Layer breeder feed consumption factors

Index	Factors	Units
A	Total number of hens (L under Layer Standard)	Hens
B	Egg production(eggs/hen/cycle)	Eggs
C	Culling age of hens	Weeks
D	Egg production per hen per year	Eggs
E	Mortality to point of lay	%
F	Total number breeding hens required	Hens
G	Average feed consumption of hens	kg/hen/day
H	Total feed consumption of laying hens	kg
I	Feed consumption of rearing birds	kg
J	Total feed consumption of rearing birds	kg

Source: Briedenhann (2001)

Calculation of layer breeder feed consumption

F	=	A / B
H	=	F * G
J	=	F * I

Calculation of layer breeder ration quantities

1. Layer rearing feed rations

Layer starter	0.18 * J
Layer grower	0.82 * J

2. Laying hens feed rations

Phase 1	0.40 * H
Phase 2	0.60 * H

3.3.1.5.2 Pigs

Figure 3.4 shows that pigs are sub-divided into standard pigs, which produce pork, and breeder pigs, which are necessary to restock the slaughtered pigs. Attached to every sub-division are the different pig rations. The model takes all these rations into consideration.

Feed contributes 70% of the production costs of any pig production system (Kleyn, 2010). Thus, the importance of correctly formulated feed is highlighted. Kleyn (2010:46) stated that feeding growing pigs multiple diets during the grower-finisher phase minimises extra feed costs and improves performance. The same principle applies to the breeding herd. Breeding pigs performing different activities are fed diets supplying in the nutritional needs.

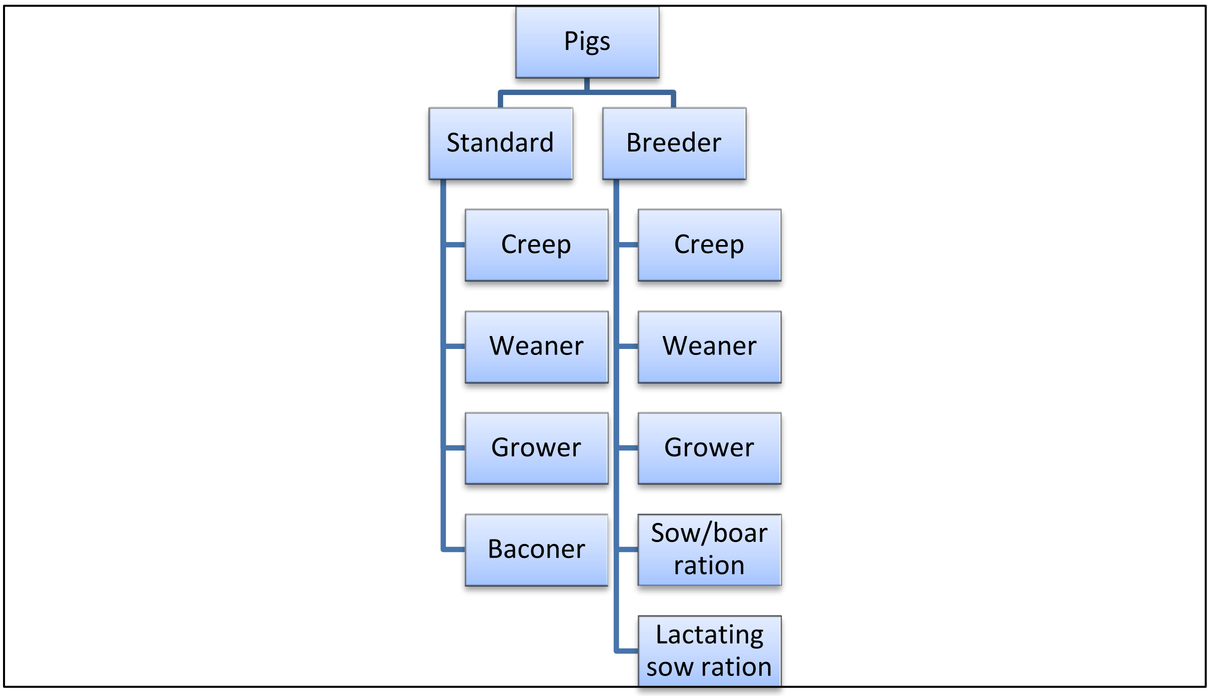


Figure 3.4: Pigs and the different rations considered in the model
Source: Adapted from Briedenhann (2001)

The consumption factors of standard pigs are shown in Table 3.7. The demand for pork is driven by per capita consumption and the population size. Furthermore, imports and exports are taken into account to determine the local pork production quantities. Different FCR ratios are used for baconers and porkers in different production systems.

Table 3.7: Pig standard feed consumption factors

Index	Factors	Units
A	Per capita pork consumption	kg
B	Population size	People
C	Total pork consumption	kg
D	Ratio of porkers to baconers	%
E	Imported pork	kg
F	Exported pork	kg
G	Local pig meat production	kg
H	Average porker weight at slaughter	kg
I	Average baconer weight at slaughter	kg
J	Average pig weight after slaughter	kg
K	Slaughter-out percentage	%
L	Total pigs slaughtered	Pigs
M	Total weight porkers	kg
N	Total weight baconers	kg
O	Average FCR porker	Ratio
P	Average FCR baconer	Ratio
Q	Total pig feed consumption	kg

Source: Briedenhann (2001)

Calculation of pig standard feed consumption

C = A * B

G = C - E + F

J = [(H * D) + (I * (1 – D))] * K

L = G / J

M = L * H * D

N = L * (1 – D) * I

Q = [(M * O) + (N * P)]

Calculation of pig standard ration types

1. Creep Q * 0.20
2. Weaner Q * 0.16
3. Grower Q * 0.72
4. Baconer Q * 0.10

Table 3.8 shows the pig breeder feed consumption factors which influence the demand for feed. The number of pigs slaughtered per annum, as seen in Table 3.7, is used to determine the number of sows required to replenish standard pig stocks. The calculation caters for pregnant and lactating sows, as well as for boars as the nutritional requirements differ for each activity and performance.

Table 3.8: Pig breeder feed consumption factors

Index	Factors	Units
A	Pigs slaughtered per annum (L from Pig Standard)	Pigs
B	Piglets marketed per sow per year	Piglets
C	Sow herd required to produce slaughter pigs	Sows
D	Ratio of sows to boars	Ratio
E	Boar herd required to produce slaughter pigs	Boars
F	Average feed consumption of pregnant sows	kg/day
G	Average feed consumption of lactating sows	kg/day
H	Average feed consumption of boars	kg/day
I	Total feed consumption of pregnant sows	kg
J	Total feed consumption of lactating sows	kg
K	Total feed consumption of boars	kg
L	Pregnant sow days	Days
M	Lactating sow days	Days
N	Days in year	Days
O	Sow and boar	kg
P	Lactating sow	kg
Q	Growing breeder feed consumption	kg
R	Total growing breeder feed consumption	kg
S	Total pig breeder feed consumption	kg

Source: Briedenhann (2001)

Calculation of pig breeder feed consumption

C = A / B

E = C / D

I = C * F * L

J = C * G * M

K = E * H * N

O = I + K

P = J

R = Q * (E + C)

S = O + P + R

Calculation of pig breeder ration types

1. Sow and boar O
2. Lactating sow P

Calculation of growing pig breeder ration

1. Creep R * 0.02
2. Weaner R * 0.15
3. Grower R * 0.72

3.3.1.5.3 Cattle

In Figure 3.5 cattle is regarded as the main animal category. It is then divided into beef cattle that produce meat and dairy cattle that produce milk. Beef cattle are then further divided into feedlot cattle and other cattle, with the rations allocated to them. Dairy cattle are divided into calves and cows. Calves have starter and grower rations, and cows have three different rations allocated to them regarding the type of system the dairy cows fall in.

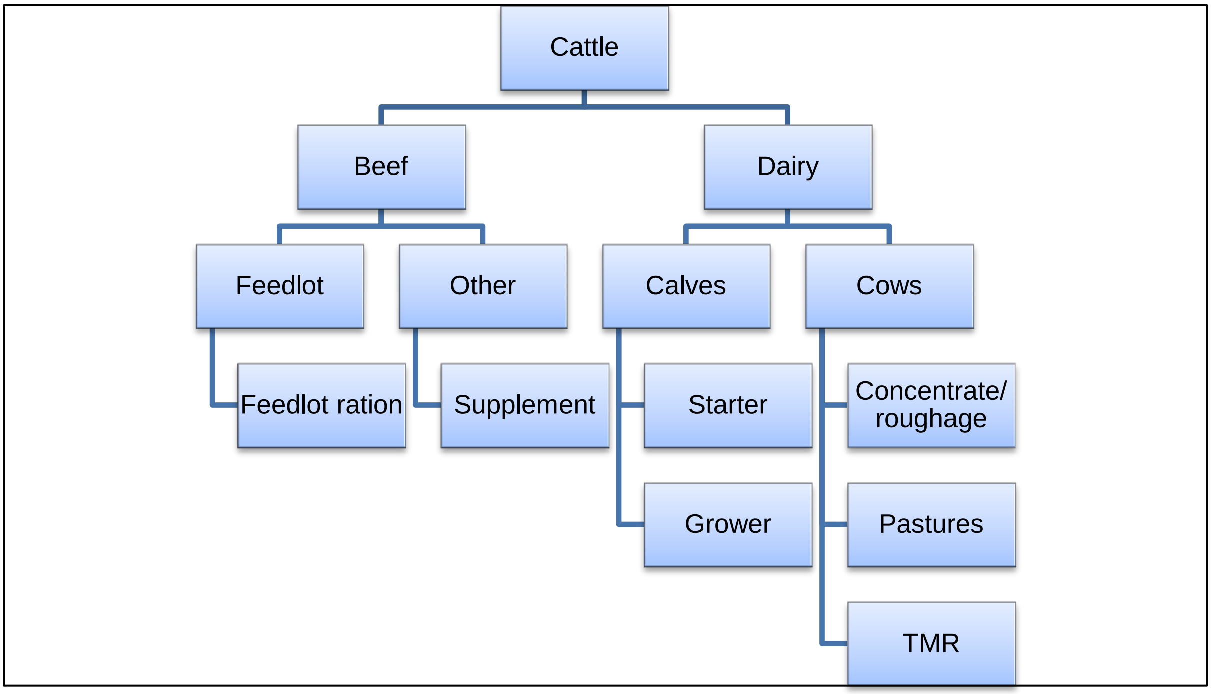


Figure 3.5: Cattle and the different rations considered in the model
Source: Adapted from Briedenhann (2001)

Table 3.9 shows the beef cattle feed consumption factors that are considered in the calculation of estimating feed demand. Beef cattle reach marketing weight through two methods: either on extensive grazing conditions or in the feedlot. The calculation separates these two as different FCRs as linked to the systems.

Table 3.9: Cattle beef feed consumption factors

Index	Factors	Units
A	Per capita beef consumption	kg
B	Population size	People
C	Total beef consumption	kg
D	Imported beef meat	kg
E	Exported beef meat	kg
F	Total local beef production	kg
G	Average feedlot weight at slaughter	kg
H	Average other cattle weight at slaughter	kg

Index	Factors	Units
I	Weight entering feedlots	kg
J	Weight gain in feedlots	kg
K	Slaughter-out percentage	%
L	Average weight after slaughter: feedlot cattle	kg
M	Average weight after slaughter: other cattle	kg
O	Total number feedlot cattle	Cattle
P	Total number other cattle	Cattle
Q	Ratio feedlot cattle to other	Ratio
R	Total weight feedlot cattle	kg
S	Total weight other cattle	kg
T	FCR feedlot	Ratio
U	FCR other	Ratio
V	Total feedlot feed consumed	kg
W	Total other feed consumed	kg
X	Total cattle beef feed consumption	kg

Source: Briedenhann (2001)

Calculation of cattle beef feed consumption

C = A * B

F = C - D + E

L = G * K

M = H * K

O = (F / L) * Q

P = (F / M) * (1 - Q)

R = J * O

S = H * P

V = R * T

W = S * U

X = V + W

Calculation of cattle beef ration types

1. Feedlot ration V
2. Supplement ration W

The feed consumption factors of dairy cattle are shown in Table 3.10. The calculation provides for various diets in the dairy industry. Diets are formulated for calves and cows. There are three feeding/grazing systems for cows, namely concentrate/roughage diets, pasture feeding, and total mixed rations (TMR) and these systems are catered for in the calculations.

Table 3.10: Dairy cattle feed consumption factors

Index	Factors	Units
A	Per capita milk consumption, dairy products converted to milk equivalent	ℓ/person
B	Population size	People
C	Total milk consumption	ℓ
D	Milk imported (dairy products converted)	ℓ/annum
E	Milk exports	ℓ/annum
F	Milk production local	ℓ
G	Cows in milk	Cows
H	Average milk production per cow	ℓ/cow
I	Dry cows	Cows
J	Average concentrate consumption per cow in lactation	kg/day
K	Average concentrate consumption per dry cow	kg/day
L	Ratio of cows in milk to calves	%
M	Calves required to replace cows	Calves
N	Heifers required to replace cows	Heifers
O	Ratio of cows in milk to heifers	%
P	Feed consumption of calves	kg/day
Q	Feed consumption of heifers	kg/day
R	Total concentrate consumption of cows	kg
S	Total concentrate consumption of calves	kg
T	Total concentrate consumption of heifers	kg
U	Cows on concentrate/roughage system	%
V	Cows on pasture system	%
W	Cows on TMR	%
X	Days in year	days
Y	Dry cow percentage	%
Z	Calve starter ration	kg
AA	Calve grower ration	kg
AB	Cows concentrate/roughage ration	kg
AC	Cows pasture ration	kg
AD	Cows TMR ration	kg
AE	Total dairy cattle feed consumption	kg

Source: Briedenhann (2001)

<u>Calculation of cattle dairy feed consumption</u>

C = A * B

F = C - D + E

G = F / (H * X)

I = (F / (H * X)) * Y

M = G * L

N = G * O

R = [(G * J * X) + (I * K * X)]

S = M * P * X

T = N * Q * X

Z = S

AA = T

AB	=	R * U
AC	=	R * V
AD	=	R * W
AE	=	AB + AC + AD

Calculation of cattle dairy ration types

1.	Calf starter	S
2.	Calf grower	T
3.	Cows concentrate/roughage	AB
4.	Cows pasture	AC
5.	Cows TMR	AD

3.3.1.5.4 Sheep

Figure 3.6 graphically explains the animal categories that have a smaller demand for animal feed than the aforementioned animal categories. In Figure 3.6, sheep are divided into sheep fed in the feedlot, and sheep on extensive grazing systems with a supplement associated with it.

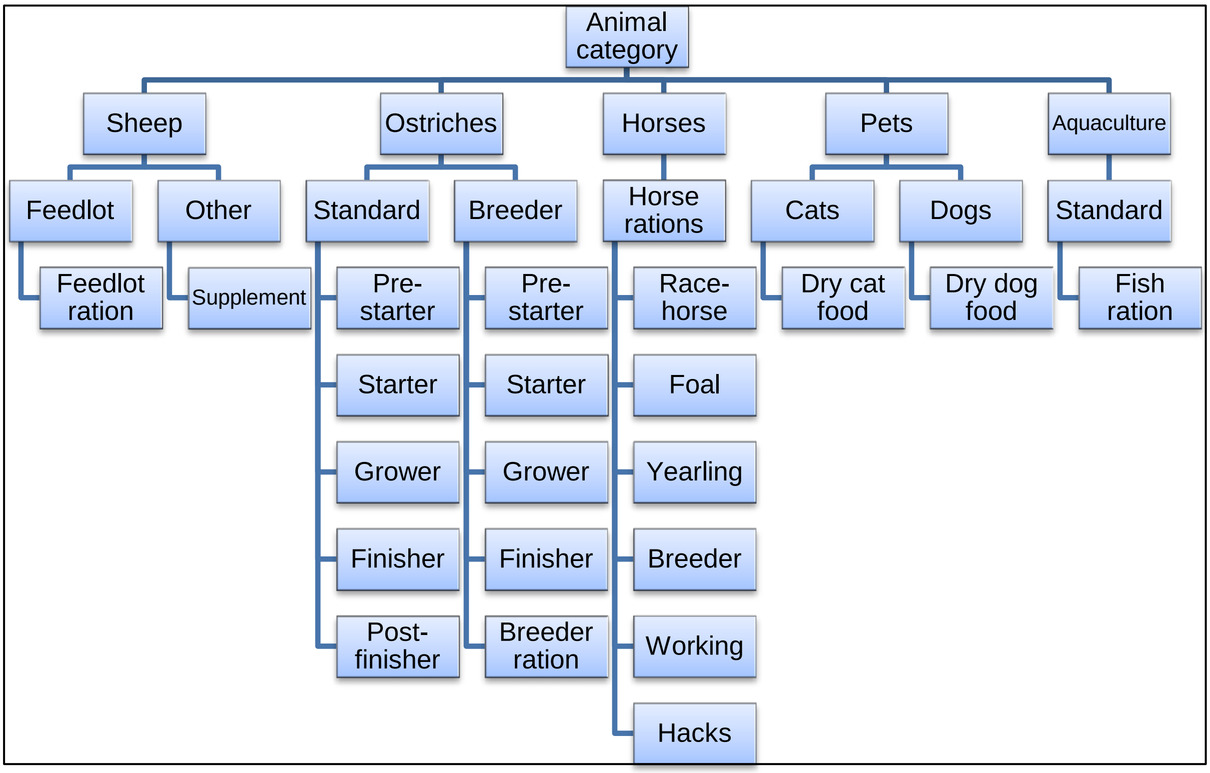


Figure 3.6: Sheep, ostriches, horses, pets, aquaculture and the rations considered in the model

Source: Adapted from Briedenhann (2001)

Sheep feed consumption factors are indicated in Table 3.11. Per capita mutton consumption and population size determine the amount of mutton demanded. When taking imports and exports into consideration, the amount of locally produced mutton is determined. Sheep are split into feedlot sheep and sheep reaching market weight on extensive grazing conditions. Both these categories have different FCRs allocated to it.

Table 3.11: Sheep feed consumption factors

Index	Factors	Units
A	Per capita sheep meat consumption	kg
B	Population size	People
C	Total sheep meat consumption	kg
D	Imported sheep meat	kg
E	Exported sheep meat	kg
F	Total local sheep production	kg
G	Average feedlot weight at slaughter	kg
H	Average other sheep weight at slaughter	kg
I	Slaughter-out percentage	%
J	Average entering feedlot weight	kg
K	Weight gain in feedlot	kg
L	Average weight after slaughter: feedlot sheep	kg
M	Average weight after slaughter: other sheep	kg
N	Total number feedlot sheep	Feedlot
O	Total number other sheep	Other
P	Ratio of intensive to extensive sheep	Ratio
Q	Total weight gain in feedlot sheep	kg
R	Total weight other sheep	kg
S	FCR feedlot	Ratio
T	FCR other	Ratio
U	Total sheep feedlot feed consumed	kg
V	Total sheep supplement feed consumed	kg
W	Total sheep feed consumed	kg

Source: Briedenhann (2001)

<u>Calculation of sheep feed demand</u>

C = A * B

F = C – D + E

K = G – J

L = G * I

M = H * I

N = [(F * P) / L)

O = [(F * (1 – P)) / M]

Q = K * N

R = H * O

U = Q * S

V = R * T

W = U + W

Calculation of sheep ration types

1. Feedlot ration U
2. Supplements V

3.3.1.5.5 Ostriches

According to Figure 3.6, ostriches are divided into standard ostriches, which produce meat for the market, and breeder ostriches, which aim to replenish the slaughtered ostriches in the meat industry. Both the standard and breeder ostriches have rations associated to it, which are specifically formulated to supply the nutritional needs of ostriches in every life stage.

In Table 3.12, the calculation uses the amount of ostriches slaughtered to determine the amount of feed demanded.

Table 3.12: Ostrich standard feed consumption factors

Index	Factors	Units
A	Number of ostriches slaughtered per annum	Ostriches
B	Average ostrich weight	kg
C	Total ostrich weight at slaughter	kg
D	FCR	kg
E	Total ostrich standard feed consumption	kg

Source: Adapted from Briedenhann (2001)

Calculation of ostrich standard feed demand

C = A * B

E = C * D

Calculation of ostrich standard ration types

1. Pre-starter E * 0.03
2. Starter E * 0.08
3. Grower E * 0.13
4. Finisher E * 0.33
5. Post-finisher E * 0.43

Breeder ostriches are used to restock the slaughtered standard ostriches. To determine the number of ostriches required to breed, the calculation uses the number of ostriches slaughtered in Table 3.12. Feed consumption is split into rearing birds and breeder birds (Table 3.13).

Table 3.13: Ostrich breeder feed consumption factors

Index	Factors	Units
A	Number of ostriches slaughtered per annum (A in Table 3.12)	Ostriches
B	Average birds per breeder per year	birds/annum
C	Mortality to point of lay	%
D	Number of breeding ostriches required	Ostriches
E	Average feed consumption of ostriches	kg/day
F	Total feed consumption of laying ostriches	kg
G	Feed consumption of rearing birds	kg
H	Total feed consumption of rearing birds	kg
I	Days in a year	Days
J	Total feed consumption of breeder ostriches	kg

Source: Briedenhann (2001)

Calculation of breeder ostrich feed demand

D = [A / (B * (1 – C))]

F = D * E * I

H = D * G

J = F + H

Calculation of breeder ostrich ration types

1. Pre-starter H * 0.05
2. Starter H * 0.14
3. Grower H * 0.23
4. Finisher H * 0.58
5. Breeder F

3.3.1.5.6 Horses

Horses are given rations specifically formulated for the work or activity performed by the animal. Thus, it is clear that every activity has specific nutritional requirements for the animal to perform optimally.

The calculation accommodates different horse diets in determining the amount of feed demanded (Table 3.14). The diets have different nutrient properties, which supply the needs of the activity the horse performs.

Table 3.14: Horse feed consumption factors

Index	Factors	Units
A	Total number of horses	Horses
B	Percentage of horses consuming concentrates	%
C	Feed consumption of foals	kg/day
D	Feed consumption of yearlings	kg/day
E	Feed consumption of breeding horses	kg/day
F	Feed consumption of hacks	kg/day
G	Feed consumption of racehorses	kg/day
H	Feed consumption of working horses	kg/day
I	Percentage of horses that are foals	%
J	Percentage of horses that are yearlings	%
K	Percentage of horses that are breeders	%
L	Percentage of horses that are hacks	%
M	Percentage of horses that are racehorses	%
N	Percentage of working horses	%
O	Days in a year	Days
P	Total horse feed consumption	kg

Source: Briedenhann (2001)

Calculation of horse feed demand

$$P = [(A * C * I) + (A * D * J) + (A * E * K) + (A * F * L) + (A * G * M) + (A * H * N)] * B * O$$

Calculation of horse ration types

1. Racehorse P * 0.07
2. Foal P * 0.05
3. Yearling P * 0.06
4. Breeder P * 0.04
5. Hack P * 0.73
6. Working P * 0.05

3.3.1.5.7 Pets

Pets are divided into dogs and cats (Figure 3.6). Dry dog and cat food rations are respectively linked to the main categories.

The demanded pet food (Table 3.15) of cats and dogs is determined using percentage consumption of body weight. The calculation accommodates dogs of different sizes for a more accurate estimation of food demand.

Table 3.15: Pet food consumption factors

Index	Factors	Units
A	Total number of pets	Pets
B	Cats as percentage of pets	%
C	Dogs as percentage of pets	%
D	Cats: percentage of body mass consumption per day	%
E	Dogs: percentage of body mass consumption per day	%
F	Cats: percentage fed dry cat food	%
G	Dogs: percentage fed dry dog food	%
H	Average cat weight	kg
I	Average small dog weight	kg
J	Average medium dog weight	kg
K	Average large dog weight	kg
L	Percentage small dogs	%
M	Percentage medium dogs	%
N	Percentage large dogs	%
O	Number of cats	Cats
P	Number of dogs	Dogs
Q	Days in a year	days
R	Dry cat food fed	kg
S	Dry dog food fed	kg
T	Total pet feed consumption	kg

Source: Briedenhann (2001)

<u>Calculation of pet food demand</u>

O = A * B

P = A * C

R = [(O * F * H) * (D * Q)]

S = [((P * L * I) + (P * M * J)+ (P * N * K)) * (G * Q)]

T = R + S

<u>Calculation of pet food ration types:</u>

1. Dry cat food R
2. Dry dog food S

3.3.1.5.8 Aquaculture

Aquaculture only has a fish ration linked to it (Figure 3.6). Table 3.16 shows the feed demand factors for aquaculture and determines the total feed demanded by using FCR.

Table 3.16: Aquaculture feed demand factors

Index	Factors	Units
A	Number of fish produced	Fish
B	Average weight of fish	kg
C	Total weight of fish	kg
D	Average FCR	Ratio
E	Total aquaculture feed consumed	kg

Source: Briedenhann (2001)

Calculation of aquaculture feed demand

C = A * B

E = C * D

The calculation of animal feed demand was explained step-by-step in the aforementioned literature. The APR_OPT model has now quantified the animal feed demand for all animal categories. With this important step completed, the APR_OPT model is now able to formulate least-cost animal feed rations according to the nutrient requirements of every animal category. Thereafter, the APR_OPT model is able to quantify raw material usage and allocation. This is explained in detail in the following sections.

3.3.2 Determining raw material requirements with the APR_OPT model

This section consists of two parts. In the first section, the input data into the model are explained. The input data are of critical importance in determining the raw materials required for animal feed. The nutritional requirements of animals, raw material availability, and animal feed demand lead to the constraints imposed on the APR_OPT model to accurately determine raw material requirements for animal feed. The second section is a detailed description of the APR_OPT model. The section contains the objective function of the model, as well as the constraints that are imposed on the model.

3.3.2.1 Important factors in determining raw material requirements

This section consists of the important nutritional animal requirements, raw material nutrient content, and the limitations of raw materials, as well as the availability and prices of local raw materials that should be taken into account when formulating rations for the various types of animals. These are important data that should be entered into the model for accurate answers. The user is able to adjust nutrient requirements in the model for different rations, as well as to add new raw materials into the nutrient matrix to model the impact thereof.

3.3.2.1.1 Animal nutrient requirements

A vast number of conversations were held with Dr E. Briedenhann in the year 2015. Dr E. Briedenhann has vast experience in animal feed formulation, and has consulted with many experts in relevant fields of animal nutrition. Briedenhann (2001) has also conducted intensive research on the nutritional requirements of animals at different phases of life, and the information is noted in the study conducted by Briedenhann (2001). References are also made to Kleyn (2010) and Kleyn (2012) for pig nutrition and poultry nutrition respectively. The work of Gillespie and Flanders (2009) is also used to examine different nutrient requirements for animals.

3.3.2.1.2 Nutritional limitations

Raw materials have certain limitations and shortfalls when formulated into animal feed rations. The nutritional characteristics of raw materials have both advantages and limitations when used for formulating feeds. The limitations are inserted into the model to ensure that animal feed is formulated and raw materials are included at feasible rates.

3.3.2.1.3 Local raw material availability

The APR_OPT model calculates the extraction of various raw materials from grains to milling by-products, wheat milling for human consumption to wheat middlings, wet maize milling to gluten 20 and gluten 60, poultry by-products from the number of broilers slaughtered, and the extraction of soya and sunflower oilcake as a by-product of extracting oil from soya beans and sunflower.

3.3.2.1.4 Raw material nutrient content

The nutrient content that each raw material contains plays a critical role in terms of the value that a raw material can add to the animal rations. These values are important in meeting the nutritional requirements of each animal in the different life stages. The nutrient content of local raw materials is inserted into the model, and the APR_OPT model allows for imported raw materials to have a different nutrient content than local raw materials. Space is made available to easily add new raw materials into the APR_OPT model.

References are made to Briedenhann (2001), Kleyn (2010), Kleyn (2012), and Gillespie and Flanders (2009).

3.3.2.1.5 Raw material restrictions

The physical and nutritional characteristics of raw materials determine the inclusion levels of each separate raw material in the diets formulated for specific animals. The maximum inclusion levels of raw materials are explained by Briedenhann (2001).

Thus, the inclusion of raw materials is restricted in the model. The restrictions are, however, accessible and can be changed to meet new compositions of raw materials.

3.3.2.2 APR_OPT model description

In order to optimise the allocation and usage of raw materials across South Africa to minimise the cost of animal feeds in all animal categories, it is necessary to identify different constraints and parameters which determine the optimal least-cost formulation of animal diets, driven by the human demand for animal-source protein and population size.

The APR_OPT model quantifies and models the protein interactions between humans and animal and protein plant sources. It includes raw material costs, transport costs of raw materials, minimum and maximum animal nutrient requirements, raw materials supply constraints, and the quantity of animal feed required to be formulated for each animal category. The objective of the function is to minimise the cost of animal rations across all animal categories. The quantification of animal feed is determined in Section 3.3.1.5 and applied as input data into the APR_OPT model.

The APR_OPT model uses the form of an LP model, as explained in Section 3.2. The model is formulated and structured as an LP model. The GAMS (Brooke *et al*., 1998) is used to develop and optimise the formulation of least-cost animal feed rations and raw material allocations. Similar to the Feed Mix problem explained in Section 3.2.2, the GAMS formulation consists of the following basic components:

1. Objective function:

The objective of this model is to minimise the cost of each animal ration mixed, taking into account raw material prices and the transport cost of raw materials.

2. Decision variables:

The key decision variable is defined as the quantity of a raw material under a specific raw material category originating from a source region to a demand region for a specific formulated diet of a type of animal under a main animal category.

3. Resource constraints:

The first constraint to satisfy is the minimum nutrient requirements needed for each animal ration, and secondly, not to exceed the maximum nutrient requirements. Thirdly, constraint is placed on the amount of animal feed required to be mixed for each animal category across South Africa. The fourth constraint is on the availability of local raw materials in South Africa and the amount of raw materials available to be imported from other countries.

The code written in the GAMS consists mainly of three sections. In the first section, all the input data required in the APR_OPT are defined as sets, scalars, parameters, and tables. In the second section, the mathematical programming is performed when the formulation of variables, equations, and constraints takes place. Finally, the third section comprises of writing output result files of the optimal solution and exporting it to a Microsoft Excel© 1997-2003 spreadsheet.

3.3.2.2.1 Objective function

The APR_OPT model is developed when making the assumption that when mixing animal feeds, the main objective of mixing it is to minimise the total cost of the rations. Least-cost animal rations are minimised in Equation 3.5:

$$\boldsymbol{MIN}: \boldsymbol{Z} = \sum_{y,a,t,d,m,f,c,r} \boldsymbol{X}_{y,a,t,d,m,f,c,r} \, (\boldsymbol{fc}_{y,m,f,c} + \boldsymbol{tr}_{y,m,f,c,r}) \tag{3.5}$$

Where:

$X_{y,a,t,d,m,f,c,r}$	Quantity of feed ingredient *f*, classified under raw material category *m*, used for a specific diet *d*, formulated for a specific animal *t*, classified under animal category *a*, from source region *c* to demand region *r* (kg), for specific year *y*.
$fc_{y,m,f,c}$	The cost of feed ingredient *f*, classified under raw material category *m*, from source region *c* (R/kg) for specific year *y*.
$tr_{y,m,f,c,r}$	Transport costs of feed ingredient *f*, classified under raw material category *m*, from source region *c* to demand region *r* (R/kg), for specific year *y*.

The objective function is formulated to minimise the cost of ration formulation. Transport costs are included in the objective function as some raw materials are not available in all South African regions and should therefore be transported from a supply region to the demand point where it is required. Thus, the model will allocate raw materials from different supply regions in South Africa to the regions demanding the raw materials to minimise the ration costs.

3.3.2.2.2 Decision variable

The decision or positive variable is used in Equation 3.5 and is present in all the constraints implemented in the APR_OPT model. The decision variable is defined as follows:

$X_{y,a,t,d,m,f,c,r}$	Quantity of feed ingredient *f*, classified under raw material category *m*, used for a specific diet *d*, formulated for a specific animal *t*, classified under animal category *a*, from source region *c* to demand region *r* (kg), for specific year *y*.

3.3.2.2.3 Constraints of the model

In the following section, the constraints that are implemented into the model are explained. The **first constraint** is the minimum nutrient requirements that every feed ration / diet *d* should include satisfying the nutritional needs of the animals, which are in different life cycle stages and performing different work activities.

Equation 3.6 represents the minimum nutritional (*MiNR*) animal requirements:

$$\sum_{a,t,d,m,f,c,r} \quad X_{y,a,t,d,m,f,c,r} \times nut_{m,f,c,n} \geq MiNR_{a,t,d,n} \times acr_{y,a,t,d,r} \tag{3.6}$$

Where:

$nut_{m,f,c,n}$	defines the *n* nutrients each *f* feed ingredient, classified under feed ingredient category *m*, originating from source region *c,* contains (g/kg)
$MiNR_{a,t,d,n}$	defines the minimum nutrient requirements *n* that that the diet *d* of each animal type *t*, classified under animal category *a*, should contain to satisfy the minimum animal nutrient requirements *n* (g/kg).
$acr_{y,a,t,d,r}$	animal consumption per region defines the amount of each diet *d*, every animal *t,* classified under animal category *a,* demands in each demand region *r* (kg), for specific year *y.*

Equation 3.7 explains the process of determining the animal consumption / feed demand per region. It is stated as follows:

$$acr_{y,a,t,d,r} = ad_{y,a,t} \times rbd_{a,t,r} \times dbd_{a,t,d} \tag{3.7}$$

Where:

$ad_{y,a,t}$	is the animal feed demand for animal type *t*, classified under each animal category *t* (kg), for specific year *y.*
$rbd_{a,t,r}$	region breakdown is the percentage dividing the three demand regions *r* in South Africa according to the amount of animals *t* in each region classified under animal category *t*(%).
$dbd_{a,t,d}$	is the diet breakdown percentage of the amount of feed required in diet *d* for animal *t* classified under animal category *a* (%).

The animals are divided into different regions in South Africa, and Equation 3.6 implements a constraint on the APR_OPT model to satisfy the minimum nutrient requirements of animals across the country.

The **second constraint** is the maximum nutrient requirements that every feed ration / diet *d* should not exceed. Once the diets exceed the maximum nutrient requirements, the diets become expensive and infeasible for the animal to eat.

Equation 3.8 represents the maximum nutritional (*MaNR*) animal requirements not to be exceeded in the ration formulations:

$$\boldsymbol{\sum_{a,t,d,m,f,c,r} X_{y,a,t,d,m,f,c,r} \times nut_{m,f,c,n} \leq MaNR_{a,t,d,n} \times acr_{y,a,t,d,r}} \quad (3.8)$$

Where:

$\boldsymbol{MaNR}_{a,t,d,n}$	defines the maximum nutrient requirements *n* that the diet *d* of each animal type *t*, classified under animal category *a*, should not exceed (g/kg).

The **third constraint** is imposed on the quantity demanded by each diet by each and every type of animal classified under the main animal categories. The quantity mixed should be equal to the amount of feed demanded by the animals.

Equation 3.8 represents the quantity of feed to be mixed to be equal to the feed amount demanded. Equation 3.8 is represented as follows:

$$\sum_{m,r,c} X_{y,a,t,d,m,f,c,r} = acr_{y,a,t,d,r} \quad (3.8)$$

The **fourth constraint** is a feed ingredient supply constraint, which states that the amount of raw materials used to compose the animal feed rations should not exceed the availability of the raw materials.

Equation 3.9 shows that raw materials are limited in South Africa and are supplemented by import sources, thus the amount of raw materials used should be equal to or less than the availability of raw materials. Equation 3.9 is defined as follows:

$$\sum_{a,t,d,r} X_{y,a,t,d,m,f,c,r} \leq rms_{y,m,f,c} \quad (3.9)$$

Where:

$rms_{y,m,f,c}$	*rms* is the raw material supply or the available feed ingredients *f*, classified under raw material category *m*, available in each source/supply region *c* (kg) for specific year *y.*

The **fifth constraint** is a non-negativity constraint which states that a decision variable cannot be smaller than zero. It is to ensure that raw materials are included in the ration formulation and do not include negative numbers.

Equation 3.10 shows the non-negativity constraint and is stated as follows:

$$X_{y,a,t,d,m,f,c,r} \geq 0 \quad (3.10)$$

3.4 FORECASTING METHODS AND DATA

This section focuses on the integration of the BFAP data into the APR_OPT model. The key assumptions underlying the data generated for the BFAP model for the period of 2015 to 2024 are well explained in BFAP (2015:16-17).

Furthermore, forecasting methods are examined closely, as the model will do a benchmark year in 2015, and will do forecasts until 2024. In Figure 3.7, the forecasting data used in the APR_OPT model are divided into three sub-divisions. The first division entails the human factor, which regards population estimates, per capita consumption of meat products, and imports and exports of meat products. The second division describes raw material forecast estimates in terms of availability and costs of raw material, as well as transports costs. Animals undergo genetic improvement in the third division in terms of FCRs and the days required by the animal to reach market weight.

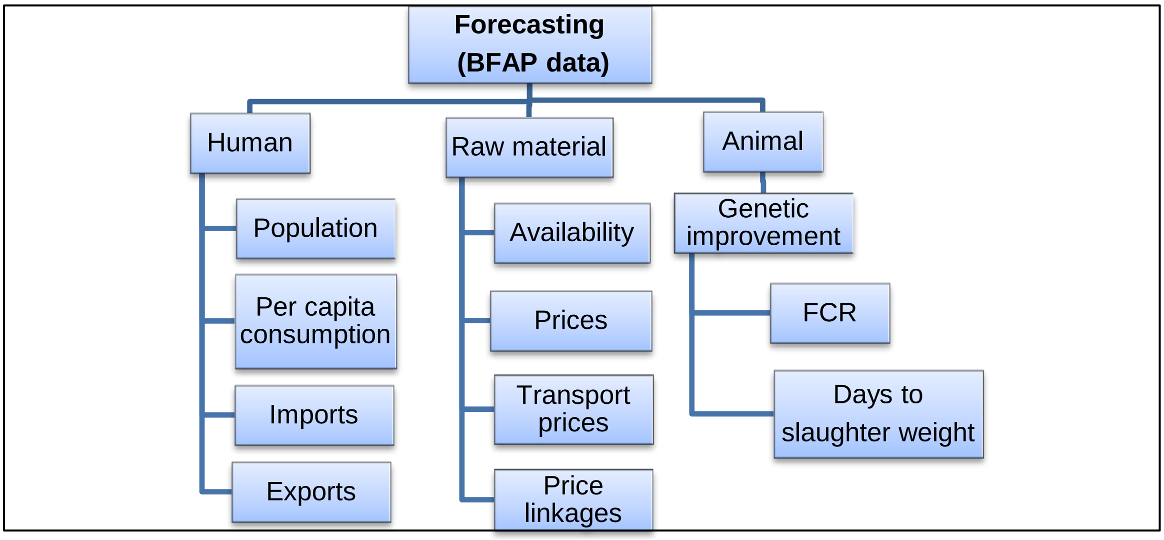


Figure 3.7: A graphical illustration of the data used for forecasting purposes
Source: Briedenhann (2001)

Data that are unavailable from the BFAP model will be derived from and determined by the APR_OPT model. The model caters for accessibility and user-friendliness. Inserting new data is an easy task and new results can be determined from the new entered data. Integrating the data generated by the BFAP model is explained in the next section.

3.4.1 Integration of the APR_OPT model with BFAP data

This section aims to explain the integration of necessary BFAP data into the APR_OPT model for forecasting purposes. The benchmark APR_OPT model generates baseline data for the year 2015. BFAP forecast data, in the form of population estimates, per capita consumption of meat products, imports and exports of meat products, and raw material prices and availability, are then integrated into the APR_OPT model to generate forecast results for the years 2015 to 2024.

In the process of generating benchmark results and integrating BFAP data into the model, both sub-objective 1 and 2 are satisfied. The process is fully explained in Figure 3.8.

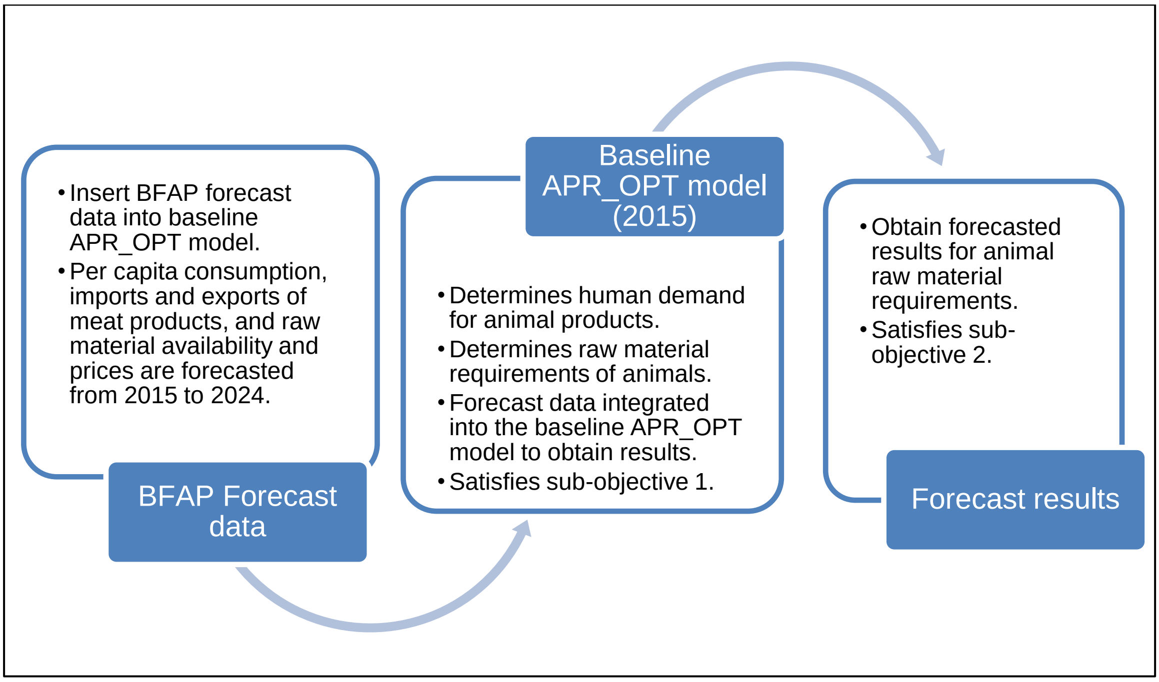


Figure 3.8: A graphical illustration of the integration of BFAP forecast data
Source: Own Process

3.4.2 Projection of human factors

The following section describes the human factors in terms of population estimates, per capita consumption of meat products, and imports and exports of meat products. The data are obtained from the BFAP model.

3.4.2.1 Population estimates

BFAP population estimates of 2015 are used in the study for the two models to correspond with one another. Figure 3.9 shows the population estimates of South Africa for the baseline period 2015 to 2024. From 2014 to 2015, the population showed a high growth rate of 1.3%, but thereafter the growth rate of the population declined and stagnated around the 0.5% mark (BFAP, 2015).

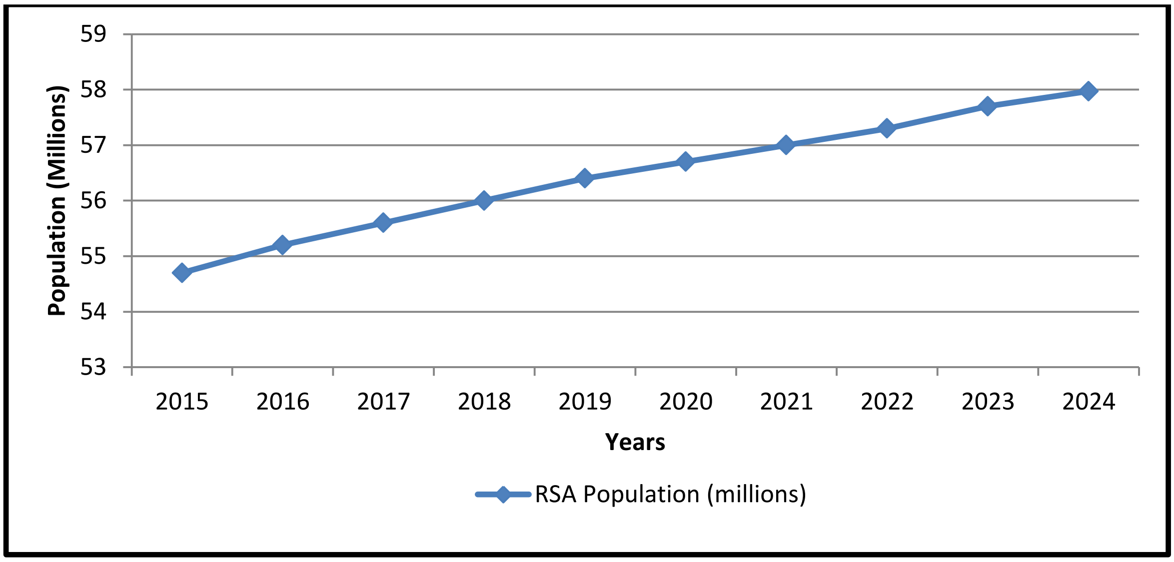


Figure 3.9: Forecast population estimates for South Africa until 2024
Source: Adapted from BFAP (2015)

The population estimates for South Africa generated by the BFAP model will be integrated into the APR_OPT model in the calculations of animal feed demand. Animal feed demand will be forecasted for the years 2019 and 2024.

3.4.2.2 Per capita consumption of livestock products

Per capita consumption remains a vital parameter for determining the amount of animal feed required by animals. Figure 3.10 indicates the per capita consumption of animal-source protein with regards to chicken, eggs, beef, dairy products, pork, and mutton.

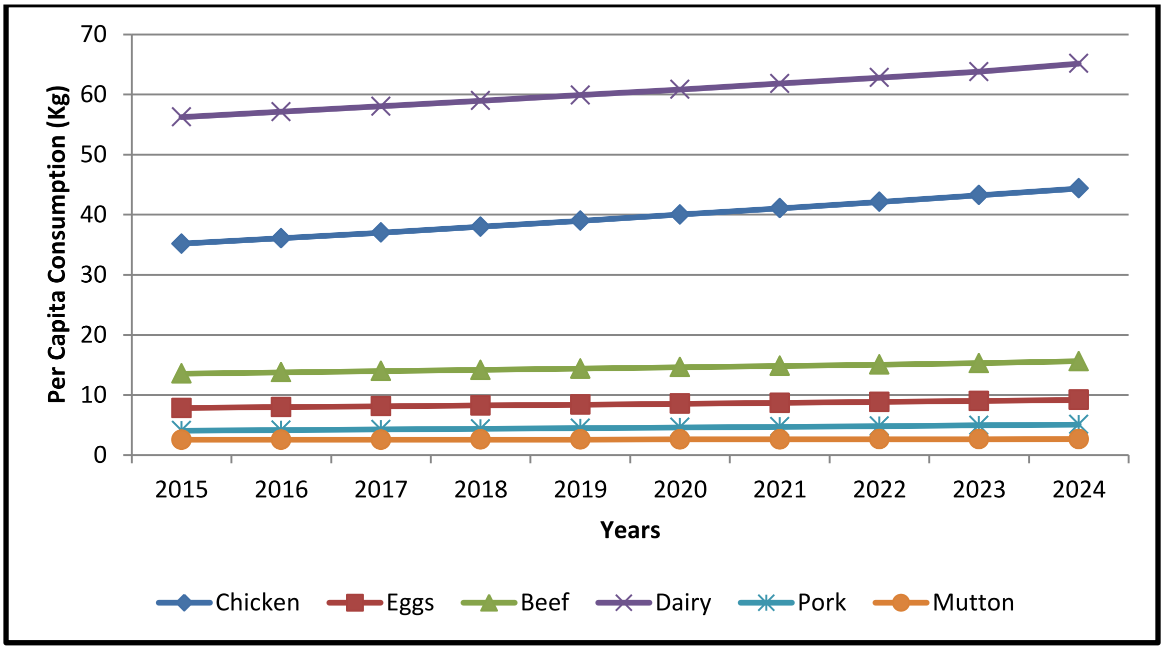


Figure 3.10: Per capita consumption of animal-source protein
Source: Adapted from BFAP (2015)

The data are incorporated into the APR_OPT model to determine the quantity of livestock produce required by the population, and thereafter the amount of animal feed is derived from the livestock production.

3.4.2.3 Imports of meat products

Table 3.17 provides current and forecast data of animal-source protein products imported into South Africa to provide for the deficit in local supply of livestock products. From Table 3.17 it is clear that chicken meat is the most imported livestock product amongst animal-source protein products and it is expected to continue to grow throughout the baseline projections of the BFAP (2015).

Table 3.17: Imports of animal-source protein products

Year	Chicken (tonnes)	Eggs (tonnes)	Beef (tonnes)	Dairy (litres)	Pork (tonnes)	Mutton (tonnes)
2015	359 100	170	63 770	282 133 800	20 080	21 080
2016	393 500	180	64 140	236 276 000	19 960	22 540
2017	426 100	190	64 310	229 835 200	20 060	24 470
2018	451 200	200	66 360	223 051 900	20 010	23 030
2019	475 700	200	67 420	223 814 000	19 790	23 020
2020	496 100	210	67 860	224 925 000	19 580	23 010
2021	515 400	210	67 560	226 213 000	19 440	22 570
2022	535 200	210	67 060	227 534 000	19 360	22 130
2023	555 600	220	66 460	226 685 000	19 440	21 210
2024	578 600	220	66 890	225 732 200	19 650	23 380

Source: BFAP (2015)

The data are necessary to determine the local production of livestock products to derive the quantity of feed demanded by animals locally.

3.4.2.4 Exports of meat products

Table 3.18 shows that the forecasted export of livestock products during the baseline period (2015 – 2024) is expected to remain relatively stable. The current export of chicken meat is the highest, followed by milk and dairy products and beef.

Table 3.18: Exports of animal-source protein products

Year	Chicken (tonnes)	Eggs (tonnes)	Beef (tonnes)	Dairy (litres)	Pork (tonnes)	Mutton (tonnes)
2015	41 160	5 660	22 480	160 489 700	7 300	1 540
2016	39 910	5 430	22 450	181 506 600	7 310	1 580
2017	39 020	5 260	22 430	183 233 600	7 260	1 620
2018	38 500	5 120	22 280	185 317 500	7 250	1 660
2019	38 050	5 000	22 200	184 999 200	7 290	1 700
2020	37 760	4 880	22 160	183 867 900	7 340	1 740

Year	Chicken (tonnes)	Eggs (tonnes)	Beef (tonnes)	Dairy (litres)	Pork (tonnes)	Mutton (tonnes)
2021	37 700	4 780	22 190	184 063 700	7 360	1 780
2022	37 700	4 670	22 220	184 226 500	7 350	1 820
2023	37 700	4 580	22 270	183 711 200	7 290	1 860
2024	37 700	4 490	22 240	182 329 900	7 180	1 900

Source: BFAP (2015)

3.4.3 Raw material forecasts

The following section describes the forecasted raw material availability, prices, and transport prices. The section also describes the ratios used to derive the availability and prices of the raw materials that are not forecasted by the BFAP model.

3.4.3.1 Raw material prices

The following section describes the forecasted raw material availability provided by the BFAP model (BFAP, 2015). However, the BFAP model only provides information regarding the main raw materials consumed in South Africa and therefore the ratios used to derive the remaining raw materials are also described and background is given. Table 3.19 provides the main raw materials used in animal feeds which are provided by the BFAP model (BFAP, 2015). From these main raw materials, milling and wet-milling by-products, rendering products, additives, minerals, and certain grains are determined using a set of price ratios.

Table 3.19: Forecasted raw material prices

Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Raw material	**R/tonne**									
White maize	2 691	2 198	2 333	2 533	2 765	2 902	3 018	2 955	3 292	3 423
Yellow maize	2 416	2 198	2 317	2 526	2 716	2 883	3 003	3 054	3 122	3 398
Sorghum	2 705	2 099	2 385	2 555	2 683	2 780	2 870	2 921	3 016	3 144
Wheat	3 827	4 000	4 155	4 387	4 553	4 728	4 905	5 091	5 277	5 477
Barley	3 502	3 671	3 824	4 051	4 214	4 385	4 559	4 741	4 923	5 119
Canola	4 994	5 018	5 149	5 586	5 911	6 118	6 461	6 751	6 953	7 185
Canola oilcake	3 215	3 151	3 242	3 501	3 717	3 882	3 964	4 017	4 028	4 092
Sunflower	5 197	5 103	5 489	5 888	6 177	6 461	6 809	7 138	7 440	7 739
Sunflower oilcake	3 350	3 325	3 440	3 695	3 916	4 096	4 209	4 301	4 359	4 465
Soybeans	4 821	4 987	5 400	5 864	6 187	6 423	6 685	6 861	7 024	7 213
Soybean oilcake	4 946	4 848	4 987	5 387	5 718	5 972	6 099	6 181	6 196	6 295
Sugar RV	4 016	4 038	4 166	4 311	4 499	4 687	4 816	4 995	5 123	5 310
Sugarcane	486	489	504	511	524	536	552	573	588	611

Source: BFAP (2015)

Table 3.20 displays the prices of the raw materials not shown in Table 3.19. In Table 3.20, the price ratios used to derive the prices of the other raw materials are also shown. The projected prices of synthetic manufactured raw materials are derived from a 5% year-on-year growth, while the other raw materials and by-product prices are derived from the main raw materials shown in Table 3.20.

Table 3.20: Raw material prices for 2015 and ratios used to derive raw material prices (R/tonne)

Raw material	Local	Imports – Cape	Imports – KZN	Ratio	Ratio of raw material
Carophyll R	150 000	-	-	62.1	Yellow maize
Carophyll Y	150 000	-	-	62.1	Yellow maize
Coccidiostats	20 000	-	-	8.3	Yellow maize
Marigold 20	30 000	-	-	12.4	Yellow maize
Pronutrient	20 000	-	-	8.3	Yellow maize
Vitamin mineral	25 000	-	-	10.3	Yellow maize
Lysine	18 000	-	-	7.5	Yellow maize
Methionine	30 000	-	-	9.5	Yellow maize
Vegetable oil	11 000	-	-	3.3	Sunflower oilcake
CMS molasses	3 000	-	-	1.2	Yellow maize
Molasses	3 000	-	-	1.2	Yellow maize
Maize germ	2 018	-	-	0.8	Yellow maize
Wheat middlings	2 679	-	2 679	0.8	Yellow maize
Maize germ full fat	4 228	-	-	1.0	Yellow maize
Gluten 20	2 054	-	-	0.9	Yellow maize
Gluten 60	4 832	-	-	2.0	Yellow maize
Fish meal	15 000	15 000	-	3.0	Soya oilcake
Canola full fat	3 537	-	-	1.1	Canola oilcake
Cotton full fat	3 850	4 000	4 000	0.8	Soya oilcake
Soya full fat	5 846	-	-	1.2	Soya oilcake
Oats	3 850	-	-	1.0	Wheat
Tritcale	-	-	-	-	Unavailable
Lupins	3 000	-	-	0.78	Wheat
Dcp	4 700	-	-	1.95	Yellow maize
Limestone	550	-	-	0.23	Yellow maize
MCP	5 200	-	-	2.15	Yellow maize
Salt	1 000	-	-	0.41	Yellow maize
Ammonium chloride	5 500	-	-	2.28	Yellow maize
Urea	4 000	-	-	1.66	Yellow maize
Cotton oilcake	4 000	4 000	4 000	0.81	Soya oilcake
Groundnut oilcake	-	4 750	4 750	0.96	Soya oilcake
Palm kernel meal	-	2 500	2 500	0.75	Sunflower oilcake
Lucerne	2 500	-	-	1.03	Yellow maize
Milk replacer	15 000	-	-	8.28	Yellow maize
Roughage	10 000	-	-	4.14	Yellow maize
Blood meal	7 500	-	-	0.50	Fish meal
Feather meal	7 419	-	-	1.50	Soya oilcake
Meat and bone meal	7 419	-	-	1.50	Soya oilcake
Poultry by-product	3 957	-	-	0.80	Soya oilcake
Bagasse	1 000	-	-	0.41	Yellow maize

Source: Briedenhann (2001); Conversation with Dr D. Strydom on 12 February 2016

3.4.3.2 Raw material availability

Table 3.21 provides the production of raw materials from 2015 to 2024. The production of raw materials data are provided by the BFAP (2015). These are, however, the main raw materials, and the by-products are derived thereof and shown in Table 3.22.

Table 3.21: Forecasted raw material production

Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Raw material	1 000 tonnes									
White maize	4 622	7 018	6 687	6 758	6 647	6 808	6 660	6 512	6 201	6 331
Yellow maize	4 758	5 972	5 883	6 127	6 305	6 487	6 805	6 962	7 057	7 044
Wheat	1 653	1 705	1 682	1 688	1 684	1 680	1 677	1 660	1 645	1 623
Barley	319	339	354	367	376	389	400	410	416	426
Canola	121	150	166	187	201	214	229	243	257	271
Canola cake	68	82	90	100	108	116	122	128	133	139
Sorghum	123	210	185	199	199	202	203	203	203	203
Sunflower	612	737	691	712	715	720	729	744	771	779
Sunflower cake	277	316	307	310	311	312	316	317	317	318
Soybeans	943	1 300	1 375	1 527	1 643	1 764	1 877	1 976	2 050	2 146
Soybean cake	704	946	1 090	1 195	1 295	1 388	1 476	1 545	1 592	1 638
Sugarcane	14 291	16 149	17 069	17 990	18 712	18 821	18 822	18 755	18 678	18 586
Sugar	1 702	1 923	2 033	2 143	2 229	2 242	2 242	2 234	2 225	2 214
Mollasses	658	744	786	829	862	867	867	864	860	856

Source: BFAP (2015)

Table 3.22 provides the availability of raw materials for 2015 and the ratios used to derive the availability of the by-products from the main raw materials shown in Table 3.21. Synthetically manufactured raw materials, including additives, amino acids, minerals, and NPN, are unlimited in supply. Where a ratio is used, the raw material therefore increases rationally the same as the main raw material of which it is derived. Where the percentages are used, the raw material shows the same annual increase as the main raw material.

Table 3.22: Raw material availability for 2015 and ratios used to derive raw material availability

Raw material	Local (tonnes)	Imports – Cape	Imports – KZN	Ratio	Ratio of raw material
Additives	Unlimited	-	-	-	Synthetically manufactured materials
Amino acids	Unlimited	-	-	-	Synthetically manufactured materials
Minerals	Unlimited	-	-	-	Synthetically manufactured materials
NPN	Unlimited	-	-	-	Synthetically manufactured materials
Vegetable oil	Unlimited	-	-	3 846.15	Sunflower oilcake
CMS molasses	12 500	-	-	0.00218	Yellow maize
Molasses	500 000	-	-	0.09	Yellow maize
Maize germ	968 004	-	-	0.16	Yellow maize
Wheat middlings	720 000	-	-	22.88	Wheat
Maize germ full fat	39 000	-	-	0.01	Yellow maize
Gluten 20	113 750	-	-	0.02	Yellow maize

Raw material	Local (tonnes)	Imports – Cape	Imports – KZN	Ratio	Ratio of raw material
Gluten 60	27 300	-	-	0.0044	Yellow maize
Fish meal	45 000	-	-	0.0639	Soya oilcake
Canola full fat	2 000	-	-	0.03	Canola oilcake
Cotton full fat	5 600	10 000	27 000	0.01	Soya oilcake
Soya full fat	120 000	-	-	0.19	Soya oilcake
Oats	9 000	-	-	0.28	Wheat
Sorghum	6 000	-	-	-	BFAP-provided
Tritcale	-	-	-	-	Unavailable
Lupins	14 000	-	-	0.44	Wheat
Cotton oilcake	-	-	128 000	34%	Soya oilcake – ratio of annual increased production
Groundnut oilcake	-	-	588	34%	Soya oilcake – ratio of annual increased production
Palm kernel meal	-	-	30 000	14%	Sunflower oilcake – ratio of annual increased production
Lucerne	500 000	-	-	0.09	Yellow maize
Milk replacers	Unlimited	-	-		Synthetically manufactured materials
Roughage	Unlimited	-	-	174.11	Yellow maize
Blood meal	25 000	-	-	64%	Yellow maize – ratio of annual increased production
Feather meal	19 124	-	-	64%	Yellow maize – ratio of annual increased production
Meat and bone meal	10 000	-	-	64%	Yellow maize – ratio of annual increased production
Poultry by-product	57 372	-	-	64%	Yellow maize – ratio of annual increased production
Bagasse	170 000	-	-	13%	Yellow maize – ratio of annual increased production

Source: Briedenhann (2001); Conversation with Dr D. Strydom on 12 February 2016

Table 3.23 provides an indication of raw materials being imported to add to the raw material supply in South Africa. Exports are shown as a negative.

Table 3.23: Forecasted imports of raw materials

Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Raw material	**1 000 tonnes**									
White maize	24	-	-	-	-	-	-	-	-	-
Yellow maize	431	-	-	-	-	-	-	-	-	-
Wheat	2 009	1 943	2 029	2 077	2 153	2 223	2 289	2 352	2 453	2 545
Barley (NET IMPORTS)	49	12	16	1	6	-3	-4	-6	-0	-4
Canola oil (NET IMPORTS)	11	5	3	0	-1	-1	0	2	-6	-4
Sorghum (NET IMPORTS)	-19	-14	-8	-9	-9	-10	-10	-10	-9	-7
Sunflower (NET IMPORTS)	41	36	85	37	35	32	31	23	-2	-13
Sunflower cake (NET IMPORTS)	123	45	39	33	37	46	55	68	84	99
Sunflower oil	142	118	132	132	137	144	144	148	156	163

Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Raw material	**1 000 tonnes**									
Soybeans (NET IMPORTS)	90	-8	93	71	82	80	79	69	57	25
Soybean cake	566	395	308	248	201	170	154	163	198	232
Soybean oil	171	130	103	79	61	47	30	19	14	9
Sugar (refined)	448	449	450	446	445	445	447	448	449	452

Source: BFAP (2015)

3.4.3.3 Raw material transport costs

Table 3.24 represents the transport cost of raw materials imported through the Durban harbour and transported inland to Randfontein.

Table 3.24: Forecasted transport cost

Transport	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
	R/tonne									
Transport: Randfontein – Durban	402	424	447	471	496	522	551	580	612	645

Source: BFAP (2015)

3.4.4 Animal performance parameters

The APR_OPT model incorporates data on the performance of animals in the industry. These performance data are required to estimate the number of animals needed to meet the human demand for animal products. Thus it is necessary to consider the performance data of each main animal category.

The animal performance data are shown in the section below, and will be used in the APR_OPT model to determine the quantity of animal feed required. The performance data are not fixed and can easily be changed to simulate improved genetics or a change in animal performance in the future.

3.4.4.1 Broiler

SAPA (2012b:45) noted that the South African broiler industry is relatively competitive efficiency-wise when compared to other global market leaders such as Brazil and America. In 2011, South Africa had a performance efficiency factor of 301, which is in line with other major exporting countries. According to Table 3.25, a South African broiler is fed for 35 days to reach the desirable market weight of 1.84 kg. The broiler gains 52.56 g/day with an average FCR of 1.671. Mortalities amount to 4.52%. These figures are representative of the broiler industry and are used in the model to calculate feed demand.

Table 3.25: Performance factors of South Africa compared to Brazil and the USA

Measures	Units	South Africa	Brazil	USA
Slaughter age	Days	35	35	35
Live weight	kg	1.84	1.883	1.805
Average daily gain	g/day	52.56	53.81	51.59
Mortality	%	4.52	3.14	2.37
FCR	Ratio	1.671	1.658	1.802
Performance efficiency factor	Factor	301	314	280

Source: SAPA (2012b:45)

The slaughter-out percentages used in the study are according to Cobb (2012), which stated that a broiler slaughtered at 1.8 kg yields a carcass of 72%.

3.4.4.2 Broiler breeders

Laughling and Hocking (2009) stated that broiler breeder management has been constantly improving over the years, and the performance of broiler breeders followed. Globally, there are only a few broiler breeder strains that predominate. Cobb-Vantress (Cobb and Avian), Aviagen (Ross, Arbor Acres, and Indian River), and Hubbard and Hybro are amongst the major broiler breeder producing companies (Kleyn, 2012). Recommendations and approaches by these different companies differ, but ultimately the same broad basic guidelines need to be applied.

Table 3.26 shows how broiler breeder performance improved from 1976 to 2007. A broiler breeder hen produces 173.2 eggs during the housing period, 4% of eggs are rejected, and from the remaining eggs the hatchability amounts to 85.2%, which yields 141.7 chicks per hen housed. Total chicks per hen housed showed a 22% improvement from 1976 until 2007.

Table 3.26: Performance numbers of the top 25% of current flocks

Year	Total eggs/ hen housed	Hatching eggs/ hen housed	Cumulative hatchability (%)	Total chicks/ hen housed
1976	154.6	144.8	80.4	116.4
2001	167.7	159.1	85.6	136.1
2007	173.2	166.6	85.2	141.7

Source: Adapted from Laughling & Hocking (2009)

The above data will be used to determine the amount of feed required by broiler breeders, and can easily be adapted in the APR_OPT model to simulate the effect of genetic improvement, as well as better management practices.

3.4.4.3 Layers

Leghorn (white-shelled eggs) and Rhode Island Red (brown-shelled eggs) are the two main genotypes used for commercial egg production (Kleyn, 2012). White shells are preferred in the United Stated of America, while brown shells predominate in Europe and Africa (Kleyn, 2012).

Table 3.27 shows the different traits of the white and brown layers. Hence, in South Africa, the traits of the Hy-Line Brown layers will be used. From Table 3.27 it can be seen that the Hy-Line Brown produces 255 eggs in 60 weeks, with an average egg weight of 64.1 grams. The feed intake of these layers during the maturation phase is 107 g/day.

Table 3.27: Genetic traits of brown and white layers

Trait	Units	Hy-Line W 98	Hy-Line Brown
Live weight at 17 weeks	Grams	1 230*	1 400
Live weight at 70 weeks	Grams	1 670	1 970
Eggs per hen housed (60 weeks)	Eggs	250	255
Egg weight 70 weeks	Grams	65.6	64.1
Feed intake 0 – 17 weeks	kg	5.05*	5.63
Feed intake 18 – 80 weeks	Grams/day	98	107
Mortality	%	3	3

*Figures for the Hy-Line W98 are given for 16 weeks of age
Source: Hy-Line (2011)

Hy-Line (2011) stated that the maturity of laying pullets has been decreasing by approximately one day per year. Now, the first layer egg appears around 16 to 18 weeks of age. Thus, genetic improvement has been a key feature of the layer industry. From Table 3.28 the genetic improvement in the genotype of the Hy-Line products is visible. Egg production per hen housed increased with 8.82%, while the amount of feed required to produce a kilogram of eggs has decreased with 15.32%, which shows a great improvement in feed efficiency.

Table 3.28: Changes in the Hy-Line performance during the last decades

Characteristics	1993	1995	2002/2004	2005/2007	2009	2011	% change 1993 – 2011
Feed consumed in rear (kg)	5.7 – 6.7	5.7 – 6.7	6	5.97	5.62	5.62	9.35%
Body weight (18 weeks)	1.55	1.55	1.43*	1.47*	1.4*	1.4*	-9.68%
Age at 50% production	153	151	145	145	142	140	-8.50%
Hen-housed eggs (60 weeks)	238	240	252	253.2	253	259	8.82%
Kg feed/kg eggs	2.2 – 2.5	2.2 – 2.5	2.06	1.96	2.02	1.99	-15.32%

*17 weeks of age
Source: Adapted from Hy-Line (2011)

3.4.4.4 Pig

Table 3.29 shows the achievable commercial performance of commercial piggeries (Gadd, 2005). The average daily gain (ADG) of weaner pigs proves to be around 490 g/day with an FCR of 1.58. Growing and finishing pigs, between the weights of 30 to 100 kg, have an average daily gain of 929 g/day and an FCR of 2.46.

Table 3.29: Achievable commercial performance of growing pigs

Growing Phase of Pig	Weight (kg)	Average daily gain (g/day)	FCR (ratio)
Weaner	7 – 30	490	1.58
Grower/finisher	30 – 100	929	2.46

Source: Gadd (2005)

Maximising herd productivity and profit can be achieved through the adequate nutrition of the breeding herd. Table 3.30 shows the room available for improvement in reproductive efficiency between average and superior herds.

Table 3.30: Reproductive efficiency of average and superior swine herds

Factor	Units	Average	Target
Piglet mortality	%	12 – 18	<10
Weaning to effective mating	Days	8 – 10	5
Farrowing rate	%	78 – 85	90
Pigs weaned/litter	Pigs	8.5 – 9.5	10.2 – 11.2
Cycles per year	Cycles	2.2 – 2.3	2.4 – 2.6
Pigs weaned/sow/year	Pigs	17 – 22	22.5 – 24

Source: Patience, Thacker and De Lange (1995)

As seen from Table 3.30, there is plenty of room available for improvement of swine herds. For this study, the average data will be used. The APR_OPT model is accessible and any changes in genetic performance of breeding pigs can be inserted or changed in the model to determine new animal feed requirements.

3.4.4.5 Dairy cattle

The structure of the South African dairy industry has changed somewhat over the years. The number of milk producers decreased from 3 899 in January 2007 to 1 834 in January 2015. This is an average decline of 53% in the number of producers (Milk SA, 2015). South Africa is currently ranked third in the average herds globally, with an average of 357 cows per herd (Milk SA, 2015). The average milk production per cow per year for 2014 was estimated at 20.2 litres.

3.4.4.6 Feedlot cattle

Ford (2015) stated that 75% to 80% of beef produced in South Africa originates from the feedlot industry. Most carcasses from the feedlot industry are classified as A-grade (95%) and only 5% carcasses are classified as AB-grade – having no permanent teeth and one to two permanent teeth respectively (Anonymous, 2005). Ford (2015) and Einkamerer (2015) stated in Table 3.31 the different performance parameters for cattle in commercial feedlots. Cattle enter the feedlot at a weight of between 200 kg and 235 kg, and are slaughtered at an average weight of 450 kg. During the feedlot period of 120 to 150 days, the average FCR and ADG are 5.5 and 1.7 kg respectively.

Table 3.31: Average performance estimates of feedlot cattle

Parameters	Units	Quantity
Intake percentage of body weight	%	3
FCR	Ratio	4.5 – 6.5
Average daily gain	Kg/day	1.6 – 1.8
Slaughter-out percentage	%	57.5
Feedlot entering weight	kg	200 – 235
Feedlot days	Days	120 –150
Slaughter weight	kg	450
Carcass weight	kg	258

Source: Ford (2015); Conversation with O. Einkamerer on 6 August 2015).

The average carcass slaughter-out percentage is 57.5%, which yields a carcass of 258 kg (Ford, 2015).

3.4.4.7 Sheep

The average performance estimates for feedlot sheep in South Africa are shown in Table 3.32. In an interview with Einkamerer on 6 August 2015 and a conversation with Van der Walt on 12 February 2016, it was confirmed that sheep enter the feedlot at an average weight of 30 kg and are slaughtered at a weight of between 45 and 55 kg. The feeding period lasts for an average of 60 days.

Table 3.32: Average performance estimates of feedlot sheep

Parameters	Units	Quantity
FCR	Ratio	4.8 – 6.1
Average daily gain	Grams/day	280 – 320
Slaughter-out percentage	%	44 – 45
Feedlot entering weight	kg	27 – 33
Feedlot days	Days	55 – 63
Slaughter weight	kg	45 – 55
Carcass weight	kg	20 – 22

Source: Interviews with O. Einkamerer on 6 August 2015 and A. van der Walt on 12 February 2016

The FCR and ADG are 5.5 and 300 grams per day respectively. The average slaughter-out percentage is 44.5%, which yields an average carcass of 22 kg (Interviews with O. Einkamerer on 6 August 2015 and A. van der Walt on 12 February 2016).

3.5 CHAPTER SUMMARY

Chapter 3 started with an introduction of the concept of LP, and later shifted its focus to the problem at hand: the Feed Mix problem.

The next section was divided into two parts. The first part described and explained the calculations used to describe animal feed demand. The following section was an in-depth description of the

APR_OPT model, the objective function of the model, and the constraints the problem exhibits. The APR_OPT model was used to determine raw material requirements (Figure 3.11).

The last part described the integration of BFAP data into the APR_OPT model, which was illustrated in Figure 3.8. Thereafter, the forecasting used in the model was explained. The data were obtained from the BFAP (Figure 3.11). The forecasting data were divided into three different parts. The first part discussed forecasting data for human factors. The second part described forecasting regarding raw material factors such as prices and availability. The third section described animal performance data, and the potential scope for improvement in animal performance.

Chapter 3 is the core of the study as it showed the reader which methods will be used to find a solution for the Feed Mix problem in South Africa, and is an important stepping stone for the different simulated external shocks in Chapter 4.

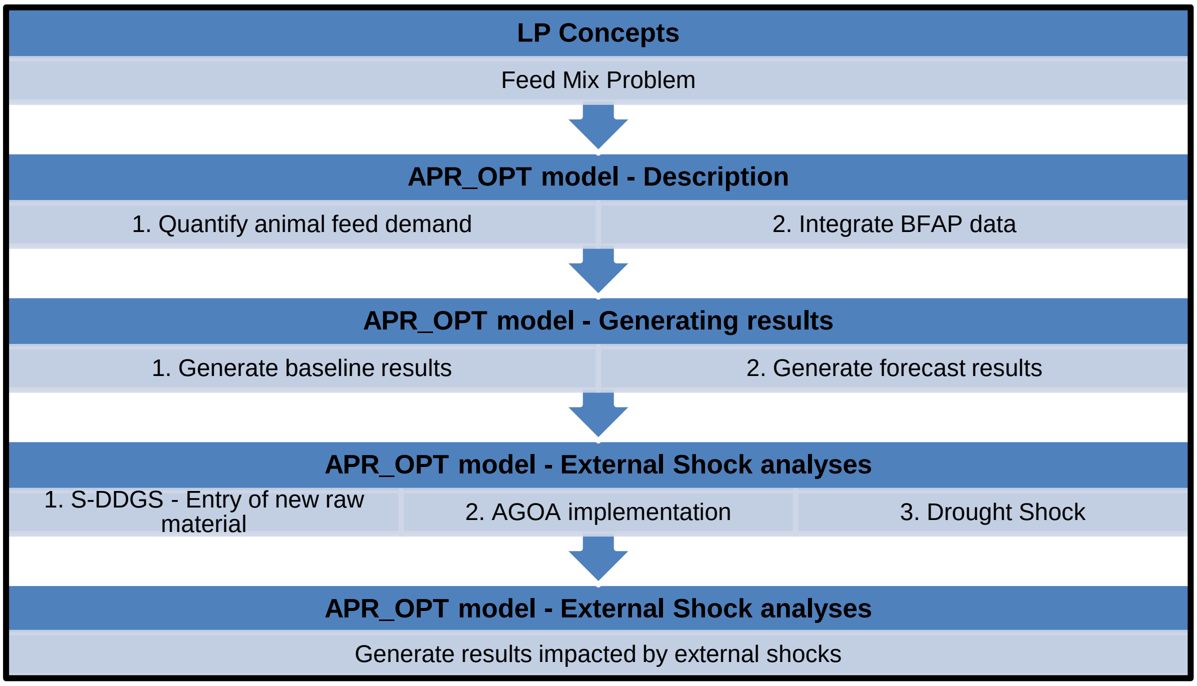


Figure 3.11: Graphical description of the APR_OPT model process
Source: Own Process

CHAPTER 4: RESULTS

4.1 INTRODUCTION

Chapter 4 is divided into two parts. The first part comprises a discussion of the baseline period from 2015, and the forecasted data until 2024. This coincides with the BFAP baseline period, which also stretches from 2015 to 2024. The APR_OPT model generates results which include animal feed demand, animals required for slaughter, raw material requirements for animal feeds, imported raw materials, ration costs, and specific raw materials consumed by specific animal categories. The second part discusses the results generated by different the external shocks simulated on the supply and demand side of the APR_OPT model.

4.2 BASELINE PERIOD RESULTS (2015 – 2024)

This section entails the forecasted results generated by the APR_OPT model for the period 2015 to 2024. The results are discussed using a “wide-narrow” approach; discussing total demand and usage of feeds and then narrowing the results down to the protein sources used.

4.2.1 APR_OPT model results

Table 4.1 summarises the amount of animal feed demanded by each animal category for the baseline period from 2015 to 2024. The total animal demand is estimated at 11.67 million tonnes in 2015 and is forecasted to reach 14.63 million tonnes by 2024. This comprises an average 2.54% year-on-year growth over the baseline period.

It is clear from Table 4.1 that broilers are the biggest current consumers of animal feed in South Africa at 30.28%, followed by feedlot cattle, dairy cattle, and layers at 26.78%, 17.66%, and 10.61% respectively. Feedlot cattle will, however, surpass broilers as the biggest animal feed consumers by 2021, with increasing feed consumption at an average of 3.97% per year compared to broilers’ increase in feed consumption of 1.41% year-on-year. The BFAP model forecasted increased imports of chicken meat to South Africa, with beef imports remaining relatively constant over the baseline period. Thus, less locally produced chicken meat is required. The genetic improvement of broilers, in terms of FCR, increases by 0.02 points per year and can be a possible reason for less animal feed required.

Table 4.1: Animal feed demand per animal category

Animal category	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
	1 000 000 tonnes									
Chickens broilers	3.535	3.563	3.595	3.646	3.710	3.772	3.835	3.900	3.972	4.032
Chickens layers	1.239	1.276	1.309	1.340	1.372	1.401	1.433	1.466	1.500	1.532
Cattle feedlot	3.126	3.254	3.381	3.505	3.638	3.771	3.911	4.058	4.217	4.368
Cattle dairy	2.061	2.136	2.178	2.218	2.258	2.296	2.337	2.382	2.430	2.472
Pigs	0.882	0.906	0.920	0.954	0.988	1.026	1.068	1.114	1.158	1.198
Sheep	0.256	0.258	0.258	0.263	0.266	0.271	0.275	0.279	0.284	0.284
Aquaculture	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.006	0.006
Horses	0.132	0.136	0.139	0.143	0.146	0.150	0.153	0.157	0.161	0.165
Ostriches	0.111	0.116	0.122	0.128	0.134	0.141	0.148	0.156	0.163	0.171
Pets	0.326	0.334	0.342	0.351	0.360	0.369	0.378	0.387	0.397	0.407
Total	**11.67**	**11.98**	**12.25**	**12.55**	**12.88**	**13.20**	**13.54**	**13.90**	**14.29**	**14.63**
Annual Growth	**-**	**2.66%**	**2.20%**	**2.49%**	**2.57%**	**2.53%**	**2.59%**	**2.67%**	**2.76%**	**2.42%**

Source: APR_OPT results generated

Table 4.2 describes the number of each animal category slaughtered to supply the human demand for animal-source protein products. The amount of feedlot cattle slaughtered shows a significant increase over the baseline period from 2015 to 2024. Cattle show the biggest increase in slaughter at 39.8%, followed by pigs (35.68%), chickens (26.5%), and sheep (10.7%).

Table 4.2: Amount of animals slaughtered

Animal category	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
	1 000 000's									
Chicken	1 062	1 083	1 104	1 133	1 165	1 198	1 233	1 268	1 307	1 343
Cattle	3.22	3.35	3.48	3.61	3.75	3.88	4.03	4.18	4.34	4.50
Pigs	2.69	2.76	2.80	2.91	3.01	3.13	3.25	3.40	3.53	3.65
Sheep	5.87	5.92	5.90	6.02	6.11	6.20	6.29	6.38	6.51	6.50
Fish	0.46	0.47	0.49	0.50	0.51	0.52	0.54	0.55	0.56	0.58
Ostriches	0.18	0.19	0.20	0.21	0.22	0.23	0.24	0.25	0.27	0.28

Source: APR_OPT model generated results

Table 4.3 summarises the quantities of each raw material used to formulate animal feed during the baseline period 2015 to 2024. The main raw materials used in animal feeds for 2015 were yellow maize (49.3%), soya oilcake (10.32%), maize germ (8.29%), wheat middlings (6.17%), molasses (4.28%), lucerne (4.28%), and sunflower oilcake (3.43%).

Table 4.3: Raw material usage in animal feeds

Raw material	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
	1 000 tonnes									
Lysine	9.98	8.83	8.43	8.83	9.40	8.70	8.94	8.55	8.64	8.28
Methionine	10.84	10.74	10.81	11.02	11.42	11.50	11.71	11.74	11.92	12.09
Vegetable oil	86.71	85.49	83.26	85.71	88.40	86.93	87.44	85.09	84.81	85.61
CMS molasses	12.50	14.12	14.93	15.73	16.37	16.46	16.46	16.40	16.34	16.26
Molasses	500	565	597	629	655	658	659	656	653	650
Maize germ	968	968	968	968	968	968	968	968	968	968
Wheat middlings	720	717	730	740	755	767	780	789	806	820
Gluten 20	114	119	125	132	138	145	152	160	168	176
Gluten 60	27	29	30	32	33	35	37	38	40	42
Fish meal	33	33	33	34	35	36	37	38	39	40
Canola full fat	2	2	3	3	3	4	4	4	4	4
Cotton full fat	43	45	47	49	52	54	57	60	63	66
Soya full fat	120	111	100	94	92	93	93	95	97	101
Yellow maize	5 757	5 875	5 980	6 112	6 257	6 411	6 564	6 725	6 892	7 023
Sorghum	-	10	8	10	12	13	15	15	17	19
Wheat	40	24	29	35	43	48	53	54	59	66
Lupins	14	14	14	14	14	14	14	14	14	14
DCP	4	4	4	4	4	4	4	4	4	4
Limestone	375	383	390	401	416	424	436	443	460	475
MCP	178	182	185	190	194	198	203	209	214	219
Salt	60	58	59	62	66	66	71	76	79	80
Urea	47	48	49	51	51	53	53	50	48	45
Canola oilcake	68	82	90	100	108	116	122	128	133	139
Cotton oilcake	98	134	130	148	156	163	172	180	189	199
Groundnut oilcake	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59
Soya oilcake	1 204	1 269	1 343	1 371	1 395	1 456	1 529	1 630	1 716	1 818
Sunflower oilcake	400	361	346	343	349	358	371	385	401	417
Palm kernel meal	30	32	33	35	36	38	40	42	44	47
Lucerne	500	525	551	579	608	638	670	704	739	776
Blood meal	4.27	8.95	5.40	5.53	5.79	5.94	6.09	4.33	4.44	4.54
Feather meal	19.12	15.29	13.71	14.10	18.58	19.30	19.90	20.65	21.44	5.72
Poultry by-product	57.37	58.46	62.00	61.16	62.93	64.71	66.57	68.49	70.57	72.50
Bagasse	170	192	203	214	223	224	224	223	222	221
Total raw material usage	**11 673**	**11 984**	**12 248**	**12 553**	**12 876**	**13 202**	**13 544**	**13 905**	**14 288**	**14 635**
Total protein usage	**1 980**	**2 050**	**2 106**	**2 158**	**2 206**	**2 298**	**2 401**	**2 538**	**2 663**	**2 806**
Total soya OC & FF usage	**1 324**	**1 380**	**1 443**	**1 464**	**1 487**	**1 550**	**1 622**	**1 724**	**1 814**	**1 919**

Source: APR_OPT model generated results

Table 4.4 is a reflection of the total oilcake requirement per animal category for the base year 2015. The largest consumers of protein sources are broilers (52.46%), followed by dairy cattle (18.18%), and layers (11.27%). The most consumed type of oilcake is soya oilcake (60.83%), followed by sunflower oilcake (20.2%). A total of 1 980 000 tonnes of protein sources was consumed in 2015.

Table 4.4: Total protein-source requirements per animal category for 2015

Protein source	Canola full fat	Canola oilcake	Cotton full fat	Cotton oilcake	Groundnut oilcake	Palm kernel meal	Soya full fat	Soya oilcake	Sunflower oilcake	Total
	1000 tonnes									
Aquaculture	-	-	-	-	-	-	-	1	-	1
Broiler	2	5	-	-	1	-	120	858	52	1 039
Cattle beef	-	-	-	41	-	18	-	-	41	99
Cattle dairy	-	49	43	50	-	12	-	27	165	360
Horses	-	5	-	-	-	-	-	7	11	22
Layer	-	2	-	-	-	-	-	165	56	223
Ostriches	-	6	-	-	-	-	-	11	1	19
Pets	-	-	-	-	-	-	-	63	24	87
Pigs	-	-	-	-	-	-	-	72	46	118
Sheep	-	-	-	7	-	0	-	-	5	13
Total	**2**	**68**	**43**	**98**	**1**	**30**	**120**	**1 204**	**400**	**1 980**

Source: APR_OPT model generated results

The increase in animal feed and oilcake requirements from 2015 to 2024 is presented in Table 4.5. The total soya oilcake and full fat consumption increased over the forecasted period from 1 324 400 tonnes in 2015 to 1 919 000 tonnes by 2024. The total growth in protein usage is 42% between 2015 and 2024, which amounts to an annual growth rate of 4.63%.

Table 4.5: Increase in protein-source requirements for animals from 2015 to 2024

Protein source	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
	1 000 tonnes									
Canola full fat	2.00	2.48	2.74	3.08	3.31	3.53	3.77	4.01	4.24	4.47
Cotton full fat	42.60	44.73	46.97	49.31	51.78	54.37	57.09	59.94	62.94	66.09
Soya full fat	120.0	110.6	99.6	93.8	92.4	93.3	92.7	94.9	97.4	101.4
Lupins	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
Canola oilcake	68.3	81.6	89.8	100.4	108.3	115.9	121.9	127.7	133.2	139.0
Cotton oilcake	98.0	134.4	130.4	148.2	155.6	163.4	171.5	180.1	189.1	198.6
Groundnut oilcake	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59
Soya oilcake	1 204	1 269	1 343	1 371	1 395	1 456	1 529	1 630	1 716	1 818
Sunflower oilcake	400.0	360.8	345.6	343.5	348.6	358.0	370.5	385.3	401.1	417.0
Palm kernel meal	30.00	31.50	33.08	34.73	36.47	38.29	40.20	42.21	44.32	46.54
Total Protein Usage	**1 980**	**2 050**	**2 106**	**2 158**	**2 206**	**2 298**	**2 401**	**2 538**	**2 663**	**2 806**
Total Soya OC & FF Usage	**1 324**	**1 380**	**1 443**	**1 464**	**1 487**	**1 550**	**1 622**	**1 724**	**1 814**	**1 919**
Year-on-Year Protein Growth	**0**	**3.54%**	**2.83%**	**2.63%**	**2.39%**	**4.66%**	**5.24%**	**6.91%**	**6.31%**	**7.19%**

Source: APR_OPT model generated results

Table 4.6 displays the requirements for protein per animal category from 2015 to 2024. The largest consumers of protein sources are broilers and dairy cattle. According to Figure 4.1, the largest growth in oilcake consumption is in the cattle industry, which includes dairy and beef. By 2024, broilers will consume 1 189 000 tonnes of protein. This is an increase of 148 000 tonnes over the forecasted period.

Table 4.6: Requirements for protein per animal category from 2015 to 2024

Animal category	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
	1 000 tonnes									
Aquaculture	1.02	1.05	1.08	1.10	1.13	1.16	1.19	1.22	1.25	1.28
Broiler	1 039	1 065	1 071	1 078	1 079	1 112	1 127	1 157	1 174	1 189
Cattle beef	99	102	112	135	162	198	239	258	291	330
Cattle dairy	360	387	412	419	430	451	484	549	601	648
Horses	22.30	22.91	23.50	24.41	25.16	25.78	26.29	26.69	27.32	27.82
Layer	223	228	230	235	245	248	256	268	283	289
Ostriches	18.85	20.90	22.02	23.10	23.32	21.60	18.37	17.51	18.39	19.35
Pets	86.93	79.55	89.90	92.15	94.45	96.80	99.22	104.37	106.98	109.67
Pigs	118	130	132	138	133	132	138	144	149	183
Sheep	12.74	12.84	12.36	12.57	12.43	10.61	12.01	12.06	12.23	0.09
Total per year	**1 980**	**2 050**	**2 106**	**2 158**	**2 206**	**2 298**	**2 401**	**2 538**	**2 663**	**2 796**

Source: APR_OPT model generated results

Figure 4.1 displays the total protein consumed by all animal categories and compares the amount of protein consumed by cattle (including feedlot and dairy cattle) and poultry (including broilers and layers). The total protein consumed by all animals shows a 41% increase from 2015 to 2024, while poultry shows a 17% increase over the period. The biggest grower, however, is cattle. Cattle show a tremendous increase in protein consumption of 113% from 2015 to 2024 – more than doubling the consumption of protein sources. Between dairy and feedlot cattle, feedlot cattle are the biggest consumers of protein sources, estimated at 234% over the baseline period.

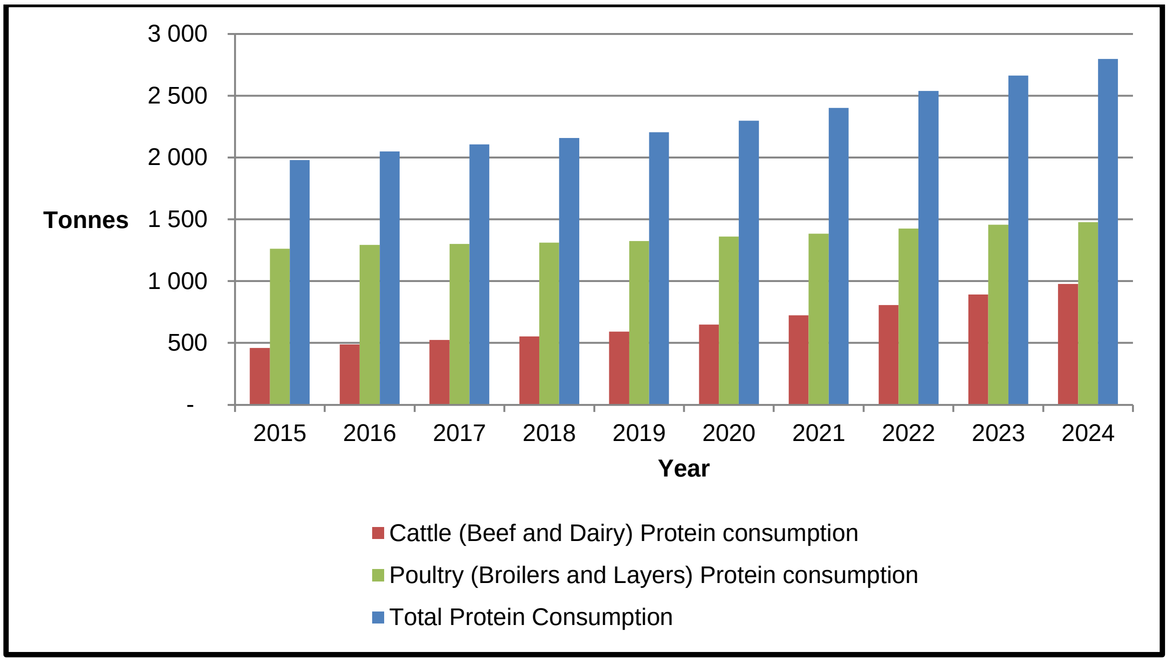


Figure 4.1: Total animal protein consumption versus poultry and cattle
Source: APR_OPT model generated results

Locally produced oilcake as a percentage of total oilcake is reflected in Table 4.7. In 2015, local protein accounted for 60% of total protein consumption. The forecasts indicated that this would increase to 79% by 2024. The soya oilcake consumption increased from 58% in 2015 to 90% in 2024 and is one of the main contributors in terms of the import reduction.

Table 4.7: Locally produced protein source as percentage of total oilcake

Raw material	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
	Percentage									
Canola full fat	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Cotton full fat	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Soya full fat	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Lupins	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Canola oilcake	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Cotton oilcake	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Groundnut oilcake	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Soya oilcake	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Sunflower oilcake	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Palm kernel meal	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Local Protein Usage as % of Total Protein Usage	**60%**	**72%**	**76%**	**80%**	**83%**	**84%**	**85%**	**83%**	**81%**	**79%**

Source: APR_OPT model generated results

Table 4.8 displays the percentage growth of local protein production to satisfy the growth in oilcake demand. In terms of trade, a country always seeks a positive trade balance, which means that the country exports more than it imports and is self-sufficient in its own supplies. The main objectives of the Protein Research Foundation (PRF) are closely linked to a positive trade balance. The PRF's main objectives are to be self-sufficient in local supply of protein feed source, replacing current import, and the better utilisation thereof (PRF, 2015). The 2015 demand for protein sources used in animal feeds was 1.19 million tonnes and the demand for 2024 is forecasted at 2.805 million tonnes. The forecasted annual growth in protein-source supply for animal feeds is estimated at 9.57%. In order to achieve self-sufficiency in protein-source supply for animal feeds by 2024, the annual growth must reach 15.06%.

Table 4.8: Percentage growth of local production to satisfy growth in oilcake demand

Percentage growth required for local protein production to reach certain targets by 2024			
Projected total protein consumption 2024	**Required annual growth rate for local production from 1 190 917 tonnes**	**Oilcake quantity**	**Percentage of projected consumption**
Tonnes	**%**	**Tonnes**	**%**
2 805 516	0.67%	1 262 482	45%
2 805 516	4.59%	1 683 310	60%
2 805 516	8.52%	2 104 137	75%
2 805 516	12.45%	2 524 964	90%
2 805 516	15.06%	2 805 516	100%
Local growth at forecasted total protein growth			
2 805 516	9.57%	2 216 358	79%

Source: APR_OPT model generated results

The data in Table 4.8 is illustrated in Figure 4.2. It is clear from Figure 4.2 that South Africa has decreased its reliance on imported protein sources for animal feeds. The results generated forecast that by 2024 South Africa would be 79% self-sufficient in protein supplies for animal feeds.

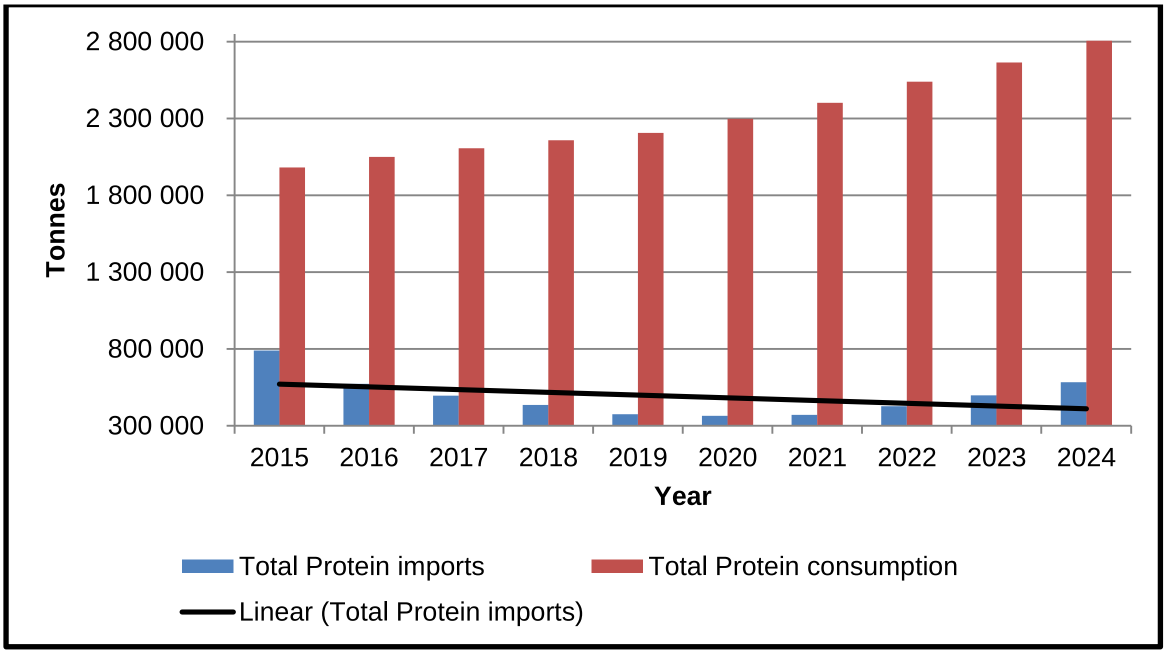


Figure 4.2: Total protein versus imported protein
Source: APR_OPT model generated results

Figure 4.3 illustrates the average ration cost per tonne across all animal categories and feed rations. The average ration cost per tonne is compared to an average cattle ration (including dairy and beef cattle) and an average poultry ration (including broilers and layers). In 2015, the average cost of one tonne of feed across all animal categories was estimated at R3 269, and shows an annual increase of 3.65% to reach the forecasted price per ration of R4 480 per tonne in 2024. The average cost per tonne of a poultry ration is very close to the average ration cost at R3 248/tonne in 2015, and is forecasted to increase to R4 423/tonne by 2024. Cattle rations are estimated lower in comparison with the average ration cost and poultry ration costs at R2 671/tonne in 2015, and are forecasted to increase annually with 4.4% to R3 877/tonne by 2024.

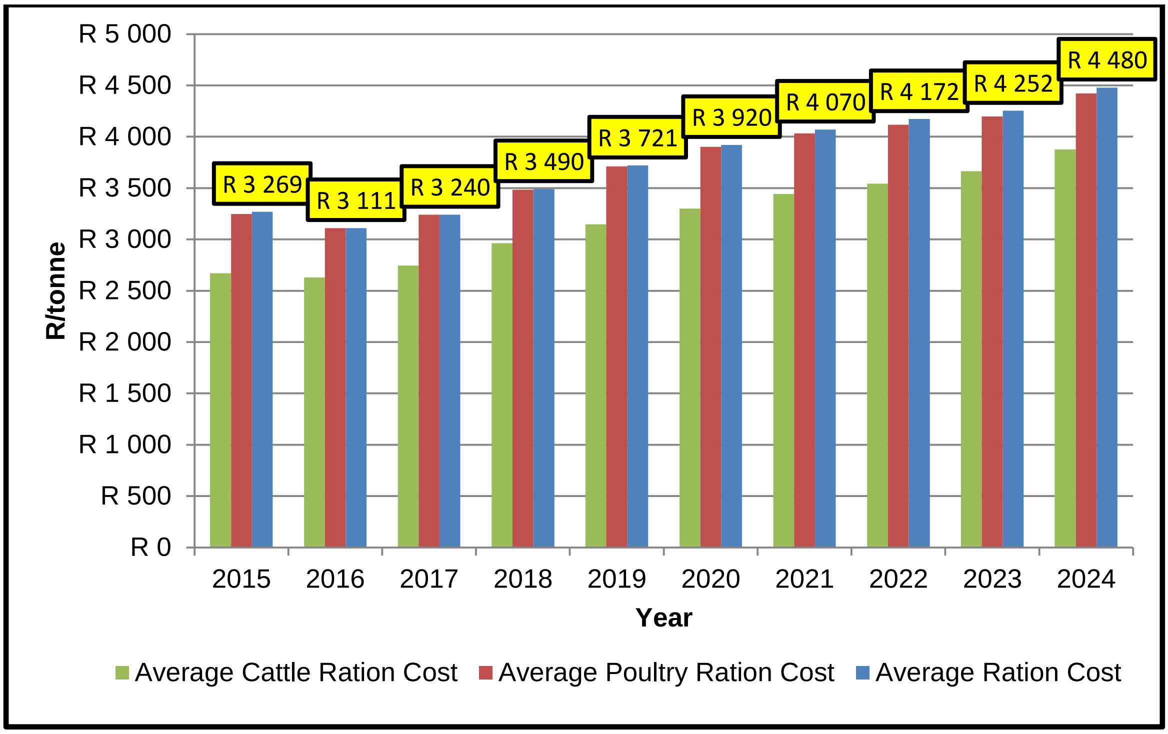


Figure 4.3: Ration costs per tonne from 2015 to 2024
Source: APR_OPT model generated results

4.3 EXTERNAL SHOCK ANALYSES

In the following section, three external shocks will be replicated in the APR_OPT model to simulate the various effects of these shocks on the animal feed industry, raw material requirements, and the ration costs. The impact of the following external shocks will be simulated:

1. The effect of 140 000 tonnes of S-DDGS per annum available at a price which is 100% of the yellow maize price.
2. The effect of AGOA being implemented on animal feed demand in 2016.
3. The effect of high commodity prices in 2016 on the average ration cost of animals.

4.3.1 External Shock 1: The effect of S-DDGS in the animal feed industry

DDGS is described as a product that is left over after sorghum or a grain mixture undergoes a distillation process to remove the ethyl alcohol. The distillation takes place after the yeast fermentation of the sorghum or grain mixture (Shurson & Noll, 2005).

Sorghum is starting to widely replace corn as the main source of energy in many feeds for swine, poultry, and beef and dairy cattle diets. The reason is that because of changing climatic conditions, the production of certain grains, like corn, is limited or the prices are too high.

In the USA, new research has found that during the processing of sorghum for feed grain, sorghum has similar, if not exactly the same, processing requirements than that of corn (Beyer, 2012).

4.3.1.1 Absorption of S-DDGS into the animal feed industry

By means of using the APR_OPT model, S-DDGS adoption into the feed industry can be calculated; assuming that 140 000 tonnes of S-DDGS will be available in South Africa and that S-DDGS will be available at 100% the yellow maize price. Subsequent to the consultation of various scientific resources, the following nutritional specifications were used for S-DDGS (Table 4.9):

Table 4.9: Nutrient content of S-DDGS

Nutrient	Value	Unit
Protein	27	%
Fat	8.5	%
Fibre	10	%
Methionine total	0.5	%
Methionine available poultry	0.44	%
TSAA total	0.48	%
TSAA available poultry	0.37	%
Lysine total	0.65	%
Lysine available poultry	0.44	%
Digestible Energy (DE) pigs	13.31	MJ/kg
Total Digestible Nutrients (TDN)	76	%
Metabolizable Energy (ME) poultry	12.23	MJ/kg
Na	0.04	%
Ca	0.2	%
P total	0.67	%
P available	0.2	%

Source: Beyer (2012:5); Tokach, Goodband & Derouchy (2012)

<u>The impact of two external shocks are simulated to determine the absorption of S-DDGS in animal feeds</u>

S-DDGS shock 1: No DDGS available, thus the current status (see Section 4.2).

S-DDGS shock 2: 140 000 tonnes of S-DDGS per annum available at a price which is 100% of the yellow maize price.

4.3.1.2 S-DDGS inclusion factors taken into consideration

The following guidelines were implemented to determine S-DDGS inclusion levels in feeds: Inclusion levels of S-DDGS depend on nutrient composition; and the main influence on nutrient composition is the quality of the cereal used and the drying process.

4.3.1.2.1 Mycotoxins

Mycotoxins still remain an evitable problem in the inclusion of S-DDGS in animal feeds. Therefore, feed companies run comprehensive quality checks on S-DDGS to ensure acceptable mycotoxin levels. Rodrigues and Naehrer (2012) conducted a review of mycotoxin levels in 455 maize DDGS samples of the period 2005 and 2010. The results generated proved high levels of mycotoxin present in DDGS in the form ofzearalenone, deoxyvalenol, and fumonisons. Mycotoxin binder can provide the solution when high levels of DDGS are used. Thus, the importance of screening grains at receipt for mycotoxin levels is critical for S-DDGS-producing companies.

4.3.1.2.2 Pigs

Recommended inclusion levels of S-DDGS for pigs are as follows:

- Young pigs up to 28 days – up to 15%
- Growing pigs – up to 30%
- Finishing pigs – up to 35%

Skaar *et al.* (2011) emphasised that the fatty acid profile of pork is influenced when feeding finishing pigs S-DDGS.

Feoli *et al.* (2008) determined the DE and ME concentration of S-DDGS for pigs, but it was only compared to the Apparent Ileal Digestibility (AID) and Standard Ileal Digestibility (SID) of amino acids in maize DDGS in 2009 (Urriola, Hoehler, Pedersen, Stein & Shurson, 2009). The results concluded that SID values and lysine were in line with maize DDGS; however, many amino acid SID values proved lower in S-DDGS compared to maize DDGS.

4.3.1.2.3 Dairy

S-DDGS provide a good source of energy for dairy cattle, have a lower lignin content, and contains high amounts of Neutral Detergent Fibre (NDF). Therefore, S-DDGS are regarded as a highly digestible fibre source, and decreases digestive upsets compared to feeding sorghum as a whole grain. Rumen Undegradable Protein (RUP) is found in higher proportional levels than in maize. A reduction in milk production can be caused by over-processing S-DDGS and damaging the protein

(Powers, Van Horn, Harris & Wilcox, 1995). For a lactating cow ration, S-DDGS should not exceed 20% of the ration dry matter.

4.3.1.2.4 Cattle

S-DDGS contain 80% of the Net Energy gain (NEg) of maize in cattle diets (Lodge, Stock, Klopfenstein, Shain & Herold, 1997). No negative impact on weight gain or total diet digestibility was observed when either maize DDGS or S-DDGS were fed in a formulated 20% crude protein supplement at 1% of body weight for heifers (Harborth, Marston & Llewellyn, 2006).

4.3.1.2.5 Poultry

Cuevas *et al.* (2012) determined the productive performance of S-DDGS in the diets of broilers and laying hens. The results concluded that maximum inclusion levels in broiler diets were 7% and 9% in laying hens, without affecting the performance of these animals. S-DDGS can therefore be regarded as a legitimate alternative source of protein and energy.

4.3.1.3 Results

Table 4.10 presents the raw materials that will be consumed by animals in South Africa for 2015 and 2024 when no S-DDGS are available. Table 4.10 indicates the results that were generated in Section 4.2 for the baseline results.

Table 4.10: Raw material consumption without S-DDGS for 2015 and 2024

Raw material	2015	2024
	No S-DDGS	No S-DDGS
	Tonnes	Tonnes
Grains	5 796 506	7 107 831
Protein sources	1 979 879	2 805 516
Lysine	9 980	8 278
Methionine	10 836	12 088
Vegetable oil	86 713	85 613
S-DDGS	-	-
Other	3 789 467	4 615 564
Total	**11 673 382**	**14 634 890**

Source: APR_OPT model generated results

Table 4.11 represents the changes and displacements of major raw materials when External Shock 2 is simulated. With the production of S-DDGS, South Africa will require 0.34% less grains, 5.86% less protein sources, 0.93% less methionine, 3.28% less vegetable oil, and 0.22% less of the remaining (other) raw materials. More lysine (4.27%) will be required.

As the quantity of S-DDGS remains constant during the forecast period (2015 to 2024), the movement trends of raw materials in 2024 remain similar to those in 2015, but just in a smaller percentage amount.

Table 4.11: Raw material consumption with and without S-DDGS for 2015 and 2024

Raw material	2015 No S-DDGS Tonnes	2015 S-DDGS Tonnes	2015 Change %	2024 No S-DDGS Tonnes	2024 S-DDGS Tonnes	2024 Change %
Grains	5 796 506	5 776 732	-0.34%	7 107 831	7 100 282	-0.11%
Protein sources	1 979 879	1 870 361	-5.86%	2 805 516	2 680 204	-4.68%
Lysine	9 980	10 426	4.27%	8 278	8 379	1.21%
Methionine	10 836	10 736	-0.93%	12 088	12 012	-0.63%
Vegetable oil	86 713	83 962	-3.28%	85 613	84 643	-1.15%
S-DDGS	-	140 000	100.00%	-	140 000	100.00%
Other	3 789 467	3 781 165	-0.22%	4 615 564	4 609 370	-0.13%
Total	**11 673 382**	**11 673 382**	**0.00%**	**14 634 890**	**14 634 890**	**0.00%**

Source: APR_OPT model generated results

Table 4.12 tabulates the species that consume S-DDGS, the type of species, as well as the ration that will contain S-DDGS as an ingredient for both 2015 and 2024. The TMR of dairy cattle will use the most S-DDGS (56 521 tonnes), followed by the dairy cattle calf starter ration (38 575 tonnes), and the dairy cattle pasture-based feeding ration (12 535 tonnes).

As the availability of S-DDGS remains constant over the baseline period (2015 – 2024), the projected consumption of S-DDGS is mostly by dairy cattle, followed by layers.

Table 4.12: Species consumption of S-DDGS for 2015 and 2024

Animal category	Animal type	Animal ration	Quantity (tonnes) 2015	Quantity (tonnes) 2024
Cattle dairy	Calves	Starter	38 575	33 233
Cattle dairy	Cows	Concentrate/roughage	162	63 829
Cattle dairy	Cows	Pasture	12 535	12 403
Cattle dairy	Cows	TMR	56 521	11 160
Horses	Horses 1	Racehorse	1 084	-
Horses	Horses 1	Breeder ration	595	740
Horses	Horses 1	Hacks	11 279	990
Horses	Horses 1	Working horses	369	476
Layer	Breeder	Starter	1	0
Layer	Breeder	Grower	12	42
Layer	Standard	Starter	415	87
Layer	Standard	Grower	4 104	15 649
Ostriches	Breeder	Grower	15	-
Ostriches	Breeder	Breeder ration	170	-
Ostriches	Standard	Grower	54	-
Ostriches	Standard	Post-finisher	187	-
Pigs	Breeder	Sow/boar	3 931	-
Pigs	Breeder	Lactating sow	3 660	-
Pigs	Standard	Baconer	3 519	-
Sheep	Feedlot	Feedlot ration	2 812	1 389
Total	**–**	**–**	**140 000**	**140 000**

Source: APR_OPT model generated results

Figure 4.4 graphically explains the consumption of S-DDGS for the animal categories. Dairy cattle will consume 77% of the total S-DDGS, horses 10%, and pigs 8%.

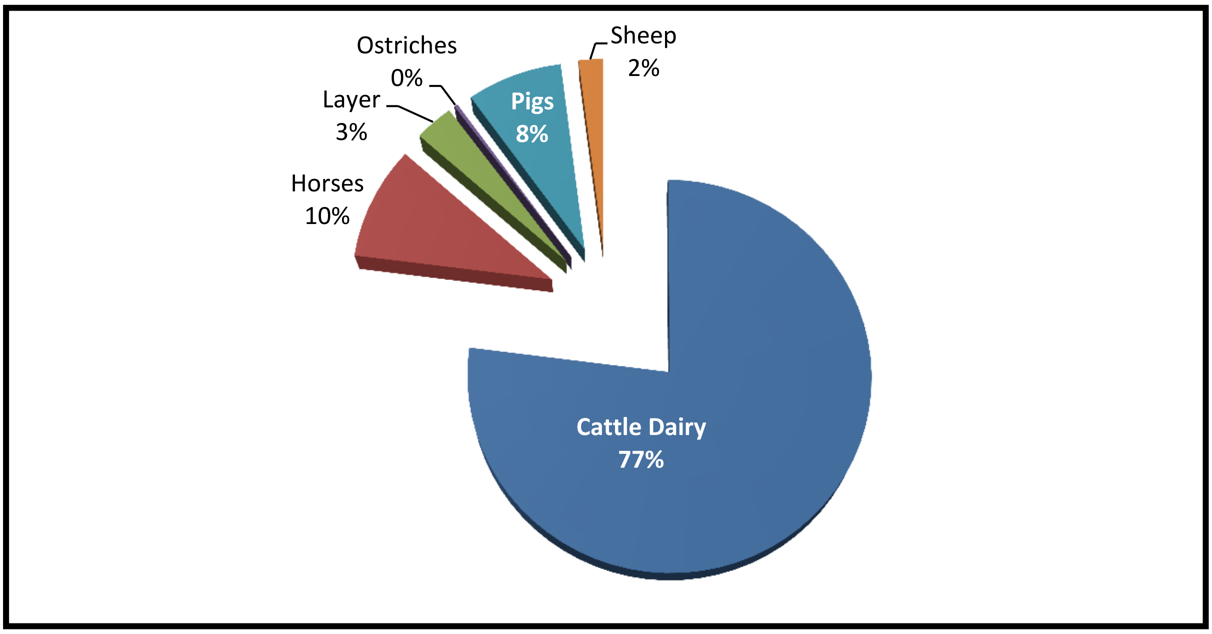


Figure 4.4: Species consumption of S-DDGS for 2015
Source: APR_OPT model generated results

4.3.1.4 External Shock 1 conclusion

S-DDGS at an availability of 140 000 tonnes per annum and with exactly the same price as yellow maize will be fully absorbed throughout the baseline period (2015 to 2024). Protein sources and vegetable oils will mostly be displaced by the introduction of S-DDGS into the animal feed industry. More amino acids (lysine) will be required to complement the raw materials in animal rations.

Dairy cattle will be the biggest consumers of S-DDGS, especially in calf rations and TMR. Horse rations will be the second biggest consumer, followed by pig rations. The quality of S-DDGS is of critical importance to ensure full absorption into the animal feed industry as the raw material contains high levels of protein and serves as a good energy source, but poses a threat in terms of mycotoxins.

4.3.2 External Shock 2: The implementation of AGOA

The USA enacted a trade act called the African Growth and Opportunity Act (AGOA) on 18 May 2000 as Public Law 106 of the 200th Congress. AGOA went from strength to strength and was recently renewed to 2025. The legislation aims to improve market access for sub-Saharan African countries to the USA (AGOA, 2016). The bilateral trade between the USA and South Africa declined during the past years. In 2012, AGOA imports amounted to the value of $2.4 billion but decreased substantially to $1.3 billion in 2014. The USA’s trade balance has always been negative with regards to South Africa, meaning that South Africa has always exported more produce to the USA than what is imported from the USA (AGOA, 2016). The 2015 AGOA agricultural exports from South Africa amounted to $153.8 million. The agricultural produce exported from South Africa comprises citrus, avocadoes, nuts, wine, sugar, table grapes, and lamb (AGOA, 2016). However, the USA’s agricultural exports amounted to $141.3 million in 2015, including the much debated poultry exports from the USA.

4.3.2.1 Description of the AGOA poultry imports

The current Act entails that South Africa should import a quota of 16 250 tonnes of frozen broiler bone-in portions before 31 March 2016, not subject to anti-dumping tariffs. Thereafter, the quota is 65 000 tonnes of bone-in broiler portions, with the quota period being 1 April to 31 March (Government Gazette, 2015:1). The growth factor will be determined by the DAFF and will be applied to the 65 000 tonnes being imported. The growth factor is determined by DAFF averages, which entail an average of poultry production and consumption figures as published by the DAFF each year in March.

The desired results in the AGOA shock are to quantify the amount less raw materials required for animal feeds and what that effect will be on total raw material imports.

To simulate the impact of the AGOA external shock on the APR_OPT model, the following assumptions were taken into consideration:

1. Sixty-five thousand (65 000) tonnes of broiler imports (Table 4.13) – Over and above the current imports projected by the BFAP baseline (2015).
2. The growth factor (Table 4.13) is determined from the increase in per capita consumption of broiler meat provided by the BFAP baseline (2015).

Table 4.13: Growth percentage, AGOA imports, and total chicken imports

Year	Kg/capita/year	Growth	AGOA imports	Total chicken imports
2015	35.18	0%	0	359 100
2016	36.06	2.50%	65 000	458 500
2017	36.99	2.58%	66 676	492 776
2018	37.95	2.60%	68 407	519 607
2019	39.00	2.77%	70 300	546 000
2020	40.04	2.67%	72 174	568 274
2021	41.08	2.60%	74 049	589 449
2022	42.15	2.60%	75 978	611 178
2023	43.22	2.54%	77 906	633 506
2024	44.35	2.61%	79 943	658 543

Source: BFAP (2015); APR_OPT model generated results

4.3.2.2 Results

In the following sections, the data in Table 4.13 were simulated in the APR_OPT model, which generated the results that follow.

4.3.2.2.1 Local broiler feed demand

As per Figure 4.5, the total feed demand in 2016 for broilers before the AGOA implementation amounted to 3.6 million tonnes, and would decrease to 3.4 million tonnes after 65 000 tonnes of bone-in cuts are imported from the USA. In 2024, imports from the USA will increase to nearly 80 000 tonnes, resulting in a 158 793 tonnes decrease in broiler feed demand.

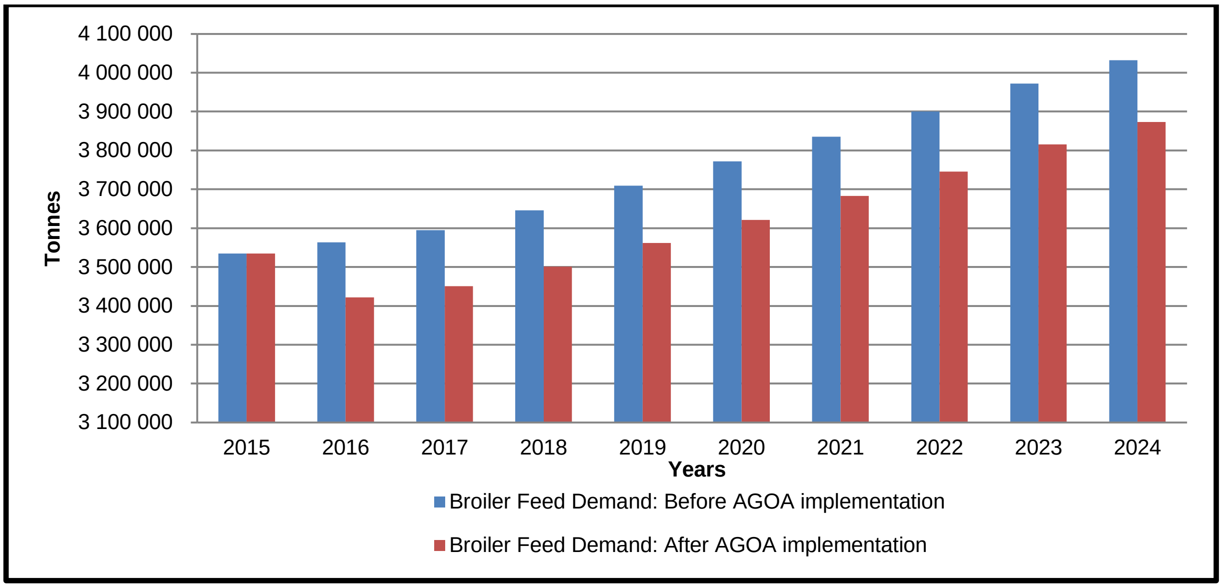
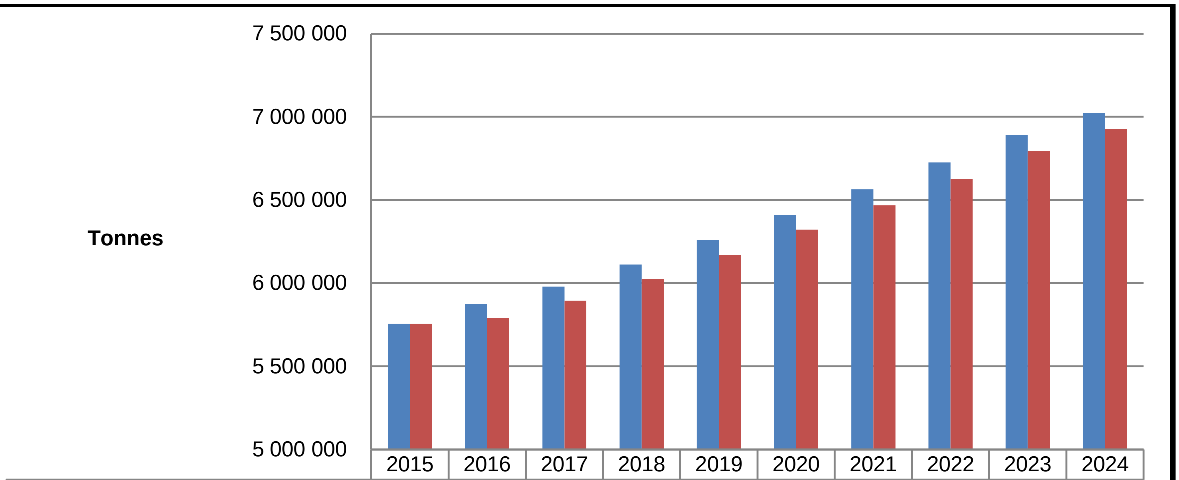


Figure 4.5: Local broiler feed demand before and after AGOA implementation
Source: APR_OPT model generated results

4.3.2.2.2 Raw material usage

As yellow maize is the main ingredient in broiler rations, Figure 4.6 graphically displays and compares yellow maize consumption before and after the AGOA implementation. Yellow maize consumption in 2016 is estimated at 5.875 million tonnes before the AGOA implementation, with yellow maize demand decreasing by 1.45% to 5.789 million tonnes after the AGOA implementation. An average annual decrease of 1.43% in yellow maize demand is expected over the forecasted period (2015 – 2024).



	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Yellow Maize Usage: Before AGOA implementation	5 756	5 875	5 979	6 111	6 257	6 411	6 564	6 725	6 891	7 022
Yellow Maize Usage: After AGOA Implementation	5 756	5 789	5 893	6 022	6 169	6 321	6 467	6 628	6 795	6 926

Figure 4.6: Yellow maize consumption before and after the AGOA implementation
Source: APR_OPT model generated results

Protein sources are the second most raw materials included in broiler rations (see Figure 4.7). Total protein consumption shows an annual 1.89% decrease in demand as AGOA imports increase and less local production is required. The biggest decrease in total protein consumption occurs in 2016 and 2019, with a 2.16% decrease in total protein consumption during the respective years.

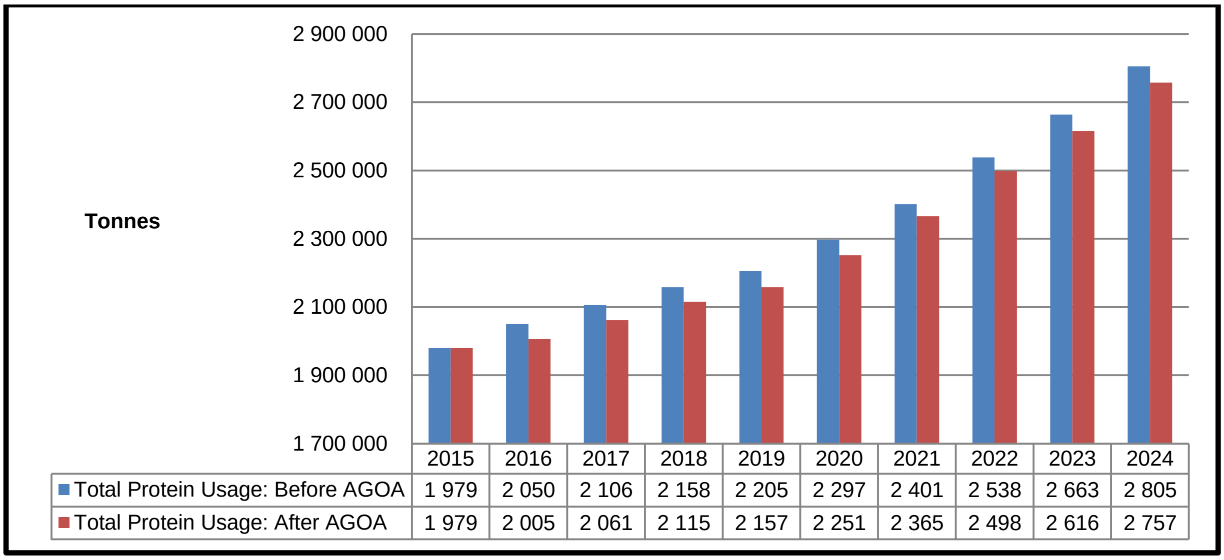


Figure 4.7: Total protein usage before and after the AGOA implementation
Source: APR_OPT model generated results

4.3.2.2.3 Soya oilcake imports

Soya oilcake is the most imported raw material used in broiler rations and the only raw material to decrease when AGOA is implemented, and thus the only raw material displayed in Table 4.14. The biggest decline in the demand for imported soya oilcake occurs in 2020 with 14.69%, followed by 2010 at 14.54%. The decline in total protein source imports is favourable for the main objective of the PRF (2015) to become self-sufficient in protein supply.

Table 4.14: Total protein-source imports before and after the AGOA implementation

	Total protein imports (tonnes)	Total protein imports (tonnes)	Percentage change
Year	Before AGOA	After AGOA	
2015	788 962	788 962	0.00%
2016	573 525	529 157	-8.38%
2017	496 480	452 113	-9.81%
2018	434 832	390 126	-11.46%
2019	374 573	327 028	-14.54%
2020	364 645	317 950	-14.69%
2021	369 714	334 088	-10.66%
2022	427 615	388 061	-10.19%
2023	496 933	449 927	-10.45%
2024	582 148	533 643	-9.09%

Source: APR_OPT model generated results

4.3.2.3 External Shock 2 conclusion

As seen from the abovementioned results, the implementation of AGOA will have a definite effect on the amount of broiler feed required, the amount of raw materials required for broiler rations, and the imported quantity of raw materials.

The importing of 'anti-dumping-free' bone-in chicken portions to the quantity of 65 000 tonnes in 2016 will cause an annual 1.14% decrease in the demand for animal feed over the baseline period (2015 – 2024). Total raw material demand will decrease with 1.41% over the baseline period, while the demand for yellow maize will decrease with an average of 1.43% over the baseline period. Total protein-source imports will decrease with an average of 11.03% yearly over the baseline period (2015 – 2024). The magnitude of this external shock is relatively small considering the current vast amounts of broiler meat being imported; however, it is important to note the ripple effect of the AGOA implementation on job losses and profitability in the South African broiler industry.

4.3.3 External Shock 3: Drought

The South African Weather Service (2016) reported that 2015 (January to December) recorded the lowest average annual rainfall (403 mm) in a 112-year dataset, dating from 1904 to 2015. The year 2015 was indeed a dry and challenging year for the agricultural sector, with severe rippling implications in the sector. The average annual rainfall over the 112-year period was estimated at 608 mm per year. Figure 4.8 contextualises the 2015 low average rainfall, and also aims to provide context for comparing the 2015 drought with the 1992 drought. This provides some context, but one should take into consideration the monthly distribution of rainfall in the context of agricultural production seasons.

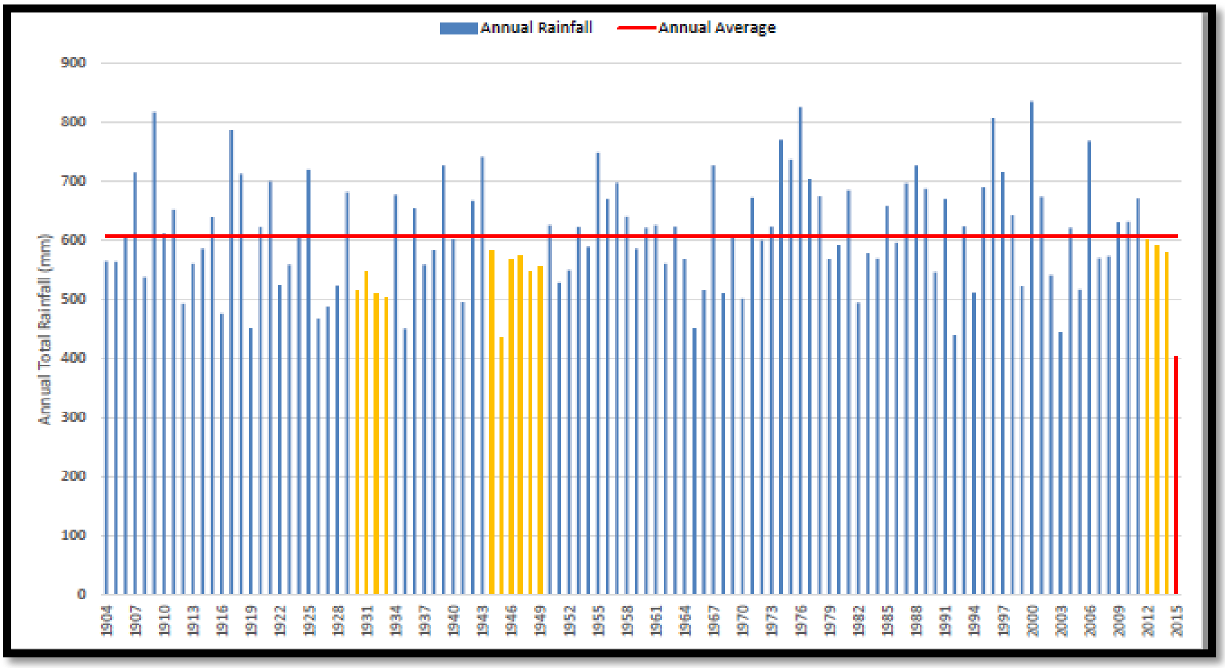


Figure 4.8: South African annual rainfall from 1904 to 2015
Source: Weather Service South Africa (2016)

Taking the importance of seasonal rainfall into consideration, the months of October, November, and December (planting months for summer crops) in the major summer crop-producing regions received below-average rainfall to the extent of being classified as severely and extremely low rainfall (BFAP, 2016:2). The drought forced the South African government to declare five provinces as disaster areas. The agricultural sector contributes only 2.5% to the GDP, but the effects and post-effects of the 2015 drought on food security and the availability and affordability of food and raw materials for the animal feed industry should not be underestimated (BFAP, 2016:2).

4.3.3.1 Description of the 2015/2016 drought shock

Given the above, the 2015 drought has caused commodity prices to increase substantially and the projected availability of raw materials is at a record low. The aim of the external supply shock is to determine:

- what the effect of high commodity prices will be on ration costs for the animal sector; and
- to quantify the amount of raw materials to be imported, given the current and projected low availability of raw materials.

4.3.3.2 Assumptions used

As conditions improved during January 2016, the Crop Estimates Committee (CEC) released an optimistic preliminary area estimate for the summer crops of 27 January 2016. This report is traditionally released at the end of February. Substantial amounts of maize were only planted early in January, which is four to six weeks out of the optimal planting period. Thus, a great risk remains evident with regards to production.

The assumptions will therefore be based on the press release from the CEC on 27 January 2016.

4.3.3.2.1 Raw material availability

Table 4.15 presents the preliminary area planted and preliminary production forecast for 2016 for summer crops. Total maize production is estimated at 7.4 million, only about 60% of the five-year average production figures (11.226 million tonnes). Soya bean production has increased drastically over the past decade and is now more or less in line with the five-year average production figure (810 000 tonnes). Sunflower planting commenced late in January, and a high risk remains for frost that could decrease yield.

Supplementary raw materials used in animal feeds will be derived using the ratios described in Table 3.24. The availability of winter crops will remain the same as in the baseline projections.

Table 4.15: Preliminary area planted and production forecast for 2016

Crop	2016			2015			
	Area planted	Production forecast	Yield	Area planted	Production forecast	Yield	Change
	Hectares	Tonnes	Tonnes/ha	Hectares	Tonnes	Tonnes/ha	%
White maize	1 032 650	3 267 000	3.16	1 448 050	4 702 700	3.25	-30.53%
Yellow maize	962 500	4 171 250	4.33	1 204 800	5 238 950	4.35	-20.38%
Sunflower seed	617 000	622 000	1.01	576 000	660 900	1.15	-5.89%
Soya beans	535 000	768 560	1.44	687 300	1 059 850	1.54	-27.48%
Groundnut	24 000	29 600	1.23	58 000	56 675	0.98	-47.77%
Sorghum	62 500	119 400	1.91	70 500	116 500	1.65	2.49%
Dry beans	25 500	35 150	1.38	64 000	73 390	1.15	-52.11%
Total	**3 259 150**	**9 012 960**		**4 108 650**	**11 908 965**		**-24.32%**

Source: CEC (2016)

According to the BFAP (2016), the current maize stocks are estimated at 1.6 million tonnes (of which 0.6 million tonnes are yellow maize) until the end of the 2015/2016 marketing season. Given the 7.4 million tonnes projected by the CEC (2016), substantial amounts of maize need to be imported, mostly from import sources other than Southern African countries, as these countries have also been severely struck by the drought (BFAP, 2016).

4.3.3.2.2 Raw material prices

The assumptions are based on BFAP (2016) reports regarding the drought. The reports are based on an average annual exchange rate of R16.80 per US dollar for 2016. Table 4.16 represents the major commodity prices used in the drought shock. The baseline prices represent the prices used in the baseline model (2015 – 2024). The CEC baseline represents the 2016 commodity prices and is based on the CEC's (2016) preliminary crop estimates report released on 27 January 2016. Thus, the baseline prices actually represent a normal year, but the 2015/2016 drought has pushed commodity prices to new levels, as displayed by the CEC baseline prices. The white maize price increased with 116%, where the yellow maize price increased with 64%, soya beans and sunflower increased with 29%, and the price of wheat increased with 30%.

Assuming the following prices sourced from the BFAP (2016) and using the price ratios from Table 3.22, these will be used as new input prices to estimate ration costs for all animals.

Table 4.16: Major commodity prices for CEC baseline compared to BFAP baseline prices

Crop	CEC baseline – Annual averages 2016	Baseline prices 2016	Change
	R/tonne	R/tonne	%
White maize	4 751	2 198	116%
Yellow maize	3 613	2 198	64%
Soya beans	6 414	4 987	29%
Sunflower	6 575	5 103	29%
Wheat	5 206	4 000	30%

Source: BFAP (2016); CEC (2016); Other raw material prices adapted according to ratios displayed in Table 3.20

4.3.3.3 Results

The following sections describe the results generated by the APR_OPT model to satisfy the aims of the drought shock mentioned in Section 4.3.3.1. The first section discusses the animal feed ration costs, and the imported raw materials are discussed thereafter.

4.3.3.3.1 Animal feed ration costs

The generated results are tabulated in Table 4.17. The results were generated for 2016. Sheep rations show the biggest increase in ration costs with 63%, followed by dairy cattle and horses (61%), and ostriches at 58%. Broiler rations show a 44% increase compared to the baseline projections – from R3 398/tonne to R4 909/tonne – while dairy rations increased from R2 604/tonne to R4 203/tonne.

Table 4.17: Ration costs in the baseline projections compared to drought shock: 2016

Animal category	Baseline	Drought shock	Increase
	R/tonne	R/tonne	Percentage
Broilers	3 398	4 909	44%
Aquaculture	8 126	10 768	33%
Cattle beef	2 673	3 940	47%
Cattle dairy	2 604	4 203	61%
Horses	3 005	4 839	61%
Layers	2 822	4 275	51%
Ostriches	2 842	4 494	58%
Pets	3 242	5 006	54%
Pigs	3 356	4 977	48%
Sheep	2 522	4 103	63%

Source: APR_OPT model generated results

Figure 4.9 illustrates the comparison between the baseline projections (normal year) and the current drought conditions causing commodity prices to increase substantially. From Figure 4.9 it is clear that profit margins for intensive-fed animals (rations high in yellow maize, soya oilcake, and sunflower oilcake) will be tight or even non-existent.

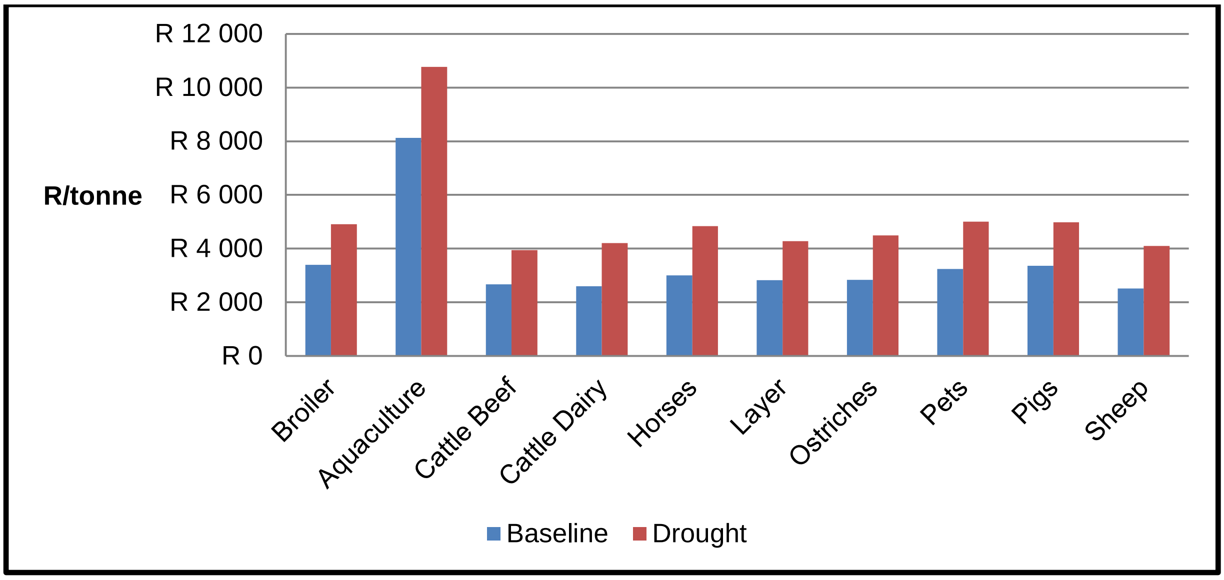


Figure 4.9: Baseline ration costs compared to drought ration costs: 2016
Source: APR_OPT model generated results

The poultry and pork industries are both net importers of respective products, and given the weak rand, local prices have found good support. However, maize is the largest ingredient used in poultry and pork feed rations. The increase in feed grain prices outpaced the increase in meat prices, which negatively impacted the profit margins of the respective sectors (BFAP, 2016:14). The statement made by the BFAP (2016) supports the results generated in the drought shock where broiler and pork rations prices showed an increase of 44% and 48% respectively.

4.3.3.3.2 Imported raw materials

According to the BFAP (2015), the production of yellow maize for 2016 was estimated at 6.385 million tonnes, which is 47% of the total production. This projection was made under normal weather conditions. Referring to Table 4.15, the 2016 yellow maize production is estimated at 4.171 million tonnes, 53% lower than the BFAP's (2015) projections. Soya beans are estimated at 769 000 tonnes and sunflowers at 622 000 tonnes. The projections are 68% and 33% lower respectively than the BFAP's (2015) projections. Thus, imports are required to satisfy the local demand. The results generated by the APR_OPT model quantify the import demand.

Table 4.18 tabulates the increase in imports caused by the drought and decreased local production. In a normal year, South Africa would be self-sufficient in its maize supply, but the drought shock demonstrates that 1.695 million tonnes of maize should be imported to supply the local animal feed demand. The BFAP (2016) projects yellow maize imports of close to 1.9 million tonnes considering the CEC (2016) report, and projects 2.236 million tonnes under a more severe supply shock. Soya oilcake imports are expected to increase with 140% in 2016, while the import of sunflower oilcake is expected to increase with 137% in 2016.

Table 4.18: Baseline imports compared to drought shock imports: 2016

Imported raw materials	Baseline	Drought	Change
	2016	2016	2016
	Tonnes	Tonnes	%
Cotton full fat	38 850	38 850	0%
Yellow maize	-	1 695 216	100%
Cotton oilcake	134 400	134 400	0%
Groundnut oilcake	588	588	0%
Soya oilcake	323 437	777 094	140%
Sunflower oilcake	44 750	106 267	137%
Palm kernel meal	31 500	31 500	0%
Total	**573 525**	**2 783 914**	**385%**

Source: APR_OPT model generated results

Table 4.19 tabulates the projected protein imports for 2016. According to Table 4.7, the baseline results generated (2015 to 2024) show that in 2016, South Africa is 72% self-sufficient in its protein-source supply. In the drought shock, however, South Africa's self-sufficiency drops to 49%. The local soya bean production is estimated to be 27% less than in 2015, with a 6% reduction when compared to the five-year average production. According to the baseline results for 2016, South Africa supplied 75% of its total soya oilcake demand. In the drought shock, local production is expected to drop to 42%. In the baseline year of 2016, South Africa provided 88% of local demand for sunflower oilcake, while this percentage drops to 72% in the drought shock. This is a worrying factor for the PRF, which aims to be 100% self-sufficient in protein-source raw material supply. However, it should be taken into consideration that the latter part of 2015 and early 2016 were extreme periods in terms of drought and that the self-provision of protein sources will stabilise to normal in the following production season (2016/2017).

Table 4.19: Protein-source imports in the drought shock: 2016

Protein source	Baseline 2016		Drought shock 2016	
	Imports	Locally produced protein	Imports	Locally produced protein
	Tonnes	%	Tonnes	%
Canola full fat	-	100%	-	100%
Cotton full fat	38 850	13%	38 850	13%
Soya full fat	-	100%	-	100%
Lupins	-	100%	-	100%
Canola oilcake	-	100%	-	100%
Cotton oilcake	134 400	0%	134 400	0%
Groundnut oilcake	588	0%	588	0%
Soya oilcake	323 437	75%	777 094	42%
Sunflower oilcake	44 750	88%	106 267	72%
Palm kernel meal	31 500	0%	31 500	0%
Total	**573 525**	**72%**	**1 088 699**	**49%**

Source: APR_OPT model generated results

4.3.3.4 External shock analyses conclusion

To conclude the drought shock, it is clear that the 2015/2016 drought had and will have devastating monetary and supply effects on the animal feed industry. Ration costs across all animal categories showed at lowest a 33% increase in ration cost (aquaculture), and at highest a 63% increase (sheep) in animal feed. Profit margins of intensive-fed animals (broiler, pigs, layers, and dairy) are impacted negatively, while feed costs increase at a faster rate than meat prices.

Raw material availability is estimated, on average, to be 24% lower than in 2015. Yellow maize needs to be imported, where in previous years South Africa was a net exporter of yellow maize. South Africa is striving to become self-sufficient in protein-source supply, but the current drought has pushed the protein self-sufficiency percentage down to 49% in 2016, compared to a 72% self-sufficiency figure in the baseline results for 2016.

4.4 CHAPTER SUMMARY

Chapter 4 displayed, discussed, and interpreted the results generated by the APR_OPT model. Firstly, baseline results were generated from 2015 to 2024, which served as the foundation to which external shock were simulated. The model generated favourable results, and its functionality proved to be working as input data can be changed user-friendly to generate new results.

Secondly, external shocks were simulated in the model. The shocks were:

- The effect of S-DDGS on the animal feed industry:
    - S-DDGS are fully absorbed into the animal feed industry at 100% of the yellow maize price at availability of 140 000 tonnes annually.
    - Dairy cattle are the biggest consumer of S-DDGS.
- The AGOA implementation:
    - Sixty-five thousand (65 000) tonnes of bone-in portions of chicken imported from the USA will decrease animal feed demand with 1.41% annually over the baseline period (2015 to 2024).
    - Yellow maize consumption will decrease with an average of 2% over the baseline period, while protein imports show a reduction of 11.03% on average per year during the baseline period.
- The 2016 drought shock:
    - Ration costs across all animal categories will increase with 52% on average in 2016.
    - Imports of raw materials to South Africa will increase, whereas South Africa will only be 49% self-sufficient in protein-source supply for 2016, compared to 72% in the baseline period.

Chapter 5 concludes the study. It emphasises the important characteristics of the APR_OPT model to justify the relativity of the APR_OPT model in the animal feed industry.

CHAPTER 5: CONCLUSION

5.1 INTRODUCTION

Increased global urbanisation and the rise of the middle class have caused an increased demand for animal-protein sources, which leads to greater demand for protein sources to feed the animals. In light of this, the study focused on quantifying the interactions of protein consumption and usage between humans and the animal and animal feed industry in South Africa. Furthermore, the study aimed to forecast the quantified interactions until 2024. A few studies regarding raw material allocation from supply to demand points have been conducted internationally. Three South African studies have been conducted that had relevance to this study. A fair comparison of generated results from these three models requires the updating of the Nieuwoudt / McGuigan model and the APR model. Furthermore, the main objectives of the APR model, Nieuwoudt / McGuigan model and the BFAP model differ materially and the results cannot be accurately compared. The comparison exercise of the three models is however, beyond the scope of this study.

In this study, the APR model was replicated to create the APR_OPT model, which is a GAMS-operated LP model. The APR model is regarded as the foundation of this study. The APR_OPT model was integrated with the BFAP model, as the outputs of the BFAP model served as inputs for the APR_OPT model.

The BFAP model's results are generated given the underlying assumptions explained in BFAP (2015:16-17). One must note that markets are extremely volatile and move in cycles and therefore, the probability that future raw material prices, raw material supply and consumption estimates will not match the baseline projections, are high. Therefore, the results of the APR_OPT model should be seen in the context of the BFAP input data. The results will serve as a benchmark to which specific external shocks can be quantified and understood. In summary, the results will portray a benchmark of what could happen given the certain set of assumptions.

Initially, the APR_OPT model generated baseline results for the period 2015 to 2024. Thereafter, three external shocks, as discussed in Chapter 4, were simulated with the APR_OPT model to measure shocks on the animal feed industry and furthermore on protein consumption. The following sections aim to justify the importance of the APR_OPT, to highlight the key success characteristics of the APR_OPT model, and to define its relevance in the industry.

5.2 APR_OPT MODEL RESULTS FOR THE BASELINE PERIOD (2015 – 2024)

In satisfying **Sub-objective 1** of the study, the APR_OPT model showed the ability to do the following:

- Determine the human demand for animal-source protein through population data, as well as the per capita consumption of each animal-source protein. Given this ability, and the correct data, the model can easily determine the amount of animal-source protein required to supply the South African demand.

- Estimate the number of animals to be slaughtered to supply the South African demand for animal-source protein. With simple calculations and technical industry data, one can determine whether or not there will be a demand for the livestock products produced. This can act as a "sanity check" for the farmer in aligning farming operations with the future demand for the products.
- After the replication of the APR model, developed by Briedenhann (2001), into a user-friendly model, together with GAMS, the APR_OPT model is able to allocate and distribute raw materials across South Africa in order to formulate least-cost animal feed rations. The model is able to determine a shortage in raw materials, and provide for the shortage by importing raw materials.
- Furthermore, the model can determine the costs of animal feed rations. This ability gives the animal feed industry the opportunity to determine and forecast the future cost of rations and to hedge accordingly to protect the animal feed manufacturers against unfavourable price movements. On the flipside, it provides the producers of livestock products with insights into what animal rations will cost. The livestock producer can determine future profit margins with the given animal feed costs, and identify future price risks and operate accordingly.

Sub-objective 2 entailed the incorporation of BFAP baseline data into the APR_OPT model. The model was able to be updated as the baseline period progressed. Therefore, the APR_OPT model can serve as a results database for baseline-generated purposes. Once a database is built from the results, the animal feed industry and the PRF can compare results in order to determine whether or not 100% self-sufficiency in protein supply is becoming a reality.

Meyer *et al.* (2008) stated, "The BFAP sector model is a dynamic system of econometric equations, which has the ability to model cross-commodity linkages." Therefore, accurate and dynamic data can be generated by the BFAP model.

With the incorporation of BFAP data into the APR_OPT model, accurate and relevant results can be formulated for the South African agricultural sector. The protein interactions between the human demand for animal-source protein, animal-source protein supply, and animal feeds were clearly shown in the results as protein transforms from one form to the other to supply ever-growing demand levels.

The APR_OPT model has the ability to forecast and quantify future protein interactions and raw material requirements. With the incorporation of BFAP baseline data, the model is able to accurately forecast and quantify the following:

- Animal feed demand.
- Quantity of animals to be fed and slaughtered.
- Raw material usage.

- Determine future local raw material demand, and the increase in production that should take place in order to supply in the growing demand for animal feed.
- Raw material usage by every animal category.
    - In order to determine which animal category will absorb the most animal feed in the future.
- Raw material import requirements.
    - Determining whether or not South Africa is becoming self-sufficient in protein demands, thus local production exceeding local demand.
- Animal feed ration cost.
    - Determining future animal feed ration costs and profit margins for a specific enterprise to establish the profitability and sustainability of such an enterprise.

In satisfying **Sub-objective 3**, three ad hoc external shocks were simulated in the APR_OPT model to determine if the APR_OPT model can handle different shocks and simulations on the baseline period. The following external shocks were simulated:

- The entry of a new protein source (S-DDGS) into the animal feed industry;
- The implementation of the AGOA trade agreement between the USA and Africa for poultry products; and
- The 2015/2016 drought shock with higher commodity prices, hampered local production, and increased protein-source imports.

The APR_OPT model reacted positively to all three shocks and satisfied Sub-objective 3. The capabilities of the APR_OPT model, in terms of external shock analyses, are explained in the following sections. As the results were already explained in Chapter 4, the following sections aim to show the relevance and capabilities of the APR_OPT model as beneficial to all protein-related industries in South Africa.

5.3 EXTERNAL SHOCK 1: THE EFFECT OF S-DDGS ON THE ANIMAL FEED INDUSTRY

In short, the shock was simulated to determine how the APR_OPT model is able to absorb a new raw material into the animal feed industry. The following conclusions are made regarding the simulated shock and can be applied to any new raw material available for animal feeds:

- The APR_OPT model was able to determine the price at which the new raw material will be fully absorbed into the animal feed industry.
    - The abovementioned will be able to guide the producers of this new raw material to the value thereof, given the nutrient specifications of the raw material.
- The APR_OPT model has the capability to determine which animal categories will absorb the bulk of the new raw material.
    - Once again, the producers of the new raw material will have an accurate indication to which livestock sector the new raw material should be marketed.

    - For example, the results indicated that S-DDGS will be fully absorbed in the animal feed industry at a price of 100% of the yellow maize price and mostly by the dairy sector.
- The APR_OPT model also provided a clear indication of which established raw materials will be substituted in the animal feed industry. Hence, the introduction of a new raw material into the animal feed industry will substitute existing raw materials, which, on the flipside, provides scope for exports, given the assumption that local production keeps increasing.
    - In 2015, at an availability of 140 000 tonnes of S-DDGS, 5.86% less protein sources, 3.28% less vegetable oils, and 4.27% more lysine will be required.
- Furthermore, S-DDGS are a by-product of the ethanol process in which sorghum is utilised. The model is capable of determining whether there will be a market for by-products once ethanol production increases, which in turn will stimulate further production of raw materials for ethanol production.

5.4 EXTERNAL SHOCK 2: THE AGOA IMPLEMENTATION

The AGOA implementation caused a great uprise in the poultry industry during the latter part of 2015 and early 2016. The AGOA implementation shock in its simplest form is one of a change in the quantity animal-source protein being imported, and derived thereof is a decreased South African demand for animal feeds. The APR_OPT model conveyed the following capabilities:

- Determining animal feed requirements given lower or higher import and export of animal-source protein.
    - Broiler animal feed demand decreased with 141 492 tonnes in 2015, with 65 000 tonnes imported, and increased to 158 793 tonnes by 2024, with imports increasing to 80 000 tonnes.
    - Protein imports showed an 11.03% average year-on-year decrease as chicken imports from the USA displace local broiler production.
- Given the above capability, the model will also be able to quantify what the effect will be of lower or higher per capita demand for an animal-source protein on the animal feed demand.
- The same accounts for population growth. An expected future shock on population growth can be simulated in the shock to quantify the demand for animal feeds.
- Furthermore, the APR_OPT model is able to quantify the amount of raw materials required for the animal feeds; whether more raw materials are required with fewer imports of animal-source proteins, or less raw materials are required with increased imports.

From the abovementioned capabilities, is clear that the APR_OPT model can provide the producers of raw materials with much-needed insights into the future demand for raw materials, given assumptions made on the import and export of animal-source protein.

This type of shock can also aid decision makers in establishing import quotas on animal-source protein. The principle should remain that locally produced raw materials and protein sources should supply the local demand for animal-source proteins. This external shock analyses can aid decision makers to create an environment for farmers where demand for the products exists.

5.5 EXTERNAL SHOCK 3: THE DROUGHT SHOCK

The drought shock of the 2015/2016 production season is a typical shock of lower availability of raw materials and higher raw material prices. The APR_OPT model showed the following capabilities:

- Quantifying the effect of higher commodity and protein prices on the cost of animal feed rations.
    - This is an important capability as it provides an indication for livestock and intensive livestock producers of possible future profit margins of a respective sector:
        - Broiler rations increase with 44% to R4 909/tonne.
        - Dairy rations increase with 61% to R4 203/tonne.
        - Layer rations increase with 51% to R4 275/tonne.
        - Pork rations increase with 48% to R4 977/tonne.
- Quantifying the amount of protein-source imports required to satisfy the local demand.
    - This external shock gives animal feed manufacturers an early warning signal for the shortage of a raw material or protein source in the market. Hence, the animal feed manufacturer is able to plan for imports of raw materials to supply the local shortage and to be able to provide sufficient supply for the local market.
    - Providing the government with accurate information regarding the total amount of imports required to supply the local demand. Having this information available, the government can create action plans for the harbours and inland transport systems to sufficiently handle the vast amounts of imported raw materials.
    - Total imports of raw materials required for animal feed production increase with 385% to 2.78 million tonnes:
        - 1.7 million tonnes of yellow maize.
        - Soya oilcake imports increase with 140% to 777 094 tonnes.
        - Sunflower oilcake imports increase with 137% to 106 267 tonnes.
- Provide an indication of self-sufficiency in raw material and protein supply:
    - 32% decrease in protein self-sufficiency to 49%.

5.6 APR_OPT MODEL SUMMARY

To summarise the beneficial and useful abilities of the APR_OPT model, the following major capabilities are highlighted:

- Determine projected animal feed demand.
- Quantify the amount of animals to be slaughtered to supply human demand.
- Generate baseline and forecast results of raw materials utilised.
- Allocate raw materials to different regions.
- Quantify imported raw materials required by the animal feed industry.

- Determine baseline animal feed ration cost and forecasted cost.
- Simulate shocks on the animal feed industry with increased animal-source protein imports.
- Simulate the effect of the entry of a new raw material into the animal feed industry:
    - Identify the animal category which will absorb the new raw material.
    - The cost effect of the new raw materials.
    - The price at which the new raw material will be absorbed.
- Simulate the effect of a low/high supply of raw materials on the animal feed industry:
    - Quantify the increase/decrease in imports.
    - Quantify the increase/decrease in the price of animal feeds.
- Quantify South African self-sufficiency in protein supply for animal feeds:
    - Important lessons and recommendations to take from the self-sufficiency estimate.

Thus, from the abovementioned, it is clear that the APR_OPT model can be applied to simulate a variety of shocks on the protein linkages from human demand to animal supply and raw material / protein consumption. These abilities can be applied beneficially to the industries to aid decision making, identify shortcomings in the linkages, and improve self-sufficiency in protein supply for animal feed.

5.7 IMPLICATIONS FOR FUTURE RESEARCH

The baseline period forecasts show a steady growth in the demand for animal feed. Therefore, it is evident that local raw material production should keep up with the demand for animal feeds. It is of critical importance that the improvement of plant genetics should keep up with the genetic improvement of animals and the increasing human demand for animal-source protein.

The APR_OPT model is only an instrument to generate results and simulate external shocks. Therefore, input data and the integrity of data are of utmost importance. The APR_OPT model recommends that more raw materials and supplementary raw materials should be simulated through the BFAP model to obtain accurate input data for the APR_OPT model in terms of raw material prices and availability.

To improve accuracy in the generated results, further research should be conducted on increasing animal performance rates and the effects thereof on raw material consumption.

Currently, the APR_OPT model imports raw materials through the Cape Town and Durban harbours. Further research is required to include the Port Elizabeth and East London harbours to the model as the transport cost of raw materials also play a critical role in which raw materials are consumed with regards to least-cost methods.

Lastly, but most importantly, the innovation of the model should be researched and developed from the current static model to a dynamic model. This will enable the user and the APR_OPT model to model “real-time” changes in the agricultural industry, economy, political and trade environment. The dynamic characteristic will also enable the APR_OPT model to work in synchronisation with the BFAP model to generate accurate and relevant results.

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