

Healthy diets and reduced land pressure: Towards a double gain for future food systems in Nigeria.

Zuzana Smeets-Kristkova^{1,2*}, Thom Achterbosch¹ and Marijke Kuiper¹

¹ Wageningen Economic Research, Wageningen University & Research, Prinses Beatrixlaan 582, 2595 BM The Hague, The Netherlands; zuzana.kristkova@wur.nl (Z.S.K.), thom.achterbosch@wur.nl (T.A.); marijke.kuiper@wur.nl (M.K.)

² Czech University of Life Sciences, Faculty of Economics and Management, Kamýcka 129, 165 21 Prague, Czech Republic (Z.S.K.)

* Correspondence: zuzana.kristkova@wur.nl; Tel.: +31645748743.

Healthy diets and reduced land pressure: Towards a double gain for future food systems in Nigeria.

Abstract: This paper aims to analyse how the food system in Nigeria is expected to transform in the next decades, and to identify the leverage points for making sure that the transformation contributes to balanced consumer diets. A well-established global economy-wide model MAGNET is applied that enables to capture the interlinkages among different food industry players in one consistent framework. By linking MAGNET to the GENUS nutritional database, it is further possible to relate the developments occurring on a macro-level with detailed macro and micro nutrient consumption. Model projections suggest that a process of intensification of agriculture in combination with land substitution appears critical for the evolution of food and nutrition security, and for shifts towards healthy diets for the population. Intensification results in greater diversity of the production systems, which in turn cascades into positive effects on the diversity in the food supply and better food security outcomes.

Keywords: Food systems, Nigeria, CGE model, land, projections.

1. Introduction

Nigeria is one of the most dynamic economies in Africa. Strong GDP growth, high fertility rates suggesting an unfinished demographic revolution, coupled with urbanization trends place tremendous pressures on natural resources and the food systems that are dependent on them. In particular, arable land is becoming increasingly scarce. Understanding the impact of these “mega trends” on food and nutrition security in the country is highly relevant. Malnutrition in all its forms remains a key concern in Nigeria. While chronic malnutrition remains widespread (in 2013, 37% of children under 5 years of age were stunted (National Population Commission Nigeria and I. C. F. International, 2014)), the need to curb the rising prevalence of overweight and obesity among adults and children is emerging as a priority for food security and health policy. Economic development and changing market conditions are associated with shifts in consumption patterns that simultaneously move towards and away from healthy diets (Imamura et al., 2015). Healthy diets typically have four characteristics – related to quantity, quality, diversity and safety of the diet – and translate into principles for adult consumption (HLPE, 2017): sufficient consumption of fruit, vegetables, pulses; moderate consumption of animal source food, with limited intake of processed meat and sugar-sweetened foods and beverages; avoid transfat and replace consumption of saturated fats with vegetable oils or other sources of unsaturated fat. We seek to contribute with macro-level foresight to the identification of leverage points in the food system of Nigeria for promoting healthy diets in these respects with the exception of safety. Of particular interest is the question how Nigeria’s national food system, given its strong bias towards staple production, could transform towards meeting these diverse nutritional needs.

The objective of this paper is to provide national-level projections of the demand for food, and to explore how various direct drivers in the food system (farm input and output prices, demand for on-farm and off-farm labour, consumer preferences, etc.) interact with the general drivers of the food system, and to evaluate ex-ante how these dynamics affect diet outcomes at population level.

This paper employs scenario methods to understand how the indirect drivers of the food system interact at multiple scales simultaneously – supra-national level, national and sub-national level for Nigeria and household level – and addressing feedback loops between national and supranational level and between producers and consumers in Nigeria. An advanced quantitative modelling framework is used for this purpose, and will be introduced in the following section. A possible policy response is explored in the discussion.

2. Materials and Methods

2.1 Economy-wide modelling framework

In this study the MAGNET model is applied, a well-established global economy-wide model used for global projections on agriculture, biobased, climate, food security and nutrition as well as country-specific assessments (see for instance (Helming and Tabeau, 2018; Kuiper et al., 2018a, 2018b; van Meijl et al., 2018)).

As an economy-wide model, MAGNET is well placed to examine the costs and benefits of policy scenarios via changes in input and output prices and allocation of competing (agricultural and non-agricultural) uses of primary factors and intermediate inputs (Woltjer, et al., 2012). From the food systems perspective, the key strength of MAGNET lies in exploring food systems dynamics, by capturing the interlinkages among different food industry players (farmers, processors, suppliers, traders and consumers) in one consistent framework (see the circular flow of MAGNET in Figure 1). Scenario analysis using MAGNET contributes to identify challenges and pathways for innovation taking into account trade-offs and synergies between various objectives. This provides a useful insight into the ex-ante impact of given policies.

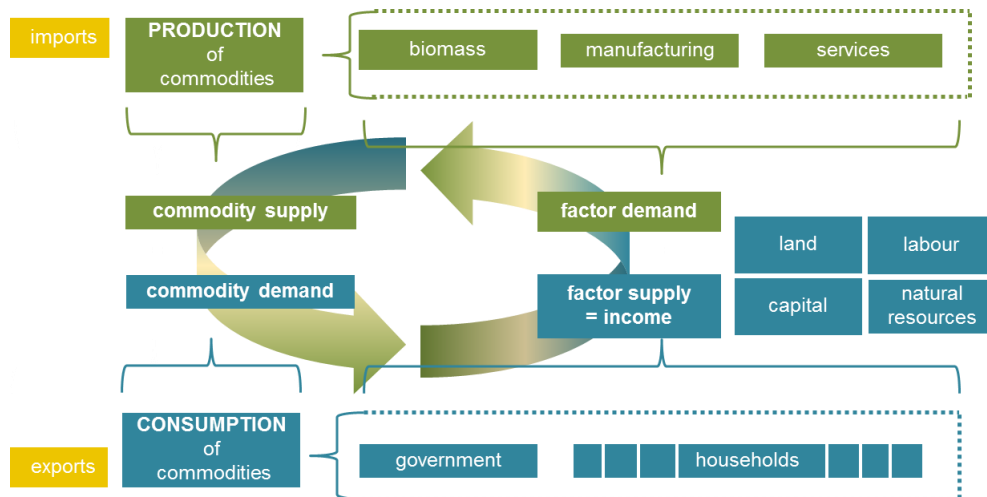


Figure 1. MAGNET – a complete economic model of nations in the global economy

MAGNET is a neoclassical recursive dynamic, multi-regional, multi-commodity computable general equilibrium (CGE) model. At its core is the well-known Global Trade Analysis project (GTAP) model and the associated GTAP database. MAGNET currently uses version 9.2 of the GTAP database with a coverage of 140 regions, 57 sectors and 8 production factors including natural resources, oil and gas (Aguiar et al., 2016). The database includes detailed information on production, gross bilateral trade flows, transport costs and trade protection data for a 2011 benchmark year.

Additional production, costs and trade data from different sources are used to disaggregate GTAP sectors to bigger detail, such as dairy, beef, pork and poultry. Therefore, the total number of individual sectors in MAGNET goes up to 87. The most detailed MAGNET sector disaggregation includes 13 primary agricultural sectors and 10 processing sectors. The fishing sector is split into aquaculture, wild fish sector and fish processing sector. An animal feed sector in MAGNET uses domestic and imported crops to be converted into concentrate animal feeds for the livestock sectors. The feeding sector also uses fishmeal from a dedicated fishmeal sector in MAGNET. In MAGNET the fertilizer sector, has been

disaggregated from the chemical sector. Fertilizer is used in the crop sectors as a substitute for land. This allows changes in intensification based on land rent and agricultural prices.

Given that MAGNET allows flexible aggregation of regions and sectors, we aggregate sectors and regions to fit the purpose of this study. Table 1 presents the sectoral aggregation used in MAGNET with focus on the food system sectors. Table 2 provides an overview of the regional aggregation with a corresponding mapping to original GTAP sectors.

Table 1. Sectoral aggregation in MAGNET (MAGNET codes in brackets)

Arable and horticulture: paddy rice (pdr), wheat (wht); other grains (grain); oilseeds (oils); raw sugar (sug); vegetables, fruits and nuts (hort); other crops (crops); plant fibres (oagr);

Livestock and meat: beef cattle (cattle); other grazing animals such as sheep, goats, horses (othctl), wool (wol); pigs (pigpls), poultry (pltry); raw milk (milk); cattle meat (bfmt); meat from other grazing animals (othcmt), pork meat (othmt), poultry meat (pulmt); dairy (dairy).

Other food and beverages: sugar processing (sugar); rice processing (pcr); vegetable oils and fats, including crude vegetable oil (vol)¹; fishing (fish); aqua culture (aqcu), fish processing (fishp), other food and beverages (ofd);

Supplying food system industries: fertiliser (fert), crude vegetable oil by-product oilcake (oilcake); fish meal (fishm), animal feed (feed), chemicals, rubbers and plastics – pesticides (othcrp); 1st generation bioethanol by-product distillers dried grains and solubles (ddgs);

Other sectors: traditional bio-based sectors, biofuels, Fossil fuels and other energy markets, other manufacturing (manu); transport (trans); other services (svcs).

Table 2. Regional aggregation in MAGNET

MAGNET Code	Description (mapping to GTAP regions and respective country codes)	Order
ROW	Rest of the World: the remaining regions	1
APTA	Asia-Pacific trade agreement: chn, hkg, kor, mng, twm, lao, ind, lka	2
EAS	East and South East Asia: xea, brn, khm, idn, mys, phl, sgp, tha, xse	3
VNM	Vietnam	4
BGD	Bangladesh	5
NAFTA	North American FTA: can usa, mex, xna	6
LAM	Latin America: arg, bol, bra, chl, col, ecu, pry, per, ury, ven, xsm, cri, gtm, hnd, nic, pan, slv, xca, dom, jam, pri, tto, xcb	7
EU	European Union: aut, bel, cze, dk, est, fin, fra, deu, grc, hun, irl, ita, lva, ltu, lux, mlt, nld, pol, prt, svk, svn, esp, swe, gbr, hr, rou	8
SSA	Sub Saharan Africa: ben, bfa, cmr, civ, gha, gin, sen, tgo, xwf, xcf, xac, ken, mdg, mwi, mus, moz, rwa, tza, uga, zmb, zwe, xec, bwa, nam, zaf, xsc	9
NGA	Nigeria	10
ETH	Ethiopia	11

Note: The description of GTAP regions and respective country codes is found at: <https://www.gtap.agecon.purdue.edu/databases/regions.asp?Version=9.211>

Production in any of the above mentioned sectors in MAGNET is modelled using flexible, multilevel nested Constant Elasticity of Substitution (CES) production functions allowing for substitution of different primary production factors (land, labour, capital and natural resources) and intermediate production factors like energy, fertilisers and animal feed components. In primary agriculture, the production tree is more complicated than in the rest of the economy, because of using various types of inputs with different substitutability in the production process.

Modelling of labour markets in MAGNET reflects the presence of rent- and wage differentials between agricultural and non-agricultural sectors (Keeney and Hertel, 2005). The land allocation module in MAGNET takes land as a heterogeneous production factor (e.g. having different biophysical characteristics) depending on commodity produced by specific sector. This is modelled by using a constant elasticity of transformation (CET) function.

The total agricultural land supply is a function of the real land price. The price elasticity of land supply for all countries in MAGNET has recently been estimated (Tabeau et al., 2017). In Nigeria, the elasticity is set for 0.07, which is comparably smaller than for instance in Ethiopia (0.22), which reflects the rigidity of the land market as well as the limited possibility of further expansion of land in Nigeria.

2.2 Extension of MAGNET for modelling nutrients supply using the GENUS database

A key strength of MAGNET is its modular structure which allows the user to easily activate those modules of most relevance to the study at hand. In our case, we make use of the MAGNET extension to incorporate the Global Expanded Nutrients Supply (GENUS) database (Smith et al., 2016). The GENUS database provides macro and micro nutrient data for 225 products in 175 countries, including Nigeria. The GENUS database combines the FAO food balance sheets (FBS) with other data sources to construct a global and historical food and nutrient supply database. From the estimates of the domestic food supply in the FBS, the edible food supply is obtained after taking into account slaughtering, peeling, etc. Using region specific composition tables, nutrient supply is derived and provided as a 95% confidence interval (median, low and upper bounds). In the MAGNET GENUS extension, the individual GENUS food items are mapped to MAGNET commodities. Changes in the growth of household demanded quantity as modelled by MAGNET are used to update the nutritional indicators in the GENUS data, resulting in consistent assessments of food and nutrient availability for the representative household in MAGNET (Kuiper et al., 2018a). In the model version applied in this paper, a single representative household is used.

It is important to make a cross-validation of the nutritional data with other sources in the literature (Table 3). Brouwer et al. (2018) explore food and nutrient intake at the household level based on the General Household Survey (GHS) for Nigeria (Brouwer et al., 2018). The GHS is a survey in the format of the World Bank's Living Standard Measurement Study - Integrated Surveys on Agriculture (LSMS-ISA). It collects data on agricultural practices, socio-economic characteristics of households and communities in a nationally representative sample of 5,000 households (NBS, 2017). Brouwer et al. report average daily caloric consumption from GHS for households in adult female equivalents, which is approximately 20% lower than the usual average adult equivalent. The study of Akerele (2015) computes per capita adult equivalents per rural and urban population, based on the most recent national food consumption and nutrition survey (FCNS) in 2003-04 (Akerele, 2015). In Aromolaran (2010), the caloric data is based on author's survey of 480 households from semirural areas of south-western Nigeria (Aromolaran, 2010). When comparing all sources, it is apparent that all agree on a high share of carbohydrates in the diets (above 60%). Cassava is one of the most important sources of carbohydrates in Nigerian diet. The GENUS database estimates the average intake of cassava of about 280g of per day, which is similar to the data collected in a local survey (Onyemauwa, 2010). It is also noted that in Aromolaran, where data comes from a specific region, the role of roots and tubers is even much higher than in the national surveys (56% of total consumption).

It is not straightforward to compare the total caloric consumption across the sources due to differences in the definitions and measurement. The total caloric consumption expressed in female adult equivalent is 2,346 Kcal. When converted to male adult equivalent (2,815

Kcal), it is close to the caloric consumption reported in the GENUS database (2,969 Kcal per capita). However, it is important to note that the GENUS database measures available caloric supply derived from food balances, whereas the nutritional surveys measure the direct caloric intake by households and individuals. To reflect this in our caloric projections, we apply a correction factor to the GENUS caloric data to downscale the caloric intake to the average female equivalent reported in the GHS analysis, which we consider the most representative, given that the data from Akerele is based nutritional surveys from 2003-2004 and Aromolaran provides nutritional data from a single region.

Table 3. Structure of caloric consumption in Nigeria by food group, across various resources

Database	Database (year), source			
	GENUS (2011)	General household survey (2015-16)	National FCNS (2003-04)	Rural SW Nigeria
Date source	Smith et al. (2016)	Brouwer et al. (2018)	Akerele (2015)	Aromolaran (2010)
cereals	41.7%	39.5%	42.0%	17.0%
Roots and tubers	26.8%	27.9%	24.0%	56.0%
Cereals, roots and tubers	68.5%	67.4%	66.0%	73.0%
sugar	3.4%	1.9%	0.5%	0.6%
legumes	2.8%	6.9%	10.0%	7.5%
seeds and nuts	4.8%	1.5%	1.7%	x
vegetables	1.8%	1.2%	2.5%	2.90%
fruits	3.5%	2.0%	0.3%	1.35%
fruits and vegetables	5.3%	3.2%	2.8%	4.3%
Tea coffee	0.0%	0.0%	0.1%	0.63%
Spices	0.4%	0.2%	x	x
Alcohol	2.1%	0.2%	0.1%	x
meat	1.4%	2.1%	1.6%	0.8%
milk	0.2%	0.6%	0.5%	0.4%
fish	0.7%	1.9%	5%	1.2%
eggs	0.4%	0.2%	0.1%	0.4%
eggs, meat and milk	2.7%	4.7%	7.2%	2.8%
fats and oils	9.9%	13.8%	9.0%	10.0%
Total	100%	100%	97%	99%
Caloric consumption	2,969	2,346 (2,815)*	2,440	1,980**

Note: Categories not reported in the respective sources are marked with x.* GHS data converted to male equivalent. **Calculated from the statistical regression tables provided by the author.

2.3 Quantified drivers of food systems change in Nigeria

The first considered driver is the **GDP growth**. The projections of the PWC outlook to 2050 assume that Nigeria would reach about 4,500 GDP per capita by 2050, belonging to the group of upper-middle income economies, comparable for instance to Albania (PWC, 2017a). For our MAGNET analysis, we opt for the PWC scenario. This choice is in line with other studies; a recent study uses an assumption of 5% growth for the periods until 2030 (Bosello et al., 2018). Adopting the PWC scenario therefore counts with a transition of Nigeria from lower-middle income to an upper middle income economy.

Another key driver for the long-term modelling is the **population growth**. In this case, the SSP2 projections are based on the UN population growth projections (the medium variant). Due to the growth rate exceeding 2% p.a., population will double in Nigeria by 2050. High population growth is also expected in other Sub-Saharan Africa regions, whereas in the EU and other high income countries, the growth is limited.

High population growth brings pressure on resources but it can also be an opportunity as country can benefit from the abundance of labour force. The **ratio of skilled and unskilled population** will be important for cashing from the demographic dividend – whether the expected mix of skills will find a place in the labour market. In order to translate this into MAGNET, we use the Wittgenstein labour projections (Lutz, Butz, and Kc, 2014). At present, the number of unskilled labour slightly exceeds the number of skilled people in the economy. By 2050, it is expected that the share of skilled labour will reach 70% up from 40% now, which is comparable with EU (77%).

The dynamic economic and population growth that is projected into the future will put tremendous pressures on natural resources in order to feed the existing population. Therefore, it is important to take into account the **availability of agricultural land** for further expansion. The estimations from the IMAGE model provide an overview of actual land available that can be used for commercial purposes (e.g. crop land and pasture land versus parks) across the world (Mandryk et al., 2015). Already at the moment, 93% of available agricultural land is occupied. This is because out of the total 79 million ha of available agricultural land, 70 million ha is being cultivated, from which about 40 million ha is arable land and the rest are pastures and other agricultural land (Table 4). This implies that the only way how to increase land use comes from a conversion of the extensively used pasture land to arable land. Indeed, various literature sources claim that about 40% of agricultural land can still be put in cultivation (Laborde, D.,Lallemant, T.,McDougal, K., Smaller, C.,Fousseini, T., 2018; Nwankpa, 2017; PWC, 2017b). However, it must be noted that these claims are only feasible by transforming the existing land use, not by adding more land into cultivation. Next to this, there are also economic barriers to land access. Administrative procedures for acquiring new agricultural land in Nigeria may be cumbersome and have been put forward as a major bottleneck in the food supply system (PWC, 2017b; UNDP, 2012) .

Table 4. Land use and land potential in Nigeria (2011)

Land type	Land use (Million ha)	Land potential (Million ha)
arable land	41	-
pastures & other	30	-
total occupied land	71	-
Full potential (based on IMAGE)	-	79
Available land for expansion	-	8
Land pressure (% of land used or left)	90%	10%

Source: land use (MAGNET database), land potential (IMAGE model)

2.4 Definition of alternative baselines

It is becoming apparent, that Nigeria will soon approach food production limits if non-land inputs are not used more intensively or if there is not a significant change in R&D policy that would boost the crop and animal sector yields. According to FAO, the potential cassava yield is 40 MT per hectare, whereas the achieved yield in Nigeria is only 13 MT per hectare (FAO, n.d.). Although the SSP2 projections of yields towards 2050 taken from the IMAGE database (Stehfest et al., 2014) count with an annual yield growth of about 1%, which is well above the high income countries, it is not enough to make a significant difference in closing the yield gap with the high income countries. At the moment, Nigeria is one of the countries with the lowest use of fertilizer input to land use. Nigerian farmers utilise in average about 10kg of fertilizer per hectare, which is very little compared to high income countries such as Netherlands, where the consumption is well above 200kg (World Bank, n.d.). In Nigeria, poor infrastructure increases transportation costs that make fertilizer prices not affordable (World Bank, 2008). Moreover, in the interaction with poor quality of seeds, the productivity impact of fertilizer has its limits (Liverpool-Tasie et al., 2014).

In order to reflect the need for the input intensification in our modelling approach, we design two foresight scenarios. The first scenario – *Land_Fixed* is the “status quo” scenario that counts with high rigidity in the land market where an increasing demand for food driven by GDP and population growth will not be able to respond either by higher land expansion and or by more intensive use of other factors. The alternative scenario – *Land_subs* incorporates features of institutional change where increasingly higher land scarcity is adjusted by substituting land for non-land inputs such that they are used more intensively in the production process (Table 5). This is operationalized by increasing the substitution elasticity between land and other inputs both in crops and land-using livestock sectors. We also set a higher substitution elasticity between land and feed in the livestock sector and land and fertilizer in the crops sector. The final choice of parameters is in Table 4. We can consider both scenario versions as extreme, where under the substitution elasticity of 0.1, which is the default option in MAGNET, there is almost no room for substituting land for other inputs. With the elasticity of 1.2, the inputs behave as substitutes and an increasingly scarcer land can be easily substituted for labour, capital and other inputs¹.

Another way how to mobilize the land market is to allow more flexible conversion between crop land and pastures on the existing land, which makes it easier to increase the share of arable land at the expense of pastures. To operationalize this in MAGNET, we impose a flat land allocation tree where all types of lands can be perfectly substituted and set the CET elasticity to 1. From the institutional point of view, both measures mean that there is a better mobility of land both for acquiring and for getting rid of.

Table 5. Overview of the alternative baseline scenarios

	LAND_FIXED	LAND_SUBS
Technical change	Exogenous - calibrated to GDP growth based on 4%-5% p.a.	
GDP growth	Endogenous	
Population Growth	SSP2 (UN Medium Variant)	
Exogenous Yield growth	1% p.a. based on SSP2	

¹ We have performed a sensitivity analysis to assess the response to various levels of substitution elasticity ranging from 0.1 (MAGNET default) to 1.2. which are the upper and lower bounds. The land pressure is notably decreased with substitution elasticities above 0.4.

Feed efficiency improvements in livestock sectors	1% - 2% p.a. based on IMAGE	
CES Substitution elasticity of NEST 1 (land bundle -other factors)	0.1 (MAGNET)	1.2
CES Substitution elasticity of NEST 3 (land-fertilizer)	0.75 land-fertilizer, 0.5 land-feed	1.2 both land-fertilizer and land-feed
Land allocation elasticity	-0.2 (NEST1), -0.4 (NEST2), -0.6 (NEST3)	1 (Non-nested)

3. Results

3.1. Agricultural inputs and factor markets

We start our analysis by looking at the agricultural input and factor markets because they directly inform about the pressures or abundance of resources driven by the combination of economic and population growth. We are first interested to see what happens with the land prices under both scenarios. Figure 2 shows that if there is no possibility to substitute land for other inputs, land prices will escalate after 2030 due to increasing demand for food. Particularly in the last period, land price growth is enormous, suggesting a real difficulty to meet up the demands for food with limited resources. This adverse development could be almost fully avoided if other inputs are used more intensively (Land_Subs scenario). In this case, land prices remain on the same level as in the base year.

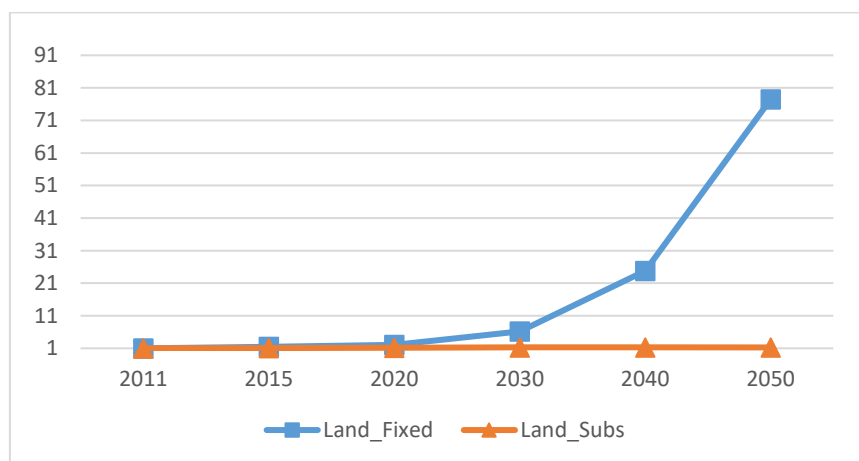


Figure 2. Growth of land price index per scenario. (2011 = 1)

It is also instructing to analyse the impact of the land market scenarios on the changes in economy-wide factor demand. Table 6 compares the endowment volumes between the two scenarios. It is apparent that with more land substitution, the agricultural sector utilizes more inputs, including the land itself (the total primary agriculture production goes up and therefore also land). This is also transmitted to the sector of food processing where all endowments increase compared to the Land_Fixed scenario. On the other hand, locking land in agriculture releases labour and capital to be employed in industry and therefore there is more value added created in industry in the Land_fixed scenario. This is especially visible in case of skilled labour. The conclusion that stems from this analysis is that better management of land markets could potentially be a strong leverage point for inclusive growth in food systems activities, yet with a trade-off in terms of industrial development. This trade-offs appears in classical theories of rural development, and has been a subject of increasing criticism (World Bank, 2008).

Table 6. Endowment volumes growth in Land_Subs in 2050 (% difference from Land_Fixed scenario) by sector in the economy

Sector (label)		Land	Unskilled labour	Skilled labour	Capital
Primary agriculture	(AGRI_PRIM)	1.3	2.5	85.4	17.3
Food processing	(AGRI_proc)		4.1	0.5	36.4
Industry (non-food)	(INDUSTRY)		-38.2	-42.2	-11.6
Services and utilities	(SERV&UTIL)		7	1.2	8.9

3.2. Price transmission in the food supply chain

The developments in the factor markets are transmitted into markets of goods and services. For our analysis, we are interested to see what are the expected price trends in the food supply chain towards 2050 and how are they affected by the rigidity of land market. Figure 3 shows the development of prices in the primary agriculture sector. The land constraint is a key factor in determining whether primary agricultural prices will grow or decline. The tipping point is the period after 2020 when there will be no available land to cultivate. Because of this, prices in primary agriculture would be 5 times higher by 2050. Releasing pressure on land would make a significant difference in the production costs of primary agriculture. In this case, producer prices would decline by 2050.

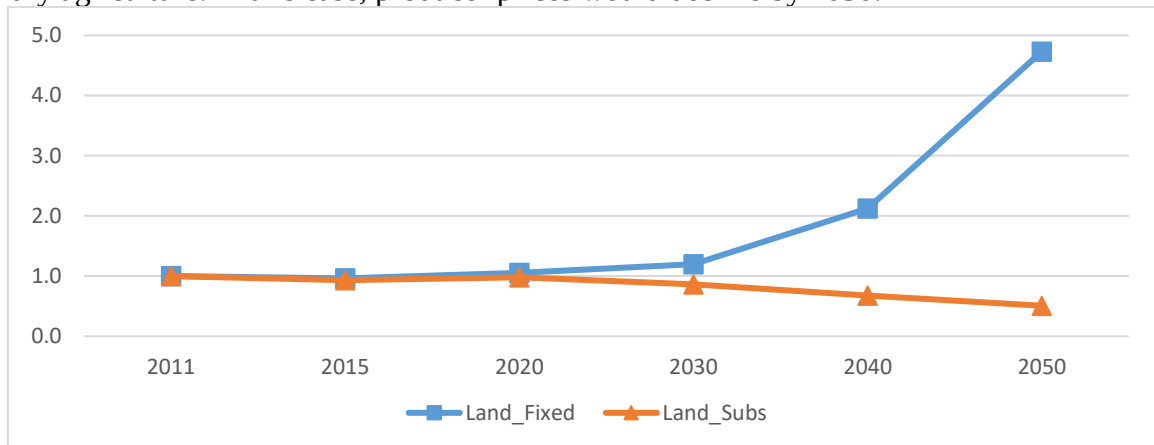


Figure 3. Index of primary agriculture prices in the two scenarios.

Figure 4 shows how the development on land market is transmitted to other sectors and to final consumers. Clearly, in the Land_Fixed scenario, the growth of land prices is so dominant, that all connecting industries face higher production costs resulting in an increase of food prices for consumers. On the other hand, with a higher land substitutability, producer prices would go down as well as consumer prices of food. The fact that consumer food prices copy more closely the development of primary rather than processed food suggests that the proportion of consumer spending coming from primary agriculture is higher than from processed industry (about 50% of all food expenditures come from land-using sectors such as horticulture and grain). It also tells that there is a low share of imports in food consumption, that could potentially moderate the food price inflation (the share of food imports in total food expenditures is 8% and is stable over time and across the scenario).

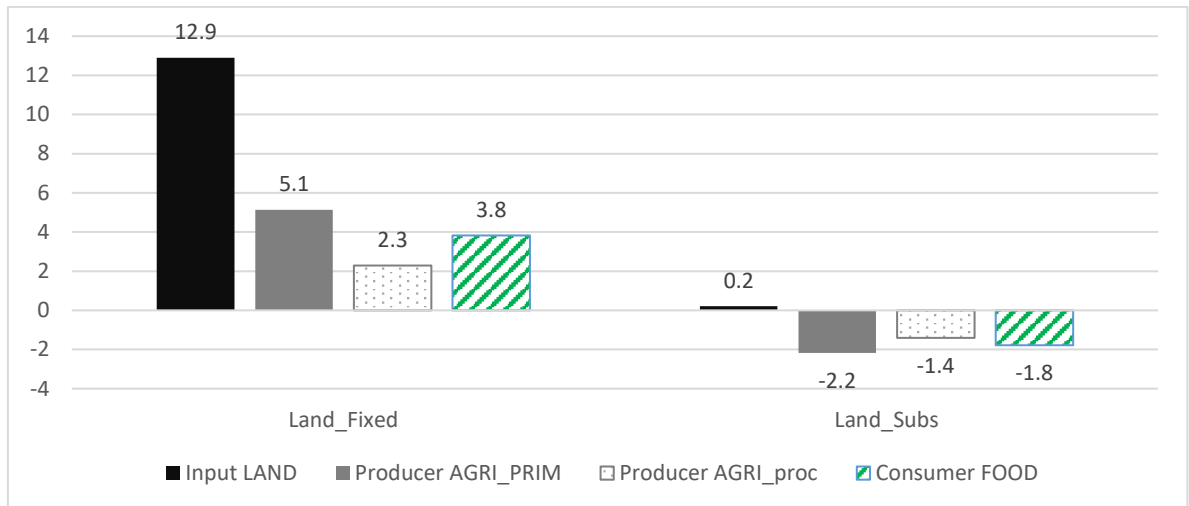


Figure 4. Annual growth of prices between 2020-2050.

3.3 Domestic production, trade and value added

In this section, we look more closely into the performance of individual agri-food production systems. Figure 5 displays annual growth of production volume of the commodities that represent 99% of total production in 2020 (both in volume and value). We also present the level of production in 2020 to understand the importance of each sector in the total agri-food complex. We can observe that in the Land_fixed scenario, meat processing sectors such as poultry meat, pork meat and other meat enjoy unusual production volume growth reaching above 5% per year. On the other hand, in the Land_Subs scenario, land-using sectors such as crops, other agriculture and horticulture flourish. Because the Land_Subs scenario favours those agricultural sectors that have traditionally strong position in the agri-food chain, the total agri-food production volume is higher in the Land_Subs scenario than in Land_Fixed (note that of course, in value terms it is the other way round).

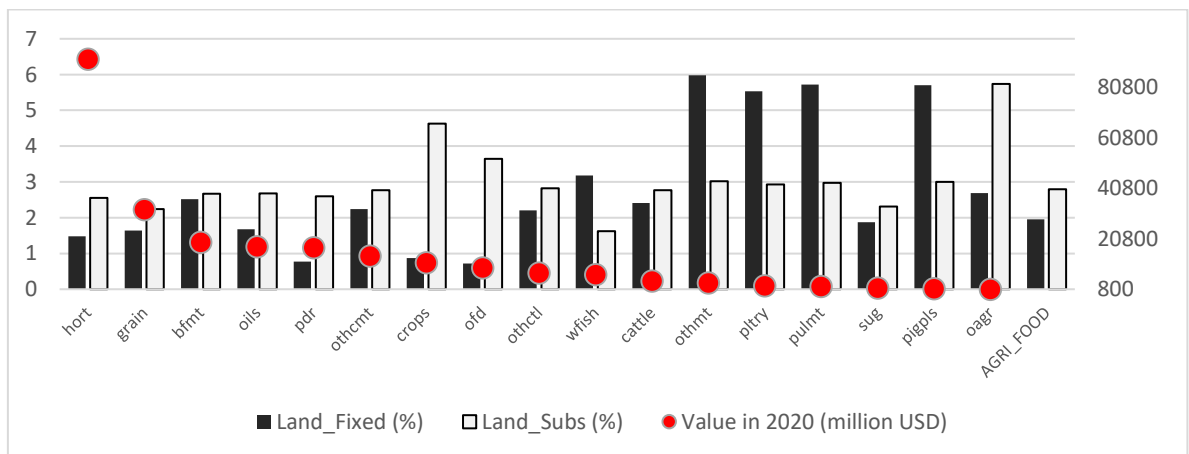


Figure 5. Annual growth of production volume (2020-2050) and volume of production of the major commodities (production volume of sugar, milk, dairy, wheat and aquaculture are too small to be reported).

The divergent development of the agri-food sectors is explained by the growth of production costs and prices. Figure 6 shows that due to an excessive growth of land prices in the Land_Fixed scenario, production costs in land-using sectors such as grain or cattle rise significantly (above 6% p.a.), whereas the non-land agricultural sectors such as other meat, poultry and pigs face a decline of prices. In concrete, prices in pigs and poultry sector reduce

5 times, whereas prices of cattle go up 10 times. Due to these price developments, meat industry enjoys an increased competitiveness compared to the crops sectors. Under the Land_Subs scenario, on the other hand, production costs in primary agricultural sector are lower than in processing industry and the crops sectors expand.

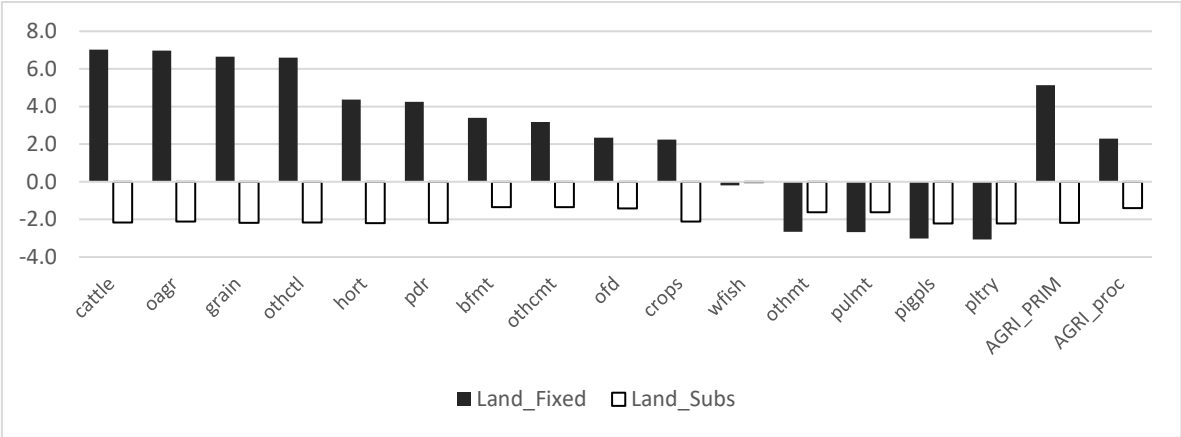


Figure 6. Annual growth of producer market prices of major agro-food commodities (2020-2050).

The developments in the food systems sectors are also projected to have a strong impact on the external position of Nigeria and the domestic supply and self-sufficiency. Figure 7 shows that the land substitutability plays a significant role in the competitiveness of Nigeria on foreign agri-food markets. Until 2020, trade balance remains stable and negative of around 20 billion USD. After 2020, the trends diverge notably where under the Land_Fixed scenario, trade balance would deteriorate significantly up to negative 140 billion USD, whilst in Land_Subs scenario, it would improve to a negative 11 billion USD.

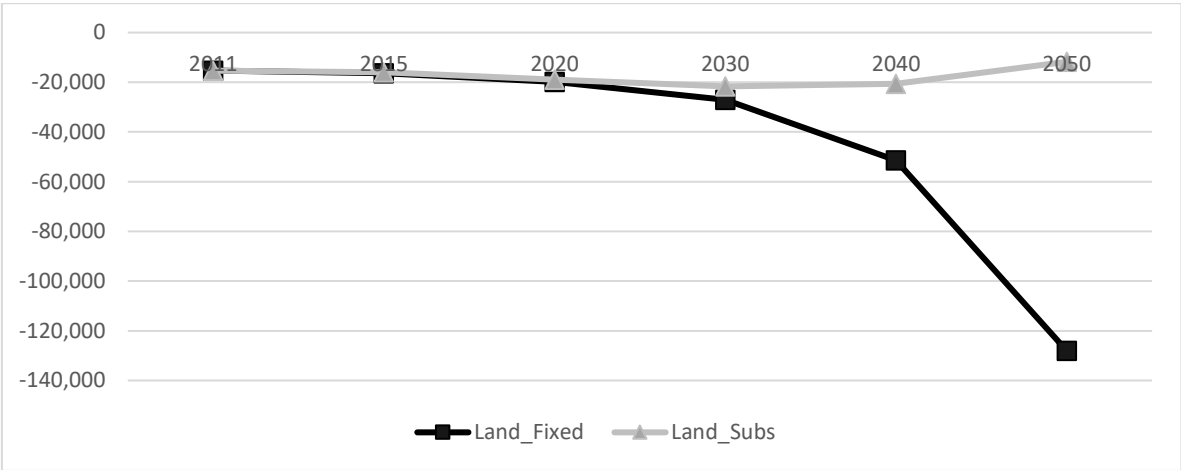


Figure 7. Agri-food trade balance expressed in world prices in million USD.

Aggregate agri-food trade balance is driven by the competitiveness of individual agri-food sectors. In 2020, there are only few sectors, which have a positive net trade with abroad, which are the sectors of horticulture, grain and other crops, oils and wild fish (similar in both scenarios). By 2050, in the Land-Fixed scenario, the trade balance in all these traditionally trade-oriented sectors would turn negative (except for wild fish). There is also a very strong deterioration of trade balance in other processed food (“ofd”), due to an increased household consumption of processed food from abroad. On the other hand, there would be a new

development on the meat markets, previewing a large increase in net exports of poultry and other meat (driven by the relative decline of producer prices of these sectors).

In the Land_Subs scenario, the competitiveness of crops sectors is improved and the deficit of Nigeria's trade balance is only moderate. The sectors that have a positive balance in 2020 remain with surplus and other sectors such as beef meat and paddy rice newly gain competitiveness on external markets.

3.4 Food environment and consumption

In this section shift our attention to the consumer side of the economy to assess the impact of the projected changes in food production on households' living standard and food security. Table 7 shows that agri-food consumer prices are expected to increase by 4% in the Land_fixed scenario, whereas in the LandSubs scenario, they decline by 1.8%. As a result of that, the quantity of food consumed is higher in the second scenario. Due to excessive growth of food prices, private expenditures on food grow quite significantly in the Land Fixed scenario and they are also reflected in the growth of total household expenditures. The lower panel in the table analyzes food accessibility as the compounding impact of food prices and household earnings, using a cereal price index divided by wage of skilled and unskilled labour as an indicator. In the Land-Fixed scenario the accessibility of staple food such as cereals declines as the cereal price index is up to 7 times higher compared to the wage of unskilled labour in agriculture, and 4 times higher compared to unskilled labour wage in other industry. The relative accessibility of food is on the other hand increasing in the Land-Subs scenario where cereal prices are below the wages. Similar developments is recorded for the skilled labour, which shows that food security problem would be threatening both skilled and unskilled labour households in the Land_Fixed scenario.

Table 7. Aggregate consumer prices and expenditures of Nigerian households		
(% annual growth, 2020 – 2050)	LandFixed	LandSubs
Price index agri-food consumption	4.2	-1.8
Agri-food consumption quantity	2.0	2.4
Agri-food expenditures	6.3	0.6
Total Household Expenditures	5.6	2.6
(Ratio of cereal consumer price index to unskilled labour wages, by sector of employment, 2050)	LandFixed	LandSubs
Household employed in primary agriculture (2011=1)	6.89	0.52
Household employed in the rest of the economy (2011=1)	3.69	0.28

Given that agri-food expenditures grow significantly, it is interesting to see if the share of food expenditures in total household expenditures increases as well. In the base year (2011), the share of food expenditures in total expenditures in Nigeria is relatively high, reaching almost 70%. This is in line with Akerele (2015) who highlights that expenditure on food claimed more than 60% of households income in 2012. In the Land_subs scenario, the share of food expenditures after 2020 declines to 30% whereas in the Land_Fixed scenario, due to excessive growth of prices, the share of food expenditures is expected to exceed 80%. Basically, most of household income would be spent on food in this case, which is alarming.

In the Land_Fixed scenario, the food groups that contribute most to total food expenditures are horticulture and other crops, cereals, red meat and other food (Figure 8). Contrary to that, in the Land_Subs scenario, the expenditures growth remains very moderate,

except for milk& dairy, sugar and processed food, which are food groups with lower share in total expenditures.

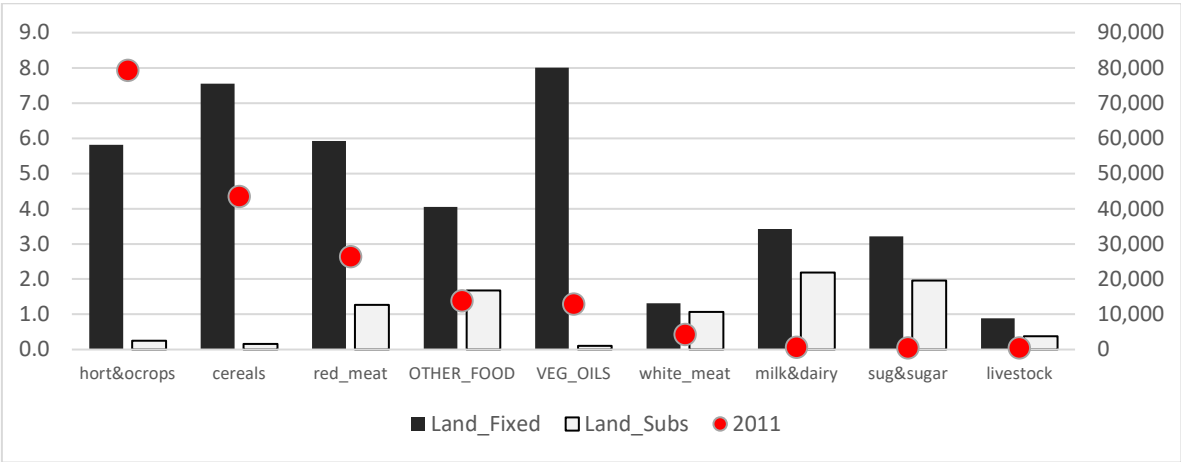


Figure 8. Annual growth of household expenditures on individual food groups (% , 2020-2050) and value of expenditures in 2011 (million USD)

3.5 Nutrient availability

In this section, we analyse the impact of the food system developments on household nutrition. Using the GENUS database, we trace the calories linked to the main food groups in MAGNET. We apply a correction factor to express the total caloric supply in terms of caloric intake of adult female equivalent. Figure 9 shows that in the Land_Fixed scenario, the projected caloric consumption would be in the range of 2,600 Kcal – 2700 Kcal, which is about 100 Kcal more than in case of the Land_Subs scenario (4% difference). This shows that improved food accessibility is not necessarily accompanied by higher caloric consumption.

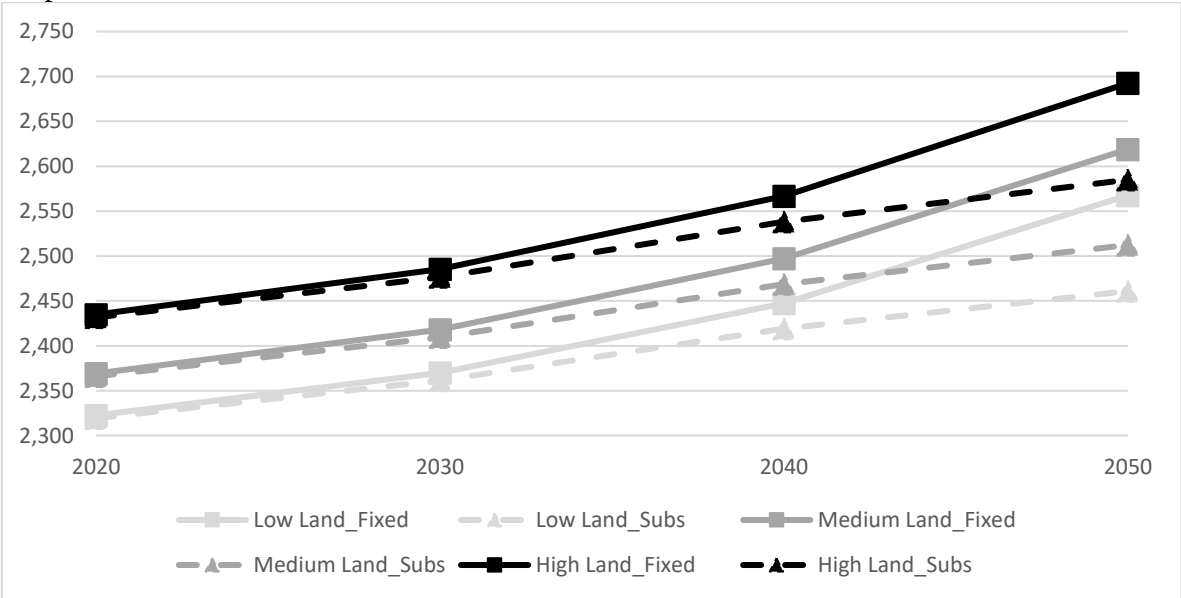


Figure 9. Projections of household caloric consumption (kcal per day) in the low, medium and high variant (converted to adult female equivalent)

Figure 10 shows the composition of caloric consumption across main food groups. As mentioned before, roots and tubers, grain and grain flour are the key sources of energy – they provide about 2,000 Kcal out of 2,900 Kcal of daily consumption. By 2050, these foods will

still remain the most important caloric sources but there will be some differences depending on the scenario. In the Land_Fixed scenario, due to a bigger role of food processing, the caloric consumption of more processed foods such as grain flour, vegetable oils and sugar would be higher compared to Land_Subs. Given that these foods have high caloric content, this explains why the caloric consumption is slightly higher in the Land_Fixed scenario.

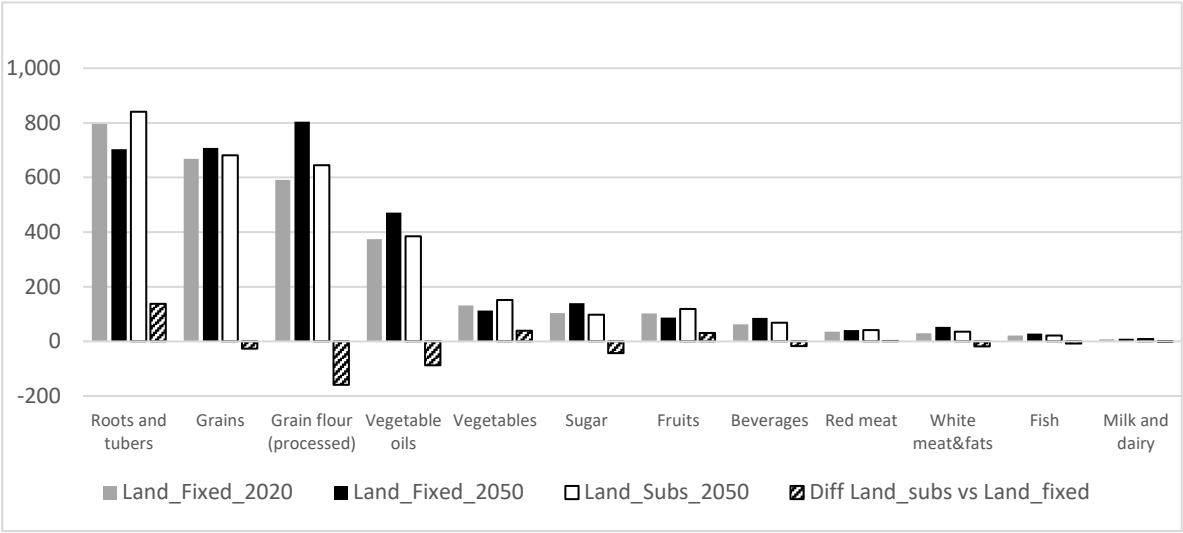


Figure 10. Projections of caloric consumption (kcal per capita day) per food group

It is also important to assess whether the energetic consumption corresponds to a higher intake of micronutrients. For instance, although in Land_Subs scenario, the total caloric consumption is slightly lower, the caloric intake from fruits and vegetables is higher, which is important from the health perspective.

Figure 11 shows that nutritional intake is projected to increase for all deficient nutrients, except for calcium, where projections diverge per scenario. In the Land_Fixed scenario, calcium intake would decline by 1% compared to 2020 whereas in the Land_Subs scenario, nutrient intake goes up to 8% compared to 2020. 50% of calcium in Nigeria is obtained from cassava, yams, citruses and okra. Because the Land_Subs scenario favours the horticulture and crops food systems, it also leads to a higher intake of calcium. On the other hand, in the Land_Fixed the intake of carbohydrates and fats would be up to 23% higher than in 2020.

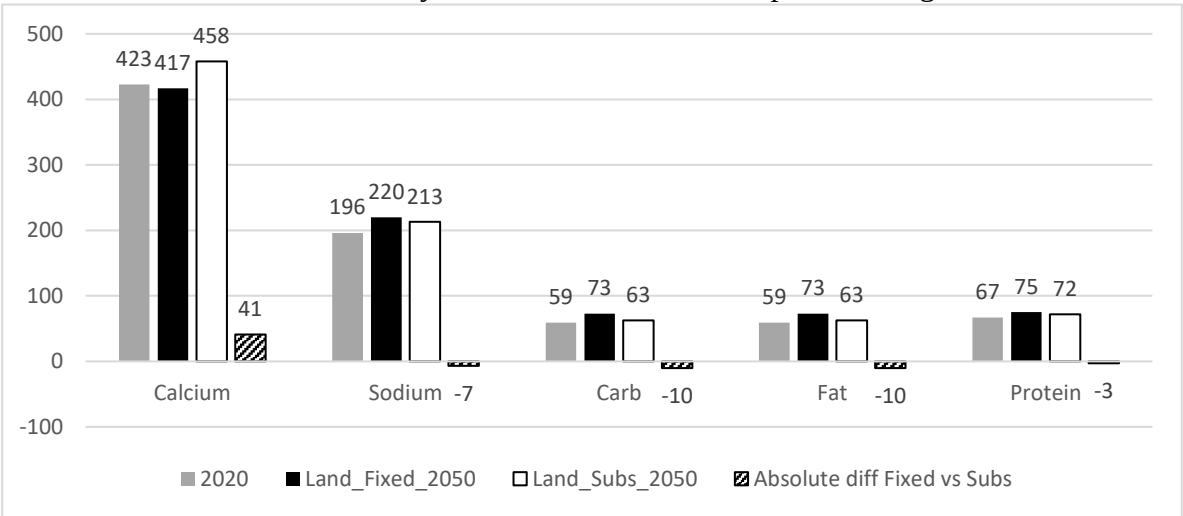


Figure 11. Overview of micronutrient intake in different scenarios (mg/capita/day or g/capita/day)

4. Discussion

The Nigeria (agri-fish-) food system is undergoing substantial change under the influence of global and domestic drivers, and model analysis gives insight into the processes of adjustment. Model projections suggest that a process of intensification of agriculture in combination with land substitution appears critical for the evolution of food and nutrition security, and for shifts towards healthy diets for the population. The strength of the analytical framework employed in this study is its capability to account for economy-wide adjustments of producer and consumer decisions under the influence of global drivers of change and the drivers related to the rigidity in the land market. A major assumption underpinning the improved food accessibility and shifts towards greater diversity and quality in the diet under the Land_Subs scenario stems from adjustments in the labour market. In particular, the model projects that unskilled agricultural employment grows by over 2%, and skilled labour by over 80%, suggesting that skilled work becomes firmly established in the agriculture sector. This is a substantial departure from today's realities, in which farming is predominantly a low-input activity. More detailed assessments will need to be done to assess confidence whether the Nigerian labour market would support such a transformational shift.

At least two implications of these scenario analyses can be assessed. First, without a significant governmental policy directed to R&D, it is not plausible to expect significant boosts of yields in the future. Coupled with the limited possibilities for the expansion of agricultural land, to prevent the collapse of the system under the dynamic growth of population and incomes, an increase in input intensification will be necessary.

The second implication is related to the nature of the land tenure system in Nigeria that has been critiqued to be expensive, cumbersome, time-consuming, and risky, creating a major bottleneck for improving the food supply system (PWC, 2017b; UNDP, 2012). If rigidity on the land market is project to remain the status quo, and under contextual changes towards 2050 (as presented by assumptions on buoyant economic growth, population growth and urbanization and technology change), demand growth from the rising middle classes are projected to take the form of more processed food and higher consumption of animal source foods. The model suggests strong import competition in Nigeria for these sectors. Meat and dairy would be produced only in part from domestic livestock systems and with limited backward linkages into domestic cropping systems because of the scarcity and low productivity on crop land. As a result, a significant portion of demand is projected to be sourced from imports.

The results of our study can be put into context with other empirical evidence, although the macroeconomic perspective on the linkage between food systems and diets is not yet sufficiently covered in the existing literature. One recent study examined the agricultural transformation and its relation to hunger and poverty eradication in Nigeria (Nwankpa, 2017). A structural change in labour markets to commercialize agriculture and develop agro-based industries was considered to be a major agricultural development pathway in Nigeria. This is in line with our study that clearly shows that in the absence of land substitution, labour currently employed in agriculture will have to seek employment outside of the primary sector, accelerating the process of urbanization. However, it can be also argued that in case of higher intensification, the agricultural labour could be used more productively within the agricultural sector and contribute thus to growth of rural wages. Second, the potential importance of increased capitalisation of the agricultural sector by improving access to credit was considered as a condition for the commercialisation pathway to materialise (Nwankpa, 2017). The findings from this study corroborate this; under assumptions that land is better

substitutable for other inputs, food-industry can absorb as much as 40% more capital, which points out to the need to improve access to credit to stimulate the intensification process of Nigerian agri-food system.

5. Conclusions

This paper provides a perspective on the future of food systems in Nigeria taking into account an interplay of various macroeconomic and biophysical drivers. Because of its highly dynamic economic growth and demographic boom, the country represents an interesting case of studying the impact of these drivers on the food systems.

It was shown by means of a modelling exercise that structural change in agriculture and transformation in the food system are important elements in diet change in Nigeria. A striking result is that intensification in the analysis results in greater diversity of the production systems, which in turn cascades into positive effects on the diversity in the food supply. This suggests that intensification in Nigeria would lead to the availability of foods with higher density in micronutrients than without intensification.

Main policy recommendations for fostering food systems development with positive nutritional impacts in Nigeria are directed to increased investments in agricultural R&D to alleviate the land pressure, reducing the rigidity of land markets to stimulate entrance and exit from the land market and to support intensification by improved access to capital markets and by replacing land for agricultural labour to stimulate agricultural wages.

For multiple reasons the evolution of impact of these food systems changes on diet and nutrient gaps warrants further analysis and interpretation in a combined micro-level and macro-level framework. Concretely, the absorption capacity of skilled labour inside of agriculture should be further assessed. An important area of future research is the analysis of heterogeneity of household response to food systems by linking the macro-level framework to simulating behaviour of individual households. This can enable to trace how the macro-drivers of food system effect individuals' nutritional outcomes and provide more insights into the nutrition inequality.

References

- Aguiar, A., Narayanan, B., McDougall, R., 2016. An Overview of the GTAP 9 Data Base. *J. Glob. Econ. Anal.* 1, 181–208. <https://doi.org/10.21642/JGEA.010103AF>
- Akerele, D., 2015. Household Food Expenditure Patterns, Food Nutrient Consumption and Nutritional Vulnerability in Nigeria: Implications for Policy. *Ecol. Food Nutr.* 54, 546–571. <https://doi.org/10.1080/03670244.2015.1041136>
- Aromolaran, A.B., 2010. Does increase in women's income relative to men's income increase food calorie intake in poor households? Evidence from Nigeria. *Agric. Econ.* 41, 239–249. <https://doi.org/10.1111/j.1574-0862.2010.00442.x>
- Bosello, F., Campagnolo, L., Cervigni, R., Eboli, F., 2018. Climate Change and Adaptation: The Case of Nigerian Agriculture. *Environ. Resour. Econ.* 69, 787–810. <https://doi.org/10.1007/s10640-016-0105-4>
- Brouwer, I.D., Nijhuis, A., Talsma, E.F., Trijsburg, L., Pastoria, G., Mekonnen, D.A., Morley, T., Linderhof, V., Achterbosch, T., 2018. The state of the dietary and nutrient gaps in Nigeria, in: A4NH Stakeholder Workshop "Food Systems for Healthier Diets in Nigeria." Presented at the A4NH Stakeholder workshop "Food systems for healthier diets in Nigeria," Abuja.

- FAO, n.d. Nigeria at a glance [WWW Document]. URL <http://www.fao.org/nigeria/fao-in-nigeria/nigeria-at-a-glance/en/> (accessed 11.15.18).
- Helming, J., Tabeau, A., 2018. The economic, environmental and agricultural land use effects in the European Union of agricultural labour subsidies under the Common Agricultural Policy. *Reg. Environ. Change* 18, 763–773. <https://doi.org/10.1007/s10113-016-1095-z>
- HLPE, 2017. Nutrition and food systems. The High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome.
- Imamura, F., Micha, R., Khatibzadeh, S., Fahimi, S., Shi, P., Powles, J., Mozaffarian, D., 2015. Dietary quality among men and women in 187 countries in 1990 and 2010: a systematic assessment. *Lancet Glob. Health* 3, e132–e142. [https://doi.org/10.1016/S2214-109X\(14\)70381-X](https://doi.org/10.1016/S2214-109X(14)70381-X)
- Keeney, R., Hertel, T., 2005. GTAP-AGR: A Framework for Assessing the Implications of Multilateral Changes in Agricultural Policies, GTAP Technical Paper No. 24. Purdue University, Purdue.
- Kuiper, M., Kalter, J., Mertens, E., Latka, C., Heckeley, T., Leip, A., Kanellopoulos, A., Havlik, P., Achterbosch, T., 2018a. The SUSFANS toolbox for assessing EU Sustainable food and nutrition security. SUSFANS, [The Hague].
- Kuiper, M., Shutes, L., Verma, M., Tabeau, A., Meijl, H. van, 2018b. Exploring the impact of alternative population projections on prices, growth and poverty developments, Background paper to the UNCTAD-FAO Commodities and Development Report 2017 Commodity markets, economic growth and development. FAO, Rome.
- Laborde, D., Lallemand, T., McDougal, K., Smaller, C., Fousseini, T., 2018. Transforming Agriculture in Africa & Asia: What are the policy priorities? ISSD and IFPRI, Washington DC.
- Liverpool-Tasie, L.S., Barrett, C.B., Sheahan, M.B., 2014. Understanding fertilizer use and profitability of rice production across Nigeria's diverse agroecological conditions, in: Annual Bank Conference on Africa.
- Lutz, Butz, and Kc, 2014. Wittgenstein Centre Data Explorer [WWW Document]. URL <http://dataexplorer.wittgensteincentre.org/shiny/wic/> (accessed 11.15.18).
- Mandryk, M., Doelman, J., Stehfest, E., 2015. Assessment of global land availability: land supply for agriculture (No. 7), FOODSECURE Technical papers. LEI Wageningen UR.
- National Population Commission Nigeria, I. C. F. International, 2014. Nigeria Demographic and Health Survey 2013.
- NBS, 2017. Nigeria - General Household Survey, Panel 2015-2016, Wave 3.
- Nwankpa, N., 2017. Sustainable Agricultural Development in Nigeria: A Way Out of Hunger and Poverty. *Eur. J. Sustain. Dev.* 6, 175-184–184.
- Onyemauwa, C.S., 2010. Analysis of Household Consumption of Cassava Products in Ohaozara, Ebonyi State, Southeast Nigeria. *Researcher* 2, 1–6.
- PWC, 2017a. The World in 2050. PricewaterhouseCoopers, London.
- PWC, 2017b. Transforming Nigeria's agricultural value chain. PricewaterhouseCoopers.
- Smith, M.R., Micha, R., Golden, C.D., Mozaffarian, D., Myers, S.S., 2016. Global Expanded Nutrient Supply (GENUS) Model: A New Method for Estimating the Global Dietary Supply of Nutrients. *PLOS ONE* 11, e0146976. <https://doi.org/10.1371/journal.pone.0146976>
- Stehfest, E., van Vuuren, D., Bouwman, L., Kram, T., 2014. Integrated assessment of global environmental change with IMAGE 3.0: Model description and policy applications. Netherlands Environmental Assessment Agency (PBL), Bilthoven.

- Tabeau, A., Helming, J., Philippidis, G., 2017. Land supply elasticity: overview of available estimates and recommended values for MAGNET.
- UNDP, 2012. The roles and opportunities for the private sector in Africa's agro-food industry. United Nations Development Programme (UNDP), Johannesburg, South Africa.
- van Meijl, H., Tsiropoulos, I., Bartelings, H., Hoefnagels, R., Smeets, E., Tabeau, A., Faaij, A., 2018. On the macro-economic impact of bioenergy and biochemicals – Introducing advanced bioeconomy sectors into an economic modelling framework with a case study for the Netherlands. *Biomass Bioenergy* 108, 381–397. <https://doi.org/10.1016/j.biombioe.2017.10.040>
- Woltjer, G., Kuiper, M., Kavallari, A., Meijl, H. van, Powell, J., Rutten, M., Shutes, L., Tabeau, A., 2012. The MAGNET model: Module description (No. Report 14-057). LEI Wageningen UR, The Hague.
- World Bank, 2008. World Development Report 2008 : Agriculture for Development. The World Bank, Washington DC.
- World Bank, n.d. World Development Indicators - Fertilizer Consumption. Washington, DC.

References

- Aguiar, A., Narayanan, B., McDougall, R., 2016. An Overview of the GTAP 9 Data Base. *J. Glob. Econ. Anal.* 1, 181–208. <https://doi.org/10.21642/JGEA.010103AF>
- Akerele, D., 2015. Household Food Expenditure Patterns, Food Nutrient Consumption and Nutritional Vulnerability in Nigeria: Implications for Policy. *Ecol. Food Nutr.* 54, 546–571. <https://doi.org/10.1080/03670244.2015.1041136>
- Aromolaran, A.B., 2010. Does increase in women's income relative to men's income increase food calorie intake in poor households? Evidence from Nigeria. *Agric. Econ.* 41, 239–249. <https://doi.org/10.1111/j.1574-0862.2010.00442.x>
- Bosello, F., Campagnolo, L., Cervigni, R., Eboli, F., 2018. Climate Change and Adaptation: The Case of Nigerian Agriculture. *Environ. Resour. Econ.* 69, 787–810. <https://doi.org/10.1007/s10640-016-0105-4>
- Brouwer, I.D., Nijhuis, A., Talsma, E.F., Trijsburg, L., Pastoria, G., Mekonnen, D.A., Morley, T., Linderhof, V., Achterbosch, T., 2018. The state of the dietary and nutrient gaps in Nigeria, in: A4NH Stakeholder Workshop “Food Systems for Healthier Diets in Nigeria.” Presented at the A4NH Stakeholder workshop “Food systems for healthier diets in Nigeria,” Abuja.
- FAO, n.d. Nigeria at a glance [WWW Document]. URL <http://www.fao.org/nigeria/fao-in-nigeria/nigeria-at-a-glance/en/> (accessed 11.15.18).
- Helming, J., Tabeau, A., 2018. The economic, environmental and agricultural land use effects in the European Union of agricultural labour subsidies under the Common Agricultural Policy. *Reg. Environ. Change* 18, 763–773. <https://doi.org/10.1007/s10113-016-1095-z>
- HLPE, 2017. Nutrition and food systems. The High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome.
- Imamura, F., Micha, R., Khatibzadeh, S., Fahimi, S., Shi, P., Powles, J., Mozaffarian, D., 2015. Dietary quality among men and women in 187 countries in 1990 and 2010: a systematic assessment. *Lancet Glob. Health* 3, e132–e142. [https://doi.org/10.1016/S2214-109X\(14\)70381-X](https://doi.org/10.1016/S2214-109X(14)70381-X)
- Keeney, R., Hertel, T., 2005. GTAP-AGR: A Framework for Assessing the Implications of Multilateral Changes in Agricultural Policies, GTAP Technical Paper No. 24. Purdue University, Purdue.
- Kuiper, M., Kalter, J., Mertens, E., Latka, C., Heckeley, T., Leip, A., Kanellopoulos, A., Havlik, P., Achterbosch, T., 2018a. The SUSFANS toolbox for assessing EU Sustainable food and nutrition security. SUSFANS, [The Hague].
- Kuiper, M., Shutes, L., Verma, M., Tabeau, A., Meijl, H. van, 2018b. Exploring the impact of alternative population projections on prices, growth and poverty developments, Background paper to the UNCTAD-FAO Commodities and Development Report 2017 Commodity markets, economic growth and development. FAO, Rome.
- Laborde, D., Lallement, T., McDougal, K., Smaller, C., Fousseini, T., 2018. Transforming Agriculture in Africa & Asia: What are the policy priorities? ISSD and IFPRI, Washington DC.

- Liverpool-Tasie, L.S., Barrett, C.B., Sheahan, M.B., 2014. Understanding fertilizer use and profitability of rice production across Nigeria's diverse agroecological conditions, in: Annual Bank Conference on Africa.
- Lutz, Butz, and Kc, 2014. Wittgenstein Centre Data Explorer [WWW Document]. URL <http://dataexplorer.wittgensteincentre.org/shiny/wic/> (accessed 11.15.18).
- Mandryk, M., Doelman, J., Stehfest, E., 2015. Assessment of global land availability: land supply for agriculture (No. 7), FOODSECURE Technical papers. LEI Wageningen UR.
- National Population Commission Nigeria, I. C. F. International, 2014. Nigeria Demographic and Health Survey 2013.
- NBS, 2017. Nigeria - General Household Survey, Panel 2015-2016, Wave 3.
- Nwankpa, N., 2017. Sustainable Agricultural Development in Nigeria: A Way Out of Hunger and Poverty. *Eur. J. Sustain. Dev.* 6, 175-184–184.
- Onyemauwa, C.S., 2010. Analysis of Household Consumption of Cassava Products in Ohaozara, Ebonyi State, Southeast Nigeria. *Researcher* 2, 1–6.
- PWC, 2017a. The World in 2050. PricewaterhouseCoopers, London.
- PWC, 2017b. Transforming Nigeria's agricultural value chain. PricewaterhouseCoopers.
- Smith, M.R., Micha, R., Golden, C.D., Mozaffarian, D., Myers, S.S., 2016. Global Expanded Nutrient Supply (GENUS) Model: A New Method for Estimating the Global Dietary Supply of Nutrients. *PLOS ONE* 11, e0146976. <https://doi.org/10.1371/journal.pone.0146976>
- Stehfest, E., van Vuuren, D., Bouwman, L., Kram, T., 2014. Integrated assessment of global environmental change with IMAGE 3.0: Model description and policy applications. Netherlands Environmental Assessment Agency (PBL), Bilthoven.
- Tabeau, A., Helming, J., Philippidis, G., 2017. Land supply elasticity: overview of available estimates and recommended values for MAGNET.
- UNDP, 2012. The roles and opportunities for the private sector in Africa's agro-food industry. United Nations Development Programme (UNDP), Johannesburg, South Africa.
- van Meijl, H., Tsiropoulos, I., Bartelings, H., Hoefnagels, R., Smeets, E., Tabeau, A., Faaij, A., 2018. On the macro-economic impact of bioenergy and biochemicals – Introducing advanced bioeconomy sectors into an economic modelling framework with a case study for the Netherlands. *Biomass Bioenergy* 108, 381–397. <https://doi.org/10.1016/j.biombioe.2017.10.040>
- Woltjer, G., Kuiper, M., Kavallari, A., Meijl, H. van, Powell, J., Rutten, M., Shutes, L., Tabeau, A., 2012. The MAGNET model: Module description (No. Report 14-057). LEI Wageningen UR, The Hague.
- World Bank, 2008. World Development Report 2008 : Agriculture for Development. The World Bank, Washington DC.
- World Bank, n.d. World Development Indicators - Fertilizer Consumption. Washington, DC.