

FOOD SECURITY PERSPECTIVES IN SUB-SAHARAN AFRICA

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Abstract

The state of global food security has been considerably improved in the last decades; however, these achievements are attributable to the “green revolutions” in Latin-America and Asia. The food shortage has remained persistent in Sub-Saharan Africa, where the proliferation of undernourishment is nearly 30%. There is a large number of studies investigating different causes and aspects of the current crisis, or evaluating the future of the African agro-food sector based on one or a few particular aspects (e.g. climate change, population dynamics). Just a small number of attempts have been made to offer a holistic approach focusing on future development possibilities. The goals of the article are (1) to set up a conceptual system-dynamic model for agro-food development in Africa, (2) test this model on examples of two representative countries, namely Uganda and Nigeria, (3) based on expert surveys, define development scenarios for the agro-food sector in these two countries and (4) determine the key actions for the improvement of the present situation. The system dynamics simulations forecast a rather gloomy future for the agro-food sector: even the historically highest development rate of agricultural production of these two countries will not be enough to meet the rapidly increasing demand for food. Scenarios based on expert estimations predict long-range stagnation in Nigeria and just a moderate probability of improvement in Uganda. Radical improvement in the food security situation and prevention of imminent social catastrophe necessitate wide-ranging socio-economic reforms focusing on (1) decreasing fertility, (2) a general upgrading of health culture, (3) promotion of cooperatives and (4) enhanced attractiveness of the agro-food sector for a wide range of business investment opportunities.

Keywords: food security, policy analysis of Nigeria, system dynamics, scenario analysis, stochastic simulation, Uganda

JEL classification: C51, Q18, O13

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Introduction

During the last two centuries the central question of studies focusing on the future of the agro-food supply chain has been the comparison of the real and potential food supply situation with the pessimistic forecast made by Malthus (Abdelhedi and Turki, 2018). The threat of global food shortages has been exercising considerable influence on strategic thinking and political decision making. For example, the former president of the World Bank, Robert S. McNamara stated in 1973: “*the threat of unmanageable population pressures is much like the threat of nuclear war*” (Teshome, 2014). The green revolution (Kumar et al., 2017) in the second half of the last century considerably improved the global food security situation (Ramankutti et al., 2018). According to data from the FAO (FAO, 2018) the absolute number of people facing chronic food deprivation decreased from 945 million to 783 million between 2005 and 2014, and the prevalence of undernutrition decreased from 14.5% to 10.6%. These results can be attributed to the improvement in the food security (Popp et al., 2018a; Popp et al., 2018b) situation in Asia and Latin-America. The prevalence of undernourishment was nearly halved between 2005 and 2017 in Central Asia (from 11.1 to 6.0%) and in Southern Asia (from 18.1 to 9.9%). This positive global trend has reverted recently: the number of undernourished people has been on the rise in the last four years, their number reached 820 million in 2017, and the global prevalence of undernourishment increased to 10.9% in 2017. While in developed countries the value of this indicator is below 2.5%, the food security situation in most regions of Africa is critical: the prevalence of undernourishment in Sub-Saharan Africa was 23.2% in 2017. Severe food insecurity is increasing in almost all region of Sub-Saharan Africa.

There are numerous publications on the historic causes of the persisting food supply problems of Sub-Saharan Africa (Rodney, 2018), as well as on analysis related to different particular aspects of the current crisis; e.g. focussing on the consequences of climate change (Raleigh et al., 2015), politics (Kannan and Kande, 2017), social factors (Mills, 2018) or the utilization of natural resources (Ebeke and Etoundi, 2017) but there are no models which could be characterized as (1) offering a complex (holistic) approach, (2) focusing on future policies and (3) relatively simple and robust.

The application of mathematical modelling is widely applied. The computable general equilibrium models have been used for studying the consequences of policy reforms (Kim et al., 2016), commodity price changes (Kim et al., 2018) and trade liberalisation (Mold and Mukwaya, 2016).

It has been widely acknowledged in the last few decades that the system dynamics approach is an important tool for describing and forecasting complex socio-economic systems (Meadows et al., 1972; Nordhaus et al., 1992). Furthermore, this approach has to be integrated into long-range planning of agro-food systems (Thomson and Scooners, 2009; von Arnim et al., 2018). The system dynamics modelling approach has usually been used in different fields (e.g. socio-economic consequences of bioethanol systems (Demczuk and Paduda, 2017), the analysis of environmental aspects of agricultural production or policy planning (Reinker and Gralla, 2018)).

The system dynamic modelling of the food supply chain in Africa has focused mainly on forecasting the consequences of climate change (Schmidhuber and Tubiello, 2007; Genesio et al., 2011), land use and carbon balance (Accorsi et al., 2016). To the best of our knowledge

this study is the first attempt to offer a relatively easily manageable method for integrated socio-economic planning for the development problems of Africa.

The goal of this study is to determine the future development trajectories of the food supply systems in Sub-Saharan Africa using the examples of two countries representing the complexity of problems in the region, namely Uganda and Nigeria, and to determine the most important steps for the improvement of the state of food security.

This paper is based on the testing of one research hypothesis: The countries of Africa will be able to cope with their increasing food demand. The results of this hypothesis test can be used to answer the research question: what is the development path of the food supply system in Africa in the next two decades?

The article is structured as follows: the methodological section describes the system dynamics approach and its computational representation as well as the expert-estimation and policy analysis methodology. The next part describes the results of the model and scenario development. The closing part presents the results of the agro-food and rural development policy alternatives.

1. Research methodology

1.1. The Pearl and the Giant: two important model-states from Sub-Saharan Africa

There are considerable differences between African countries and that is why it is rather hard to choose “typical” ones, but based on their geopolitical position, historic development and natural endowments Uganda (the former colony characterised by Churchill in 1908 as “*the pearl of Africa*”) and Nigeria (proverbially known as “*the giant of Africa*”) reflect relatively well the current challenges of food security in Africa. The most important characteristic features of these two countries are summarised in table no. 1.

Table no. 1: Main characteristics of Uganda and Nigeria

Indicators	Nigeria	Uganda
Geographic position	Western Africa	Eastern Africa
Population size (million cap.)	186	37.5
Area (thousand km ²)	923	236
GDP per cap. PPP, current international \$	5860	1863
Share of population ages 0-14 (%)	44	48
Life expectancy at birth (years)	53	60
Most important export products	96% oil, gas and minerals	gold 25%, coffee 14%

Source: World Bank, 2018

Uganda’s fertile agricultural land has the potential to feed 200 million people. 80% of Uganda’s land is arable but only 35% is being cultivated. Agriculture accounts for about 24% of GDP and 50% of export earnings, and about 72% of the working population is employed in agriculture. Although Uganda is generally self-sufficient in terms of domestic food availability, the country does import limited volumes of wheat (and wheat products), vegetable oils, rice, and sugar. Uganda’s food imports fluctuated substantially in recent years,

tending to decrease, and ending at 0.7 billion USD in 2016. Exports also tended to decrease, ending at 1.9 billion USD in 2016. This means that the trade balance for agri-food products has been positive in recent years (Knoema, 2018a).

Nigeria is Africa's largest economy, a major oil producer with a population of over 180 million people. Earnings from crude oil and gas exports account for 80% of the country's total revenue. In Nigeria, there are over 30 million hectares of farmland under cultivation season to season, falling substantially short of the estimated 78.5 million hectares of land that is required for farming to feed Nigeria's growing population. Nigeria is a net importer of food and major agricultural products. In 2017, food imports for Nigeria accounted for 740 million USD and food exports for 75 million USD, leading to a negative trade balance for agri-food products (Knoema, 2018b).

1.2. System dynamics approach

Based on an analysis of the agro-ecological conditions and the anticipated trajectories of agriculture in Nigeria and Uganda, we have set up a stochastic system-model for prediction of the production and consumption balance in these two African countries. We have applied a relatively simple model because the application of a more sophisticated one could involve so much bias that it could jeopardise the interpretation and practical application of results.

Food security is a result of a complex interplay of natural and socio-economic factors. However, the expected future values of these factors are hard to quantify and predict. To circumvent this problem, we employ a system dynamics approach to analyse the future development trajectories of the systems investigated. Sterman (2001) outlined the most important features of systems characterised by dynamic complexity of phenomena. The main features of a dynamic systems can be summarised as follows: (1) constantly changing character; (2) tightly coupled sub-systems; (3) governed by feedback; (4) nonlinearity; (5) history-dependence; (6) self-organising character; (7) adaptive behaviour; (8) characterisation by trade-offs; (9) counterintuitive character and (10) policy resistant feature. All of these features are valid for the food supply and demand systems and that is why we have applied the system analysis method. To operationalise this conceptual framework we have used the Vensim software (Systems, 2018).

1.3. Scenario analysis method

The system dynamic analysis in itself is not capable of describing future development trajectories because it is not able to grasp the structural changes in the system and its environment. That is the reason we have applied some expert-estimation methods as well.

The goal of scenario analysis is to determine the potential set of future events. In the last decades, numerous algorithms have been developed to account for the effect of one event on another. The goal of these cross-impact algorithms is the manipulation and harmonisation of probability estimates (Joung and Kim, 2017). We applied the Smic-Prob-Expert cross-impact analysis tool developed by the Lipsor Institute, led by Michael Godet (Godet, 2002). This approach has been widely used in different fields of future research, e.g. in the ICT sector (Yalamov, 2018), the military (Petrescu, 2018), regional (Chavez et al., 2017; Sarkki et al., 2017), and health policy planning (Ortega et al., 2018).

The production and consumption data have been downloaded from the official website of the FAO (FAO, 2018a), the population forecast data from the World Population Prospects of the UN Population Division (UN, 2018).

The key methodological problem of future scenarios is the fact that opinions, formulated in response to the specific questions about the probability of non-independent events always have a relatively high degree of inconsistency (Amer et al., 2013). That is why the primary opinions must be corrected. The algorithm of Smic-Prob Expert (Godet, 2002) is capable of handling this problem. The main mission of the software is to generate a hierarchical rank of scenarios, based on their probabilities. The input of the analysis consists of three blocks: a vector of a priori estimations of the probability of the different outcomes, and two square matrices, representing conditional probabilities. The first matrix contains the experts' estimation of the pairwise probability of the co-occurrence of events. The second matrix contains the estimated probabilities of the occurrence of processes in pairwise form, should the other process in the pair not occur.

Due to the fact that the chemical compositions of agricultural products show considerable differences we have applied the grain unit (Getreideeinheit) concept widely used in the European Union, mainly in German-speaking countries (BMEL Statistik, 2018).

The participants in the expert interviews were carefully selected. We considered experts to be people, (1) who have direct "field" experiences in agricultural production, food processing, or the trade in food and agricultural products; (2) who are involved in scientific research or higher education, or (3) public servants who have been especially active in the development of the agro-food sector. The list of potential participants was collected on the basis of the personal recommendations of our partners in Uganda (Kiambogo University, Kampala) and in Nigeria (Kebbi State University of Technology, Alliero). The socio-demographic characteristics of the participants are summarised in table no. 2.

Table no. 2: Socio-demographic characteristics of participants

	Highest Qualification			Gender		Age			Place of residence			
	BSc	MSc	Ph.D.	male	Female	<35	36-50	>50	Capital	Regional center	Town	Village
Nigeria												
Agricultural extension service specialist	2	1		2	1	2	1				1	2
Local public administration	0	2		2			2	1		2		
Central government officer		1		1				1	1			
Entrepreneur in agriculture	1			2		1				2		

	Highest Qualification			Gender		Age			Place of residence			
	BSc	MSc	Ph.D.	male	Female	<35	36-50	>50	Capital	Regional center	Town	Village
Entrepreneur in food processing and/or trade	1			1			1			1		
Researcher/teacher in higher education	1		2	1	1	1	1			2		
Uganda												
Agricultural extension service specialist	2	1		2	1	2	1			1		2
Local public administration	0	2		2			1	1		2		
Central government officer		1		1				1	1			
Entrepreneur in agriculture	1	1		2		1	1			1		1
Entrepreneur in food processing and/or trade	2	1		2	1	2	1		1	1		1
Researcher/teacher in higher education		1	1	1	1	1	1			2		

Under Sub-Saharan African conditions an expert opinion collection for input analysis turned out to be extremely complicated. The simplest way would have been a Delphi-type questioning of experts, however, it became obvious in the case of the Nigerian experts that even after two rounds of questioning there were still considerable differences. Finally, four workshops were organised for experts, two in Uganda and two in Nigeria.

The length of each workshop was 6-7 hours. The Nigerian workshops took place in 2016 in the Northern region of the country; the workshops in Uganda were held in 2018 in the capital city, Kampala.

Each workshop had ten phases:

- Introduction of the project (30 min).
- Introduction of the concept of probability and conditional probability (30 min).
- Individual estimation of a/priory probabilities (30 min).
- Discussion of individual estimations (60 min).
- Individual estimation of conditional probabilities (30 min).
- Discussion of individual estimations (60 min).
- Determination of scenarios (30 min).
- Evaluation of the reality of different scenarios (60 min).

- Prioritising possible future actions (120 min).
- Summary of results (20 min).

The outcome probabilities were estimated by consensus and the probabilities were then used to develop the scenarios and their probability of occurrence. The various panels of experts were selected in order to ensure that the chosen experts had wide-ranging and diverse expertise across a broad range of problems affecting the agro-food system.

Nevertheless, the input values for the scenarios were subjected to the estimations of the chosen experts and in this way a relatively high level of convergence of opinions could be achieved. From this it follows that there is some room for subjectivity, even taking into consideration the heterogeneity of the groups.

1.4. Ethical issues

Before beginning the study, following the guidelines of international professional organisations (e.g. Association of Social Anthropologists of the UK and Commonwealth (Anon, 2018) and Chartered business schools (Anon, 2015), the authors analysed ethical aspects of this research, involving two independent ethical experts (one expert from Hungary and one expert from the Muslim community in Central-Europe). It was unanimously decided that the research did not infringe ethical guidelines. To avoid any complications in reporting we have followed the Chatham House rule (*“When in a meeting... participants are free to use the information received, but neither the identity nor the affiliation of the speaker(s), nor that of any other participant, may be revealed”*, Wilmshurst, 2006). All of the participants signed an informed consent, which described the procedure of the research in detail. All the discussions were electronically recorded and at the end of the study finally deleted from each electronic device.

2. Results

In the first phase of our research the hypothesis was tested by system dynamic modelling.

2.1. System dynamic modelling

In first phase we developed a conceptual model (figure no. 1). This model consists of two main parts: from the production and the consumption subsystems. On the demand side we have taken into consideration the effect of structural changes in food consumption patterns (e.g. increasing meat demand), too.

The models applied for practical calculations are been identical with the conceptual ones as for practical purposes the consequences of climate change have not been taken into consideration. The reason for that is that different climate scenarios (Girvetz et al., 2009) show totally different prognoses for Sub-Saharan Africa (as opposed to another regions, e.g. Northern Africa or Middle-East, where practically all climate-scenarios predict similar results).

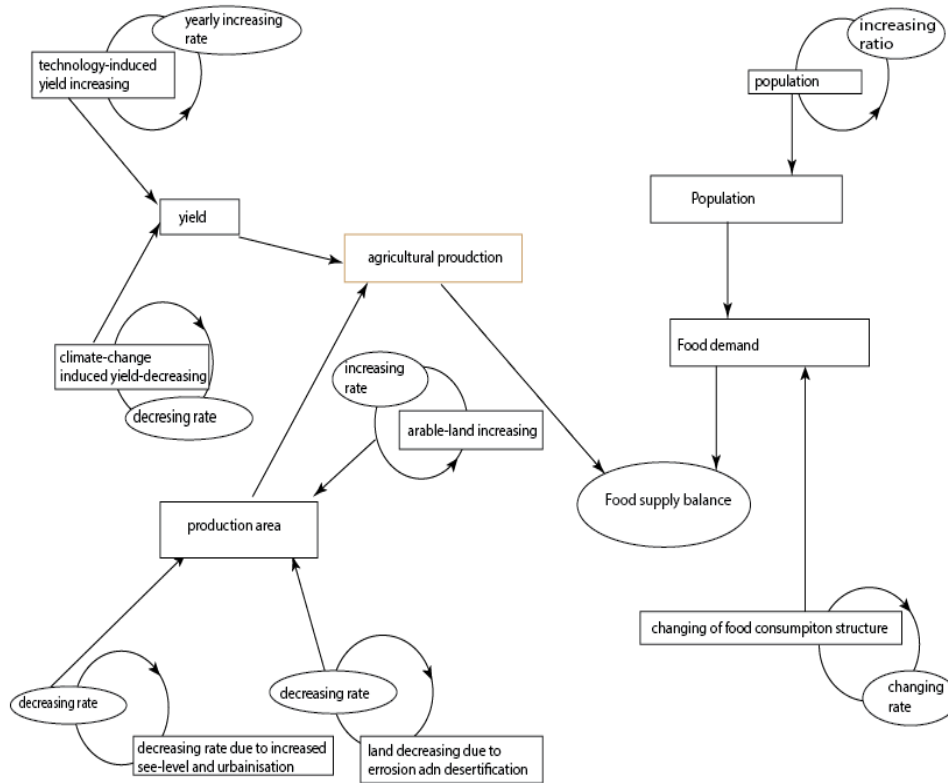


Figure no. 1: Conceptual model of the simulation

The reliability of statistical data are different in the case of Nigeria and Uganda: that is why in the case of Nigeria we have calculated with cereals, leguminous and tubular plants, while with Uganda only the data on cereals was considered reliable.

In the case of Nigeria, the system dynamic simulation forecast an imminent collapse of the food supply system: the yields of the most important staple foods will stagnate or decrease (figure no. 2). This is attributable to the one-sided policy of the central government: in the era of cheap crude oil prices agro-food development has not been given a priority (Onoh, 2017) and that is why the agricultural sector is not able to achieve self-sufficiency for domestically-grown food. The current stagnating world energy prices forecast a severe food supply crisis.

For Uganda, a decreasing fertility ratio (0.00037%/year) has been calculated, which is in line with the UN forecast), and an increasing per-capita food demand of 1%/year (in quantity).

Figure no. 3 shows the food deficit (the difference between supply and demand) as a stochastic function of annual increasing yield. A 3% increase in cereal yields has been calculated, with a standard deviation of 1%

As a summary, it can be concluded with a high level of confidence that the current food supply systems will not be capable to cover the increasing demand for food in both countries included in the model.

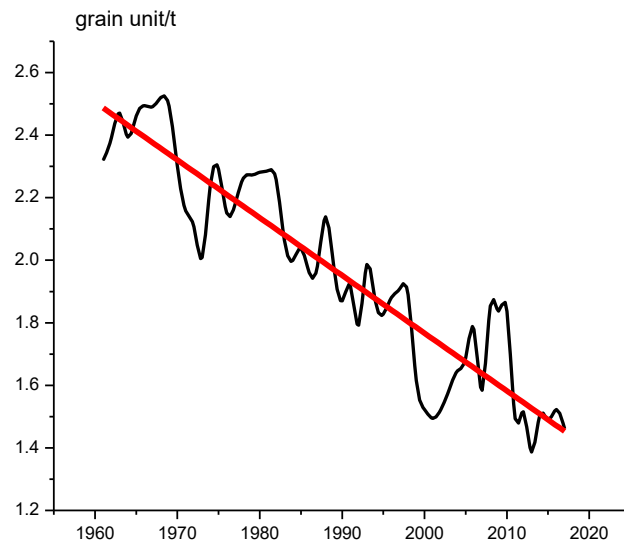


Figure no. 2: Decreasing performance of the Nigerian plant production sector and its approximation by linear trend

The hypothesis has not been proved by the results. This fact does not mean that the research is without value, and it has highlighted the importance of scenario analysis to characterise the future development of the agro-food chain in Africa by using expert opinion.

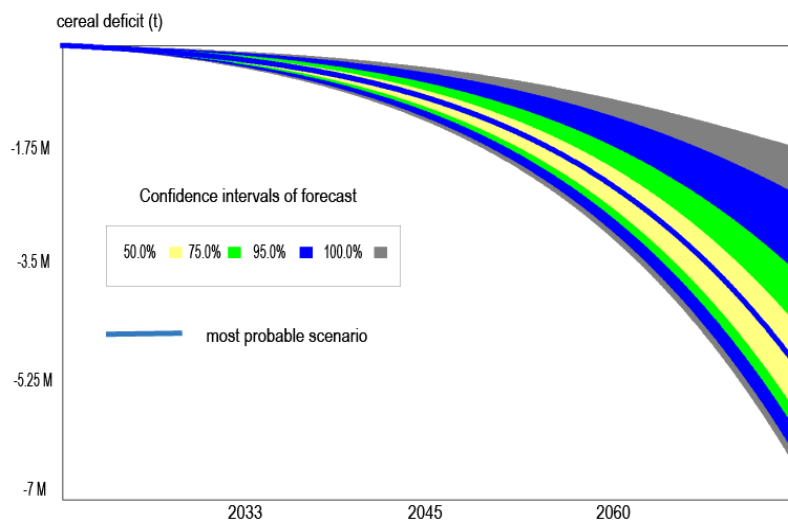


Figure no. 3: The expected value of cereal deficit in Uganda

2.2. Scenario analysis

In the first phase of investigations some potential states (modes/conditions of being) were determined for the time horizon 2040. These were identical for Nigeria and Uganda. These were as follows:

- The number of people in the country suffering from undernutrition can be halved (FOODSECURITY).
- The number of workplaces in agriculture and the food industry will be increased by 30% (EMPLOYMENT).
- The fertility ratio in rural regions can be reduced to 2.1%/year (FERTILITY).
- The agro-food export of the country will double compared to the average of 2012-2017 (EXPORT).
- The share of processed products in the value of agro-food exports will increase by 30% compared to the average of 2012-2017 (VALUE ADDED).
- Food safety and quality can be considerably improved and food safety-related health problems can be halved (FOODSAF).

In the expert-workshops the experts were asked to estimate the probabilities and conditional probabilities of the two counties. The a priori priority of Nigeria and Uganda is summarised in table no. 3. Experts were much more optimistic in the case of Uganda compared to Nigeria; however, even in the case of Uganda three experts were fairly pessimistic about increasing employment, reducing the fertility ratio and increasing the share of value added products in food exports.

Table no. 3: The a priori probabilities of Nigeria and Uganda

States (abbreviated)	Nigeria	Uganda
Foodsecurity	0.6	0.7
Employment	0.2	0.3
Fertility	0.2	0.3
Export	0.3	0.6
Value added	0.1	0.3
Foodsafety	0.4	0.7

Pairwise estimation of the probability of each state occurring, given that the other event in the pair occurs (table no. 4) and pairwise estimation of the probability of each event occurring, given that the other event in the pair does not occur (table no. 5) offers further information for scenario-development.

Table no. 4: Conditional probabilities of different states based on the occurrence of conditional states

Conditional state (state occurs)	Probability of state					
	Food-security	Employment	Fertility	Ex-port	Value added	Food-safety
Food-security	0.7	0.2	0.3	0.7	0.5	0.8
Employment	0.4	0.3	0.3	0.3	0.5	0.5

Conditional state (state occurs)	Probability of state					
	Food-security	Employment	Fertility	Ex-port	Value added	Food-safety
Fertility	0.9	0.3	0.3	0.3	0.3	0.3
Export	0.7	0.5	0.3	0.6	0.6	0.7
Value added	0.4	0.3	0.3	0.8	0.3	0.5
Foodsafety	0.8	0.6	0.3	0.7	0.6	0.6

Table no. 5: Conditional probabilities of different states based on the occurrence of conditional states

Conditional state (state does not occur)	Probability of state					
	Food-security	Employment	Fertility	Ex-port	Value added	Food-safety
Food-security	0	0.2	0.3	0.1	0.2	0.2
Employment	0.4	0	0.3	0.3	0.2	0.3
Fertility	0.3	0.1	0	0.3	0.3	0.3
Export	0.7	0.3	0.3	0	0.5	0.6
Value added	0.4	0.3	0.3	0.4	0	0.5
Foodsafety	0.4	0.2	0.3	0.05	0.05	0

Obviously, the improvement of the food security and safety situation would be a considerable step towards an export-oriented development in the food sector. Based on the opinion of experts the growing employment possibilities in the agro-food sector could increase the production potential. Decreasing the fertility ratio could be an important step towards improving the food security situation.

Based on input-data by Smic-Prob Expert, 27 different scenarios could be generated (table no. 6). Table no. 6 demonstrates that the seven most likely scenarios ($p=25\%$) predict stagnation: neither of the previously determined goals could be achieved. This rather pessimistic scenario forecasts a rather gloomy future for the development of Uganda with an increasing threat of complex socio-economic crisis. The second most probable scenario ($p=8.7\%$) is export-oriented development without any improvement in the state of food security and safety, combined with the output of a low level of value added food products. This scenario is based on increasing food demand in the world market but does not offer any solution to the deep-rooted problems of the country. The probability of a scenario with an improvement in food security is just 8.3%. As a summary, it can be stated that according to expert estimation there is only a low probability of radical improvement in the current food security situation in Uganda.

Table no. 6: The most probable scenarios

Elementary Processes	Scenarios						
	No.1	No.2	No.3	No.4	No.5	No.6	No.7
	25	8.7	8.3	7.2	7	6.8	6.5
Food sec.	0						
Employment	0						
Fertility	0						
Export	0						
Value added	0						
Foodsaf.	0						

Notes: The elementary process/state is a part of the scenario

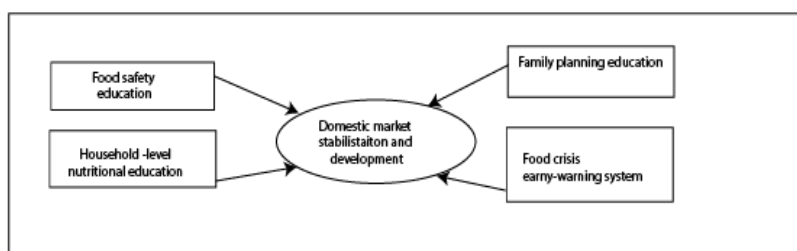
The elementary process/state is not part of the scenario

In the case of Nigeria the estimated probabilities of an improvement of the situation are more negative. To make the paper shorter, the conditional probability matrices have been omitted. The most probable scenario is the stabilisation of the current status in which neither parameter will change. The probability of this scenario is above 63%.

It follows from the facts outlined above that a persistent crisis characterises Africa. From this it follows that a coherent, long range strategy should be formulated in Nigeria, Uganda and other regions in Africa.

2.3. Policy recommendations

In the closing part of the workshops we asked the participants to collect and prioritise the most important steps to improve the food security situation in their countries, in order to make it obvious that the improvement of food security demands a complex set of actions. The most important ones are summarised in figure no. 4. When we asked the participants of the workshop to prioritise the most important steps for development in both countries, the further strengthening of food security and stability and the decreasing fertility ratio were highlighted. Without these steps the food crisis will increase in Africa, with all its adverse global consequences.



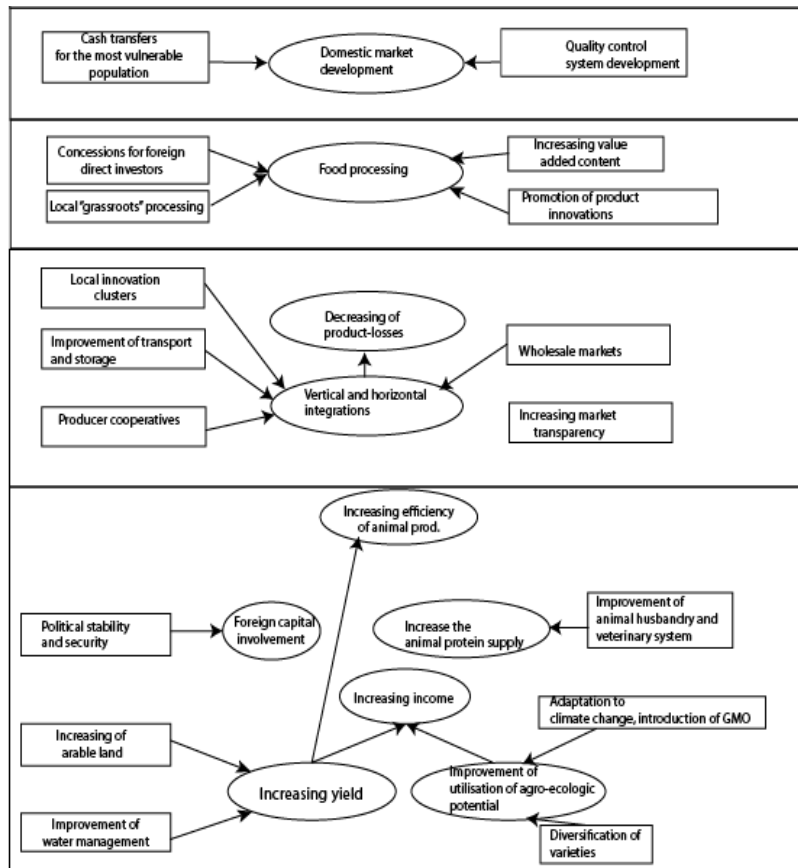


Figure no. 4: Key areas of development of food security along the food supply chain

Conclusions

System dynamics analysis has been used to prove that, on the basis of two important, relatively rich African countries, namely Nigeria and Uganda, without radical changes the current rate of the development of agricultural production will not meet the rapidly increasing food demand. From this it follows that considerable, concerted efforts are needed to focus on (1) increasing yields and production rates; (2) optimising the use of farm resources by improving land use; (3) reducing losses along the food chain; (4) changing the structure of food consumption to address food overconsumption by preventing a “western-type” diet

The expert interviews highlight that in the next decades even the relatively stable and developed countries in Africa will not be able to become self-sufficient. This fact enhances the importance of an increasing integration of their economies into the global value chain in order to create tradable goods and services. Under current conditions the most important short-term goal is to stop capital (assets or money) flight out of the continent.

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