Competing agricultural paradigms to meet urban and rural food needs in Senegal – An Integrated System Approach

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Abstract

Developing coherent plans to achieve food and nutrition security is complicated by the multi-disciplinary, interconnected and complex nature of the food systems that must be managed. To support such a planning process in Senegal, we analyse the impact of alternative interventions targeting food security through an integrated socioeconomic-environmental framework (the Millennium Institute's Threshold-21 model) that allows the assessment of multisectoral long term impacts of alternative policies. Based on the System Dynamics method, T21 is well suited to capture the elements of dynamic complexity that make public policy analysis in this area particularly difficult. Our study explores and evaluates two scenarios representing two competing paradigms in agricultural policy and farming practices, and their implications for availability and access to food. In the first scenario government support is mainly directed towards subsidizing the intensive use of high external inputs and large-scale farming; while in the second scenario the government mainly supports a transition towards high agro-ecological knowledge intensity, less intensive use of external input and small-scale farming. Results indicate that, in terms of food availability, the first scenario yields better results in the short term, while the second scenario shows more desirable results in the long run. The agriculture system that emerges from the second scenario is also more resilient and thus less susceptible to changes in the price of external factors. The development of social indicators and consequently access to food are also substantially better in the second scenario, which supports more equitable socio-economic progress. Our work highlights how the non-linear response of the system to the policies implemented lead to worse-before-better dynamics, and how a failure to account for the interconnected and complex nature of the food-development nexus can lead to sub-optimal strategies.

1. Introduction

Achieving and sustaining food and nutrition security continues to be a huge challenge for the global community. The tragedy of hunger still persists for more than 800 million people today (FAO, IFAD, WFP 2014), 25 percent of whom live in urban areas. This proportion is rising (WFP 2015) and will likely continue to rise spurred by the continuous global process of urbanization (UN DESA 2014). Addressing this situation calls for reversing the vicious cycle of poor nutrition, poor health, low productivity, persistent poverty, and stagnating economic growth. Against the background of growing food demand, especially in urban areas, the need for effective, coordinated and sustainable intervention remains. Developing coherent plans to achieve food and nutrition security is complicated by the multi-disciplinary, interconnected and complex nature of the food systems that must be managed. Therefore, it is essential that the strategies developed to tackle these issues are based on comprehensive and sound analyses addressing their key dimensions in an integrated manner (UN 1992; UN 2000; UN 2014a; UN 2014b).

To support such a planning process in Senegal, we analyse the impact of alternative interventions targeting food security through an integrated framework, Millennium Institute's Threshold-21 (T21). T21 is a simulation model that enables transparent cross-sectoral analyses of the impacts of policies, and enables exploration of their direct and indirect long-term consequences on social, economic and environmental development (Pedercini 2010). Our framework is implemented with the System Dynamics method, which is well-suited to capture the elements of dynamic complexity, such as feedback loops, delays, and non-linearity (Forrester 1961; Sterman 2000) that make public policy analysis in this area particularly difficult. That is why System Dynamics has proven very effective for the analysis of a variety of development issues over the last decades (Parayno 1993; Qureshi 2008; Saeed 1987). The method also facilitates the integration of knowledge from different sectors and stakeholders into a single framework (Pedercini 2005). In comparison with other tools that support policy design, analysis, and evaluation in the public sector, such as Computable General Equilibrium (CGE), Macro-Econometric (ME) and Disaggregated Consistency (DC) models, these characteristics make T21 ideally suited to analyse development issues from an integrated and long-term perspective on an aggregated level (Pedercini 2005; UNEP 2014).

We use T21 to address a research question that is key to food security: which types of agricultural practices can most effectively contribute to make food systems more efficient, inclusive and resilient in order to meet urban food needs in Senegal? To accomplish this, we evaluate two scenarios representing two competing paradigms in agricultural policy and farming practices. Agricultural policies play a key role in food and nutrition security with regard to both availability and access dimensions as the majority of the population in Senegal depends on agriculture, either directly or indirectly, for their livelihoods. In the first scenario government support is mainly directed towards subsidizing the intensive use of high external inputs and large-scale farming. In the second scenario the government mainly supports a transition towards high agro-ecological knowledge intensity, less intensive use of external inputs and small-scale farming.

More specifically, this paper focuses on:

- assessing and comparing the mid-and long term impacts of alternative strategies to meet urban and rural food needs, and
- illustrating how, by adopting a systemic and integrated perspective, more appropriate policies, strategies and investments plans can be formulated.

Section 2 outlines the methodology used to analyse the two scenarios and includes a description of the T21-Senegal simulation model. Section 3 describes the scenarios analysed with the model and the simulation results. Section 4 summarizes and discusses the findings and draws conclusions.

2. Methodology: The T21-Senegal model

T21-Senegal was designed based on the T21-Starting Framework, which is a generic version of T21 that has evolved over the past 30 years from extensive research and application by the Millennium Institute (Barney 2002). The model was customized in collaboration with the Senegal Ministry of Finance and became functional for the first time in 2010. Since mid-2012 the model has been significantly improved within the 'Changing Course in Global Agriculture' (CCGA)1 project in the areas of agriculture, food and nutrition security, and rural poverty in collaboration with the Ministry of Agriculture and based on the input of representatives from relevant stakeholder groups, including government, farmers and farmer's organizations, private sector, non-governmental organizations, research institutions, and international organizations.

The model underwent an intensive validation process involving structural and behavioural validation tests (Barlas 1996). Structural validation involved direct verification of structural assumptions and parameters. Behavioural validation involved the assessment of the model's ability to replicate the historical behaviour of the main indicators for the period 1980-2010.

2.1. General model structure of T21-Senegal

Figure 1 presents a conceptual overview of T21-Senegal, with linkages between the economic, social, and environmental spheres. Within each sphere are sectors that interact with each other and with sectors in the other spheres. The fact that all the major concepts in each sphere are modelled endogenously implies that causes are determined by the interlinked structure of the system itself. A major strength of T21 is that it captures the complex web of causal interrelations and numerous important feedback loops.

[1] CCGA is a joint project of Millennium Institute and Biovision Foundation, financed among others by the International Fund for Agricultural Development and the Swiss Agency for Development and Cooperation, and implemented in collaboration with the Ministry of Agriculture (Senegal, Kenya and Swaziland).

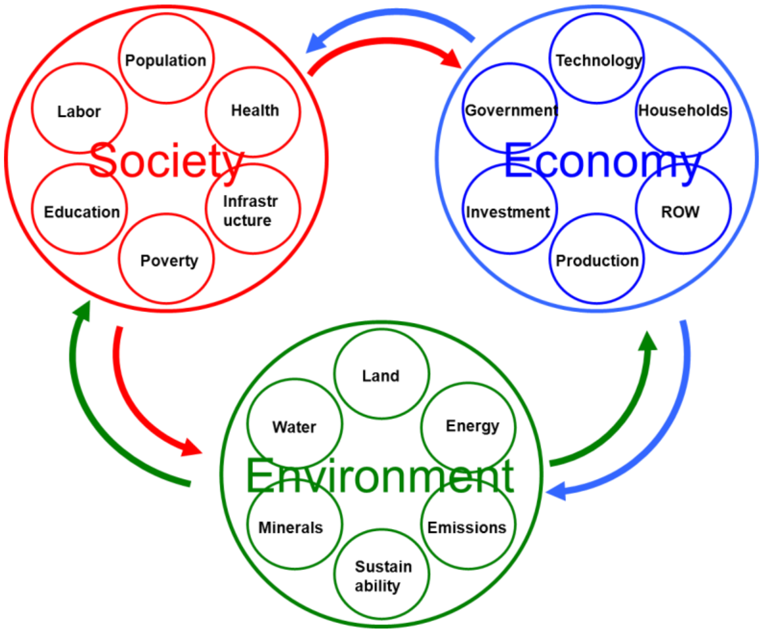

Figure 1 – T21 Spheres and Sectors

The Economy sphere contains the major production sectors (agriculture, industry and services), which are characterized by expanded Cobb-Douglas production functions with inputs of resources, labour, capital, technology and an inclusive total factor productivity (TFP) variable. Production activities especially relevant to our study, such as crops production, animal production, fisheries, forestry, etc. are included in specific sub-sectors. The government sector generates taxes based on economic activity and allocates expenditures by major category. Public expenditure impacts the delivery of public services. Standard IMF budget categories are employed and key macro balances are incorporated into the model. The household sector traces household revenue and disposable income (based on economic activity, government's subsidies and transfers, remittances, etc.), which is then used to support private saving and consumption. In the investment sector, private and public investment is allocated to the different production sectors. The Rest-of-World sub-sector comprises trade, current account transactions, and capital flows (including debt management).

The Society sphere contains detailed population dynamics by sex and age cohort and accounts for urban migration; health and education challenges and programs; basic infrastructure; employment; and poverty levels and income distribution. These sectors take into account, for example, the interactions of income, healthcare, nutrition, and adult literacy rates on fertility and life expectancy, which in turn determine population growth. Population determines the labour force over time, which shapes employment. Education and health, together with other factors, influence labour productivity and life expectancy. An HIV/AIDS sector is also included, which shows the impacts of the disease on population and productivity, and the effects of different treatment programs. Food sufficiency and nutrition availability and their effects on human well-being are addressed in this sphere.

The Environment sphere tracks the consumption of natural resources – both renewable and non-renewable – and can estimate the impact of the depletion of these resources on production and other factors. It examines the effect of soil erosion and other forms of environmental degradation and their impacts on other sectors, such as agricultural productivity and nutrition. Additional issues addressed are fossil fuel use and emissions, biodiversity loss, forest depletion, land and water degradation, air and water pollution, and greenhouse gas emissions.

2.2. Model structure of Agriculture, Food and Nutrition security and Rural Poverty in T21-Senegal

A highly simplified schematic overview of the model structure of T21-Senegal concerning agriculture (food production), rural poverty and food and nutrition security is shown in Figure 2.2 Food and nutrition security are defined by the following dimensions: food availability, economic and physical access to food, food utilization and stability (vulnerability and shocks) over time (FAO, IFAD, WFP 2013).

As depicted in Figure 2, food and nutrition security affect social resources, especially the health of the population, while their components are driven by other factors of the system. Food availability is determined by Food Production (Agriculture) and net food import, food aid and food stocks; food use is predominantly a result of education and health; and food access depends on food prices (an external input to the model) and Rural Poverty. Rural Poverty is determined by income (in rural areas mainly income from agriculture) and the distribution of this income. Income distribution is governed by access to social services, markets and credit, and employment levels, all of which are results of the interplay of social and economic factors.

Food Production, reduced by exports, feed, seed and other non-food uses, losses and waste, comprises the main food source of the people. It is also the main driver of income for farmers, which reduces rural poverty and also enables savings and investment in various productive resources. Food production is a function of numerous factors in every sphere: the economy (e.g. infrastructure, agriculture machinery, processing capacity, irrigation equipment and storage capacity), the environment (such as water availability, temperature, solar radiation and soil nutrients), and society (mainly education, R&D, employment and health).

Therefore, in order to produce sufficient food to provide food and nutrition security for a growing population and to reduce rural poverty, it is necessary to ensure the availability of the contributing resources, whether economic, social, or environmental, as well as external inputs. In most cases, this can be done through investment. However, the availability of environmental resources is also affected by agriculture production and the use of inputs. Synthetic inputs, such as mineral fertilizer and chemical pesticides, must be bought by farmers, as they cannot be produced on-farm, while natural inputs can be produced on-farm by the farmers themselves. In the latter case, the knowledge and resources needed are in reach of farmers through training; in the case of synthetic inputs the resource needed is cash. That is why the model assumes that synthetic inputs can be

[2] For more details, see Millennium Institute, 2014.

provided through expenditure for subsidies while natural external inputs such as natural fertilizer (e.g. manure) or biological pest control mainly depend on the level of social resources, specifically of knowledge, and hence their use can be strengthened through expenditure for training. The sources of funds for the investments in resources can be either public or private. Public allocation of funds for different expenditures is a policy decision, explicitly left for the user to decide in T21-Senegal. The levels of private investment are mainly driven by income levels but also influenced by government decisions and the quality of governance since these affect the population's propensity to save.

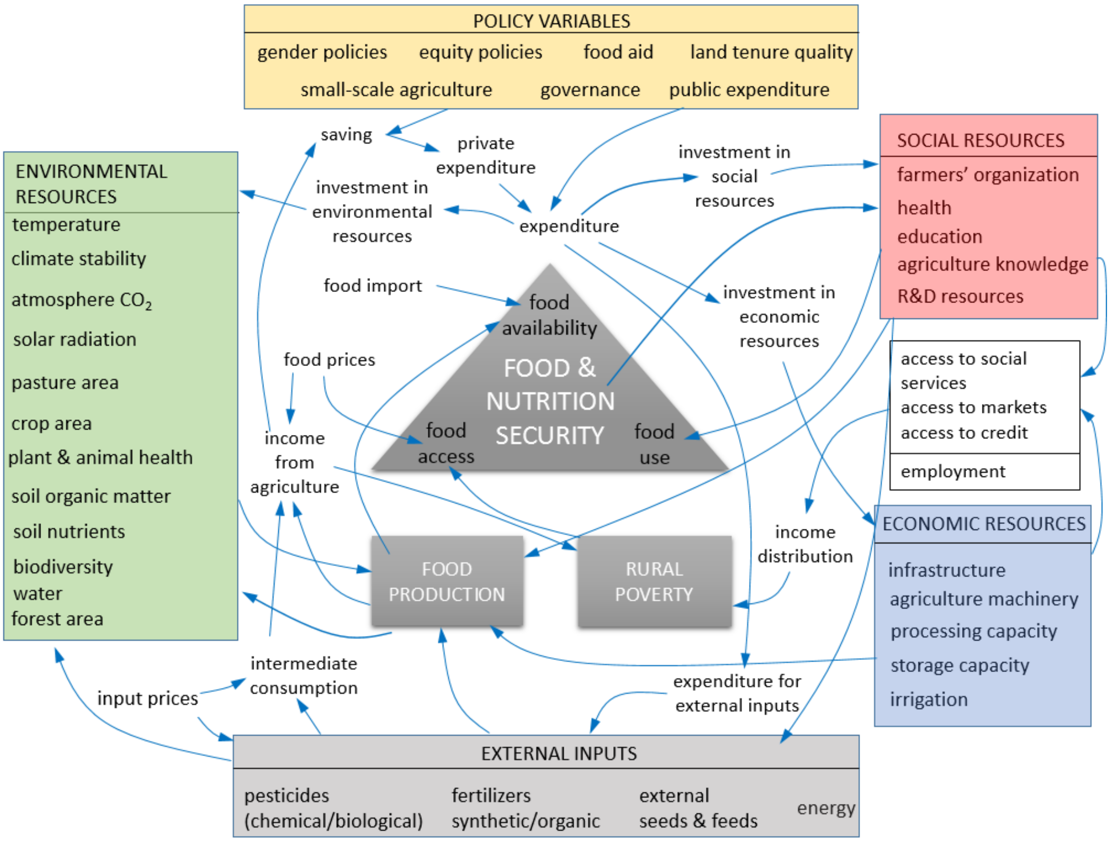

Figure 2 – Schematic representation of the CCGA structure

Thus, as seen in Figure 2, ensuring food and nutrition security requires the concerted interplay of numerous factors coming from very different spheres and sectors. This entails a network of cause-and-effect interrelationships that embody hundreds of feedback loops. The policy analysis functionality of T21-Senegal is, therefore, indispensable for designing coherent policies that create maximum positive synergies.

3. Scenario Description and Results

To answer our central research question – which types of agricultural practices can most effectively improve the efficiency, dynamism, inclusiveness and resilience of food systems to meet urban food needs? – we analyse two scenarios representing two competing paradigms in agricultural policy and farming practices, based on selected key indicators.

3.1. Scenario definition

According to the FAO, the systems of agricultural production can be divided into three main categories (FAO, OECD 2011): High External Input (HEI) systems, Intermediate External Input (IEI) systems and Low External Input (LEI) systems, with HEI and LEI systems being the extremes of a continuum. In general terms, HEI agriculture is characterized by high use of capital, chemical products (such as mineral fertilizer and pesticides), energy and low labour intensity. LEI agriculture is characterized by low use of capital and chemical products, but high labour and agro-ecological knowledge intensity, and it is associated with sustainable production methods (e.g. conservation agriculture, integrated pest management, etc.). Hence, a suitable policy to support the use of HEI agriculture is to provide subsidies for mineral fertilizer and pesticides, while a suitable policy to support the use of LEI techniques is to provide farmers with LEI focused training.

Supporting policies can be directed towards small-scale or towards large-scale farmers. Small-scale farmers are mainly characterized by limited amounts of land (usually less than 2 ha), high labour and low capital intensity, and are often challenged by limited access to markets, credits, new skills and knowledge resulting in low productivity (IFAD et al. 2011; Heidhues, Brüntrup 2002; Afenyo, 2012).

This paper investigates the impact of policies supporting the realization of two differing agricultural production systems. It distinguishes between a LEI + small-scale farming system with low capital and high labour intensity, and an HEI + large-scale system with high capital and low labour intensity (Figure 3).

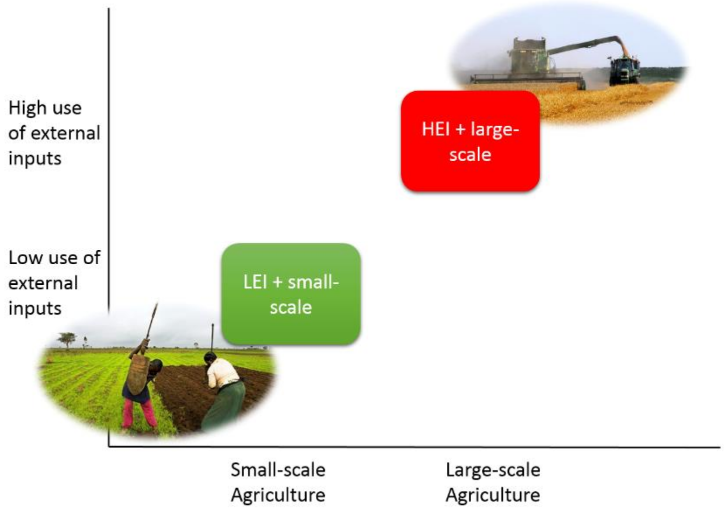

Figure 3 – Two major agricultural production systems

In the HEI + large-scale scenario government support is mainly directed towards subsidizing the intensive use of high external input and large-scale farming, while in the LEI + small-scale scenario the government mainly supports a transition towards high agro-ecological knowledge intensity, less intensive use of external input and small-scale farming. To test the resilience of the two production systems, the paper further analyses the two scenarios, HEI + large-scale and LEI + small-scale, assuming a price shock for synthetic fertilizer, a possible scenario due to likely increases in oil and phosphorous prices (Owen, Inderwildi, King 2010; Cordell, Drangert, White 2009). The assumptions of these two additional scenarios are the same as the previous ones, except for additional assumption that the price of mineral fertilizer doubles between 2020 and 2025. Table 1 provides an overview of the scenario assumptions. The quantitative description can be found in Annex 1.

Table 1 – Assumptions for Scenarios of Different Agricultural Production Systems

Scenario	Main Assumptions Compared to *Base Run*
HEI + large-scale	• Increase of public expenditure for inputs (mineral fertilizer and pesticides) • Increase of large-scale agriculture (as % of employment)
LEI + small-scale	• Increase of public expenditure for training on LEI practices • Increase of small-scale agriculture (as % of employment)
Price shock	• Doubling of price of mineral fertilizer between 2020 and 2025

3.2. Simulations results

To assess the efficiency, dynamism, inclusiveness and resilience of food systems, this paper evaluates the impact of the described agricultural production systems on key indicators, concerning food needs, food availability, access to food and environmental impact. Annex 2 provides an overview of the selected key indicators, a brief description of each indicator, as well as its major driving forces within T21.

3.2.1. Food needs

Food needs are mainly driven by population. Figure 4 shows that total population increased from around 5.7 million in 1980 to 12.5 million in 2010 and is simulated to grow further to 22.7 million in 2035, matching the United Nations Population Division's 'low variant' projections (around 22.9 million in 2035). In addition, the figure shows that the share of urban population increases steadily over time: in 1980 around 35 percent of the total population lived in urban areas, approximately 42 percent in 2010, and for 2035 the simulation shows an equal distribution for urban and rural areas. That means that according to the simulation urban population increases by 120 percent between 2010 and 2035 (from around 5.2 to 11.4 million people) and consequently also urban food needs. The population development is very similar for all the scenarios. Hence, to meet this growing demand, access and availability must be improved in an inclusive, sustainable and resilient way.

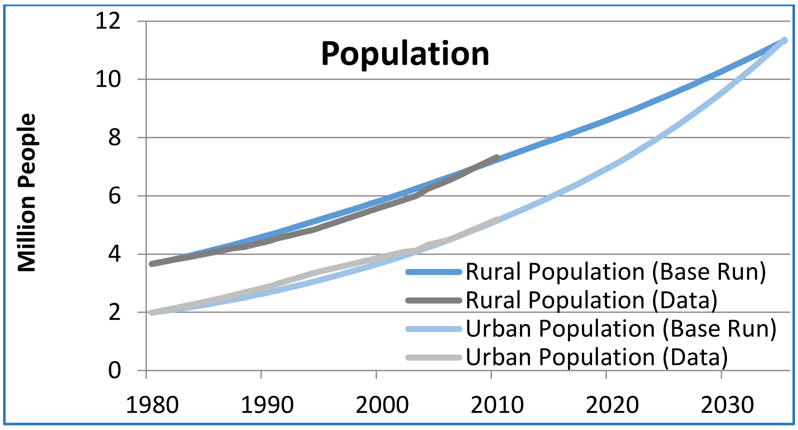

Figure 4 - Population by area

3.2.2. Food availability

Figure 5 compares the two production systems and the Base Run for two of the main food and nutrition security indicators concerning food availability: total crops production in tons and cereal import dependency ratio. The graph shows an improvement of the two variables for both scenarios compared to the Base Run after introducing the corresponding policies in 2014. Crops production is ascending in both scenarios. Cereal import dependency stays fairly stable in the HEI + large-scale scenario (red), while it initially increases slightly before heading back down in LEI + small-scale (green). When comparing LEI + small-scale to HEI + large-scale, a worse-before-better behaviour pattern can be observed: the green curve displays the less favourable behaviour until around 2033 when it crosses over the red curve for both indicators. In the HEI + large-scale scenario, mineral fertilizers are used extensively in order to attain higher yields. However, these fertilizers have the side effect of destroying soil organic matter, thus undermining the natural fertility and biological fixation capacity of the soil in the long run. Furthermore, in addition to having serious human health consequences, extensive use of pesticides jeopardizes the biodiversity of the ecosystem, which reduces the pollination capacity and tends to backfire, increasing pest problems in the long run. Such effects limit the long-term viability of high external input farming practices. On the other hand, under low external input policies, biological methods are used for pest control, which keep the farm's biodiversity intact. Also, for soil fertilization, natural methods such as farmyard manure application, intercropping, crop residues and cover crops are used. However, the positive effects are not as immediate as in the HEI + large-scale scenario because firstly, there is a delay between the provision of training and the actual application of the newly acquainted knowledge and secondly, because these methods need a relatively long time to take effect and restore the fertility of the soil, which is why the green curve lags behind the red curve in Figure 5 in the short term. In contrast, towards the end of the simulation period, the LEI + small-scale scenario overtakes the HEI + large-scale scenario in terms of results because of more sustainable practices in the long run.

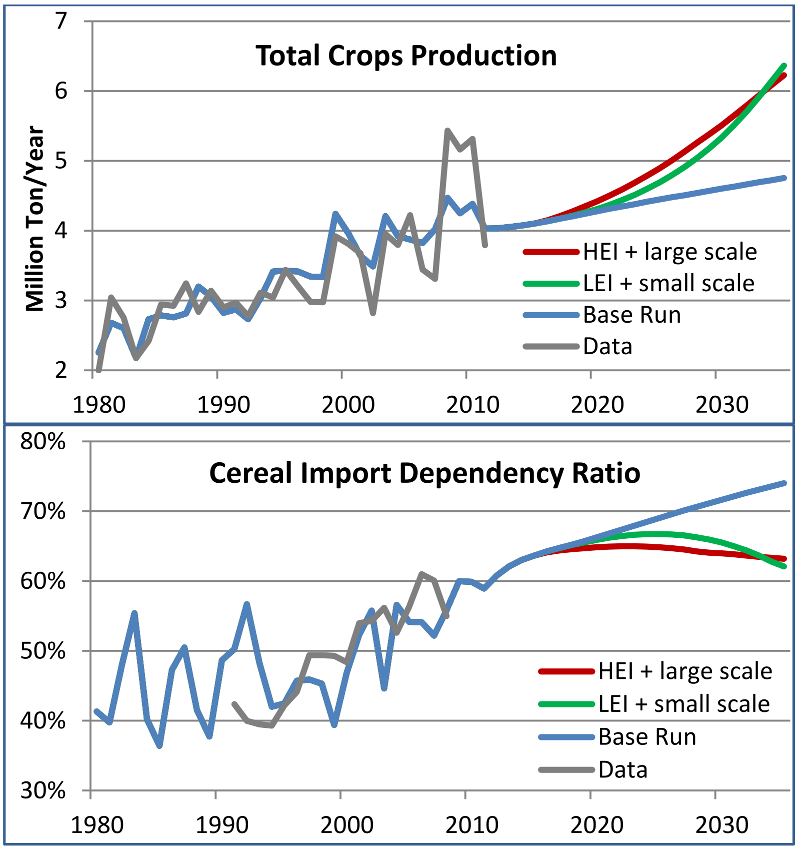

Figure 5 – Food Availability Indicators for Base Run, 'HEI + large-scale', and 'LEI + small-scale'

The higher sustainability of the LEI + small-scale scenario can also be seen when looking at indicators representing the impact on environment. Figure 6 presents the simulation results for agricultural emissions.

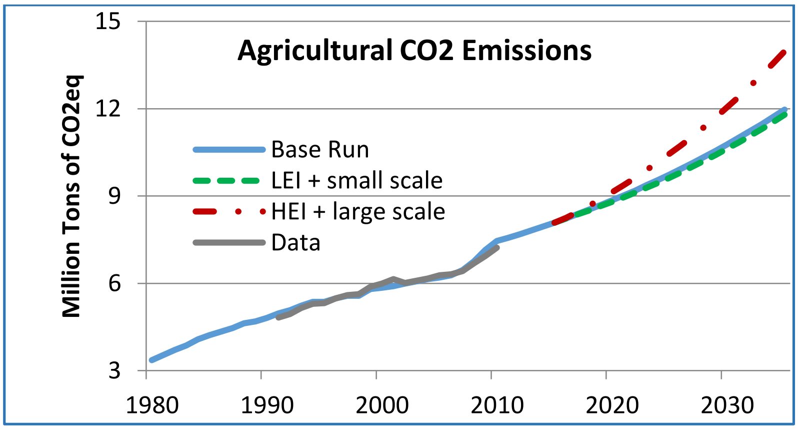

Figure 6 – Agricultural CO2 Emissions for Base Run, 'HEI + large-scale', and 'LEI + small-scale'

Agricultural emissions are around 17 percent higher in the HEI + large-scale scenario because of the increase of emissions from mineral fertilizer while it can be slightly decreased in the LEI + small-scale scenario due to the reduction of mineral fertilizer use. Natural fertilizer use is increased in the LEI + small-scale scenario, but there are no additional emissions because the manure emissions are already accounted for as emissions from animal production, and the manure produced by the livestock of Senegal is more than enough to provide the natural fertilizer used in the LEI + small-scale scenario. Also on other environmental indicators, such as fertilizer dispersion in the environment, the LEI + small-scale scenario shows less negative impact than the HEI + large-scale scenario.

3.2.3. Food access

Figure 7 presents the simulation results for indicators of food access, showing the development over time (left hand side) and comparing the results of the Base Run with the scenarios of the two production systems for 2035 (right hand side). This includes graphs of GDP and employment since they are relevant for income and income distribution, and hence play a significant role in poverty and access to food. As can be seen, in the case of all the selected indicators the ‘Green Scenario’ (LEI + small-scale) fares better than the ‘Red’ one (HEI + large-scale).

Figure 7 shows that agricultural GDP in the LEI + small-scale scenario is around 16 percent higher than the Base Run in 2035 while it is only around 14 percent higher in the HEI + large-scale scenario. This can mainly be explained by the differences in crops production in tons (see Figure 5). However, if the HEI + large-scale scenario farmers themselves pay for fertilizers and pesticides instead of the government, value added decreases as production value must cover the costs of inputs. For total GDP, the difference between the two production systems is even higher than for agricultural GDP. This is due to the fact that in the LEI + small-scale production system, improvements in poverty reduction as well as food and nutrition security lead to better health conditions, increasing total factor productivity in the service and industry sectors, generating higher industry and services production and facilitating higher savings and reinvestments, which eventually reinforces improvements in all production sectors. Figure 7 also shows that agriculture employment in the HEI + large-scale scenario is lower than in the Base Run (around 12 percent) in 2035 while LEI + small-scale is more than 20 percent higher. This is due to the fact that LEI techniques as well as small-scale agriculture are more labour intensive. The production and application of natural fertilizer, for example, creates jobs while the increase of capital-intensive HEI and large-scale agriculture tends to replace manual labour with machinery.

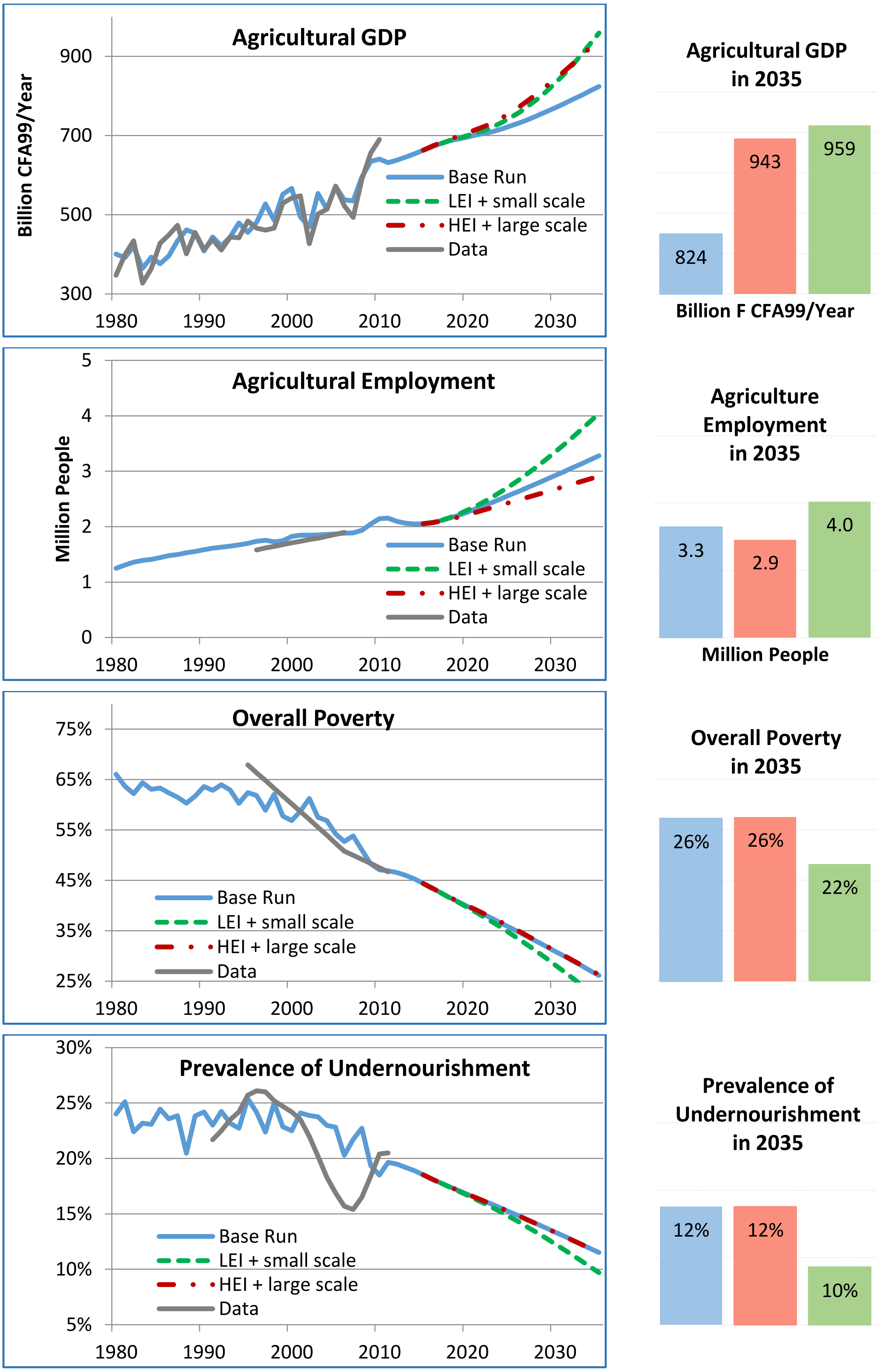

Figure 7 – Food Access Indicators for Base Run, 'HEI + large-scale', and 'LEI + small-scale'

Concerning poverty, Figure 7 shows that rural poverty in the LEI + small-scale scenario is significantly lower than in the Base Run (around 17 percent) while the difference is small for the HEI + large-scale scenario (around 3 percent compared to Base Run). Although production and consequently average income increase considerably in both production systems, income distribution is more equitable in the LEI + small-scale system due to broader involvement of the rural poor in the production process. For overall poverty, the deterioration of income distribution balances the improvements in average income so that there is nearly no difference between the HEI + large-scale scenario and the Base Run while the LEI + small-scale scenario is around 17 percent lower. Similarly, prevalence of undernourishment in the HEI + large-scale scenario is the same as in the Base Run although there is an increase of production and therewith availability of food. Nevertheless, access to food does not change due to the lack of change in poverty rates. In contrast, prevalence of undernourishment in the LEI + small-scale scenario decreases by 16 percent because of the improvements in terms of poverty and consequently of access to food.

3.2.4. Resilience: Impact of external shock

As a test of resilience to external shocks such as severe oil price increases, this section analyses the two scenarios, HEI + large-scale and LEI + small-scale, under the assumption that the price of mineral fertilizer doubles between 2020 and 2025.

Figure 8 shows that all scenarios entail much better performance than the Base Run since the nutrient levels in the soil are improved and pest density is reduced due to the increased use of mineral fertilizer and chemical pesticides in the HEI scenarios, and natural fertilizer and biological pest control in the LEI scenarios. However, the graph also shows that in the high external input scenario value-added from crops production is visibly undermined by the price shock (the dashed red curve lying clearly lower than the solid red curve) because the price increase leads to lower use of mineral fertilizer, which decreases the improvements in crop production. In contrast, the price shock only slightly decreases value added from crops production in the low external input scenario in the short term because this production system does not fundamentally depend on mineral fertilizers. Hence, the analysis shows that the LEI + small-scale scenario is more resilient to this external price shock than the HEI + large-scale scenario.

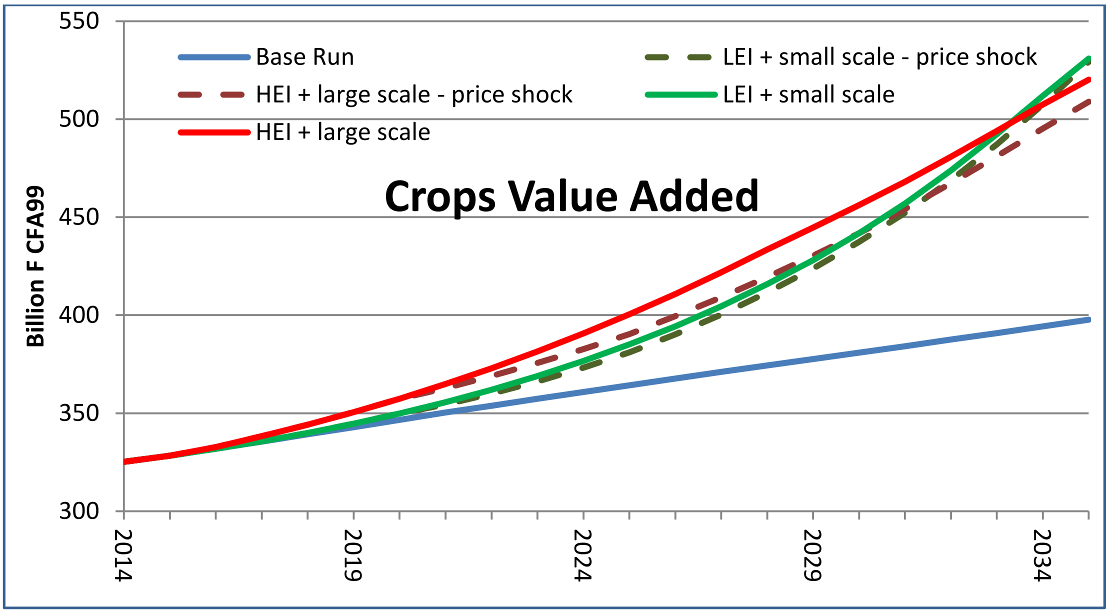

Figure 8 – Crops Value Added in Billions of F CFA99, under a fertilizer price shock scenario

4. Summary Findings, Discussion and Conclusions

The research question of this paper is to assess which types of agricultural practices can most effectively contribute to efficiency, inclusiveness and resilience of food systems to meet urban food needs. According to the model simulations it can be expected that urban food needs in Senegal will more than double between 2010 and 2035. However, there is no need to double food production because of two reasons. First, rural population grows at a slower rate (increases by nearly 60 percent between 2010 and 2035) as urbanization continues so food demand of the total population increases (only) by around 80 percent in the mentioned period. Secondly, the unequal distribution of food among the population is an important causal factor for insufficient access to food and hence undernourishment (FAO, IFAD, WFP 2014). Simulations show that under current policy the growing food demand is not met: for instance cereal production only increases by about 35 percent by 2035. To meet the growing food demand, food supply, and consequently production, needs to grow at a faster pace. The two tested policy options lead to a substantial increase in food supply (e.g. cereal production grows more than 80 percent by 2035). However, simulation results show important differences between the two policy options especially concerning inclusiveness, sustainability and resilience. Specifically, our simulations show that re-allocation of the agricultural budget, either towards HEI + large-scale or LEI + small-scale, increases agriculture production compared to Base Run developments because of higher nutrient density in the soil and lower pest density. However, supporting small-scale and LEI farming practices has additional benefits in terms of employment, poverty, food security and nutrition. LEI practices also increase the resilience and sustainability of the agriculture production system. Investing in training in LEI practices will have a positive impact despite the occurrence of external shocks such as a sharp increase in energy prices. In addition, low external input policies create less environmental pollution, while maintaining the natural fertility of the soil and leaving the biodiversity of the farm intact. It should be noted that with such policies, the increase in production is less pronounced in the short term and more gradual, but that the long-term performance of the LEI + small-scale scenario is superior to the HEI + large-scale scenario. Figure 9 presents the explicatory causal loop diagram.

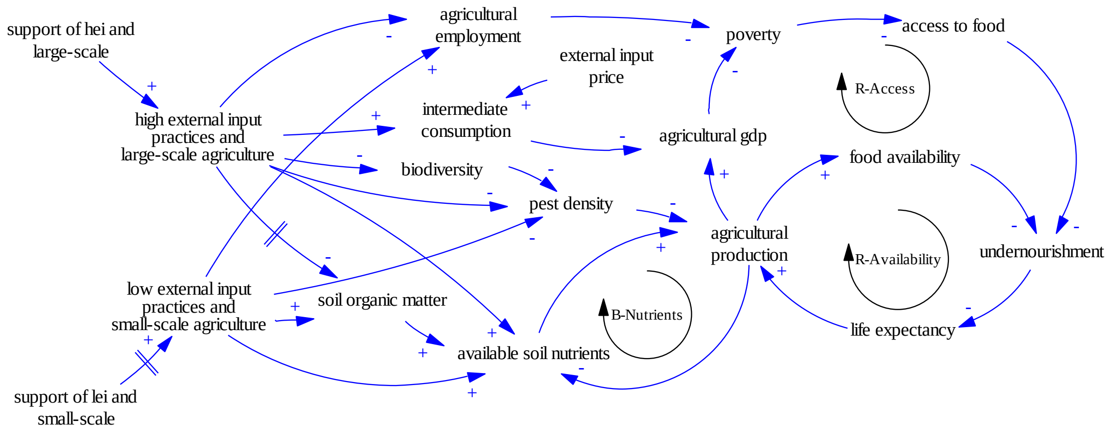

Figure 9 - Causal Loop Diagram for the two agricultural production systems

To meet the food needs of the population in an inclusive, sustainable and resilient way in the coming years, the agricultural production system has to undergo a profound transformation. Our simulations show that agricultural policy that supports a transition towards high agro-ecological knowledge intensity, less intensive use of external input with small-scale farming, is better equipped to support the necessary transformation: First, the supported agricultural production system increases production and consequently food supply. Second, it ensures sustainability, by minimizing negative impacts on environmental resources and consequently not being counteracted by negative feedback in the long term. Third, it is more resilient, reducing the negative impacts of external shocks. Last but not least, it is more inclusive since the increase of agriculture production is pro-poor. This is especially important, since agriculture is a key contributor to poor households' income. Worldwide, more than 70 percent of the people living in extreme poverty, and consequently susceptible to undernourishment, live in rural areas and over 80 percent of rural households are involved in farming activities (IFAD 2010). Also in Senegal the majority of the population depends on agriculture and livestock, either directly or indirectly, for their livelihoods. Of course, the effect of agriculture on poverty is more direct in rural areas. However, due to the prevalent tight family structure poverty changes in rural areas have an effect on urban poverty (and consequently their access to food) since the demand on urbanized family members to send support is reduced if poverty is reduced for the family members that remain in the rural area.

Our conclusions are twofold: First, results from the analysis call for a paradigm shift in public policy for agricultural development, food and nutrition security, and poverty alleviation from the current governmental support for external inputs such as mineral fertilizer and pesticides, currently accounting for 60 percent of the agriculture budget, towards public support for training and investment in low external input farming techniques (such as use of natural fertilizer, biological pest control, conservation agriculture etc.). Since model simulations show that the benefits of a paradigm shift are mostly visible in the long run, implementation of the required policies for realizing the paradigm shift should thus consider the inclusion of measures with short-term benefits so that the momentum of change can be maintained while the required human and social capital is built. Examples of an effective combination of mineral and natural fertilizer, for example, can be found in Kearny et al. (2012). Equity policies such as social safety nets are also effective in a fairly short period of time and can thus help farmers and other stakeholders in the Senegalese food system build human, social and institutional capital. Additional ways of smoothing the transition towards low external input and small-scale production systems would involve a gradual process of design, introduction, evaluation and adjustment of policy programs in individual agro-ecological zones.

The second conclusion concerns the importance of integrated analysis to support the formulation of appropriate policies, strategies and investments plans. Our work highlights how a failure to account for the interconnected and complex nature of the food-development nexus can lead to sub-optimal strategies: the long-term impacts of HEI agriculture on the environment, and the non-linear, multi-dimensional effects of small scale agriculture on poverty and nutrition, are fundamental elements shifting the balance between the two scenarios. Despite the overall better results obtained in the long-term, the increase in production in the LEI-small scale scenario is less pronounced in the short term than in the HEI-large scale ('worse-before-better' behaviour). Missing such non-linear dynamics might mistakenly lead decision makers to choose the policy option with the better results in the short run, rather than the more sustainable and resilient policy option. System dynamics simulation models such as T21 can facilitate integrated country-specific analyses, assess the ability of alternative policies to achieve given socio-economic goals, and support the realization of paradigm shifts by providing decision makers with critical information on the long-term multi-sectoral impacts of proposed policies and strategies.

References

Afenyo, J. S. 2012. "Making Small Scale Farming Work in Sub-Saharan Africa." Global Forum on Food Security and Nutrition “FSN Forum”, FAO.

Barlas, Y. 1996. Formal Aspects of Model Validity and Validation in System Dynamics, System Dynamics Review, 1996. 12(3): p. 183-210.

Barney, G.O. 2002. The Global 2000 Report to the President and the Threshold 21 model: influences of Dana Meadows and system dynamics, System Dynamics Review, 2002. 18(2): p. 123-136.

Cordell, D., Drangert, J.-O., White, S. 2009. The story of phosphorus: Global food security and food for thought. Global Environmental Change 19 (2): 292–305.

FAO, IFAD and WFP. 2013. The State of Food Insecurity in the World 2013. The multiple dimensions of food security. Rome, FAO.

FAO, IFAD and WFP. 2014. The State of Food Insecurity in the World 2014. Strengthening the enabling environment for food security and nutrition. Rome, FAO.

Forrester, J.W. 1961. Industrial Dynamics. Cambridge, MA: Productivity Press.

FAO/OECD. 2011. Expert Meeting on Greening the Economy with Agriculture. Paris.

Heidhues, F., Brüntrup, M. 2002. Subsistence agriculture in development: Its role in processes of structural change. Hohenheim: Universität Hohenheim. Tropenzentrum. Institut für Agrar-und Sozialökonomie in den Tropen und Subtropen.

IFAD. 2010. Rural Poverty Report 2011: New realities, new challenges: new opportunities for tomorrow’s generation. Rome, Italy.

IFAD, IMF, OECD, UNCTAD, WFP, WB, WTO OMC, IFPRI, UN-HLTF on Global Food Security. 2011. Price Volatility in Food and Agricultural Markets: Policy Responses.

Kearney, S., Fonte, S.J., Salomon, A., Six, J., Scow, K.M. 2012. Forty percent revenue increase by combining organic and mineral nutrient amendments in Ugandan smallholder market vegetable production. Agron. Sustain. Dev. , pp. 831–839.

Millennium Institute. 2014. T21-Senegal: Agriculture, Food and Nutrition Security, and Rural Poverty Scenarios. Scenario Analysis and Policy Recommendations. Washington DC: MI.

Owen, N.A., Inderwildi, O.R., King, D.A. 2010. The status of conventional world oil reserves—Hype or cause for concern? Energy Policy 38 (3): 4743–4749.

Parayno, P.P., Saeed, K. 1993. The Dynamics of Indebtedness in the Developing Countries: The Case of the Philippines, Socio-Economic Planning Sciences, 1993. 27(4): p. 239-255.

Pedercini, M. 2005. Potential Contributions of Existing Computer-Based Models to Comparative Assessment of Development Options.

Pedercini M., Barney, G.O. 2010. Dynamic analysis of interventions designed to achieve Millennium Development Goals (MDG): The Case of Ghana. Socio-Economic Planning Sciences, 44 (2010) 89–99.

Qureshi, M.A. 2008. Challenging Trickle-down Approach: Modelling and Simulation of Public Expenditure and Human Development - The Case of Pakistan, International Journal of Social Economics, 2008. 35(4): p. 269-282.

Saeed, K. 1987. A Re-evaluation of the Effort to Alleviate Poverty and Hunger, Socio Economic Planning Sciences, 1987. 21(5): p. 291-304.

Sterman, J.D. 2000. Business Dynamics: System Thinking and Modeling for a Complex World. McGraw-Hill Companies.

UN. 2014a. The Road to Dignity by 2030: Ending Poverty, Transforming All Lives and Protecting the Planet – Synthesis Report of the Secretary-General on the Post-2015 Agenda. United Nations, http://www.un.org/disabilities/documents/reports/SG_Synthesis_Report_Road_to_Dignity_by_2030.pdf.

UN. 2014b. Open Working Group proposal for Sustainable Development Goals. United Nations, http://sustainabledevelopment.un.org/content/documents/1579SDGs%20Proposal.pdf.

UN. 2000. United Nations Millennium Declaration. UN General Assembly, United Nations, A/RES/55/2

UN. 1992. Rio Declaration on Environment and Development, Report of the United Nations Conference on Environment and Development. Rio de Janeiro, 3-14 June 1992, Annex I, A/CONF.151/26 (Vol. I)

UN DESA (United Nations, Department of Economic and Social Affairs, Population Division). 2014. World Urbanization Prospects: The 2014 Revision, Highlights (ST/ESA/SER.A/352).

UNEP. 2014. Using Models for Green Economy Policymaking.

WFP (World Food Programme). 2015. Frequently Asked Questions on Hunger, http://www.wfp.org/hunger/faqs. Last access: 26.01.2015

Annex 1: Quantitative Scenario Description

Table 2 – Quantitative Scenario Description

Policies	Values in 2035			
	Base Run	**HEI + large-scale**	**LEI + small-scale**	**Price shock**
Agriculture Budget				
Allocation of Agriculture Budget to Expenditure Categories				
Training Expenditure	1%	Base Run	30%	HEI or LEI
Training on LEI Practices[3]	50%	Base Run	100%	HEI or LEI
Input Expenditure	60%	Base Run	30%	HEI or LEI
Subsidies for Pesticide[4]	0%	25%	Base Run	HEI or LEI
Subsidies for Fertilizer[5]	9.4%	35%	Base Run	HEI or LEI
Allocation of Agriculture Budget to recipients				
Small-scale Agriculture[6]	83%	70 %	90%	Large or small-scale
External Conditions				
Relative mineral fertilizer Price	100%	Base Run	Base Run	200%

Annex 2: Key Indicators

Table 3 – Key Indicators

Indicator	Description	Driving forces
Food Needs		
Total Population	Sum of total country population (disaggregated in the model into 101 age cohorts, and by gender).	total fertility rate, life expectancy at birth
Food Availability		
Total Crops Production in Tons	The sum of all crops production (disaggregated in the model into 10 types of crop), in physical quantity (tons).	environmental resources (e.g. soil nutrients, water availability, loss due to pests), Social resources (e.g. health, education, research and development, labour), Economic resources (e.g. capital, energy availability, roads density)
Cereal Import Dependency Ratio	Defined as cereal imports divided by cereal production plus net imports. The complement of this ratio to 1 would represent that part of the domestic food supply that has been produced in the country itself (cereal self-sufficiency).	cereal production, net cereals import[7]

[3] As share of Training Expenditure
[4] As share of Input Expenditure
[5] As share of Input Expenditure
[6] As share of Agricultural Employment
[7] In the model, it is assumed that imports close the gap between cereals production and the target for cereal food supply based on a target for calories consumption (2650 kilocalorie per capita per day) and total population.

Indicator	Description	Driving forces
Food Access		
Gross Domestic Product (GDP)	The value added of all officially recognized final goods and services produced within a country in a year, and in the model it is formulated as the sum of production in the three sectors of agriculture, service, and industry.	agriculture, industry, and services production
Agricultural GDP	The monetary value of total agriculture production (value added)	crops, livestock, fishery, and forestry value added
Agricultural Employment	The stock of people formally working in the agriculture sector.	agriculture labour demand (agriculture area, capital, education level, natural fertilizer use, small-scale agriculture), labour force availability
Poverty Rate	The proportion of population living below the poverty line, distinguishing between rural, urban, and overall poverty rate.	income per region, income distribution
Prevalence of Undernourishment	Population below minimum level of dietary energy consumption, i.e. the percentage of the population whose food intake is insufficient to meet dietary energy requirements continuously.	food availability, access to food (infrastructure (roads), poverty, food prices)
Environmental Impact		
Total Emissions from Agriculture	The sum of emissions from agriculture in CO_2 equivalent	CO_2 emissions from livestock (including manure), fertilizer, and agriculture energy consumption