A systems analysis and conceptual system dynamics model of the livestock-derived food system in South Africa: A tool for policy guidance

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Abstract

Global food production systems are currently under scrutiny, in particular the health, nutrition, and environmental impacts of livestock-derived food (LDF). Despite South Africa's recent socio-economic transformation and increased per-capita LDF consumption, the triple burden of malnutrition persists. Policy responses to such complex problems often fail because of linear thinking with short-term goals. However, a systems approach helps identify root causes, feedback mechanisms, potential unintended consequences, and opportunities for integrated, durable solutions. Participation in the systems-thinking process improves

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stakeholder understanding and buy-in. Our participatory workshop facilitated the development of a systems map for South African LDF, identifying key system elements, linkages, and nexus points. The latter included climate change, land access and management, livestock management and productivity, farming systems, food safety, policy articulation, agricultural knowledge, and income. Based on these findings, and an overview of related literature, we produced a conceptual system dynamics model of the LDF system. We identified key variables and causal relationships, vicious and virtuous loops, system archetypes, conceptual stock and flows, and links to Sustainable Development Goals. The LDF system is complex and dynamic, with a dominance of commercial enterprises across agriculture and food retail, presenting barriers for small and medium-scale individuals. Other key elements relate to population growth and urbanization, land access, deregulation of international trade, climate change vulnerability, feed production limitations, and food safety. Our work provides a unique reference for policymakers, identifying the need for deep structural change, highlighting the possible unintended consequences, and thereby mitigating the risk of system destabilization.

Keywords
Food Systems, Systems Thinking, System Dynamics, Livestock-Derived Food, Animal Source Food, South Africa

Note on Implications of COVID-19
This research was conducted prior to the COVID-19 pandemic, which has further highlighted inequalities in agriculture and food systems, both globally and nationally.[1]

Introduction
Food systems are increasingly disconnected from delivering healthy and nutritious food in a sustainable manner for all (Alders, Ratanawongprasat, Schönfeldt, & Stellmach, 2018). The provision of nutritious food is challenged by a rising population and the planetary boundaries for sustainable production (Conijn, Bindraban, Schröder, &

Jongschaap, 2018). However, current global food production is considered sufficient to feed even the predicted population of 2050, but it falls short due to poverty, distribution, and waste (Berners-Lee, Kennelly, Watson, & Hewitt, 2018; FAO, 2018a; Holt-Giménez, Shattuck, Altieri, Herren, & Gliessman, 2012). As a result, global food production has failed to address the triple burden of malnutrition and diet-related noncommunicable diseases (NCD) (Gómez et al., 2013; Swinburn et al., 2019; Willett et al., 2019). In addition, the current global burden of food-borne diseases (FBD) is comparable with the major infectious diseases of HIV/AIDS, malaria, and tuberculosis and is linked closely with poverty (Havelaar et al., 2015).

Livestock-derived food (LDF) is a major contributor to climate change, habitat destruction, and biodiversity loss (Godfray et al., 2018; IPCC, 2019). The predicted trends of increased global LDF consumption are considered environmentally unsustainable (IPCC, 2019; Tilman & Clark, 2014). Livestock keeping, however, provides rural communities with multiple benefits and plays an important cultural role (Eisler et al., 2014; FAO, 2009, 2018b). Carefully managed livestock can be used to positively manage ecosystems and their services (Diaz et al., 2012; Feliciano, Ledo, Hillier, & Nayak, 2018; Huruba, Mlambo, Mundy, Sebata, & MacFadyen, 2018). Livestock-derived food is rich in energy, protein, and essential amino acids and micronutrients, and it plays an important role in the nutrition of children and pregnant women in low and middle-income countries (LMICs) (Grace et al., 2018; Neumann et al., 2003). However, excessive consumption, of especially red and processed meat, increases the risk for some cancers, obesity, and related NCDs (Godfray et al., 2018; Willett et al., 2019). Changes in food systems, and the associated growth of LDF consumption, are most noted in countries undergoing rapid economic transition (Ritchie & Roser, 2018; Schneider et al., 2011). Demand for LDF in LMICs often increases at a pace that outstrips the development of effective food safety governance (Grace, 2015).

South Africa has undergone significant change

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[1] See https://www.worldbank.org/en/topic/agriculture/brief/food-security-and-covid-19

since the end of apartheid in 1994, including a 40% population growth and improving socioeconomic status, which are key drivers for increased consumption of LDF (Schneider et al., 2011; STATS SA, 2018a). Poultry meat has shown the greatest rise of LDF consumption over the past 20 years (Directorate Statistics and Economic Analysis [DSEA], 2018). Gaps in food safety surveillance were highlighted by the 2017–2018 outbreak of listeriosis, which was linked to a low-cost, processed LDF product containing poultry meat (Salama, Embarek, Bagaria, & Fall, 2018). South Africa's plant-based food production capacity is limited by the relatively small proportion (13.5%) of agricultural land suitable for cropping, its dependency on rainfall, and the associated vulnerability to climate change (Conway et al., 2015; DSEA, 2016). Despite socioeconomic change and advances in ensuring national food security, South Africa remains one of the most unequal countries in the world (World Bank, 2011). Inequality is embedded in land access, agriculture, and food retail, and this is also reflected in the triple burden of malnutrition (National Department of Health [NDoH], Statistics South Africa [STATS SA], South African Medical Research Council [SAMRC], & ICF, 2019). While adult obesity rates are rising to over 30%, stunting in under five-year-olds (27%) remains unresolved, and micronutrient deficiencies are especially high in vulnerable groups (Kolahdooz, Spearing, & Sharma, 2013; NDoH et al., 2019; World Bank, 2011).

The Wellcome Trust funded Sustainable and Healthy Food Systems (SHEFS) program aims to provide policymakers with novel, interdisciplinary evidence to define future food system policies that deliver nutritious and healthy foods, in an environmentally sustainable, and socially equitable manner. Holistic systems thinking is advocated to better understand such complex, wicked food system challenges (Alders et al., 2018; Zhang et al., 2018). Narrowly focused agricultural and food security interventions fail to recognize unintended consequences and opportunities for synergies that are often highlighted by more integrated approaches (Ruegg et al., 2018; Ruel & Alderman, 2013). Systems thinking and system dynamics modeling identifies key elements and archetypes (and their interconnections and feedbacks) within a system, and are useful tools in food system analysis, especially when looking for trade-offs and synergies within the "eco-agri-food system" (Zhang et al., 2018). When used in a truly transdisciplinary and participatory manner, a system dynamics model (SDM) provides stakeholders and policymakers with a more comprehensive understanding of the broader food system, builds their confidence and acceptance of the model, and allows for forecasting the outcomes of policy scenarios (Turner, Menendez, Gates, Tedeschi, & Atzori, 2016; Zhang et al., 2018). Examples include those published by Lie, Rich, & Burkart (2017) (dairy value chains), Stave (2002) (transport and air pollution), and Allender et al. (2015) (obesity).

Given its triple burden of malnutrition, ongoing socioeconomic and dietary transition, and vulnerability to climate change, South Africa is one of three countries selected by SHEFS (Govender, Pillay, Siwela, Modi, & Mabhaudhi, 2016; Ziervogel et al., 2014). This paper aims to provide a broad overview of recent dynamics within the South African LDF system and demonstrate the complexity of the system, using a systems map based on stakeholder participation. Furthermore, through a conceptual SDM, we aim to provide a tool for decision-makers, when considering food system recommendations, associated with nutrition and health, environmentally sustainable food production, food security, and equitable access.

Methods
We drew on methods described in several publications, within a broad range of disciplines, where groups of key stakeholders or community members participated in developing system maps and SDMs (Allender et al., 2015; Lie et al., 2017; Maani, 2002; Stave, 2002; Vennix, Akkermans, & Rouwette, 1996). A broad literature review was conducted for our own understanding of the South African LDF. We held a participatory workshop to map the overall system and to identify key nexus points, which were used to structure a more focused literature review. Thereafter, we created a conceptual system dynamics model based on the analysis of the results from the previous steps.

The participatory workshop, held at the Uni-

versity of KwaZulu-Natal (UKZN) in March 2018, aimed to understand better the broad structure and key elements of the South African LDF system. Twenty-nine participants (13 female, 16 male) represented various stakeholders and key inform-ants within the LDF system. These included indi-viduals from the national Department of Agri-culture, Forestry and Fisheries (DAFF), and the Department of Agriculture and Rural Develop-ment and local municipalities within KwaZulu-Natal (KZN) province. Nongovernmental organ-izations (NGOs) and not-for-profit organizations, including the Institute of Natural Resources (Agricultural and Rural Livelihoods), Wise Waze Water Care, and the World Wildlife Fund (Sus-tainable Agriculture), represented the local farming communities in which they work. Academic staff were included from various disciplines and research centers within UKZN, including Animal Science (Livestock Production), Crop Science, Grassland Science, Conservation, Public Health, Indigenous Knowledge, and Transformative Agriculture and Food Systems. They were joined by academic research staff from the University of London's Royal Veterinary College (RVC) (Veter-inary Epidemiology, Economics and Public Health) and School of Oriental and African Studies (SOAS) (School of Interdisciplinary Studies, Centre for Development, Environment and Policy).

Leading researchers within the SHEFS pro-gram opened the workshop with an introduction to SHEFS, and the concept of systems mapping. Thereafter, as a warm-up exercise and to encourage broad systems thinking, four predetermined break-out groups, representing an approximately equally diverse mix of backgrounds conducted a strengths, weakness, opportunities, and threats (SWOT) analysis of the South African livestock sector, and shared their findings for discussion and feedback during a plenary.

Then, after briefing participants on the pur-pose of a holistic approach to systems mapping using examples from previous research, each group was tasked with creating a systems map of the LDF system, identifying nexus points and indicating interrelational or causal loops between them. Participants were also asked to consider cross-cutting issues, such as food choice, nutritional status, environment, biodiversity, and socioeco-nomic variables. A facilitator (NS) experienced in systems mapping engaged with groups, questioning clarity on interrelationships and causalities, main-taining system boundaries, and made notes on overlaps and common elements in the maps. Each map was presented during a plenary, for feedback and discussion.

After the workshop, the four maps were ana-lyzed by a panel, which included the authors and other participants with relevant expertise within UKZN. The systems mapping facilitator then created a single, merged system map that was shared electronically with workshop participants for comment and verification. Participants were also asked (via SurveyMonkey) to identify (with motivations) their top five nexus points from the map. Responses were collated and analyzed to give a weighted ranking to each nexus point.

Using themes based on these main nexus points, a more focused literature review was con-ducted to provide evidence for the system elements and their interrelationships when constructing the conceptual SDM, as described later. The review covered academic journal articles and grey litera-ture, including government reports and statistical releases, farmers associations' and NGOs' reports, and websites of local and international press agencies, United Nations agencies (including FAOSTAT), and the World Bank. These were accessed through Google searches, using multiple disaggregated terms based on the nexus point themes. Further resources were identified through snowballing from primary results, using related references and citations. Results from this review were also used to identify the main livestock species used to produce the most consumed LDF. The dynamics of each species' production system and outputs were researched, as were the import and export dynamics for the associated LDF product. The most recent data from FAOSTAT, national statistics reports, and review articles were collated and presented in tables, graphs, and/or maps. Quantec EasyData (www.quantec.co.za), a data resource for South African economic data, supplied import and export data on request, which the authors analyzed and presented in graphs. During this review, several terms were identified in

the literature that were used (often inconsistently) to describe the different types of livestock farmers and farms. An overview of these terms and description was therefore included in our review, for clarification (Box 1).

Using logical reasoning and professional judgment, the authors created a conceptual SDM of the South African LDF system, based on a thorough, iterative, and collaborative systemic analysis of the workshop results and literature review. We identified interrelationships, feedback loops, balancing and reinforcing causal loops,[2]

conceptual stocks and flows, underlying structural issues, including system archetypes,[3] and links to the Sustainable Development Goals (SDGs) (United Nations, 2015). Finally, key gaps and challenges pertaining to the sustainability of the South African LDF system, and its nutritional and related health outcomes, were identified.

Ethics approval for the study was gained from the UKZN Human and Social Sciences Research Ethics Committee (HSS/0235/018D) and the RVC Social Science Ethical Review Board (URN SR2018-1624).

Box 1. South African Livestock Farmer Typology

Before 1994 and within the early post-apartheid transformation period, two terms are commonly used.

- **Commercial:** Business-orientated farms of large, medium or small scale, privately owned by White farmers, often practicing a high level of formal market engagement (Kirsten & van Zyl, 1998).

- **Communal:** Black subsistence or smallholder farmers residing in "homelands" (separate development territories), mostly engaged in local informal markets, if any (Meissner, Scholtz, & Palmer, 2014). "Communal" traditionally refers to a system of livestock management and land tenure in which privately owned livestock graze together with other herds on communally owned land.

In more recent literature, several additional terms are used (with some overlap):

- **Subsistence farmers or household producers:** Those with the lowest productivity, producing food primarily to support their household consumption needs (Tihanyi & Robinson, 2011).

- **Smallholders:** Farmers of higher productivity than subsistence, but still primarily for their own consumption, using more labor-intensive traditional methods, and perhaps marketing any excess production (Pienaar & Traub, 2015).

- **Small-scale farmers:** This term refers to *both subsistence and smallholders* and replaces the term communal, above (Aliber & Hall, 2012). Communal is still sometimes used, when referring to the communal management practice of small-scale livestock farmers (Mahlobo, 2016).

- **Commercial smallholders or market-oriented smallholders:** Smallholder farmers who produce for both home consumption and more regular income (Aliber & Hall, 2012; von Loeper, Musango, Brent, & Drimie, 2016).

- **Small-scale commercial (emerging) farmers:** Farmers who are transitioning from commercial smallholders to medium and large-scale commercial farming (Aliber & Hall, 2012; von Loeper et al., 2016).

- **Commercial farmers:** Both **medium-scale** (annual turnover US$360,000 to US$1.44 million)[1] and **large-scale** (annual turnover greater than US$1.44 million)[1] (DAFF, 2018b), privately owned farms (no longer exclusively White-owned as in commercial, above), business-orientated farms, often with high inputs and investment, practicing a high level of formal market engagement (Tihanyi & Robinson, 2011).

- **Noncommercial:** Refers to all others except medium and large-scale commercial farmers (DAFF, 2017a; RMRD, 2016).

[1] Conversion rate 1 ZAR=US$0.072 on November 27, 2018, per https://www.xe.com

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[2] A reinforcing loop is one where an increase in a variable, when traced around the loop, leads to a further increase in itself, while a balancing loop is one where an increase in a variable leads to a counterbalancing decrease in itself.

[3] System archetypes classify generic patterns of behavior over time (in particular counterintuitive behaviors), and demonstrate intended and unintended reactions and delayed reactions, and are a powerful tool to understand and communicate the underlying system's dynamic behaviour.

Results

1. System Mapping and Nexus Point Ranking

The workshop's merged systems map is presented in Figure 1. The participants' post-workshop analysis of the merged map, to identify and rank key nexus points, yielded the following results. In a highest-to-lowest, weighted-ranking analysis, the first 10 points were: (i) land access and (i) climate change (joint first place); (iii) small-scale vs. commercial farming; (iv) livestock management; (v) livestock productivity; (vi) food preservation/safety; (vii) policy articulation; (viii) agricultural education; and (ix) income, and (ix) land management (joint ninth place).

2. Literature Review

The review focussed on the following six themes developed from the workshop participants' nexus point ranking.

2.1. Human population statistics

In July 2018, South Africa's population was estimated at 57.5 million, a rise of 17% over the previous 10 years (STATS SA, 2018a). Approximately 30% of the national population is aged 15 years or less, while 8.5% are 60 or older. Life expectancy is 61 years for men and 67 years for women, while the infant mortality rate is 3.6%. Overall HIV prevalence estimates are 13.1% of the total population and 19% of the 15-49-year-old category (STATS SA, 2018a).

Despite government-funded social grants and Black Economic Empowerment (BEE) policies, South Africa is one of the most unequal countries in the world: 10% of the population holds 70% of the wealth, while 60% hold only 6% of the wealth (World Bank, 2018). The Black middle class has reportedly grown from 1.7 to 6 million since 1995, yet half the population lives in poverty and unemployment is approximately 28% (City Press, 2018a; Labadarios et al., 2011; World Bank, 2018).

2.2 Consumption dynamics of LDF

Actual LDF consumption data are not readily available, but various proxies are used, including household expenditure, and national production figures per capita. Due to extreme wealth polarity, national average consumption estimates do not represent the extremes, which are likely to mirror the tenfold difference between low-income and high-income countries (Meissner et al., 2014; Ritchie & Roser, 2018). A review of South African dietary surveys reported that red meat was unaffordable for most low-income households (McHiza et al., 2015).

The percentage of national expenditure on LDF has increased from approximately 40% in 2005 to 48% in 2015, with 5% attributed to meat and 3% to milk, milk products, and eggs (DAFF, 2018a; DSEA, 2016) (Table 1).

Average consumption per capita estimates (Table 2) show that red and white (poultry) meat

Table 1. Private Expenditure on Food by Main Food Categories, 2005, 2010, 2015, and 2017/18

Main food categories[a]	Expenditure on food consumption in billion South African rand (% of total food)			
	2005[b]	2010[b]	2015[b]	12 months prior to June 30, 2018[c]
Meat (red and white)	56.4 (30%)	121.6 (34%)	186 (35%)	225 (35%)
Milk, milk products, eggs	19.6 (10%)	42.2 (12%)	68.3 (13%)	83 (13%)
Bread and grains	54.5 (28%)	92.9 (26%)	128.9 (24%)	152 (24%)
Sugar	3.8 (2%)	5.5 (2%)	6.4 (1%)	7.9 (1%)
Fruit and vegetables (including potatoes)	28.0 (15%)	50.5 (14%)	71.1 (13%)	87 (14%)
Oils and fats	4.5 (2%)	7.3 (2%)	12.0 (2%)	12.8 (2%)
All Foods	189.3	362.8	536.0	644

[a] Categories as per Directorate of Statistics and Economic Analysis (DSEA) reports.

[b] Data source: DSEA, 2016.

[c] Latest available figures from Department of Agriculture, Forestry and Fisheries (DAFF), 2018a.

Figure 1. The Workshop's Merged Livestock-Derived Food Systems Map

Interrelational connections between elements are shown as causal loops. The elements are categorized and color-coded as relating to governance, environment, livestock, food, socioeconomic, and land.
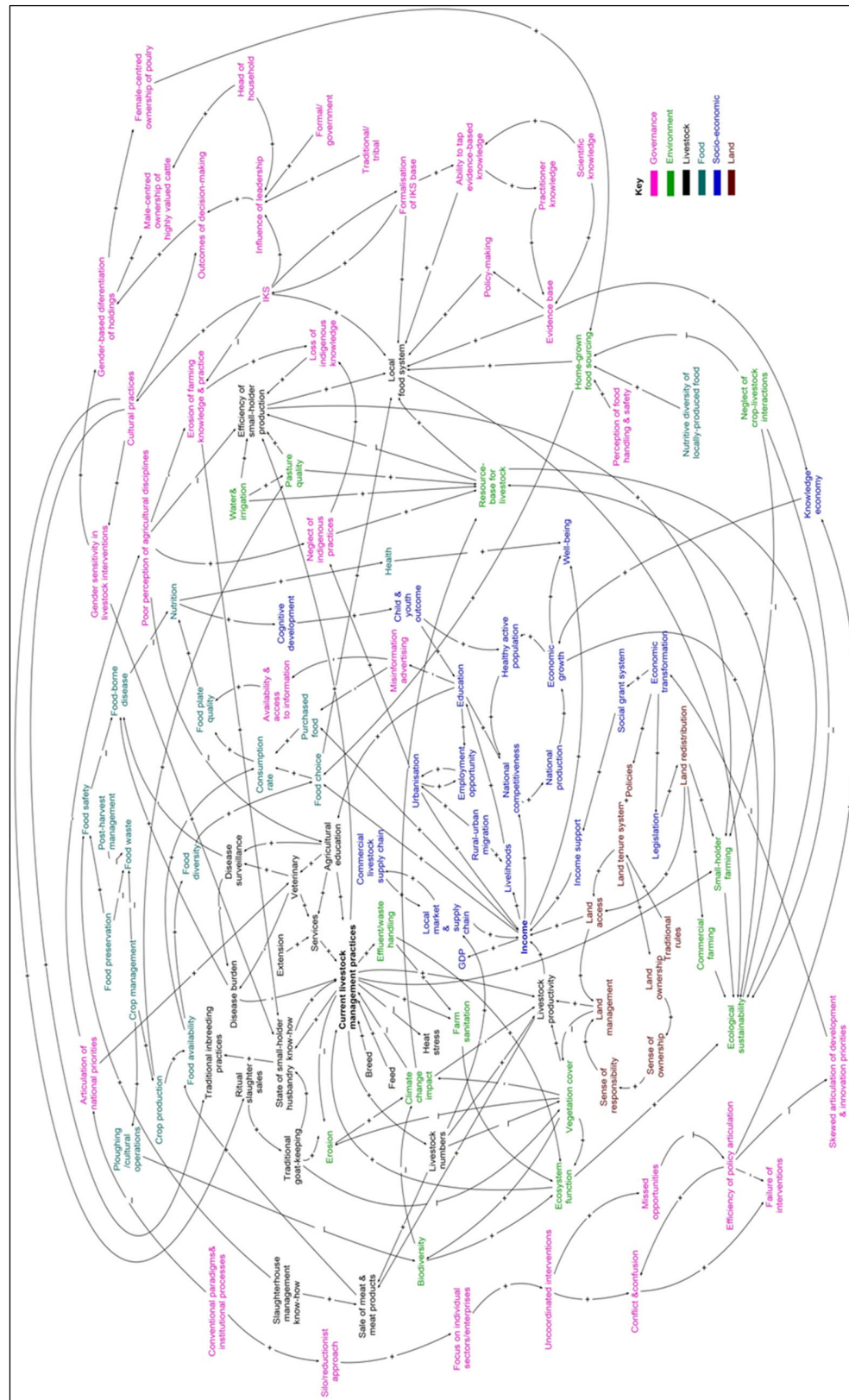
consumption increased by 39% between 1985 and 2015, most occurring in the last 20 years (DSEA, 2016). Beef consumption dropped from 48.5 lb (22 kg) in 1985 to 33.5 lbs (15.2 kg) in 1995, but has subsequently risen to 42 lbs (19 kg) in 2015. By contrast, poultry has seen a 250% increase from 34.6 lbs (15.7 kg) in 1985 to 87.3 lbs (39.6 kg) in 2015 (DSEA, 2016). Consumption of fresh cow's milk in 2015 was 83.7 lbs (38 kg), with little change since 1985. Pork consumption, although relatively low, has increased by 40% from 1985 to 10 lbs (4.6 kg) in 2015. Similarly, mutton consumption is low, but over the same period (1985–2015) has increased by 40% to 8 lbs (3.6 kg) in 2015 (DSEA, 2016). From 1985 to 2015, consumption of hen eggs increased by 83% to 19.4 lbs (8.8 kg).

Diets are strongly affected by the local food environment (Claasen, van der Hoeven, & Covic, 2016). During apartheid, supermarkets became established in urban locations, focussing on higher-income White consumers, but with time they extended their reach into rural areas (Stroebel & van Schalkwyk, 2012). Four main supermarket groups (Shoprite/Checkers, Pick 'n Pay, Spar, and Woolworths), with close links to commercial farmers, control over 75% of food retailed (Heijden & Vink, 2013; Tihanyi & Robinson, 2011). The informal food retail sector consists of independent small-scale enterprises, such as cafes, street vendors, hawkers and "spaza shops" (small, home-managed shop attached to a home or on street

frontage), with most procuring their merchandise from larger wholesalers or supermarkets (Stroebel & van Schalkwyk, 2012). South Africans, as individuals, are buying more and producing less of the food they consume (Pereira, 2014).

2.3 Agriculture and the Livestock Sector

South Africa has a diverse range of climate, soils, and ecosystems. The total land surface area is 302.2 million acres (122.3 million hectares), of which 247 million acres (100 million ha) are considered agricultural (arable and grazing) (Red Meat Research and Development [RMRD], 2016). Of the total agricultural land, 84.4% is suitable for grazing only, 13.5% for cropping, and 1.2% for commercial forestry (DEA, 2016; DSEA, 2016). Agriculture contributed 2.5% to the country's annual gross domestic product (GDP) (DSEA, 2016). Within agriculture, the single largest contributor by value is poultry (16.5%), followed by cattle and calves (13.5%) and maize (9.2%) (DAFF, 2018a). Of the national export value, agriculture contributes approximately 8% (DSEA, 2016).

In the literature, several terms are used for different types of livestock farmers and farms, and they vary depending on the source and time period of publication. There are little consistency and no formally agreed-upon definitions, even in government reports. Refer to Box 1 for a brief overview of terms and explanation.

South Africa's agricultural sector is still under-

Table 2. South African per Capita Consumption Dynamics for Livestock-Derived Food Groups, Showing Five-Year Interval Trends

	Per capita consumption in kg/year (5-year intervals)						
	1985	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**
Beef	21.6	19.3	15.2	15.6	15.5	17.8	19.0
Mutton (includes lamb and goat)	7.3	5.3	3.1	3.8	3.6	3.5	3.6
Pork	3.3	3.6	3.2	3.0	3.9	4.4	4.6
Red meat subtotal	32.3	28.2	21.5	22.4	23.0	25.7	27.2
White meat (poultry)	15.7	17.5	17.1	21.5	31.2	38.4	39.6
Red and white meat total	48	45.7	38.6	43.9	54.2	64.1	66.8
Eggs	4.8	5.9	6.9	7.1	7.6	8.6	8.8
Butter	0.5	0.5	0.4	0.2	0.3	-	-
Cheese	0.9	1.2	1.0	0.9	0.8	-	-
Fresh milk	38.6	31.9	35.4	29.4	39.1	37.4	38.6

Data source: DSEA, 2016.

going post-apartheid transformation. Before 1994, agricultural and related land policies supported White commercial farmers, estimated to number 60,000 and owning 86% of agricultural land (Boudreaux, 2010). By contrast, an estimated 3.4 to 4.8 million Black communal farmers resided in homelands (designated areas for Black settlement and land ownership) (Feynes & Meyer, 2003). Homelands contained less fertile and marginal land, were overcrowded, and lacked infrastructure (Tihanyi & Robinson, 2011). Landholdings were generally inadequate to support a household's needs, and communal lands were shared, under allocation from traditional leadership, for grazing individually owned livestock (Feynes & Meyer, 2003).

Despite the post-1994 government's vision for "a united and transformed" agricultural sector (DAFF, 2015, p. 2), the sector remains racially polarised and dualistic. Most Black farmers have limited access to predominantly state-owned or tribally controlled lands (Hornby, Nel, Chademana, & Khanyile, 2018). Commercial farming is characterized by large-scale systems, is strongly connected to global markets, and requires capital, sophisticated knowledge, equipment, standards, and practices (Hall, 2004). Between 1993 and 2007, commercial farm unit numbers dropped by 31% (DSEA, 2016), mostly through the aggregation of smaller cattle farms that was driven by declining profitability and environmental factors such as drought (Goldblatt, 2015).

Estimates of noncommercial farmer numbers, from around 1998/2000, vary from 2 to 3 million household farmers and approximately 240,000 commercially oriented smallholders (Aliber & Hart, 2009). The 2016 national household survey stated that less than one-fifth of households was involved in agricultural production; 93% were limited to "backyard" production (STATS SA, 2017). Reasons for production were for diet supplementation (77%), main food source (8%), additional income (6%), and main income (2%) (STATS SA, 2017). Because of historical commercial farming dominance, government policies have focused on the transition of commercially orientated smallholders into "emerging" commercial farmers (Meissner et al., 2014; Tihanyi & Robinson, 2011). However,

progress has been limited by dwindling agricultural investment, incoherent rural development, persistent poverty, and delayed land reforms (Adey, Kotze, & Rijkenberg, 2004). Moving from subsistence to commercial production requires a major change in mindset and comes with greater risk, which may diminish its attraction (Poole, Chitundu, & Msoni, 2013). Aliber and Hall (2012) argue against the supporting of a few emerging farmers, and rather for investing in developing a commercial orientation of small-scale farmers, and improving their access to inputs and services, and the knowledge and skills required to access the formal value chains and high-end markets (Aliber & Hall, 2012; Binswanger-Mkhize, 2014).

Implementation of the government's land reform in 1997 (to redistribute approximately 62 million acres (25 million ha) of land to those forcibly removed or discriminated against under apartheid, on the principle of "willing buyer, willing seller") has been inadequate and inefficient (Binswanger-Mkhize, 2014). In 2018, President Ramaphosa announced a "re-prioritisation" of funding in agriculture and rural areas to support Black commercial farmers' contribution to the food system (City Press, 2018b). The ruling party in government also aims to change the constitution to allow "land expropriation without compensation" to speed up land reform, while ensuring economic stability and national food security (Reuters, 2018).

Agriculture plays a key role in a wider socio-economic-ecological context. Many district towns developed off the back of local commercial farming enterprises (Meissner et al., 2014). In resource-poor households, livestock plays an important role as social and financial capital (Mahlobo, 2016; Randolph et al., 2007). Rural communities typically have strong spiritual and cultural ties to nature, embedding the environment in their social and economic societal structures (Hamann, Biggs, & Reyers, 2015). Livestock farmers are key to managing and preserving South Africa's natural rangelands (Meissner et al., 2014).

2.4 Livestock production systems and outputs
Livestock production systems in South Africa mirror the dualistic nature of the agricultural sec-

tor, with highly productive, high-input commercial production systems, often part of increasingly vertically integrated supply chains, contrasted against low-input, low-productivity small-scale production systems. This is most obvious in the poultry, dairy, and beef systems, which produce the highest quantities of LDF.

Poultry: The commercial poultry industry is comparable with global intensive systems, having high levels of supply-chain integration and productivity throughout (Louw, Davids, & Scheltema, 2017). Broiler meat production represents the highest tonnage of meat produced (1.8 million tonnes in 2016) and shows the strongest growth, with an increase in production of 89% between 2007 and 2016 (FAOSTAT, 2018). Three major vertically integrated producers (controlling their breeding, feed manufacture, slaughter, meat processing, and distribution), are responsible for 53% of total production (DAFF, 2017b). Small-scale producers mainly sell live birds, and most households keep backyard chickens (Louw et al., 2017; Malatji, Tsotetsi, van Marle-Koster, & Muchadeyi, 2016). The commercial layer industry is similar, dominated by three vertically integrated companies producing 51% of the total eggs. Given the intensive nature of both industries, they are sensitive to rising feed costs (as a result of drought and variable exchange rates) and disease outbreaks (avian influenza and salmonella) (SAPA, 2016).

Dairy: The commercial dairy industry has seen a 60% reduction in the number of farmers from 2007-2016, although national herd levels have remained stable, with increased productivity and efficiency (MilkSA, 2017). Two main feed-based production systems exist, namely irrigated pastures with winter silage supplement and daily concentrate, or a partial or total mixed ration system (Lassen, 2012). Fresh milk production was approximately 3.5 million tons in 2016, an increase of 18% over the previous decade (FAOSTAT, 2018). It is estimated that 38% of milk produced in 2016 was processed into concentrated products (cheese, butter, whey powder, and condensed milk) (MilkSA, 2017).

Beef: On both commercial and small-scale farms, beef cattle are primarily grazed extensively on natural grasslands, although 75% of formal abattoir-slaughtered cattle are finished for approximately 110 days in feedlots on cereal-based feeds (Scholtz, Van Ryssen, Meissner, & Laker, 2013). Commercial farmers own approximately 57% of the national beef herd (Meissner et al., 2014) and feed into vertically integrated supply chains (DAFF, 2017a). Noncommercial herd productivity is low due to higher mortality and lower reproductive rates (RMRD, 2016). Beef production was approximately 1.1 million tonnes in 2016, showing an increase of 34% over the previous decade (FAOSTAT, 2018).

Sheep, Goats, and Pigs: Commercial sheep farmers hold 87% of the total stock, and production relies primarily on extensive grazing in the drier and semi-arid areas (Cloete, Olivier, Sandenbergh, & Snyman, 2014). Noncommercial farmers keep sheep within mixed farming systems, with low inputs and low productivity (Mthi, Skenjana, & Fayemi, 2017). Total sheep meat production was approximately 0.18 million tonnes in 2016, showing an increase of 6% over the previous decade (FAOSTAT, 2018).

Noncommercial farmers keep the majority of goats, which play an important role in traditional rituals and customs; less than 1% enter the formal market, and most are sold informally as live animals for ritual slaughter (DAFF, 2017d; Meissner et al., 2014). Commercial farmers primarily keep meat breeds, or Angoras for mohair, or exotics for milk (DAFF, 2017d). Goat meat production was approximately 0.01 million tonnes in 2016, showing no change over the previous decade (FAOSTAT, 2018).

Commercial pig producers hold 95% of the pig population, typically in closed intensive systems with 300 or more sows (BFAP, 2014). Noncommercial producers housed pigs with varying degrees of intensification, either for home consumption (63%) or to sell to formal abattoirs (10%) (Gcumisa, Oguttu, & Masafu, 2016). Pig meat production was approximately 0.24 million tonnes in 2016, showing an increase of 31% over the previous decade (FAOSTAT, 2018).

Trends in production outputs of the main LDF products in South Africa are presented in Figure 2.

2.5 Imports and exports of LDF

Two key issues affecting international trade of LDF are: (a) the deregulation of several previously subsidized industries and the dismantling of tariff barriers (Hall, 2004), and (b) the fluctuating value of the South African rand (ZAR) against the U.S. dollar (US$), which has peaked at US$0.15/ZAR and troughed at US$0.06/ZAR in the past decade. Trade liberalization has opened internal markets in both directions; however, South African farmers struggle to compete internationally since many exporting country producers receive government subsidies (Meissner et al., 2014).

The agricultural export value for 2017 was an estimated US$10.2 billion, and the import value was US$6.9 billion (DSEA, 2018). Poultry meat was the only LDF listed in the top five agricultural imports by value during 2012–2017 (DSEA, 2018). Import and export data for individual LDF for 2008–2017 are presented in Figure 3.

Poultry: Poultry meat has shown a sustained rise in imports over the past decade. In 2017, 555,730 tonnes of poultry meat were imported, compared to 220,278 in 2008, which represents 30% of the total consumed (GAIN, 2017). Approximately 94% of the poultry meat was chicken, of which 99.8% was broiler meat, and 38.6% of this was mechanically deboned meat (MDM) (SAPA, 2018). The biggest suppliers in 2017 were Brazil (62%), the U.S. (16%), and Argentina (6%) (SAPA, 2018). Apart from South Africa's avian influenza out-break, which reduced exports by 20% to 62,222 tonnes in 2017, there has been little export variation over the past seven years, with 66% exported to Mozambique, Namibia, and Lesotho collectively (GAIN, 2017).

Exports of eggs in-shell in 2017 were 13,646 tonnes (includes 3,669 tonnes for hatching) compared to 1,175 tonnes in 2008, with the bulk to Mozambique (78%) while imports are negligible (SAPA, 2017b). In 2017, total exports for not in-shell eggs totaled 386,980 tonnes, while imports were similar at 361,476 tonnes, which was almost entirely in the form of dried

Figure 2. Production in Tonnes of Livestock-Derived Food Products, 1985–2015
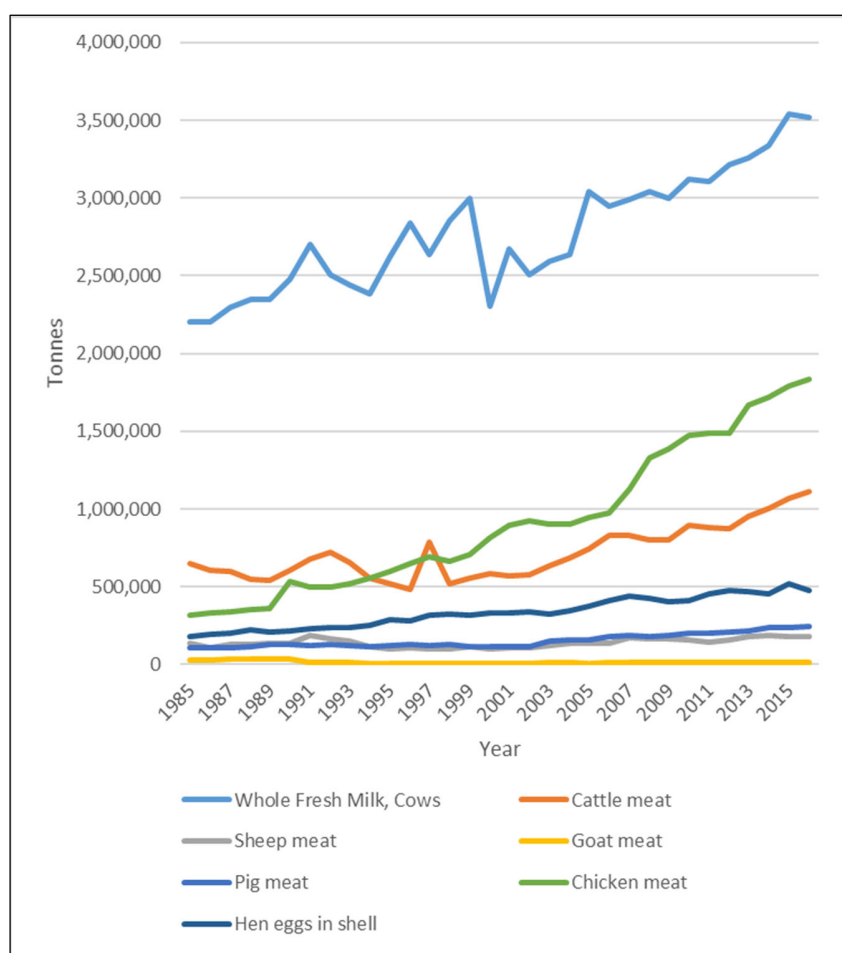
Data source: FAOSTAT, 2018.

Figure 3. Import and Export Quantities of LDF in Million Kgs, 2008–2017
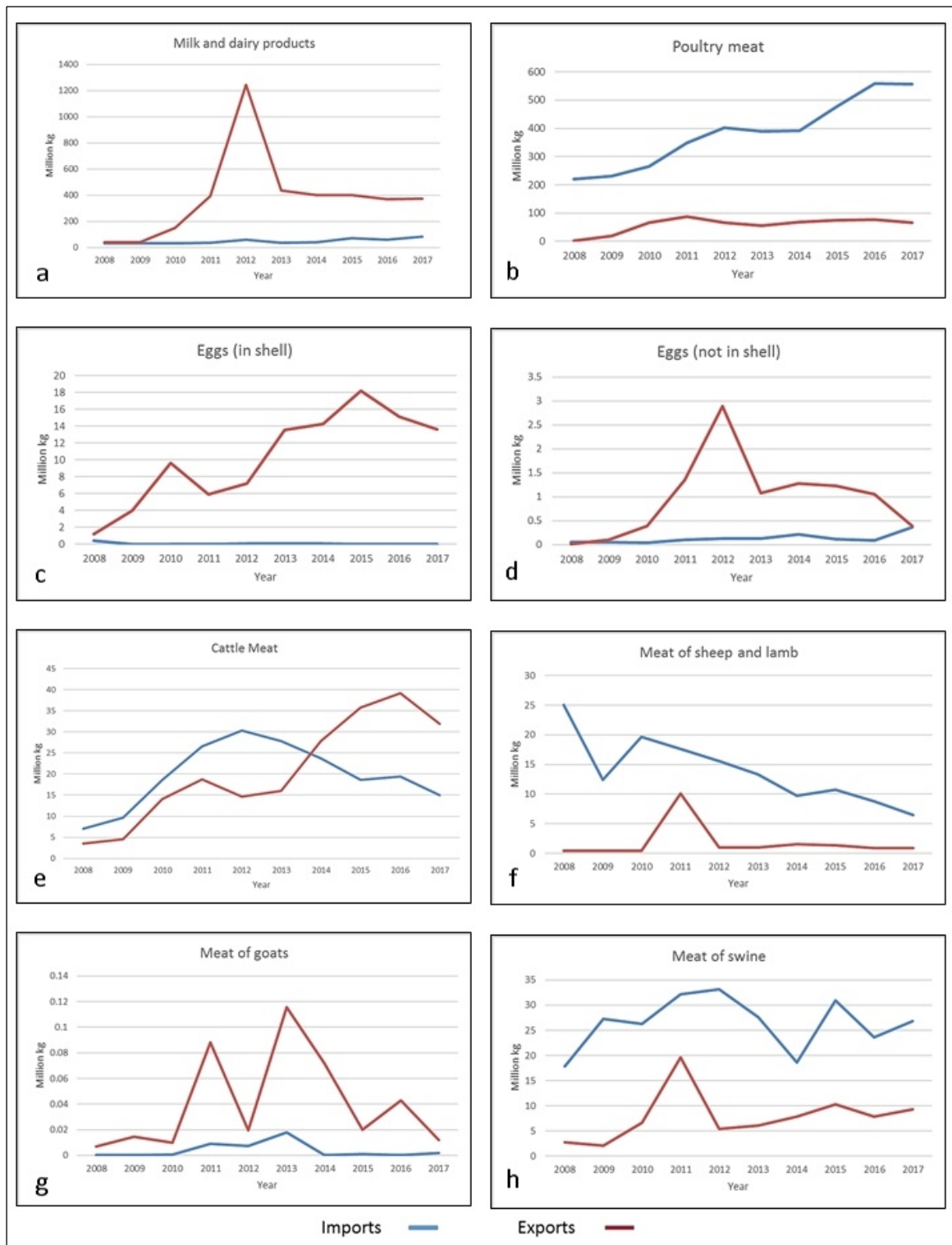
Data source: Quantec Easydata (https://www.quantec.co.za/easydata/).

eggs, the bulk of which were from Italy (44%), France (33%), and Denmark (20%) (SAPA, 2017b).

Dairy: The dairy industry in South Africa has remained stable in terms of production and domestic demand. It is one of the most deregulated dairy industries globally, and it struggles to compete with countries where governments subsidize production (DAFF, 2017c; MilkSA, 2017). Despite some lower-priced imports, South Africa is still a net exporter of milk and dairy products. Almost all exports go to Southern African Development Community (SADC) members (41% to Botswana in 2016); imports in 2016 were primarily from the European Union (France and Poland), in addition to New Zealand and Uruguay (DAFF, 2017c).

Beef: Exports of beef peaked at 39,132 tonnes in 2016, primarily due to South Africa regaining its status of being free of foot and mouth disease (DAFF, 2017a), and a high off-take rate due to drought-related poor grazing and high feed costs in 2015–2016 (GAIN, 2018). Exports are primarily to SADC members (predominantly Mozambique 11%), but in 2015–2016, exports to Vietnam reached 13%, and those to the United Arab Emirates, Kuwait, and Jordan collectively reached 32% (DAFF, 2017a). Imported beef in 2016 was primarily from neighboring Botswana (49%) and Namibia (33%) (DAFF, 2017a).

Mutton, Goat Meat, and Pork: Mutton imports recently declined from 25,027 tonnes in 2008 to 6,499 tonnes in 2017, due to rising international prices (DAFF, 2017e). Imports originate predominantly from Namibia (50%), Australia (37%), and New Zealand (13%), while a small export market exists with local neighbors, with 45% going to Mozambique in 2016 (DAFF, 2017e).

Although the export market for goat meat (chevron) is very small, South Africa was a net exporter, varying from 115,719 tonnes in 2013 to 11,777 tonnes in 2017. In 2016, exports were almost entirely destined for Lesotho (85%), with the remainder to the Seychelles (10%) and Zambia (5%); imports were negligible (DAFF, 2017d).

Pork imports varied between 17,795 tonnes in 2008 to 33,180 tonnes in 2012. In 2016, 63% of total imported pork was in the form of frozen ribs and originated from Spain (37%) and Germany (31%), with the rest, in almost equal share, from Brazil, the UK, France, Belgium, and Canada (DAFF, 2017f).

2.6 Food-borne disease burden and LDF
The South African National Institute for Communicable Diseases (NICD) is responsible for public health surveillance of communicable diseases and outbreak response advice. The Centre for Enteric Diseases (CED) is a part of NICD and focuses on diarrhea and enteric fevers, including food-borne and waterborne diseases.

Although South Africa commonly experiences food-borne diseases (FBD) outbreaks, official estimates underrepresent the burden, due to poor reporting and a lack of definitive diagnosis for broad presenting symptoms, such as diarrhea (Smith, Gouws, Hoyland, Sooka, & Keddy, 2007). Statistical reports do not disaggregate data beyond, for example, "intestinal infectious diseases" (STATS SA, 2018b). An NICD review of reported FBD outbreaks during a five-year period prior to December 2017 listed an average of 65 outbreaks a year, with an average of 2,230 affected individuals and 10 deaths per year (Shonhiwa, Ntshoe, Essel, Thomas, & McCarthy, 2018). The most common enteric pathogens were *Salmonella* spp., *Clostridium perfringens, Bacillus cereus, Shigella species, Listeria monocytogenes,* and *Escherichia coli.*

Listeriosis is an FBD caused by *Listeria monocytogenes,* a bacterium commonly found in soil, vegetation, and water (Manganye, Desai, Daka, & Bismilla, 2018). Between January 2017 and May 2018, the largest reported listeriosis outbreak worldwide to date occurred, affecting all South African provinces, with 1,034 human cases and a 28.6% case-fatality rate (DoH, 2018; Salama et al., 2018). The source was traced to polony (a low-cost, processed meat product containing broiler MDM) that was contaminated in a processing factory and was only identified in March 2018 (Salama et al., 2018). The size and duration of this outbreak reflect the underinvestment in national food safety systems and the need for robust food safety regulations and standards and their implementation (Salama et al., 2018).

3. Conceptual Model of the South African Livestock-Derived Food System

The conceptual model (Figure 4) contains the LDF system's key variables and causal relationships, reinforcing (Rn) (either vicious/destructive or virtuous/healthy) and balancing (Bn) causal loops, feedbacks, conceptual stocks and flows, and underlying archetypes. Variables relating to nine SDGs are highlighted, namely, SDG 1: No poverty, 2: Zero hunger, 3: Good health and well-being, 8: Decent work and economic growth, 10: Reduced inequality, 11: Sustainable cities and communities, 12: Responsible consumption and production, 13: Climate action, and 15: Life on land.

Since 1994, South Africa's democratically elected government has worked toward an economic transformation for all by creating policy frameworks, including the 2013 National Development Plan 2030 (NDP, 2013). These frameworks intend to address the persistent inequalities in society (theoretically a balancing loop B1).[4] However, a more long-term and multifaceted solution to inequalities is achievable by aligning the NDP more closely to the SDGs (Fourie, 2018), albeit with a time delay (B2). Due to gaps in governance, the creation and implementation of policies remain fragmented and aimed at short-term successes, in many cases compounding the inequalities due to unintended trade-offs (reinforcing loop R1). Furthermore, as an unintended consequence, the current fragmented policies are eroding the potential to achieving the SDGs and ultimate long-term solutions, characterized by "shifting the burden" archetype as described by Meadows (2009).

The policies relating to the analysis of the LDF system with the SHEFS aims of sustainability, health, and equitable access are categorized as Health and nutrition, Economic, Land, Agriculture, and Trade.

A fundamental outcome of transformative economic policies is the systemic structure behind the country's widening inequality in wealth, which underpins many of South Africa's problems. This can be characterized by the "success to the successful" archetype described by Meadows (2009). In these connected reinforcing loops (vicious

cycles) (R2, R3), the majority share of the economy is held by the minority, that is, middle- and high-income societal groups, which in turn favors their ability to gather a greater share. In the process, the low-income group has access to an ever-decreasing share, which, in turn, restricts its members' ability to access opportunities for more.

The agricultural sector is highly polarized, with a small number of large-scale and highly commercialized farmers, and a large number of small-scale (subsistence and smallholder) farmers, with some small and medium-scale commercial (emerging) farmers. Agricultural policies have focused on developing new commercial farmers while withdrawing subsidies from existing large-scale commercial farmers and giving little attention to small-scale farmers. Investment in developing small- and medium-scale commercial farmers improves their production, reinforcing their support (a potentially virtuous cycle) (R4). A lack of investment in small-scale farmers further reduces their productivity, reinforcing the idea that they are a lost cause in contributing to food production (vicious cycle) (R5). A lack of investment in large-scale commercial farmers, including the withdrawal of subsidies (and deregulation of trade), has reduced their profitability and potentially the overall production outputs from the sector. This may provide a stimulus for further support of small and medium-scale commercial farmers to fill the production deficit (R6). Through supporting a small number of commercial farmers and neglecting a large number of small-scale farmers, these policies maintain a polarized agricultural sector.

Interwoven in this are policies on land redistribution, which promise to be more proactive in the future. While this would support the development of new commercial farmers and small-scale farmers, the discussions around "land expropriation without compensation" may negatively affect established commercial farmers, reducing their ongoing business investment and their contribution to commercial production.

Commercial production contributes the most to formal LDF production, with a lesser contribution from the small-scale farmers, and is balanced

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[4] Hereafter such references pertain to labels in Figure 4.

Figure 4. Conceptual Model of the South African Livestock-Derived Food System

Dotted lines draw out five categories of policies (relevant to the LDF system and SHEFS, underlined in blue font). Variables, which relate to the Sustainable Development Goals (SDGs) are denoted in bold italic green font (see text).
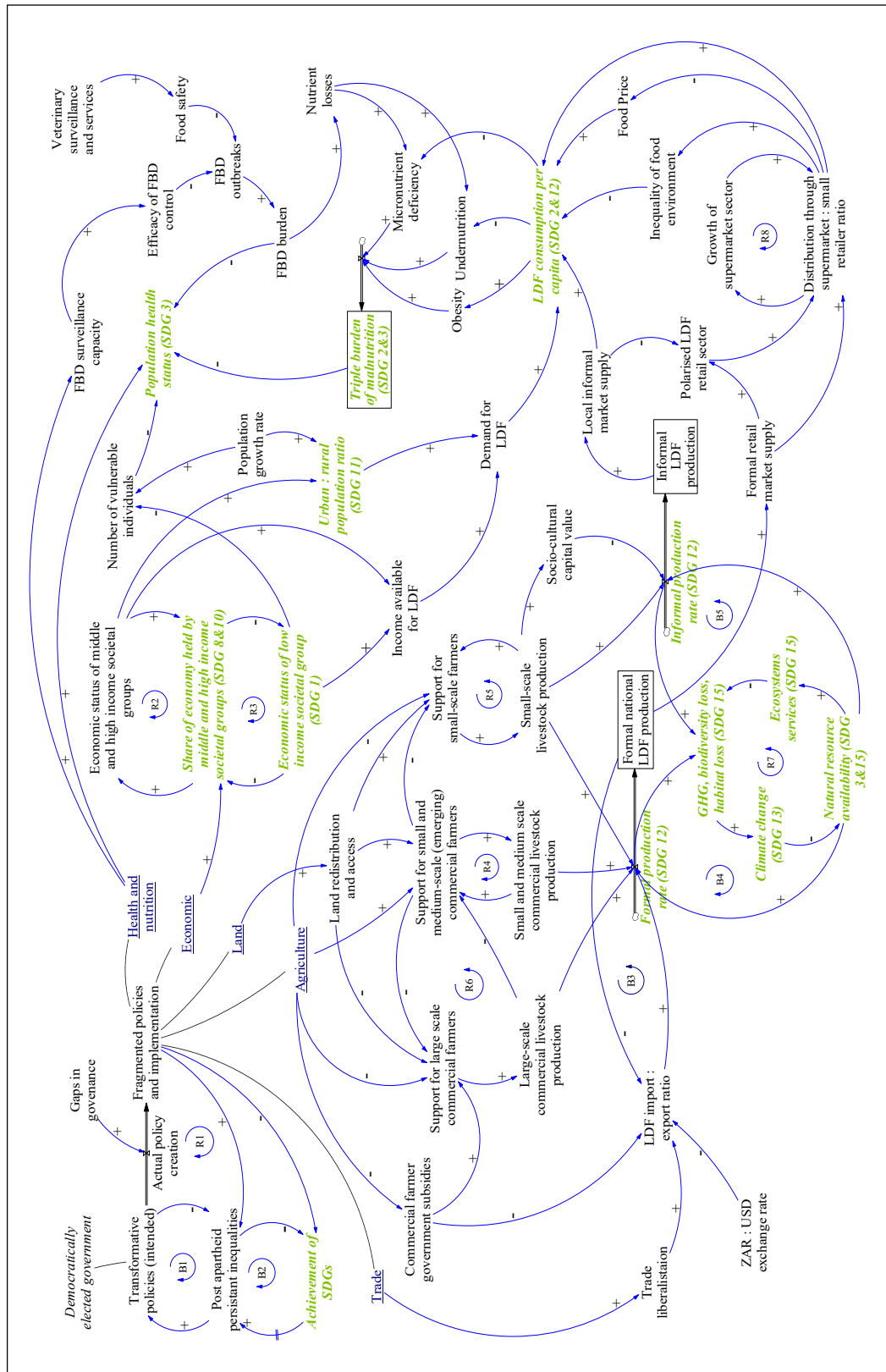
by the import-export ratio (B3). The liberalization of South African trade laws and the loss of government subsidies have decreased the competitiveness of exports, increasing the import-export ratio. When the value of local currency weakens against the U.S. dollar, it reduces the affordability of imports, lowering the ratio.

Both the informal and formal production of LDF rely on natural resources, either directly as grazing or indirectly through supporting feed production. However, increased LDF production leads to increased greenhouse gas (GHG) emissions, biodiversity loss and habitat destruction, increased climate change, loss of natural resources, and reduction in ecosystem services, in a reinforcing feedback loop (R7). This, in turn, has a balancing effect of reducing the production potential of LDF (B4, B5).

The formal and informal LDF production systems each supply a formal and informal retail market, respectively. The dominance of the formal retail sector increases the distribution of food via supermarkets, rather than smaller retailers, and this, in turn, further polarizes the retail sector. The greater the proportion of food retailed through supermarkets, the greater their growth and dominance (vicious cycle) (R8). Increasing supermarket distribution may increase access and consumption, while also reducing prices due to economies of scale, but may also add to the inequality of the food environment.

Per capita LDF consumption estimates are rising due to increasing demands, driven by a growing and increasingly urbanized population, and the level of income available to spend on LDF, which is related to economic status.

The consumption of LDF directly affects obesity, stunting, and micronutrient deficiencies, all of which contribute to the triple burden of malnutrition. The latter impacts on the overall population health status, as does the burden of FBD, both directly, and indirectly through adding to the burden of malnutrition through links to stunting and micronutrient deficiencies, caused by nutrient losses. The overall health status of the population is dependent on health policies and budget and is affected by many additional factors, including the proportion of vulnerable individuals (children,

pregnant women, the elderly, and individuals with HIV/AIDS or tuberculosis [TB]), which is influenced by population growth and economic status.

Health policies are directly related to FBD surveillance capacity, and, consequently, the efficacy of FBD outbreak control, which would reduce the outbreaks and the FBD burden and, indirectly, the triple burden of malnutrition. Veterinary surveillance and food safety–related services will reduce a proportion of FBD cases by reducing the hazards at the preprocessing stage of LDF production.

Discussion

We used a participatory and systems approach to investigate the South African LDF system. A wide range of local stakeholders and key informants took part in a workshop and follow-up survey in which they demonstrated the system's complexity by populating a systems map and identifying and ranking main nexus points. The detail and dynamics of key structural elements around these nexus points were unpacked through a focused literature review, and their causal relationships, unintended consequences, and feedback loops were analyzed and presented in a conceptual system dynamics model.

Involving a broad spectrum of participants adds to a better understanding of the problem and of the scope of the associated system (Bérard, 2010). Furthermore, it encourages double-loop learning, where a person's underlying beliefs and assumptions are challenged and operating norms are questioned, thereby improving an individual participant's mental model, which in turn can feed back into organizational learning (Bérard, 2010; Ruegg et al., 2018).

Similar participatory research methods have been used elsewhere. Lie et al. (2017) and Rich, Rich, and Hamza (2015) used an LDF value chain as the system, and thereby identified the key stakeholders for group model-building. Von Loeper et al. (2016) used a thematic literature review with ethnographic, participatory research to develop an SDM, analyzing market-access challenges for South African smallholders. Our work adds to these examples, demonstrating the value of a participatory and systems approach to food systems. It also

provides a methodology for studying similarly dynamic food systems elsewhere. A limitation was a lack of representation of nutrition specialists in the workshop, and hence nutrition and related health issues were not identified as key nexus points by participants. We also recognize our work would have been strengthened by a follow-up workshop to critique, discuss, and validate the conceptual model. Nevertheless, our participatory process facilitated ongoing contact between researchers and participants, enriched social capital, and snowballed introductions to further stakeholders and key informants within the LDF system and subsystems.

South Africa's post-apartheid transition toward a more equal society is far from complete (World Bank, 2018). Government policies attempting to address inequality have been unsuccessful and, to some degree, reinforcing. In our conceptual model, we presented nine SDGs linked to the LDF system, as well as vicious cycles and archetypes that maintain inequality in the agricultural and food retail systems. With "No poverty" arguably the root of all SDGs, a better alignment of future LDF system policies with the SGDs is crucial to move South Africa closer toward the 2030 Agenda for Sustainable Development (United Nations, 2015).

Historic land-access inequalities underpin commercial livestock farmer dominance, with the bulk of production arising from integrated companies (most notably in broiler production), using capitally intensive, sophisticated systems, maximizing efficiencies, while maintaining market-based quality and safety standards and still remaining profitable. This presents a significant barrier for small and even medium-scale producers to enter this predominantly high-end value chain. Similar to elsewhere in sub-Saharan Africa, livestock-keeping among smallholders and subsistence farmers is primarily for financial and social capital, as well as for cultural purposes (Mahlobo, 2016; Malatji et al., 2016). With an overall trend, particularly in sub-Saharan Africa, toward urbanization, with aspirations of a "modern lifestyle," livestock ownership and the agricultural life become the less attractive and realistic livelihood choice. The current and potential contribution of small-scale farmers to LDF production is unquantified and needs further

research. Support and investment aimed at small-scale farmers in the form of better access to finance and inputs, together with extension services to improve knowledge and skills, is required to improve access to existing value chains (Aliber & Hall, 2012; Binswanger-Mkhize, 2014).

Commercial producers have close links to supermarkets that demand reliable supply chains and high standards in quality, safety, packaging, and labeling. Supermarkets dominate food retail and extend widely into rural areas, changing rural food environments and leading to greater consumption of purchased rather than self-produced food. Both supermarkets and fast-food companies employ typically aggressive, price focused, and aspirational-lifestyle marketing. This, together with urbanization and improving socioeconomic status, has driven LDF consumption. The impact of increased levels of LDF consumption on the health and nutrition of consumers, and the links to the intractable triple burden of malnutrition, requires further research. While playing an important role in providing essential nutrients to the undernourished and vulnerable, LDF's role in obesity, which affects both the wealthy and the poor, is less clear. More research on consumers' choice and their food environment is needed to understand what drives the choice of LDF purchased, how LDF products are prepared in the home, and which pre-prepared and food consumed away from home products are favored.

Land access, climate change, and livestock feed costs all affect LDF production. Intensive commercial livestock production, especially broiler production, relies heavily on cereals (DAFF, 2017b; SAPA, 2017a). The sustainability of this trend requires further investigation for the following reasons. South Africa has limited arable land area, most of which is rainfall dependent and vulnerable to climate change (Conway et al., 2015). The increasing consumption of LDF (especially broiler meat) creates greater pressure on land and other natural resources, competing with cereal production for human consumption. The international demand for cereal-based feed is likely to become increasingly competitive, given the global rise in consumption of pork and broiler meat. Higher costs of imported raw material for feed may

push local broiler producers out of business or be passed on to consumers. Since price plays an important role in broiler meat preference, retail price increases will affect affordability for the poor (McHiza et al., 2015). Alternatively, relying on cheaper, imported broiler meat and products to meet increasing demand risks destabilizing the local industry, which remains internationally uncompetitive without local government support (through import tariffs and subsidies).

Food safety is a major consideration with LDF, as it may involve zoonotic pathogens, contaminants, parasites, toxins, and/or chemicals, including antibiotic residues. These affect human health directly through FBD, and indirectly through malnutrition, affecting nutrient absorption in the short and long term. In addition, the risk of FBD in South Africa may have greater significance than elsewhere, given the proportion of the population suffering from poverty, malnutrition, and HIV/AIDS. The listeriosis outbreak was blamed on a processed broiler meat product, which for many poorer consumers was the only affordable animal protein option. Consumers' pathways and barriers to accessing affordable LDF products of high nutritional value and hygiene standards need to be explored further. In addition, qualitative research is needed to explore consumers' understanding of food safety, their risk-mitigation behavior, and the role this plays in their choice and consumption of LDF. The delay in controlling the listeriosis outbreak raises questions around the capacity of FBD surveillance, risks associated with increased LDF consumption, choice and affordability of LDF products for the poor, and the enforcing of regulations and standards on small-scale producers and informal markets.

Our research, while working toward the policy aims of SHEFS, delivers a reference for stakeholders and policymakers to better understand the complexity and depths of the linkages between the LDF system's elements and its archetypes, when considering recommendations associated with nutrition and health, equitable access, sustainable production, and food security. In addition, we have identified several key research gaps. Identifying options to improve smallholder and subsistence farmers' access to and participation in existing LDF value chains is crucial, given the uncertainties facing commercial producers, such as land redistribution and imports. The dynamic relationship between increasing local broiler production and local feed production, importing cereals for feed and cheap broiler meat, and the impacts on availability and affordability of broiler meat for the poor requires further investigation before developing policy recommendations.

Conclusions

The South African LDF system is unique within sub-Saharan Africa, and while it is undergoing significant development and transformation, it remains challenged by deep historic roots. Transdisciplinary research is needed to provide evidence for decision-makers and stakeholders to consider leverage points for change. Our systemic analysis demonstrates the importance of a wider contextual analysis when considering the debate around food security, nutrition, health, and sustainable agriculture, and presents an alternative methodology for investigating complex LDF food systems in a state of dynamic transition.

Furthermore, this research provides a unique reference for policy-makers. Creating policy recommendations for the sustainable production of safe, healthy, and nutritious LDF, with equitable access, will need to consider profound structural changes in the system. Our work presents a deeper understanding of the LDF system's complexity and linkages between key elements. It therefore has the potential to guide policy toward more integrated and durable solutions, highlighting possible unintended consequences, and mitigating the risk of system destabilization that may accompany the deep structural change required.

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