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Trends and Drivers of Crop Biomass Demand: Sub-Saharan Africa vs the Rest of the World

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Abstract

The global demand for crop biomass for both food and non-food use has markedly increased during the last decade. This recent trend was driven by population growth, income growth by consumers, industrial demand for non-food raw materials, and demand for energy in the form of crop biofuels. Consequently, relative price levels for plant biomass have intermittedly doubled since 2006. The aim of this study is identify and compare global drivers, trends and projections of this process, looking at biomass production, consumption and related resource use in Sub-Saharan Africa as opposed to the Rest of the World. Model-based quantitative projections of global crop biomass markets are reviewed and compared, and supplemented by own projections.

Keywords: crop production, long-term projections, land use
JEL classification: Q02, Q11

1 Introduction

The global demand for biomass from crops has markedly increased during the last decade (Timilsina & Shrestha 2010), and not only in total, but also on a per-capita basis. Table 1 illustrates this trend at the example of global food versus non-food use of cereals and vegetable oils. While food use (including use as animal feed) has largely remained stable in absolute terms, non-food use was the main driver of overall increases in use, particularly after the beginning of the new millennium.

Table 1**:** Global use of cereals and vegetable oil per capita, and the food versus non-food use share for the years 1992, 2000, and 2011

	Cereals			*Vegetable oils*		
	1992	*2000*	*2011*	*1992*	*2000*	*2011*
Use per capita in kg/year	310.2	306.5	329.7	12.2	15.0	22.0
Food (incl. feed) as % of supply	85.1	85.2	79.1	74.8	67.5	52.1
Non-food use as % of supply	6.0	7.0	13.7	25.3	32.8	48.4

Source: FAOSTAT Online Database 2014

Beyond the classical drivers of population and economic growth which led to accelerating food biomass needs during the second half of the 20th century, increasing demand for biofuels has further accelerated growth rates in total biomass demand. To satisfy non-biofuel demand alone, total production of calories from crop biomass would have to increase by about 70% world-wide (Alexandratos and Bruinsma 2012) until the year 2050. Biomass demand for energy use is also likely to grow further. First, biofuel production for climate change mitigation is still supported politically through subsidies and mandatory blending in major industrial and emerging economies such as the EU, US and Brazil. But even with diminishing political support due to the food versus fuel debate, positive long-term trends for fossil fuel prices make biofuel production lucrative in different world regions, increasing the demand for land (Timilsina et al. 2010) and raising prices for food and non-food crops[1] (OECD 2011). The 2007/2008 food price crisis is widely regarded as a turning point towards higher international price levels for crop biomass. Lastingly higher prices for food biomass would make access to food more difficult for poor and undernourished people, a high percentage of whom live in Sub-Saharan Africa.

While both the share and the number of undernourished people worldwide declined dramatically in recent decades thanks to increased food production per capita, Sub-Saharan Africa (SSA) has considerably lagged behind these positive developments. On a continental scale, SSA's food production per capita has actually decreased since independence, which stands in stark contrast to almost all other major world regions. While production per capita rose by 74% between 1961 and 2005 in developing countries, it decreased by almost 12% in SSA. As a consequence, the share of undernourished people in SSA is still at 25% and thus not much below the level of 1970, while in the developing world as a whole, the share of the undernourished was more than halved to 15% during the same period. Matters would have been worse if world price levels for cereals and other food had not steadily decreased in real terms since the beginning of the 1970s.

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[1] Terminological clarification: Biomass from crops may be used for food or non-food purposes. 'Food purposes' include direct consumption of the raw or processed crop as well as feed use by animals that are kept for food production. 'Non-food biomass from crops' is any biomass from crop origin that is not meant for food or feed. The opposite is true for 'food biomass from crop origin'. 'Food crops' are crops that can be partly processed into food biomass. This is the vast majority of crops. 'Non-food crops' cannot deliver any food biomass, for instance cotton. Moreover, many crops mainly considered as food crops are increasingly used for both food and non-food purposes, for instance food crops that can also be processed into biofuels.

Low real food prices made staple food affordable for urban consumers and net-consumers among rural smallholders, while production shortfalls could be cushioned by imports. This changed to some extent with the global food price crisis in 2007. Rising international price levels are inevitably transmitted to domestic markets in developing countries (Sharma 2011), where more costly food erodes purchasing power and thereby raises the number of income-poor people. The World Bank (2011) estimates that the second wave of the food price crisis in 2010 increased the absolute poverty rate (daily income per capita below 1.25$) by 1.1 percentage points world-wide. As purchasing power for food declined, the share of undernourished people in the world has grown since 2007 for the first time after decades of improvement (FAO 2011a, p.65 ff). In SSA the number of undernourished people is estimated to have increased by almost 10% from 2007 to 2008 following the first food price spike.

Many of the reasons of the food price increases since 2007 are not short-term events such as regional harvest failures, but originate from increased demand for non-food use of biomass world-wide. This accelerating global biomass demand represents the second challenge to SSA's food sector. It is partly caused by higher oil prices which make the production of biofuels profitable, adding to the existing 'non-market' demand for biofuel use that is driven by mandatory blending schemes for automotive fuel in the US and the EU. The second major source of biomass demand is feed use in the livestock sector to accommodate the swiftly rising demand for meat and dairy products in emerging and developing economies (Keyzer et al. 2005). Both these megatrends, i.e. crop use for biofuels and feed, are unlikely to abate in the near future, driving crop prices, but also prices for input factors such as land, machinery and fertilizer to levels which were unexpected at the beginning of the new millennium. Land and water scarcity in major importing regions, higher and more volatile food prices, and the demand for biofuels have induced a global run on land resources, many of which can be found in SSA (Brüntrup 2011). But even though the elevated international price levels for biomass are largely perceived as a shock and invoke questions regarding long-term global food availability (Koning et al. 2008), it is important to also point out positive effects for the producers of crop biomass. Elevated world price levels provide incentives for African smallholders to increase the use of inputs and expand production, which may be the reason that food production per capita in SSA has increased by 6% between 2004 and 2010, representing the first persistent upward trend in food output since the beginning of the 1960s (FAOSTAT 2014). Taking a macroeconomic perspective, the food price crisis has not prevented African economies from growing at almost unprecedented rates since 2005 (World Bank 2012). This African growth acceleration may be the major reason why changes in poverty rates and undernourishment in the face of doubled food prices have been still modest since 2007.

Given this combination of global and internal driving forces, SSA's food sector will have to swiftly increase both its production and productivity in the coming decades in order to meet the demands of a population that is projected to more than double from today's 925 million to above two billion in 2050. As the per-capita incomes of SSA's population in 2050 will be considerably higher than today, the production of cereals and other staple crops for food, feed and processing purposes will have to much more than double, which will both require an expansion of cropland area and a catch-up of crop yields. All this will have to be achieved under the expectation of higher global price levels for crop biomass, part of which will be demanded for non-food use. Undoubtedly, SSA still has vast land reserves – at least the continental scale – and unused yield potential (Alexandratos and Bruinsma 2012). This study aims at identifying and quantifying the most important driving forces for crop biomass demand and supply, contrasting SSA to the rest of the world (Non-SSA). This distinction is justified due to the still exceptional population growth in SSA, combined with its lag in economic and agricultural productivity, the latter which are both expected to continue their catch-up process that started in the new millennium. For that purpose, section 2 presents a systematic framework of driving forces and constraints, compares the trends of these drivers between SSA and Non-SSA, and suggests a statistical model to project the required arable land that SSA will need per inhabitant by 2050. Section 3 summarizes projections from other sources and compares these with our own assessments. Section 4 concludes with a discussion of possible crop biomass strategies for land abundant versus land-scarce African countries.

2 Driving factors for SSA's biomass demand and supply up to 2050

Conceptual framework

Figure 1 serves as a conceptual framework for the assumed interaction between key driving factors for SSA's biomass markets. Functional relationships between drivers (or variables) are denoted using arrows to which +/- signs are attached. An arrow pointing from variable A to B with a + attached means that an increase in A leads to an increase of B. Key drivers for the change in biomass demand are growth in population numbers and per-capita income. Meanwhile, productivity in farming, land scarcity and degradation, and climatic warming have the potential to influence biomass supply. With the exception of climatic warming, all 'driving' variables displayed in Figure 1 are subject to feedbacks from other variables in the model, even though the latter may not be complete or difficult to express in numbers. The functional relationships expressed by Figure 1 are discussed in the following.

Higher income per capita has an important long-term demographic effect, first by driving down infant mortality, and second by reducing total fertility thanks to the increasing opportunity costs of times spent for childcare with rising incomes.[2] Moreover, higher incomes influence the demand for biomass by boosting the consumption of animal calories, which in turn increases both overall biomass demand (fodder) and land scarcity. But higher per capita incomes also boost the supply of biomass thanks to increasing farm productivity, higher levels of economic development usually go along with better supply of inputs, credit, and training for farmers.

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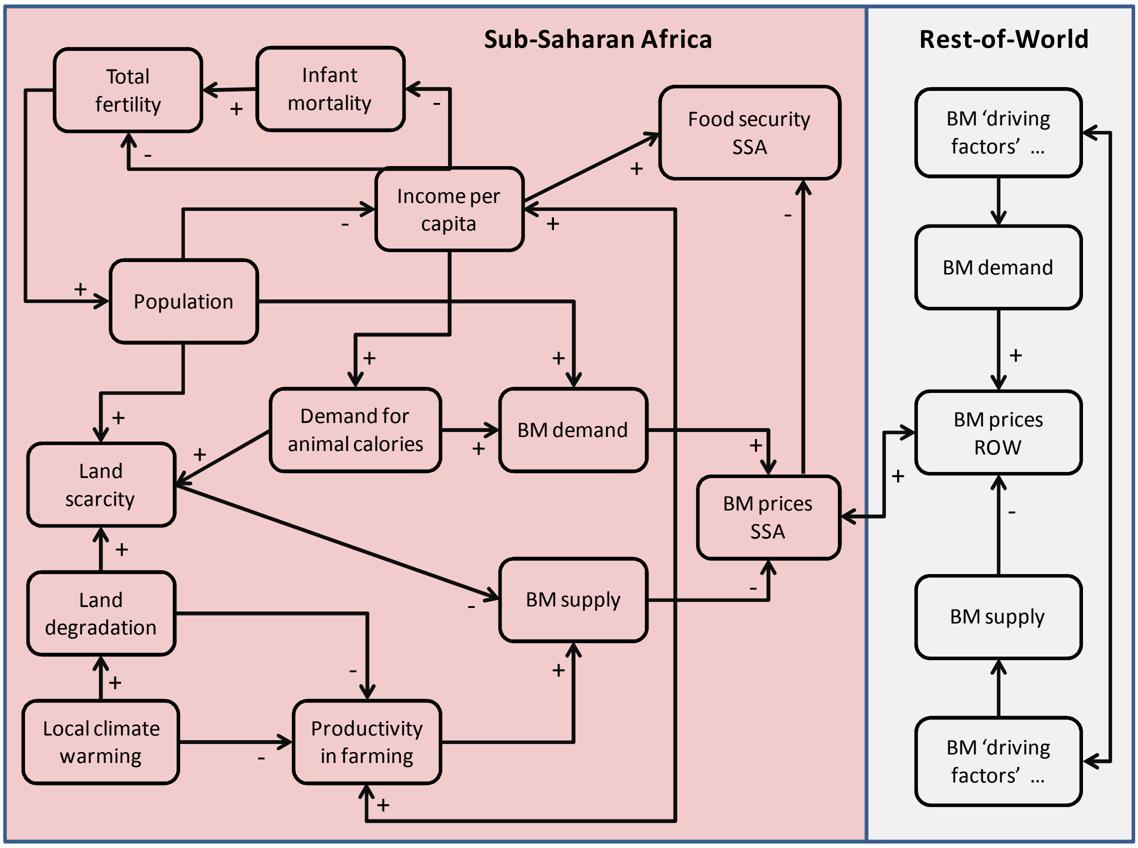
[2] There are numerous other drivers of total fertility, such as cultural norms, availability of contraceptives, education of women, or degree of urbanization. Most of these are closely correlated with the level of economic development (expressed by per-capita income) and therefore not mentioned separately in Fig 1.

Figure 1: Interaction of important factors driving prices of plant biomass commodities (BM) in SSA and the rest of the world. All variables should be interpreted as ‘change rates’.



Lower infant mortality lowers the need to have numerous children, thus driving down total fertility and, as a consequence, population growth. Lower population growth has three main effects in this context: first, it increases incomes per capita, as the same total GDP has to be distributed to relatively fewer people, and second, it lowers demand growth for biomass. Moreover, lower population growth reduces scarcity of farm land, at least under the conditions prevailing in most parts of SSA where typically a substantial share to the population works as semi-subsistence farmers. Under these conditions, lower land scarcity increases at least the marketable supply of biomass. A largely exogenous driver is climatic warming which, at least in most countries of SSA, is expected to accelerate land degradation processes, thus leading to higher land scarcity. Further, a depressing effect on farm productivity (i.e. lower crop yields through heat stress) and, by this, biomass supply and per-capita incomes is expected.

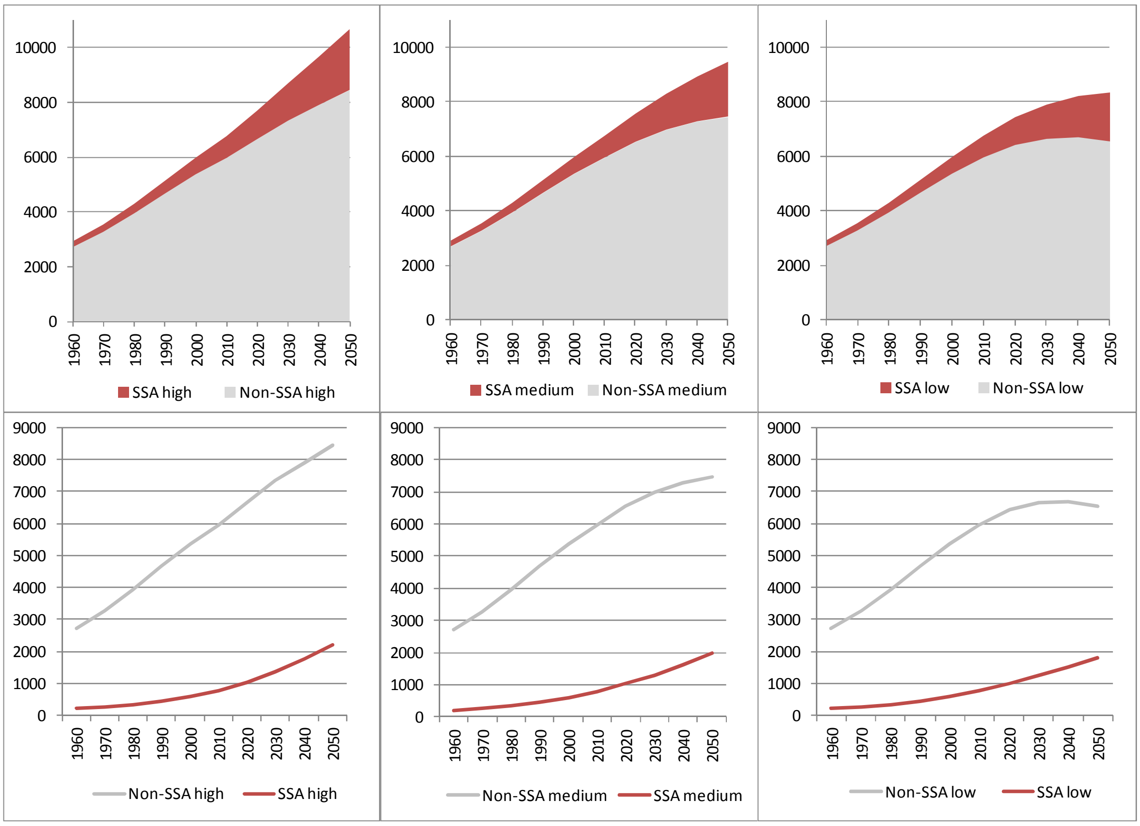
Trends in SSA’s biomass demand and supply determine trends in overall biomass price levels for SSA. Moreover, SSA’s biomass prices are positively influenced by biomass prices in the rest of the world (and vice versa). Non-SSA biomass price levels are assumed to be influenced by largely the same driving factors as in SSA, though the future trends of those or their significance for biomass demand and supply may differ. This functional symmetry is indicated by the grey-shaded right-hand area in Figure 1 which features driving factors for Non-SSA only summarily. Finally, as most biomass is used for food, it fair to assume that lower prices of biomass increase economic access to food and thus food security.

The remainder of this section discusses the proposed relationships between driving forces and biomass demand and supply by contrasting historical data and projected figures for SSA and the rest of the world.

Demographic drivers

The most important driver of biomass demand is population growth which drives demand for both food and non-food use. This sub-section gives on overview on global population projections by the UN Population Division (2012 revision) with a focus on the difference between SSA and the rest of the world. Projections are based on different fertility scenarios (high, medium, low) for 2010-2050.

Figure 2: Population developments (1960-2010) and projections (until 2050) for Sub-Saharan Africa (SSA) and the Rest of the World (Non-SSA). The stacked area charts in the upper row show global population with SSA (red) and Non-SSA (grey) shares, while the line charts of the lower row show absolute numbers for Non-SSA (grey) and SSA (red).

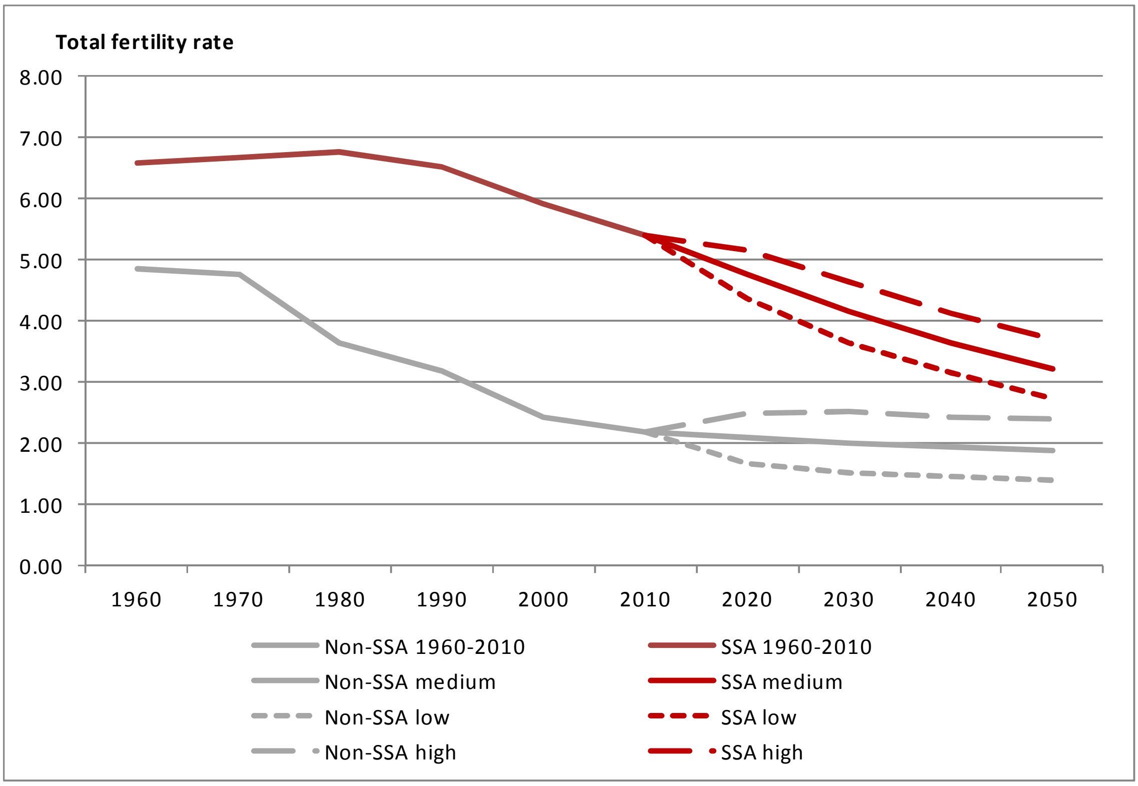


Note: All vertical scales denote million people. Source: UNPD 2014

The upper row of Figure 2 shows that total global population is expected to reach between 8.3 bn (low) and 10.7 bn (high) people, with the medium scenario arriving at 9.5 bn. SSA's population is projected at 1.79 bn (low), 1.99 bn (medium), and 2.22 bn (high) for 2050, providing between 21 and 22% of the projected global population, as compared to 11.7% in

2010. This means that SSA's share in global population could almost double within the next 4 decades, which is explained by its higher projected population growth rates for that period. SSA's population would continue growing almost unabatedly until 2050 while absolute growth in the rest of the world would almost come to a halt by 2050 (medium fertility) or 2030 (low fertility) already, which is demonstrated by the lower row of graphs in Figure 2.

Figure 3: Developments (1960-2010) and projections (until 2050) of total fertility rates for Sub-Saharan Africa (SSA, red) and the Rest of the World (Non-SSA, grey). Projections are based on different fertility scenarios (high, medium, low) for 2010-2050.



Source: UNPD 2014

The underlying fertility assumptions of the different population scenarios can be seen in Figure 3 where historical and projected Total Fertility Rates (TFR) are shown for SSA and ROW. Obviously, the 'medium' scenarios are attempts to extend past trends in total fertility into the coming decades, which makes them the most plausible ones. For SSA, medium-scenario TFR stands at 5.5 children per woman in 2010 and is project to decrease relatively steeply to 3.2 in 2050. This value, however, was reached in non-SSA in 1990 already, meaning that SSA is 'demographically delayed' by 60 years compared to the rest of the world. ROW, by contrast, will have fallen below the replacement level TFR of 2.1 by 2020. Nevertheless, demographic momentum and increasing life expectancy is projected to provide further total population growth in ROW until roughly 2060.

Assuming that the medium fertility variant is the most likely one, the further discussion of driving forces will be based on this scenario. Table 2 gives an overview on important demographic drivers and the resulting population growth based on the medium fertility scenario for 1990 and 2010 (observed), and for 2050 (projected). The differences between SSA and the rest of the world are striking. While population growth outside of Sub-Saharan Africa is expected to almost cease by 2050, SSA's population growth was hardly reduced between 1990 and 2010 and is expected to be at still substantial 1.9% by 2050. ROW would fall well below a replacement level TFR of 1.89 by 2050, while SSA's TFR would still stand at 3.2. Both parts of the world would decrease their infant mortality rates by two-thirds, but Africa's would still stand at 31 by 2050, which is very high as compared to industrialized countries where IMRs are about to fall below 5 already today. The use of contraceptives – a negative driver of fertility – is on a steep rise in SSA, but from a very low level, so that current use rates worldwide will only be reached some decades ahead (no projections were available for this item). Finally, projected crude death rates reveal another contrast: while projected to increase sharply outside SSA until 2050 due to a rising share of the elderly, in SSA, sharply decreasing death rates until 2050, mainly thanks to improving health care, would further contribute to projected total population growth.

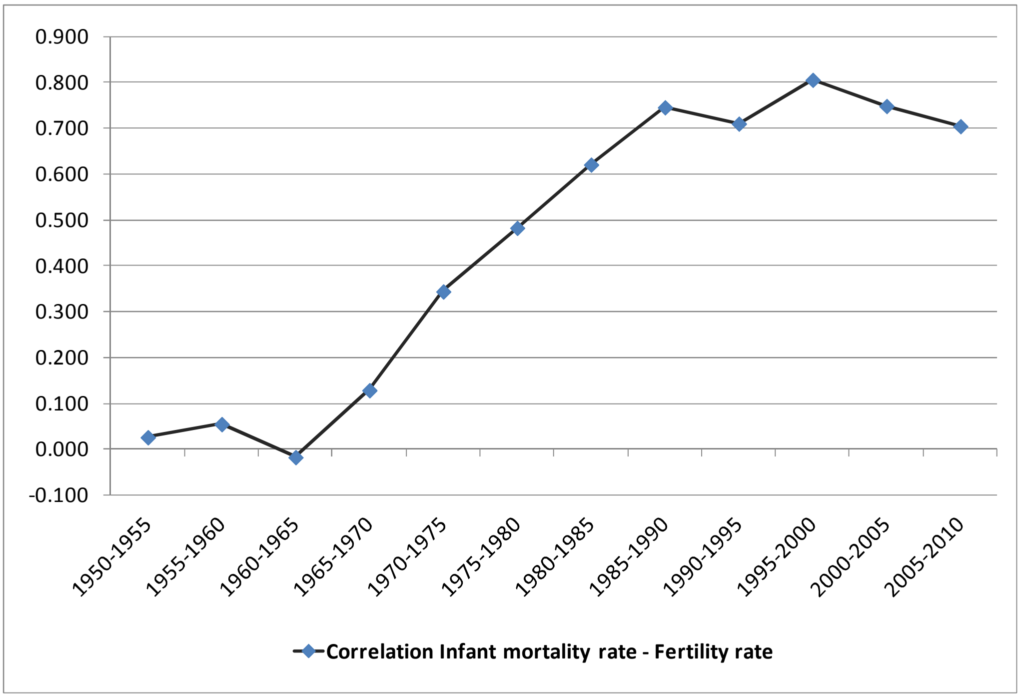
Table 2: Projected population growth and important demographic drivers for SSA and Non-SSA, medium fertility projections

		1990	*2010*	*2050*	*Observed change 1990-2010, in %*	*Projected change 2010-2050, in %*
Population growth rate (annual)	Non-SSA	1.72	0.99	0.11	-42.40	-88.90
	SSA	2.80	2.66	1.90	-5.00	-28.60
Total fertility rate (children / woman)	Non-SSA	3.25	2.18	1.89	-32.90	-13.30
	SSA	6.51	5.39	3.22	-17.20	-40.30
Infant mortality rate (per 1000)	Non-SSA	53.00	32.00	12.00	-38.80	-62.60
	SSA	112.00	79.00	31.00	-29.50	-61.20
Contraceptives use (percent)	Non-SSA	58.15	67.02	*n.a.*	15.30	*n.a.*
	SSA	11.90	24.40	*n.a.*	105.00	*n.a.*
Crude death rate (per 1000)	Non-SSA	8.92	7.61	10.75	-14.70	41.30
	SSA	16.34	13.00	6.69	-20.40	-48.50

Source: UNPD 2014

Reducing the total fertility rate is the key to achieve lower population growth rates in the longer term. Long-term changes in TFR itself are driven by changes in a vast array of other factors such as child mortality, household incomes, availability and costs of education, use of contraceptives, education and labor market participation of women, urbanization, functioning social safety networks, and cultural norms and habits. Identifying the most crucial among these factors to better prioritize policy interventions is empirically challenging due to multicollinearity problems. Practically all of the mentioned variables are systematically correlated with GDP growth per capita and therefore display typical trends during economic development. Still, the initial theoretical assumption of demographic transition theory that child mortality is the most crucial among the more specific drivers of fertility seems to hold empirically (Conley et al. 2007). Figure 4 nicely shows how a robust correlation between IMR (as a proxy for child mortality) and TFR emerged in the course of the second half of the 20th century for SSA countries, peaking at 0.8 between 1995 and 2000.

Figure 4: Trend in correlations of infant mortality rates (IMR) and total fertility rates (TFR) for SSA for different periods, 1950s to 2010



Source: UNPD 2014

Moreover, Table 3 shows that the correlation between IMR and TFR is consistently higher compared to GDP-IMR and GDP-TFR in lower-income country groupings, which further supports the prominent role attributed to low child mortality rates as a necessary condition for slowing population growth.

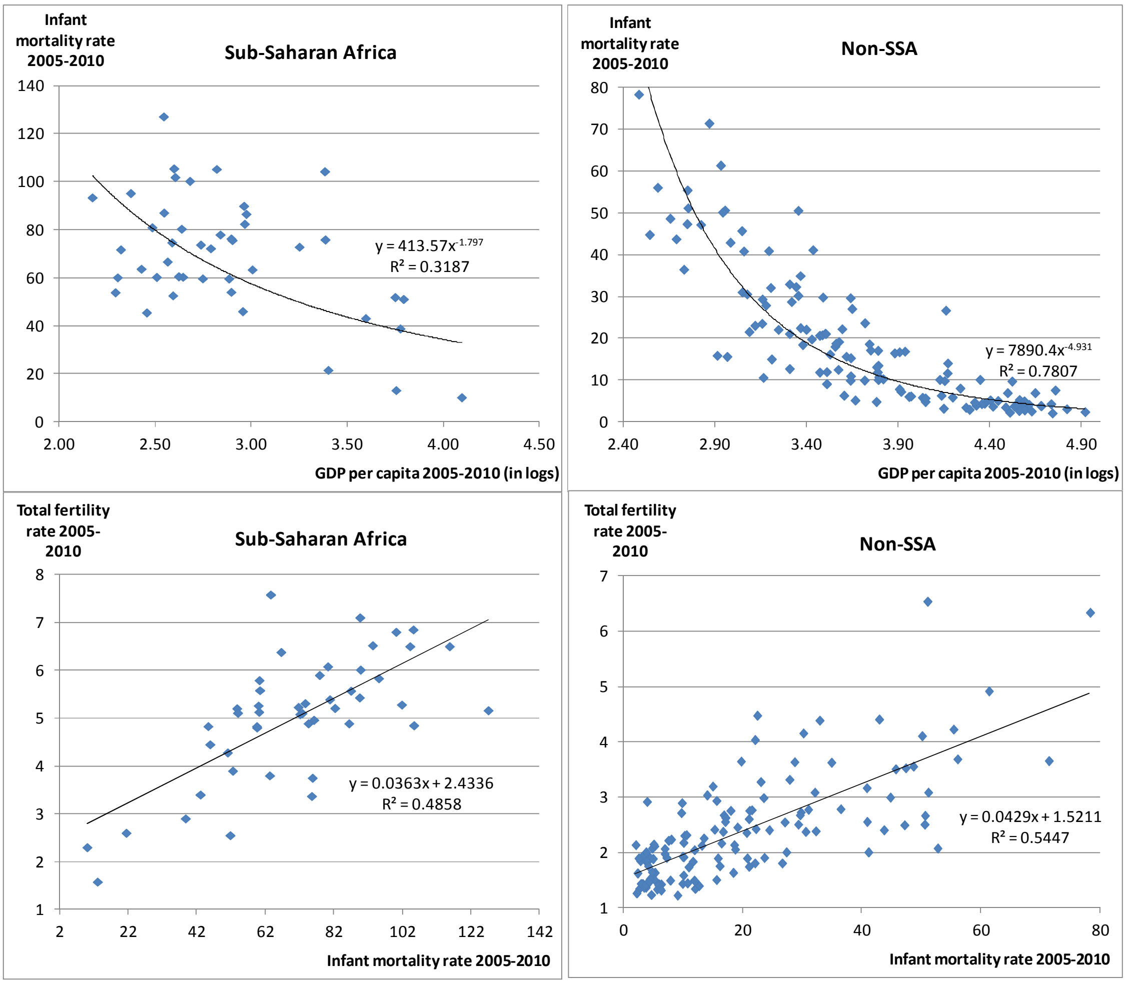
Table 3: Correlations between GDP per capita, infant mortality (IMR), and total fertility (TFR) for selected country samples, averages from 2005 to 2010

	GDP p.c. - IMR	*GDP p.c. - TFR*	*IMR - TFR*
Sub-Saharan Africa	-0.511	-0.697	0.697
Rest-of-World (Non-SSA)	-0.822	-0.598	0.738
Low-income countries	-0.255	-0.403	0.687
Middle-income countries	-0.463	-0.454	0.767
High-income countries	-0.545	-0.123	0.596
Income, lower half of countries	-0.620	-0.619	0.793
Income, upper half of countries	-0.588	-0.260	0.696

Sources: UNPD 2014, World Bank 2014

Despite relatively high correlations of GDP to IMR, and of IMR to TFR, Figure 5 shows the degree of heterogeneity that is still found in the country-level cross sections. For instance, the SSA country with the highest fertility rate of 7.6 (Niger, which also has one of the lowest per-capita income levels) has an infant mortality rate of under 64 which is below the SSA average.

Figure 5: IMR, TFR, and GDP per capita for SSA and Non-SSA countries, 2005-2010



Sources: UNPD 2014, World Bank 2014

By contrast, in oil-exporting Angola, which has a per-capita GDP that is almost ten times higher as that of Niger, the IMR still stands at 105, and TFR at 6.5. An unequal income distribution and lacking public investment in healthcare can tremendously skew the otherwise well-established GDP-IMR-TFR causality triangle. On the other hand, Niger shows that a declining IMR alone will not lead to lower TFR if overall economic development fails. Under such circumstances, isolated efforts to lower infant mortality rather contribute to accelerated population growth, as all the other, complementary incentives for smaller families that result from GDP growth could not have started working.

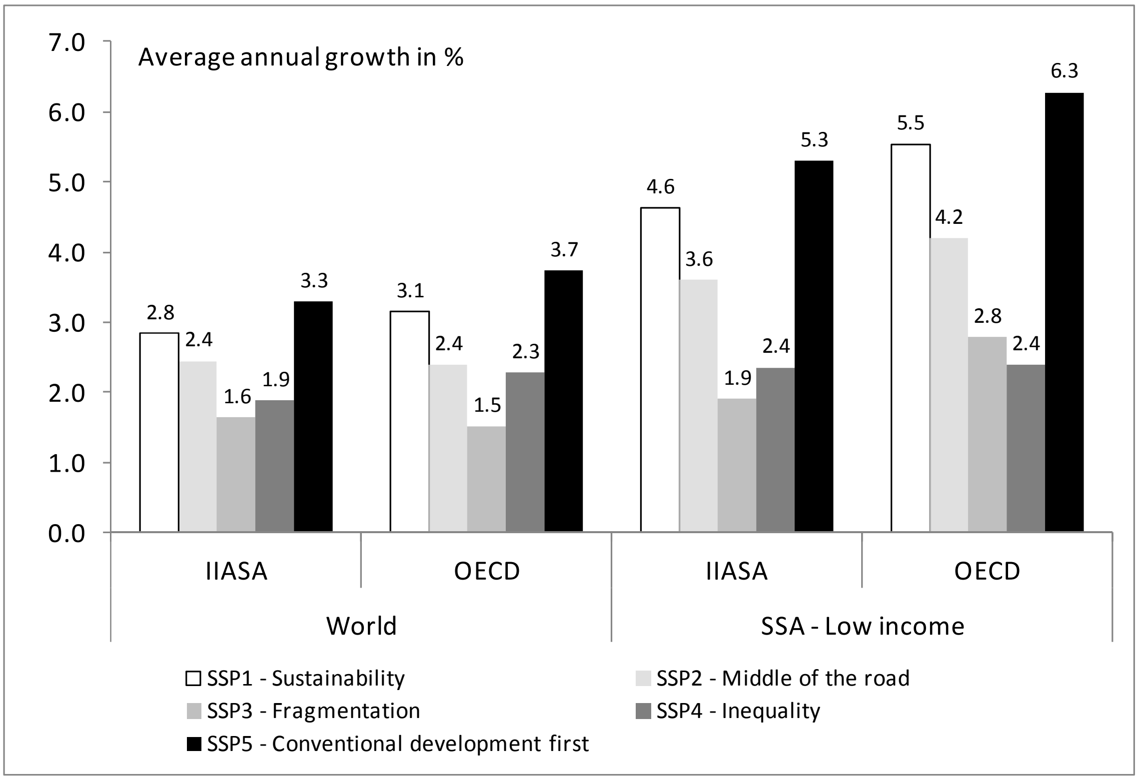
The following conclusions about the demographic drivers of biomass demand and supply can be drawn: first, food and thus biomass demand per capita, at least for vegetal staples, will likely grow considerably faster in SSA than in the rest of the world until 2050, and also far beyond.

Second, projections for population growth for SSA and ROW crucially depend on assumptions about economic and income growth in both country groups.

Projections and consequences of economic growth

Projections of economic development tend to be much more diverse than demographic projections, as economic processes have strong cyclical elements, and their underlying drivers (technical progress, economic policies, and institutional change) are considerably less predictable. This is illustrated by Figure 6 where projected annual per-capita-GDP for the world and lower income countries of SSA (the vast majority of SSA countries) are on display. The five scenarios mainly differ with respect to trends in a) economic productivity and human development of countries, b) economic convergence within and between countries, and c) efforts to improve resource use efficiency and environmental protection. For the world as a whole, projected annual growth rates range from 1.6 (IIASA, SSP3) to 3.7 (OECD, SSP5), while those for SSA-L range from 1.9 (IIASA, SSP3) to 6.3 (OECD, SSP5). For SSA-L, this would mean an increase of 2010 income levels of USD 1173 (IIASA) and USD 1334 (OECD) by factors ranging from 2.1 (IIASA, SSP3) to 11.4 (OECD, SSP5), resulting in wildly diverging income levels from USD 2384 to USD 15250 for the year 2050.

Figure 6: IPCC-SSP projections for annual economic growth rates (%) per capita from 2010-2050 by IIASA and OECD. SSP1 – SSP5 are different scenarios of socio-economic development for the 21st century



Source: IPCC 2014a

We take a similar approach to economics as in demography and consider the scenario that is supposed to continue observable underlying trends, SSP2 ('Middle of the road'), as the most plausible. For SSA, the projections distinguish between low-income (SSA-L) and medium-income countries (SSA-M), the latter comprising just nine countries exemplified by Botswana, Gabon or the Seychelles. Table 4 shows GDP-per-capita for SSA-low-income, SSA-medium, and the world for 2010 and 2050, and the resulting average annual growth rate.

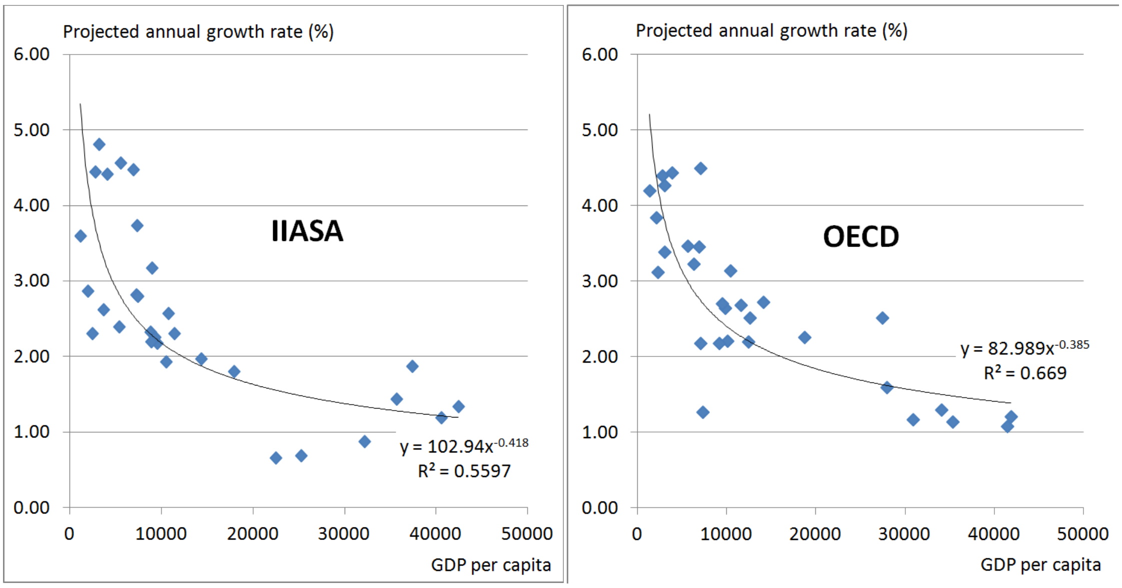
Table 4: Comparison of projected GDP per capita growth for SSA and the world as a whole, according to projections by IIASA and OECD (SSP2 'middle-of-the-road' scenario)

	IIASA			*OECD*		
	GDP p.c. 2010	*GDP p. c. 2050*	*Aver. ann. growth 2010-2050*	*GDP p. c. 2010*	*GDP p. c. 2050*	*Aver. ann. growth 2010-2050*
SSA, low income	1173	4825	3.60	1334	6904	4.19
SSA, medium income	8893	21252	2.20	7250	12023	1.27
World	9666	25431	2.45	9760	25107	2.39

Source: IPCC 2014a

While projections are very optimistic for SSA-L countries which are expected to increase their 2010 income levels by four (IIASA) to five times (OECD), respectively, projections for SSA-M countries are rather moderate by just more or less doubling their current incomes, which would be even below the projected global growth rates. To a certain degree this result reflects the expectation of economic convergence among world regions. This expectation of convergence is reflected in the growth projections for all the world regions covered by IIASA and OECD as shown in Figure 7. The higher the current GDP per capita (horizontal axis), the lower the projected growth rates until 2050 (vertical axis). As SSA is largely a low-income world region, projected GDP increases per capita are quite high, as specified in Table 3.

Figure 7: Current GDP per capita (horizontal) and projected annual growth rates (SSP2 scenario, vertical) for larger world regions from 2010-2050, projections by IIASA (left diagram) and OECD (right diagram)



Source: IPCC 2014a

If these projections for economic and income growth would roughly materialize, they would have profound implications for the region’s biomass demand. On average, higher GDP per capita almost linearly translates into higher household expenditure,[3] the latter which might be interpreted as a proxy for disposable household income. Furthermore, practically everywhere in the world higher disposable household income is correlated with characteristic preference changes for food items, particularly a higher demand for livestock products, which is illustrated by Figure 8. There is only a slight (and non-significant) upward trend for vegetal products with increasing household expenditure (81 Kcal per capita and day for a ten-fold increase). The bulk of additional calorie consumption following increased expenditure originates from animal products. An e.g. four-fold increase of household expenditure for instance results in an average increase of animal consumption of 266 Kcal per day, regardless of the expenditure level.

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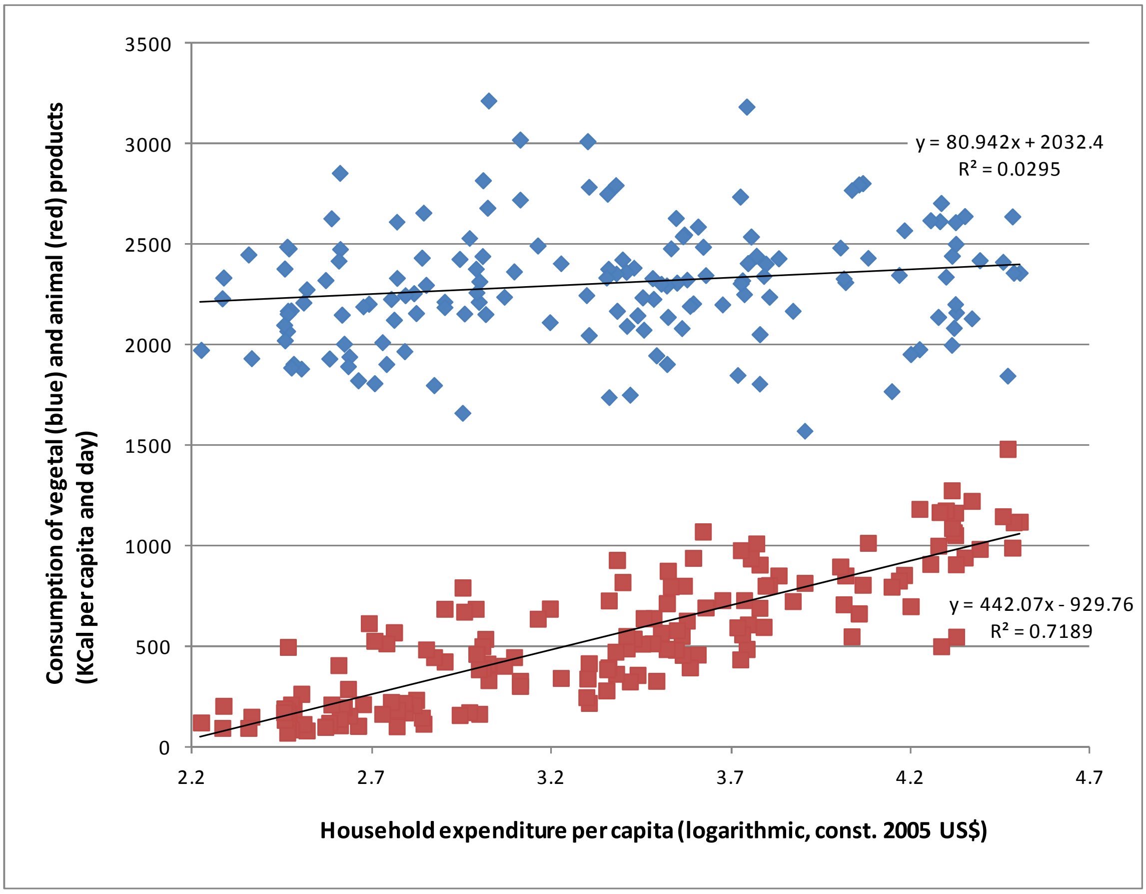
[3] This relation is skewed by countries with very unequal income distributions.

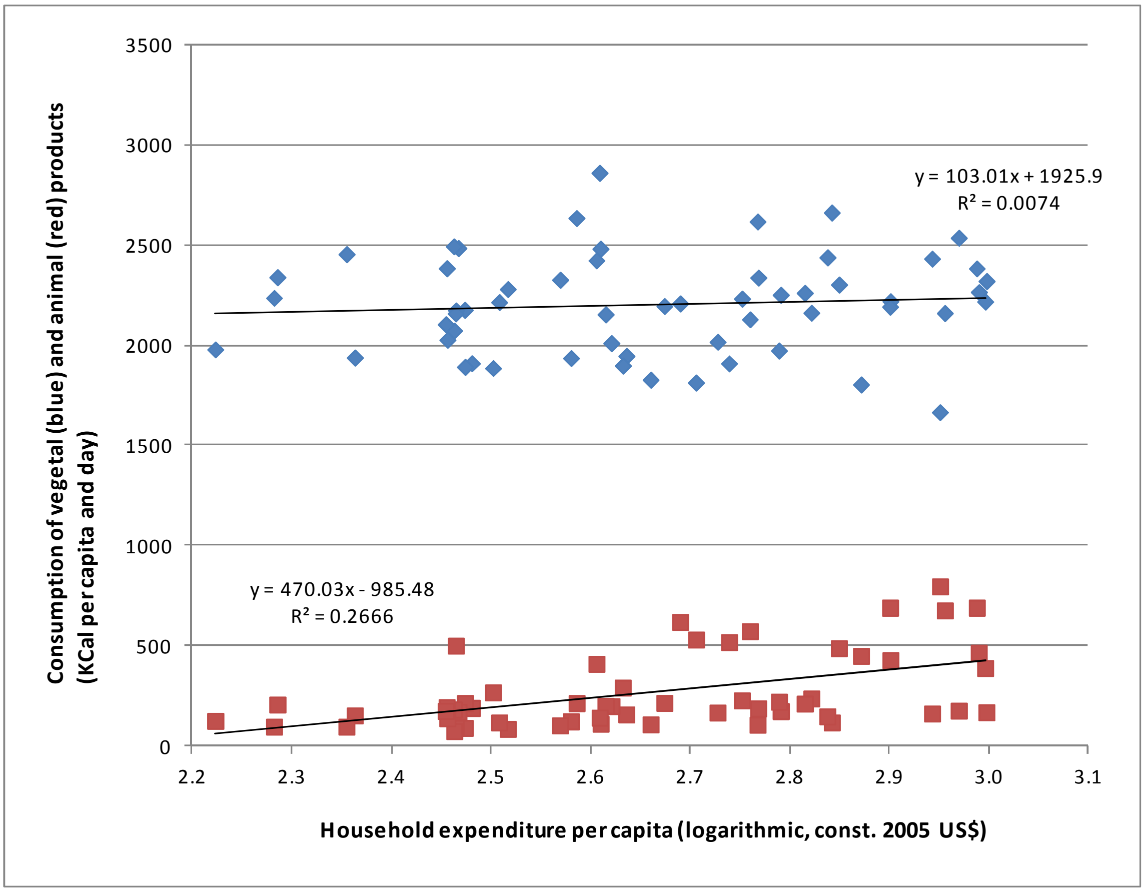
Figure 8: Current household expenditure per capita (horizontal) and consumption of vegetal (blue) and animal calories (red) for a global country sample



Source: FAOSTAT Online Database 2014, World Bank WDI database 2014

Low-income countries below 1000 US $ household expenditure per capita and year also reveal a small and non-significant trend for vegetal products (Figure 9). The trend for animal products is also much less significant than for the total sample in Figure 8, but a ten-fold increase of household expenditure results in an average increase of animal consumption of 470 Kcal per day in this sub-sample, which is similar to the global picture. Most Sub-Saharan African countries belong to this sub-sample of low-income countries.

Figure 9: Current household expenditure per capita (horizontal) and consumption of vegetal (blue) and animal calories (red). Global country sample with household expenditure of less than 1000 USD.



Source: FAOSTAT Online Database 2014, World Bank WDI Database 2014

Higher future demand for animal calories requires higher supply of livestock products in SSA, which can be met by a combination of imports and domestic production. As long as most countries of SSA have not built up export sectors that grow faster than their populations, their economic potential for imports will – despite the expected economic growth in general – remain limited. The bulk of additional livestock demand will therefore have to be met by domestic production. As livestock production requires fodder and feed, it competes with food crop production for agricultural area and thus increases land scarcity, as suggested by Figure 1. Currently, an overwhelming share of SSA's livestock are ruminants that graze on permanent pastures and rangeland in "low-input/low-productivity" farming systems. In more developed countries, livestock is increasingly fed with crops, mainly from cereals.

Table 5: Cereals import and feed shares for SSA, SSA without South Africa, and Non-SSA countries (averages of 2009-2011)

	Cereals imports (% of domestic supply)	*Cereals feed use (% of domestic supply)*
SSA	22.3	12.1
SSA w/o South Africa	22.9	10.0
Non-SSA	15.8	36.3

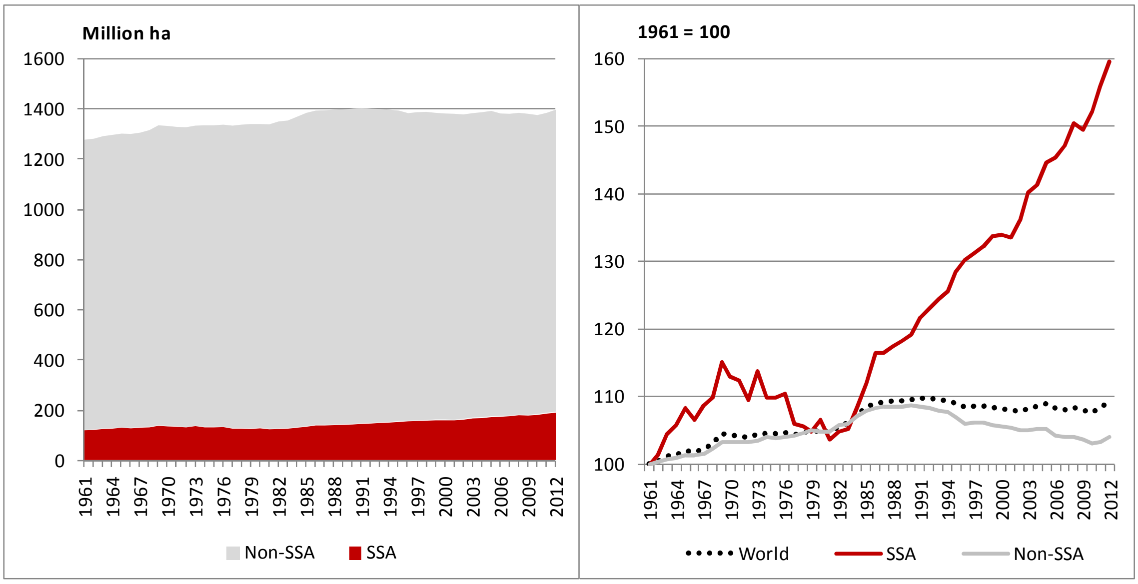
Source: FAOSTAT Online Database 2014

This has not yet taken hold in SSA to a larger degree, as Table 5 shows: while importing a substantial share of its cereals domestic supply, SSA only uses 12% of supply for animal feed, or 10% if South Africa with its relatively industrialized farming and livestock sector is left out of the picture. Outside SSA, more than one-third of cereals are fed to livestock on average, with 40% in North America and 58% in Western Europe. Increasing feed use of crops will increase land scarcity in SSA, which is why land use trends are examined next.

Trends in land scarcity and agro-environmental problems

Given that the global population has almost tripled between 1960 and 2010, it is surprising to see that the global use of cropland has just grown by about ten percent within the same period (Figure 9, left), as this growing population has also tripled its demand for e.g. cereals. This finding means that the overwhelming share of crop production increases were achieved thanks to higher area productivity, i.e. higher crop yields per hectare.

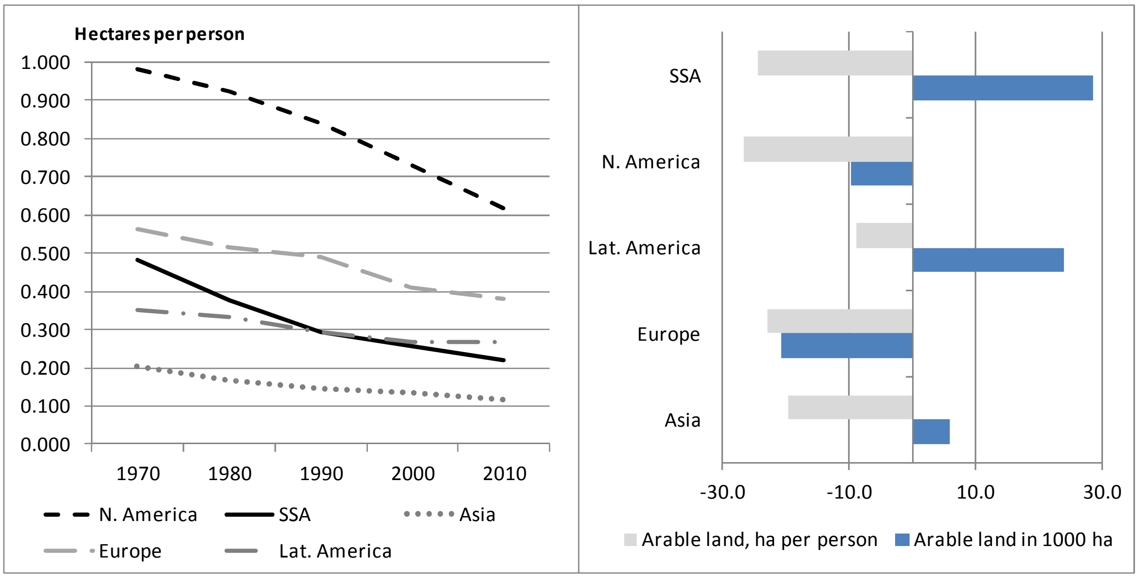
Figure 10: Development of arable land in SSA and Non-SSA (left), and index of arable land in SSA, Non-SSA and World (right) from 1961-2012



Source: FAOSTAT Online Database 2014

However, this was not the case in all world regions. SSA in particular stands out as a region where yield improvements were relatively low, which has required continued rapid growth in cropland use (see the right diagram in Figure 10). Despite increasing total *arable land*[4] use in SSA, rapid population growth in the region still causes arable land per person to decline, as Figure 11 proves. Of the selected major world regions, only North America's land use per person has decreased faster than SSA's since 1990, and SSA's is the second-lowest after densely-populated Asia. So even the 26% increase of land use in SSA since 1990 (right diagram of Figure 11) could not prevent a steep decrease of cropland availability per inhabitant.

Figure 11: Development of arable land in different world regions 1970-2010 (decadal averages, left diagram); changes in arable land use from 1990 to 2010 (in percent, right diagram)



Source: FAOSTAT Online Database 2014

The swift increase in cropland use in SSA raises the question when and where this trend will run into constraints represented by limited availability of land. Table 6 shows recent global estimations for suitable cropland (i.e. suitable for the major food crops and their regional varieties) split into SSA and Non-SSA.

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[4] In FAO terminology, area under ‚arable land‘ accounts for all cropland that is used for annual crops, fodder or rotational fallow. In the following, 'arable land' and 'cropland' are used synonymously.

Table 6: Land with rain-fed crop production potential for SSA and Non-SSA (million ha)

	Non-SSA			*SSA*		
	Million ha	*% of suitable land, non-SSA*	*% of global*	*Million ha*	*% of suitable land, SSA*	*% of global*
Suitable land	3422	-	76.1	1073	-	23.9
Total cropland	1077	31.5	85.5	183	17.1	14.5
Gross reserve	2345	68.5	72.5	890	82.9	27.5
Prohibited use	1386	40.5	76.0	438	40.8	24.0
Net reserve	959	28.0	68.0	452	42.1	32.0

Source: GAEZ v3.0 in Fischer et al. (2011)

It turns out that SSA has a net potential of cropland of more than twice its current use, and one-third of global net reserves. SSA's gross land reserves – that include also forests and protected areas – are even almost five times above current cropland use. Between 1980 and 2012, arable land increased by an average annual rate of 1.3%. If this growth rate continued despite slowing population growth and increasing crop yield trends, SSA would see a further increase of 66% from 2010 to 2050, which would change the ratio of 'cropland' : 'net reserve' from 183 : 452 (2010) to 303 : 332 (2050). But this sufficient continental land endowment does not preclude the regional emergence of problematic land scarcity in more densely populated countries in Western and Central Africa. Chamberlin et al. (2014) point out that land abundance is very unequally distributed across SSA (Table 7), with West Africa likely to become land-scarce even before 2050.

Table 7: Cultivated and potentially available cropland for sub-regions in SSA (million ha)

	East/Central	*Southern*	*West*	*SSA*
Cultivated land (CL)	82.9	39.9	87.8	210.5
PAC excl. Forests	125.7	94.0	27.7	247.4
CL + PAC excl. forests	208.5	133.8	115.5	457.9
CL ¸ (CL + PAC excl. forests)	39.7%	29.8%	76.0%	46.0%

Source: Chamberlin et al. 2014

Not only the total area of suitable land, but also the degree of suitability of this land is relevant for a future land scarcity assessment. The suitability of land for agricultural production is threatened by various biophysical processes (e.g. soil loss, salinization, and desertification) that are summarized under the term 'land degradation'. Land degradation is a concept that is difficult to quantify empirically. The most recent comprehensive attempt to assess land degradation on a global scale is the GLADIS database (Nachtergaele et al. 2010). It contains a list of locations – usually countries – the soils of which are assessed regarding status and trends of different criteria such as vegetation cover, water, biodiversity or pollution. Table 8 compares different degradation aspects for SSA and the rest of the world.

Table 8: Comparison of results of the GLADIS land degradation assessment for SSA and Non-SSA

	SSA	*Non-SSA*	*World*	*Difference SSA to Non-SSA*	*Standard deviation (World)*
Status					
Carbon above ground status	22.1	28.5	27.0	6.4	21.4
Soil constraints status	74.5	80.6	79.2	6.0	14.7
Water status	65.9	67.7	67.3	1.7	33.4
Biodiversity status	39.3	42.3	41.6	3.1	13.4
Biophysical status of land	38.3	46.2	44.4	7.9	17.8
Trends					
Greening and deforestation trend	50.2	50.8	50.7	0.6	3.9
Trend in soil health	42.7	41.0	41.4	1.7	6.7
Trend in water stress	48.1	46.2	46.6	1.9	6.6
Biodiversity risk trend	37.1	36.3	36.5	0.7	4.8
Biophys. land degradation trend	43.6	43.0	43.2	0.6	2.9

Interpretation of the values: status criteria range from 0 (worst) to 100 (best); trend criteria above 50 denote positive, and below 50 denote negative degradation trends. Regional averages weighted by national agri-cultural areas. Sources: Nachtergaele et al. (2010), FAOSTAT Online Database 2014

Generally, the biophysical status of soils in SSA is worse as compared to the rest of the world. For instance, SS-African soils have less above-ground biomass (carbon), or suffer more from constraints such as aluminum toxicity. However, the slightly negative land degradation trends for SSA as a whole are not significantly different from other world regions. This means that, provided that SSA strives to raise land productivity and close existing yield gaps, it is fair to expect that negative effects of land degradation can be alleviated or compensated – in the same fashion as happened e.g. in Southern Asia – in the coming decades. Unfortunately, GLADIS was still considered to be at a preliminary stage when externally reviewed in 2011,[5] and no further progress has been made since then.

Finally, future climatic climate change expected as a result of rising human CO2 emissions will potentially have an impact on crop yields world-wide, with SSA not being an exception. The most important regional weather impacts of climate change are a) warming of regional land surface temperatures, b) changes in amount and temporal patterns of regional precipitation, and c) possible increases of extreme weather events. As to precipitation and extreme weather, divergences among climate models on continental and regional scales are still high, while observable trends are rather weak (IPCC 2014b, p. 64-65), so that coherent and reliable projections for e.g. SSA until 2050 are difficult. For SSA, the most recent IPCC Assessment

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[5] See 'GLADIS peer review report and Management response' from Dec. 2011, p. 12: "However, at the present stage of data availability and quality GLADIS is not yet in the position to provide reliable information for the large majority of stakeholders that would use it".

Report projects slightly more precipitation for Western and Eastern Africa, and lower precipitation for Southern Africa (IPCC 2014c, pp. 1360-65).

Observed and projected temperature trends are more coherent across sources and models, so that a comparison between SSA and other parts of the world are possible. Centennial trends based on temperature observations since 1960 for selected world regions (BEST Project 2014) are compared in Table 9, which shows that climatic warming has predominantly happened in the northern hemisphere, and particularly those countries bordering the polar region. SSA with 1.8°C warming per century ranges below the world average of 1.98°C. Within SSA, the semi-arid Sahel region has warmed fastest, and the tropical and southern regions to a lesser extent. When assuming a continuation of this long-term warming trend until the year 2050, SSA would see 0.72°C additional warming, ranging between 0.61°C for southern Africa and 0.87°C for the Sahel.

Table 9: Warming trend since 1960 in degrees Celsius per century for selected world regions, non-weighted averages across country-wide trends

	°C per century	*Warming until 2050*
Global average	1.98	0.79
Countries bordering polar regions	3.27	1.31
Europe	2.69	1.08
Middle East and North Africa	2.52	1.01
Sub-Saharan Africa (SSA)	1.80	0.72
SSA (Sahel Belt)	2.17	0.87
SSA (Subtropical and tropical)	1.77	0.71
SSA (Southern part)	1.52	0.61
Southeast Asia (tropical)	1.09	0.44

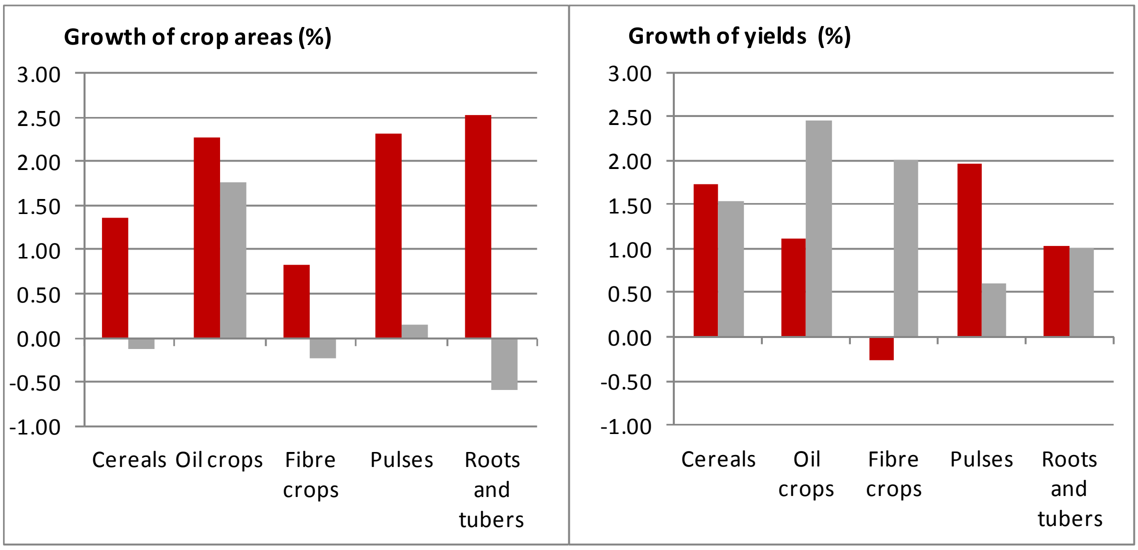
Source: BEST Project (2014)

Modestly increasing temperatures will have profoundly different impacts on the conditions of crop production between different climatic regions. In temperate and polar regions, and wherever else low temperatures act as a limiting factor on yields, increasing temperatures are rather likely to increase crop productivity. In regions with relatively high temperature, further temperature increases would rather depress yields. This is a likely partial effect for practically all of SSA, but the expected interplay of changes in temperature and precipitation makes a regional assessment of resulting impacts more complex: in Western and Eastern Africa, higher temperatures might be compensated by better water availability from rainfall, while in Southern Africa negative effects from rising temperatures could be compounded by less precipitation. The next section explains in more detail how such climate projections influence regionally differentiated global outlook studies on biomass demand and supply.

Trends in crop productivity

For most of the time since data on crop production were collected by FAO, SSA showed a tendency to increase production by expanding crop areas rather than by increasing area productivity. This is illustrated by Figure 12 which compares area and yield growth trends for important crop groupings for the last two decades. All observed crops experienced substantial area expansions in SSA, while in the rest of the world only oil crops increased in area of to considerable extent. During the same period, crop yields in both regions tended to increase (at least for food crops). For cereals, SSA's average growth rates were slightly higher than in the rest of the world, and even much higher for pulses.

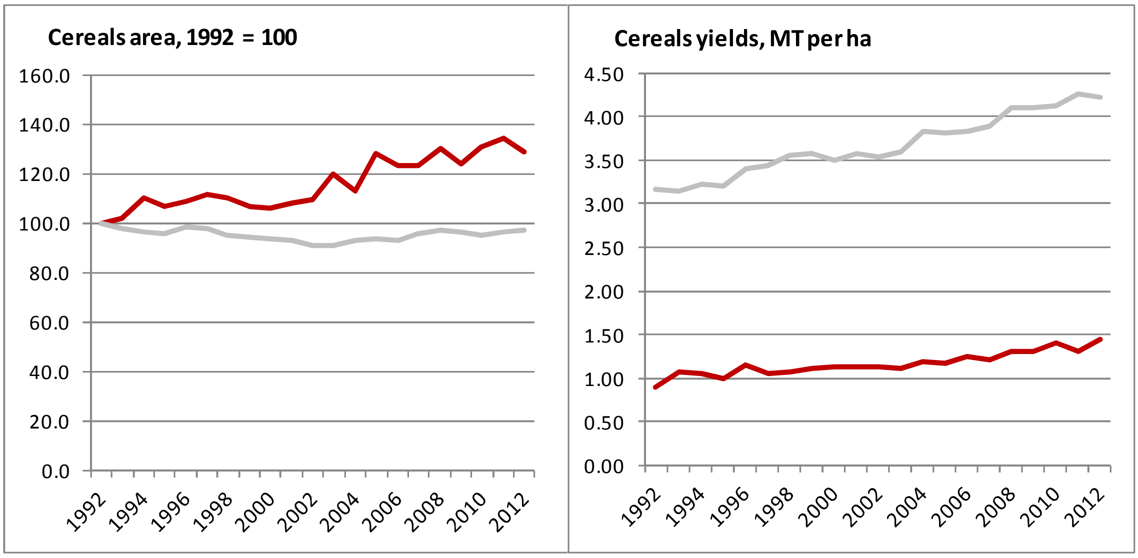
Figure 12: Average annual growth rates (in percent) of areas and yields for 5 different crop groups for SSA (red) and Non-SSA (grey) from 1992 to 2012



Source: FAOSTAT Online Database 2014

But one has to bear in mind that SSA yield levels are usually much lower than outside SSA, which means that the same percentage growth rate results in much lower incremental yield increases. Figure 13 nicely illustrates this by again comparing time series of cereal areas (indexed) and yield levels (MT/ha) between SSA and Non-SSA. In the latter, areas have practically remained flat since 1992, while yields have improved by roughly 1 MT/ha. In SSA, by contrast, areas have expanded by about 35%, while yields improved only by 0.5 MT/ha, which means that SSA would further fall back even when continuing to have the same growth rates as the rest of the world. Given that current cereal yield levels in SSA are still so low, current growth rates should be twice as high to facilitate a catch-up in staple crop productivity at least during the second half of the 21st century.

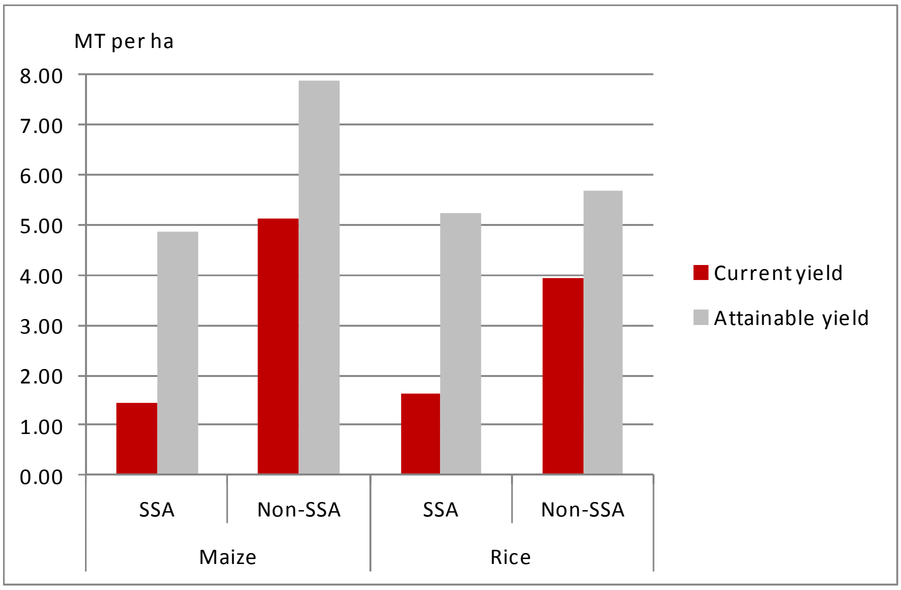
Figure 13: Area (left) and yield (right) trends for cereals in SSA (red lines) and the rest of the world (grey lines) from 1992 to 2012



Source: FAOSTAT Online Database 2014

Part of the explanation for lower yield levels is SSA is that attainable yields for important cereals may be lower than for the rest of the world. In Figure 14 the average yield potential for maize (the most important staple cereal for SSA) is assumed to be almost 40% lower than outside SSA, hardly reaching 5 metric tons per hectare.

Figure 14: Current and attainable yield for maize and rice in SSA and the rest of the world



Source: Own calculations based on Mueller et al. (2012)

For rice, however, the disadvantage of SSA is almost non-existent. Most striking, however, are the huge yield gaps for both maize and rice in SSA, i.e. the difference between the – estimated –

attainable and current yield levels. SSA's yield gap for maize is 70% of the attainable yield (36% for Non-SSA) and 67% for rice (30% for Non-SSA).

What do yield developments and attainable yield levels tell us about plausible yield trends for SSA until 2050? The use of exponential versus linear functional forms is of great importance here. To illustrate the difference between linear and exponential yield growth assumptions, Table 10 gives an overview on alternative cereals yield scenarios for SSA until 2050.

Table 10: Cereals yield scenarios for SSA based on different growth models and base periods

	Trend parameter	*Yield increase 2010-2050 (MT/ha)*	*Yield level in 2050 (MT/ha)*[a]
Exponential trend 1992-2012 (annual growth factor)	1.017	1.39	2.79
Exponential trend 2003-2012 (annual growth factor)	1.026	2.49	3.89
Linear trend 1992-2012 (MT/ha/year)	0.020	0.80	2.20
Linear trend 2003-2012 (MT/ha/year)	0.032	1.30	2.70
Linear trend 1992-2012 (based on Non-SSA, MT/ha/year)	0.056	2.24	3.64

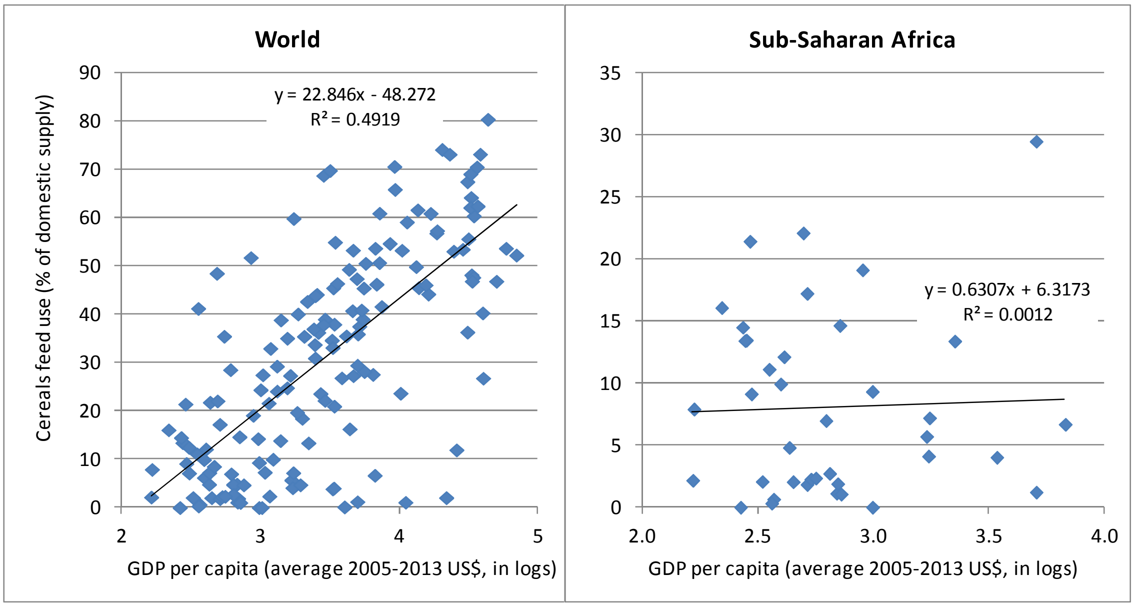
[a] *Calculated by using 1.40 MT/ha as 2010 value. Source: own calculations, FAOSTAT Online Database 2014*

The first two rows display exponential yield trends calculated on the basis of two different estimation periods, 1992-2012 and 2003-2012. The latter period was added because the year 2003 seems to represent a watershed after which yield growth in SSA was markedly larger than before. Assuming exponential trends for yield growth is not realistic. On multidecadal scales, crop yields tend to increase in an almost strictly linear fashion, which is nicely illustrated by Figure 13. This means that the exponential projection of cereal yields based on the period 2003-2012 (second row in Table 10, at 3.89 MT/ha) for the year 2050 is certainly too optimistic. The linear trends from both estimation periods reveal much lower, but more realistic yield projections (rows 3 and 4). Alternatively, one might argue that SSA has a lot to catch up in the area of crop productivity. This catch-up process might be expressed by a linear projection that assumes annual yield increases of the same magnitude as in the rest of the world from 1993-2012 (row 5). Such a linear catch-up process would facilitate 2050 cereal yields of almost the same magnitude as the exponential trend of row 2. However, the attained magnitude of cereals yields (approaching 4 MT/ha) would come close to 80% of attainable yields for cereals in SSA when taking 5 MT/ha from Figure 14 as a rough benchmark. A narrowing of SSA's yield gap within four decades to an extent that so far is only found in highly industrialized countries looks optimistic, in particular when contrasted to the disappointing productivity improvements in the second half of the 20th century.

Impact of driving forces on future land use in SSA

When it comes to assessing the effect of projected increases in population numbers, consumption patterns and crop productivity on land scarcity in SSA (which involves both the additional demand for pasture for fodder, and cropland for feed production), the simple bivariate approaches that have worked fairly well so far are bound to fail. More specifically, if we want to figure out the effect of higher livestock consumption on arable land per person (further dubbed ALPP, the change over time of which is a common proxy for the land scarcity trend), this interferes with a couple of other factors that also impact upon arable land use. One might start by trying to estimate the effect of GDP growth on additional feed use, and continue from there. Figure 15 shows that there is a fairly good correlation between GDP and feed use intensity worldwide (left side), but this causal relation has not yet been established for the SSA country subsample (right side).

Figure 15: GDP per capita (horizontal) and cereal feed use in percent of domestic supply (vertical), worldwide and for SSA



Source: FAOSTAT Online Database 2014, World Bank WDI Database 2014

Moreover, the link from feed use intensity to ALPP is weaker than intuition might suggest, as the correlation matrix in Table 11 demonstrates. This table contains arable land (i.e. cropland) per person plus five factors that should have an influence on the amount of ALPP that is needed to supply the population of a country at a certain stage of economic development and international trade integration. If a country simply imports its additional cereals[6] demand, which means negative net trade (exports minus imports), required ALPP is lowered.[7] Increasing cereal

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[6] As cereals typically constitute the bulk of crops harvested and traded, they are used as a proxy for the entire crop portfolio for trade, yields, and feed use.

[7] Higher exports (positive net trade), by contrast, require more cropland per person in export-oriented countries.

yields per hectare *c.p.* also reduce required ALPP. More demand for animal calories drives up the need for feed, which increases demand for ALPP, and the same effect holds for feed use itself. Finally, a high share of pasture in the total agricultural area of a country suggests two countervailing effects: first, lots of available pasture area may reduce the need to produce feed on cropland, reducing required ALPP. On the other hand, a high pasture share also indicates that still a lot of land reserves are available, thus relaxing land scarcity and thereby reducing the profitability of high crop yields. This latter effect rather drives up ALPP, making the overall effect of this variable ambiguous.

Table 11: Correlation matrix of arable land per person and contributing factors (161 countries worldwide, averages of 2009-2011)

	Net trade (% of supply)	*Cereal yields*	*Animal calories*	*Feed use (% of supply)*	*Pasture (% of ag. area)*
Arable land per person	0.665	-0.124	0.233	0.217	0.131
Net trade as % of cereals supply		0.237	0.259	0.280	-0.093
Cereal yield levels per ha			0.601	0.604	-0.266
Calorie cons. of animal origin				0.745	-0.141
Feed use as % of cereals supply					-0.229

Source: FAOSTAT Online Database 2014

With the exception of net trade, the partial correlations of other variables with ALPP are – despite having the expected signs – relatively small, a situation which suggests the use of multivariate regression to arrive at more reliable partial effects of variables while controlling for covariates. Feed share in domestic supply of cereals is omitted, as it is highly correlated to the consumption of animal calories. The results of the regression model ALPP = *f*(net trade in % of supply; cereal yields; animal calories consumption; pasture as % of agricultural area) are listed in Table 12. The regression is a cross-sectional OLS estimation using an average of the years 2009-2011 from 159 countries world-wide.

Table 12: Multivariate OLS regression results of ALPP (cross-section of 159 countries worldwide) on four explanatory variables

Dependent variable: Arable land per person (square meters)	*Coefficient*	*Standard error*	*Lower 95%*	*Upper 95%*	*t-value*	*P-value*
Constant	5391.5	589.8	4226.3	6556.7	9.141	0.000***
Net cereals trade (% of domest. supply)	32.9	2.4	28.2	37.6	13.805	0.000***
Square root of cereal yields (MT per ha)	-2342.2	317.5	-2969.4	-1714.9	-7.376	0.000***
Animal calorie cons. (per person & day)	2.8	0.5	1.8	3.8	5.474	0.000***
Pasture share (% of agricultural area)	9.2	4.6	0.1	18.3	1.988	0.049**
Multiple correlation coefficient	0.788					
R^2	0.621		Standard error		1635	
Adjusted R^2	0.611		*N*		159	

*** Coefficient significant at the 5% level; *** coefficient significant at the 1% level*

Three explanatory variables of the cross-sectional regression (net trade, yields, animal calories) are significant at the 1% level, and one (pasture share) at the 5% level. This result means that the calculated coefficients are suitable to parameterize functional relations in the conceptual framework that underlies this section. Scenarios for ALPP change until 2050 involving all four explanatory variables are presented in Table 13. The columns represent three scenarios for SSA and one for Non-SSA. All scenarios are based on a common 'medium' trend values for cereals yields, animal calorie consumption (ACC), and the pasture share in agricultural area (see notes below the table for details). Simulations for SSA are varied over the expected net trade share for cereals in total use, which does not reveal a clear trend for SSA. One reason for this unclear trend is that trade is rather a result of market developments driven by fundamental factors, and not a driving factor itself. Thus three varieties for the trade variable were simulated: no growth of net imports to SSA (first column); medium growth of net imports (+7.2% points to 2050, second column); and high growth of net imports (+14.5% points to 2050, third column). Results for Non-SSA were calculated using a small net import trend of +1.7% points towards 2050.

Table 13: Scenarios on ALPP change for SSA and Non-SSA until 2050: combined effects on ALPP

	SSA			*Non-SSA*
	no import growth	*medium import growth*	*high import growth*	
Growth of cereals trade share in % pts.	0.0	-7.3	-14.5	1.7
Partial effect of cereals trade share (m^2)	0.0	-238.1	-476.3	55.8
Partial effect of ACC change (m^2) [a]	666.9	666.9	666.9	569.3
Partial effect of cereals yield change (m^2) [b]	-1077.3	-1077.3	-1077.3	-1086.2
Partial effect of pasture share (m^2) [c]	-73.6	-73.6	-73.6	15.6
Change in ALPP to 2010 level (m^2)	-484.0	-722.1	-960.2	-445.4
ALPP in 2050 (m^2)	1725.1	1487.0	1248.9	1578.2
Change of ALPP by 2050 in %	-21.9	-32.7	-43.5	-22.0

[a] Increase in animal consumption (KCal/cap./day to 2010 level): 242 for SSA, 207 for Non-SSA. Per-capita GDP increase in SSA (average between IIASA and OECD, see Table 4) results in an animal calorie consumption increase of 242 Kcal per capita and day (trend calculation in Figure 9). For Non-SSA, a linear time trend was chosen. [b] Cereal yield change (MT per ha to 2010 level): plus 1.3 for SSA, 2.1 for Non-SSA. [c] Change in pasture share (% points to 2010 share): -8.0 for SSA, 1.7 for Non-SSA. [d] Current ALPP (m2): 2209.1 for SSA, 2023.5 for Non-SSA.

To put these projections of ALPP into perspective, it is useful to compare it with the historical trend for SSA. Between 1970 and 2010, ALPP in SSA decreased by 54.4%, which is lower than even the strongest further reduction of ALPP suggested by Table 13. This means that the driving forces of cropland demand are likely to slow the decrease of ALPP as compared to the recent past, thus contributing to a continuation of total cropland use expansion in SSA. As shown in Figure 10 above, arable land in SSA is expanding unabatedly since the middle of the 1980s at accelerating growth rates. Between 2001 and 2012 an average annual growth rate of 1.5% was observed. On the basis of the medium import growth scenario (second column in Table 13), the combined growth trends of population (+153%) and ALPP (-32.7%) would result in an increase of arable land by 70% to 311 million hectares (from 183 million in 2010, see Table 6). This corresponds to an annual growth of 1.34%, a slight deceleration of the current growth rate. But assuming lower or higher future capacities cereals imports, total cropland use may increase between 43% and 98%, which is shown in the third row in Table 14. That table also illustrates the consequences of projected yield, area and import growth on cereals production and use in SSA and the rest of the world. The most striking feature across the different variables is that changes in SSA can be expected to be much higher than in Non-SSA as a whole. Outside SSA, due to rather moderate population growth, neither total land use nor the different per-capita positions of the cereals balance are likely to change significantly, in stark contrast to SSA. This allows the conclusion that SSA will itself be a major driver of scarcity for biomass commodities in the coming decades, at least under the assumption that the use of energy crops in Non-SSA will not further expand significantly. From an aggregate perspective, SSA itself would not face a shortage of cropland by 2050, but cropland is already becoming scarce in many individual countries. Another doubling of SSA's population towards

2100 would certainly lead to absolute land scarcity for major parts of the region.

Table 14: Scenarios on ALPP change for SSA and Non-SSA until 2050: resulting cereals production, imports and total domestic use

	SSA			*Non-SSA*
	no import growth	*medium import growth*	*high import growth*	
Cereals yields in 2050 (2010 = 1)	1.93	1.93	1.93	1.52
ALPP in 2050 (2010 = 1)	0.78	0.67	0.57	0.78
Total land use in 2050 (2010 = 1)	1.98	1.70	1.43	0.97
Cereals production per cap. 2010 (kg per year)	136	136	136	369
Cereals production per cap. 2050 (kg per year)	205	177	148	437
Cereals production per cap. in 2050 (2010 = 1)	1.51	1.30	1.09	1.18
Cereals imports as % of domest. supply 2010	-19.2	-19.2	-19.2	1.9
Cereals imports as % of domest. supply 2050	-19.2	-26.4	-33.7	3.6
Cereals imports per cap. 2010 (kg per year)	31.8	31.8	31.8	-6.8
Cereals imports per cap. 2050 (kg per year)	48.6	63.4	75.3	-15.0
Cereals total use per cap. 2010 (kg per year)	166	166	166	365
Cereals total use per cap. 2050 (kg per year)	253	240	224	422
Increase in total cereals use 2050 (2010 = 1)	1.53	1.45	1.35	1.16

Notes to the calculation of values: Area and yield changes were multiplied to arrive at the production change, from which future production quantities per capita can be calculated. As the net trade change is part of each scenario, future net trade quantities could also be calculated. Future total use is then production minus net trade, and the change value for total use can then be finally calculated.

The most effective tool to avoid the regional shortages of cropland is the increase of cereals yields above their current, relatively slow growth rate. Cropland use would also increase with the per-capita consumption of calories from animal origin, or a higher pasture share in 2050. The impact of scenarios with varying trends of all variables on total cropland use in SSA are shown in Table 15. ‘Medium change’ values are based either on simple time trends (yields, imports and pasture share) or derived from projections of income per capita (ACC). ‘Low’ and ‘high’ change values are meant to outline a plausible range for future values of exogenous variables.

Table 15: Estimated change in total cropland use in SSA under varying changes for import shares, cereals yields, animal consumption, or pasture share towards 2050 (multiple of 2010)

Variable subject to change	*Low change*	*High change*	*Medium change*
Import share in domestic use [a]	1.98	1.43	all 1.70
Cereals yields [b]	2.13	1.31	
Animal calorie consumption (ACC) [c]	1.32	2.08	
Pasture share in agricultural area [d]	1.79	1.62	

Notes: Each presented value is a combination of a low, medium or high change trend of the variable denoted in the same line with medium growth trends of the three other variables. Values were calculated using estimated ALPP from the regression model multiplied by the projected population growth factor (2.53). The changes 2010 – 2050 are:

[a] *Import share – low: 0; medium: -7.3; high -14.6 (percentage points, from 19.2% in 2010)*

[b] *Cereals yields – low: 0.8; medium: 1.3; high 1.8 (MT/ha, from 1.4 MT/ha in 2010)*

[c] *Animal calorie cons. – low: 121; medium: 242; high 363 (kCal/cap./day, from 337 kCal/cap./day in 2010)*

[d] *Pasture share – low: 0; medium: -8.01; high -16.03 (percentage points, from 76.9% in 2010)*

The results of Table 15 indicate that total cropland in SSA might increase by between 30% and more than 100%, with 70% as a central value. Future crop yields trends in particular will play a pivotal role for the development of biomass potential and demand in SSA. This is further demonstrated in the next section which compares projections by selected global agricultural market modeling systems under harmonized scenarios of driving forces.

3 A comparison of quantitative projections to 2050

Projections of future world market quantities and prices for food and non-food use of biomass are complex and have therefore until recently been carried out by a limited number of research groups and agencies only. The Food and Agriculture Organization (FAO) and the Organization for Economic Cooperation and Development (OECD) regularly prepare an agricultural outlook for a ten-year period (OECD 2011) based on trend projections of basic driving forces (population and economic growth, preference shifts, productivity trends) that are fed into a jointly developed modeling system that is composed of the OECD's AGLINK and on the FAO's COSIMO models. The OECD-FAO outlooks contain projections on commodity production, consumption, trade and prices. In a similar manner, the US Department of Agriculture (USDA) prepares a global medium-term agricultural outlook for a ten-year period based on assumptions on macroeconomic development, population, the value of the US Dollar, the oil price, and assumptions on domestic, trade, and biofuels policies. It focuses on the projection of prices and trade volumes for agricultural commodities that are of importance for US agricultural policy (USDA 2012). The FAO also publishes longer-term commodity outlooks for 2030/2050, albeit on a less regular basis. FAO's most recent long-term outlook (by Alexandratos and Bruinsma 2012) is based on expert projections of key drivers, and not on a global economic market model. Nevertheless, the resulting commodity balances were ensured to be numerically consistent.

In addition to FAO's expert-based approach, the emergence of ever more detailed global databases for global economic simulation models such as the Global Trade Analysis Project (GTAP), and the linking of these to earth observation datasets based on remote sensing have eased the implementation of model-based simulations of global land use, agriculture, and crop biomass markets. In 2014, members of the Agricultural Model Intercomparison Project (AGMIP) made an effort to evaluate ten global economic models that allow long-term (i.e. multi-decadal) commodity outlooks in a series of publications (Nelson and Shively 2014).[8] The numerical outcomes of this model comparison were further processed by us to contrast projected market and resource use trends for SSA against the rest of the world, the results of which will be discussed below.

Two classes of models are employed to create the AGMIP scenarios of global biomass demand: partial equilibrium (PE) and computable general equilibrium (CGE) models. The major difference between these models is that the PE models are limited to few set of commodities with greater level of details. CGE models, by contrast, include all the sectors of the economy at a relatively high level of sectoral aggregation, and are subject to macroeconomic constraints. Further, PE models use reduced-form demand functions to approximate the full demand system while CGE models derive the demand functions from theoretically consistent utility functions involving demand for all commodities (Valin et al. 2014). The main drawback of PE is that they do not capture the non-agro-food sector and thus cannot simulate economy-wide welfare effects. On the other hand, in contrast to CGE models, PE models can explicitly simulate the interplay between resources availability and production technologies in a very detailed fashion.

Consolidated results from selected AGMIP models

The aim of the AGMIP global commodity outlook comparison was to identify differences between model outcomes under comparable scenarios regarding basic driving factors. This section reports average commodity outcomes across AGMIP models with a focus on the difference between SSA and the rest of the world, mainly for a 'middle-of-the-road' scenario (S1) that extends current global trends in driving factors, resembling IPCC scenario SPP2. Other scenarios used made alternative assumptions on the combination of population and GDP growth (S2, see Figure 6 and Table 16), climate change effects on agricultural productivity (S3 - S6), and the growth of the biofuels sector (S7 and S8).

For the S1 scenario, the global population by 2050 in the AGMIP scenario assumed to be 9.264 billion, and 1.969 billion for SSA, probably based on older, lower fertility projections (Table 16). The UN population division (2012 revision) projects 9.55 billion by 2050, and 2.074 billion for SSA in its medium fertility variant. The S2 scenario is based on the IPCC SSP3 scenario which is based on an increasingly fragmented world with higher population and significantly lower economic growth. S2 projects 422 million more inhabitants for SSA by 2050 than S1, and one billion more people globally.

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[8] For related articles, see the special issue of Agricultural Economics 45 (2014).

Table 16: Underlying population projections for scenarios S1 and S2 [R: millions, I: 2005=100]

		2005	*2030*		*2050*	
		R	*R*	*I*	*R*	*I*
SSA	S1	755.5	1350.9	179	1969.1	261
	S2	757.9	1477.7	195	2391.6	316
Non-SSA	S1	5710.3	6952.2	122	7294.6	128
	S2	5717.3	7172.2	125	7866.9	138

Source: Own calculations based on AGMIP projections (Schmitz et al. 2014)

Average assumptions regarding economic development across AGMIP models are displayed in Table 17. Higher population growth is assumed to be coupled with lower growth of per-capita GDP, leading to substantial differences between the scenarios, particularly for SSA. Scenario S1 expects incomes to more than quadruple between 2005 and 2050, being roughly in line with the IIASA and OECD scenarios that rest on the same IPCC storyline (Table 4 above). S2 involves ‘only’ a doubling of incomes, accompanied by much higher population growth.

Table 17: Underlying projections of GDP per capita for scenarios S1 and S2 [R: USD/year, I: 2005=100]

		2005	*2030*		*2050*	
		R	*R*	*I*	*R*	*I*
SSA	S1	819.8	1683.7	205	3742.6	457
	S2	812.7	1288.0	158	1770.9	218
Non-SSA	S1	7646.9	12912.7	169	19185.6	251
	S2	7600.7	10723.2	141	12135.6	160

Source: Own calculations based on AGMIP projections (Schmitz et al. 2014)

The impact of these projections of basic drivers on global biomass markets is reported in the following tables. We restrict results to the average across AGMIP models for the S1 “Middle of the road” scenario. Table 18 addresses changes in global use and production patterns for cereals for 2030 and 2050. Cereals’ total use outside SSA would increase by 27%, overwhelmingly driven by increasing feed use. In SSA use would increase by 44%, mainly driven by food use and less by feed use. This is despite the expectation that feed use in SSA would more than double, but from very low current levels. At the end of the day cereals use in SSA would increase slightly faster than production, thus increasing the need for imports by almost 60%. Taking the per-capita production trend together with population growth by 2050 (see Table 16), total production of cereals is expected to increase by a factor of 3.68 between 2010 and 2050 (1.41 x 2.61).

Table 18: Cereal feed/food use [R: kg/capita/day, I: 2005=100]

		2005	*2030*		*2050*	
		R	*R*	*I*	*R*	*I*
SSA	Production	136.1	166.4	122	191.8	141
	Imports	31.3	36.1	115	49.6	158
	Total use	167.4	202.4	121	241.3	144
	Feed use	13.8	21.0	152	30.9	224
	Food use	127.3	150.9	118	177.3	139
Non-SSA	Production	369.5	429.9	116	475.8	129
	Total use	364.8	423.1	116	461.9	127
	Feed use	126.9	157.2	124	181.7	143
	Food use	181.4	193.2	106	201.2	111

Source: Own calculations based on AGMIP projections (Schmitz et al. 2014)

The increase of feed use in Non-SSA of 43% corresponds with a similar increase in the production and use of the different animal products (Table 19). In SSA, feed use is expected to increase faster (124%) than animal production (72% - 92%, resp.), which can be explained by the expected intensification of animal husbandry in SSA, involving less extensive grazing and higher use of compound feed in animal diets. Production increases would not keep pace with consumption, leading to rising import demand by SSA until 2050 for animal products also, particularly meat.

Table 19: Production (P) and consumption (C) of animal products [R: kg/capita/day, I: 2005=100]

			2005	*2030*		*2050*	
			R	*R*	*I*	*R*	*I*
SSA	Dairy products	P	40.3	56.4	140	69.5	172
		C	33.1	45.3	137	63.2	191
	Non-rum. meat	P	6.3	9.0	143	12.1	192
		C	7.1	10.2	144	14.6	206
	Ruminant meat	P	8.0	11.2	139	14.9	185
		C	7.7	10.8	141	15.4	200
Non-SSA	Dairy products	P	117.5	141.3	120	165.3	141
		C	116.7	139.8	120	165.9	142
	Non-rum. meat	P	40.9	51.3	126	57.8	141
		C	40.8	51.1	125	57.3	140
	Ruminant meat	P	12.6	15.5	123	18.1	144
		C	12.6	15.5	123	17.9	142

Source: Own calculations based on AGMIP projections (Schmitz et al. 2014)

The provision of food energy for SSA's population is expected to improve considerably by 2050 (Table 20), raising average daily intake to an average level (2927 Kcal) that is likely to largely eradicate the problem of protein-energy-malnutrition as a mass phenomenon.

Table 20: Projected calorie intake [R: kCal/capita/day, I: 2005=100]

	2005	*2030*		*2050*	
	R	*R*	*I*	*R*	*I*
SSA	2201.7	2508.5	114	2927.6	133
Non-SSA	2802.2	3059.2	109	3233.7	115

Source: Own calculations based on AGMIP projections (Schmitz et al. 2014)

The substantial increase in the total production of cereals noted above will require both increases in land area and in area productivity (see Table 21 - Table 23). Total cropland use in SSA is projected to increase by 54%, and pasture area by 33%. This contrasts to the development in Non-SSA where cropland is projected to increase by just 8% on average across continents, with the bulk of increase in South America. For SSA this result means that cropland increase as a whole would happen by reducing total pastureland, even though this may be the case in many densely populated areas where crop farmers and herders increasingly compete for land. The result implies that new pastures are likely to emerge from bush, savanna and forests.

Table 21: Projected agricultural land use, total [R: million ha, I: 2005=100]

		2005	*2030*		*2050*	
		R	*R*	*I*	*R*	*I*
SSA	Cropland	172.18	227.49	132	265.99	154
	Pastures	741.02	887.77	120	987.97	133
Non-SSA	Cropland	1014.80	1087.91	107	1091.87	108
	Pastures	1770.49	1794.60	101	1763.38	100

Source: Own calculations based on AGMIP projections (Schmitz et al. 2014)

The overall increase in the use of cropland would not, however, mean an increase in arable land per capita (ALPP), as Table 22 shows. By 2050, ALPP in SSA is projected to decline by -41% from its 2010 value. Cropland endowment per capita would thus decrease dramatically faster in SSA than in the rest of the world (-16%).

Table 22: Projected agricultural land use per capita [R: square meters, I: 2005=100]

		2005	*2030*		*2050*	
		R	*R*	*I*	*R*	*I*
SSA	Cropland	2275.76	1682.42	74	1349.54	59
	Pastures	9776.44	6561.33	67	5011.22	51
Non-SSA	Cropland	1786.05	1572.85	88	1504.54	84
	Pastures	3104.93	2588.44	83	2423.84	78

Source: Own calculations based on AGMIP projections (Schmitz et al. 2014)

In order to achieve the projected production increases 264% in total for cereals, this magnitude and pattern of land use expansion would by far not suffice. The productivity of cropland would also have to increase substantially, as shown in Table 23. The average across the model simulations by Schmitz et al. (2014) suggests that yields would have to increase 2.6-fold per ha for cereals by 2050. Given the sluggish long-run trends of crop yield development in SSA, this is a very optimistic outlook, despite the fact that cereal yields have started to increase at roughly the same rate as in Non-SSA, as noted above. But the AGMIP results also imply that absolute yield gains in SSA for cereals (+1756 kg/ha) are projected to be lower than those outside SSA (+2426 kg/ha).

Table 23: Projected yield trends [R: kg/ha, I: 2005=100]

		2005	*2030*		*2050*	
		R	*R*	*I*	*R*	*I*
SSA	Cereals total	1099.3	1908.8	174	2854.9	260
	Coarse grains	1021.5	1758.1	172	2589.9	254
	Rice	1567.4	2733.7	174	4257.7	272
Non-SSA	Cereals total	3614.9	5017.3	139	6040.4	167
	Coarse grains	3979.5	5810.2	146	7079.8	178
	Rice	4273.1	5689.7	133	6598.5	154

Source: Own calculations based on AGMIP projections (Schmitz et al. 2014)

Long-term projections of coarse grain yields by the FAO (Alexandratos and Bruinsma 2012, p. 16) also contend that land use expansion in SSA could be rather limited until 2050, and that the required production increases would be obtained by 2.3-fold yield increases. Such gains in crop productivity, however, are way above any observed African trends of recent decades. Even the most promising episode of cereals yield development that started in 2003 would just point to a doubling of crop productivity by 2050, at best.

Synopsis

Table 24 summarizes the different outlook versions presented so far (Alexandratos and Bruinsma 2012, further called ‘FAO 2012’; Schmitz et al. 2014, further called ‘AGMIP’, and ‘own projections’). The index numbers displayed are harmonized to the year 2010 as base year. The first four rows show the most crucial factors (population, per-capita GDP, animal consumption, and cereals yields) driving the variables in the last four rows (cereals production and imports per capita, and total and per-capita arable land). The first three rows are drivers of demand, while cereal yields is an important supply driver. All drivers differ significantly between the three sources. As to population growth, this is because population growth projections by UNPD have been strongly revised upwards very recently. While FAO 2012 still calculated with a population number well below one billion for SSA, UNPD projected more than a billion recently after a substantial revision of African growth figures. Income growth per capita differs even more, with FAO assuming just a doubling of incomes. Consistently, the FAO outlook assumes just modest increases in animal consumption (26%), while AGMIP and own calculations rather suggest increases between seventy and eighty percent. On the other hand FAO 2012 is relatively optimistic regarding future cereals productivity increases, and AGMIP even more so.

Table 24: A synopsis of projections for SSA for 2050 from different sources (index, 2010 = 100[a])

	FAO 2050 outlook	*AGMIP average*	*Own projections*[b]
Total population	214	234	253
GDP per capita	239	386	468
Animal calorie intake per capita	126	181	172
Cereals yields	206	234	193
Cereals production per capita[c]	135	147	130
Cereals domestic supply per capita	129	147	145
Cereals net imports per capita	103	151	199
Total arable land	140	147	171
Arable land per capita	65	63	67

Notes: [a] AGMIP and FAO trend indices were re-based to 2010. [b] ‘Own calculations’ are based on an increase in net cereal imports of 7.3 percentage points and a decrease in the share of pastures in agricultural area of 8 percentage points by 2050, respectively, that are fed into the ALPP regression model. [c] Change in cereals production is calculated by multiplying cereal yield and ALLP change factors for all sources, based on the assumption that the share of cereals in total cropland will not change significantly. Sources: Alexandratos and Bruinsma (2012) for ‘FAO 2050 outlook’; Schmitz et al. (2014) for ‘AGMIP average’.

Due to ‘optimistic’ population and animal consumption prospects, the FAO 2012 outlook presumes only modest increases in total use of cereals. Consequently, increases in required cropland use and imports are modest, too. The AGMIP average results also suggest only modest total cropland increases of less than 50% towards 2050 despite higher projections of total use, which is helped by very optimistic cereal yield projections. Our own projections are less optimistic that future supply can meet demand without a faster expansion of total arable land. Most recent trends suggest that FAO 2012 and the AGMIP average may underestimate population and income growth in SSA towards 2050, while both assume a rather optimistic catch-up process for cereal yields that is not supported even by recent positive trends.

4 Conclusions

What are the consequences of these divergent expectations on SSA's possible role in global biomass markets? Less optimistic assumptions about future demographic, economic technological developments have substantial impacts on the cropland resources that SSA will have to mobilize to meet future food demand. Our own projections result in a necessary land expansion that is twice as high as assumed by FAO 2012 or the average across the AGMIP models. Looking back at Table 6, these additional 190 million hectares are still well below the 'net reserve' of 452 million hectares of potential cropland in SSA. Two caveats apply here: first, population growth in SSA will not stop by 2050, but continue to the year 2100 and beyond. The total population of SSA is projected to reach almost 4 billion by 2100 (UNPD 2014), which would almost be a further doubling from 2050 levels. Of course these additional 1.8 billion people would require much less cropland per capita than today due crop yields further increasing towards and beyond 2050. Nevertheless, it cannot be denied that such a demographic development would seriously threaten to exhaust SSA's net cropland capacities until the end of the century. Second, perspectives become even more unsettling when considering the fact that these cropland reserves are not evenly distributed across African nations. Half of the region's potentially available cropland is concentrated in just 7 (of 50) countries. At the same time African regions facing both high population growth and densities are suffering from increasingly severe cropland scarcity already today (Chamberlin et al. 2014). Rural-rural migration driven by cropland scarcity has thus become an increasingly familiar phenomenon in many African countries. This form of agrarian migration is a conflict-prone process even within existing nation-states. To tap SSA's net land resources effectively while alleviating land scarcity in densely populated countries, enormous migration or resettlement between African countries would have to happen during the 21st century. As such a partial re-distribution of SSA's rural population would require the crossing of international borders, it would be difficult to be organized peacefully *and* on a sufficiently large scale at the same time.

It is rather likely that regional land scarcity in SSA will lead to a continuation of the smallholder farm structure, accompanied by accelerated rural-urban migration. This indicates at a further accentuation of the already existing gulf between land-abundant and land-scarce countries with respect to their potential role on world crop biomass markets. Land-abundant countries will be able to substantially expand their cropland area, which would give them the capacity to produce biomass for non-food use for industrial or export purposes. Land-abundant countries would thus have the opportunity to reap the benefits of classical comparative advantage by specializing on the production of biomass for both food and non-food use, and the processing and trading of this biomass. On the other hand, relatively land-scarce countries will more likely focus on the production of food biomass unless they have favorable conditions for profitable, exportable non-food crops such as cotton in Benin or cocoa in Ghana. Nevertheless, most land-scarce countries will likely adopt a food-first strategy accompanied by aggressive job creation in non-agricultural sectors to absorb rural surplus labor and earn foreign exchange to finance food imports. These will be the two principal strategies, but their concrete implementation will depend to a large part on the future degree of cooperation between SSA's countries. The more mobile goods, capital and labor become across the continent, the less will individual countries be bound by their 'geographical destiny'. This will require the removal of intra-African trade barriers, heavy investment in transport infrastructure, and the legal movement of labor and people between countries. The more flexible goods and people could move within SSA, the less will land-scarce countries be tied to a food-first strategy, thus allowing them more degrees of freedom to participate in global biomass markets.

SSA's projected population growth sets the continent far apart from the rest of the world. From 2010 to 2100, the population of Non-SSA is projected to increase by 953 million or 15.6%, while SSA's population is projected to almost quadruple to 3.82 billion or 358% (UNPD 2015). This means that SSA will itself become a major driver of biomass demand, supply, and relative prices in the 21st century, while changes in outside SSA will remain comparatively modest. A major uncertainty regarding the role of Non-SSA is the future level of first-generation biofuel use of crops. Biofuel use is largely dependent first on political decisions and on the price of fossil fuels, both of which are difficult to forecast, as the most recent plunge in oil prices exemplifies. But politically driven biofuel use is unlikely to be sustained in the longer term outside SSA if it can be blamed to drive up food prices worldwide. A further expansion of biofuel production on cropland would thus run into a negative feedback on food-political grounds.

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