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Abstract:

The IPCC community's Shared Socio-economic Pathways (SSPs) are a set of alternative global development futures focused on drivers of challenges to mitigation of and adaptation to climate change. However, the impacts and drivers of plausible future development at any national or regional level have yet to be examined for consistency within the global narrative.

In this paper, we present four globally-consistent regional scenarios on Western Africa's development that have been used to test and develop a range of national and regional policies. The regional scenarios were outlined independently by regional stakeholders but built around the context of the SSPs. The scenarios were quantified using two agricultural models, GLOBIOM and IMPACT, in interaction with drivers outlined by the SSPs and guided by semi-quantitative information from the stakeholders.

Our paper 1) demonstrates how linkages of global SSPs and regional multi-stakeholder scenarios can be achieved through a process of critical comparison, starting from regional priorities, to produce consistent scenarios for future regional development; 2) provides insights for Western Africa on the future of development, agriculture, food security and climate impacts in both qualitative and quantitative scenarios; 3) reports on a set of scalable scenarios for regional decision makers and the scientific community to use to build and test robust agriculture and climate policies.

1. Introduction

The IPCC community has developed a new set of global scenarios that provides various combinations of radiative forcing scenarios (Representative Concentration Pathways or RCPs) and socio-economic development scenarios (Shared Socio-economic Pathways or SSPs) (O'Neill et al. 2014; van Vuuren et al. 2013; O'Neill et al. 2015). These scenarios provide a global background or template for processes at lower geographical levels that seek to use scenarios to guide regional, national or sub-national planning. The SSPs/RCPs can provide assumptions about global socio-economic and climate drivers. Conversely, there is scope for sub-global processes to complement the SSPs/RCPs with more regionally detailed assumptions and results, and help in the regional contextualization of the global scenarios. Finally, linking sub-global scenario assessments to the SSPs/RCPs allows for a degree of consistency across regions within and between scenario projects.

This paper focuses on regional scenario development for policy guidance on climate adaptation, agriculture, food security and development for West Africa, conducted by the CGIAR research program on Climate Change, Agriculture and Food Security (CCAFS). In this process, regional scenarios have been developed, linked to the SSPs/RCPs and quantified using agricultural economic models, and used for policy guidance in the region.

The CCAFS regional scenarios provide multiple narratives and quantitative assessments of plausible futures based around the SSPs, and when used together, they provide a meso-scale representative agricultural pathways (RAPs) which can be disaggregated and downscaled for other sub-regional, national and sub-national assessments (Valdivia et al. 2015; Kihara et al. 2015).

The objective of this paper is to demonstrate how global SSPs and regional multi-stakeholder scenarios can be linked to produce consistent but critically independent scenarios for future regional development, including development in the agricultural sector. We quantifying the scenarios using global partial-equilibrium models to provide insights from multi-stakeholder scenarios on the future of food security, environment, and rural livelihoods through both qualitative and quantitative scenarios for West Africa

The CCAFS scenarios project takes the region as a starting point, because many of the drivers of food insecurity, poverty and climate vulnerability can be productively analyzed at the regional level (Ingram 2011). In this paper we highlight the development process and use of scenarios in West Africa, where the focus is on the ECOWAS (Economic Community of West African States) region, with a case study focus on policy guidance in Ghana, Burkina Faso, Niger, Senegal and Mali. Though beyond the scope of this paper, the use of scenarios for policy guidance is a main focus for this project, as reported by Vervoort et al. (2014).

The framework to develop the scenarios has been thoroughly documented (van Vuuren et al. 2013; O'Neill et al. 2014; Müller and Robertson 2014; Schweizer and O'Neill 2013), linked to previous scenario assessments (van Vuuren and Carter 2013), and is beginning to be scrutinized through a national (Absar and Preston 2015) and human impact (Hasegawa et al. 2015) lens.

The purpose of this paper is not to explore the process by which the integrated scenarios were created but instead to explore their usefulness in addressing the uncertainty of future development as a tool to build globally-consistent regional scenarios. This regional context serves to assist policy makers in developing robust agriculture and climate adaptation plans and strategies but also provides the scientific community working at the regional, national, and sub-national level with multiple pathways for development, of the land use and agriculture sector in particular, that can be disaggregated or linked to adaptation assessments (Valdivia et al. 2015; Antle et al. 2015; Kihara et al. 2015). As the concept of the SSPs is vital to this purpose, it serves to present a summary of the narratives here. Rather than using two drivers of uncertainty, as many future scenarios processes have considered (Nakicenovic et al. 2000; Vervoort et al. 2014), these scenarios were built on two-axis, adaptation and mitigation challenges, where the outcome, or level of, challenge are the end points of each axis (high and low challenges) and the combination of these define "challenge space" of the scenario (O'Neill et al. 2014) and are presented in Figure 1. The combination of challenges from which scenarios emerged were then constructed by identifying the drivers of the challenge outcomes such as population and urbanization (Kc and Lutz 2014; Jiang and O'Neill 2015) and economic growth (Crespo

Cuaresma 2015; Leimbach et al. 2015; Dellink et al. 2015) and building a rich narrative of each pathway using the quantitative and semi-quantitative drivers (O'Neill et al. 2015).

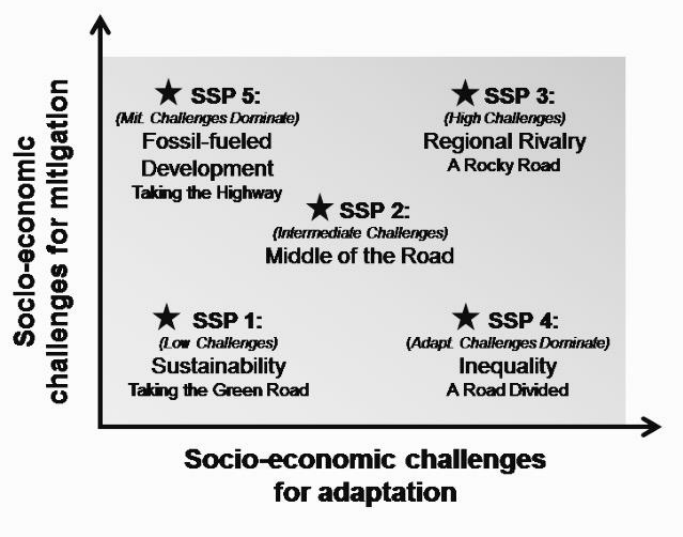


Figure 1 Five Shared Socio-economic Pathways (SSPs) and each SSPs' representation of challenges to adaptation to mitigation.(Source: O'Neill et al., 2015)

2. Methodology

2.1 Scenario framework

The CCAFS scenarios process in Western Africa was started to examine the impact of future climate and socio-economic drivers on food security, environment and rural livelihoods with regional stakeholders. Because the main focus of the regional scenarios exercises was on Mali, Niger, Burkina Faso, Senegal and Ghana, participants in the process were from these countries– but broader regional perspectives (ECOWAS representatives, the CORAF/WECARD research network) were also involved. 94 participants from governments (agriculture and environment ministries, meteorological institutes) research organizations, national and regional civil society organizations, international non-governmental organizations (INGOs), academia and the media participated in the original development of the scenarios over three workshops. Following the development of the qualitative scenarios by stakeholders, the scenarios were quantified using two global partial-equilibrium economic models, each with different assumptions – GLOBIOM (Havlík et al. 2014), developed by the International Institute for Applied Systems Analysis (IIASA) and IMPACT (Rosegrant and Team 2012), developed by the International Food Policy Research Institute (IFPRI).

The CCAFS scenarios were ultimately developed to represent developments over time on the way to a 2050 time horizon. Stakeholders outlined four scenarios, structured along two axes of uncertainty, using narrative flowcharts, conceptual maps, storylines, and a range of semi-

quantitative indicators including information on governance, agriculture, food security and livelihoods. Participants selected two axes from a broad set of future uncertainties in the region to define the four regional scenarios. The axes identified were 1) whether state or non-state actors dominate the regional development process; and 2) whether short or long-term priorities dominate policy-making.

Regional stakeholders took ownership of the process along the three workshops by creating narratives of each scenario and offering information on the relevant drivers of change as they related to agriculture, food security and climate adaptation/mitigation in the future of West Africa: workshop 1 focused on driver identification; workshop 2 focused on scenario narrative development; workshop 3 focused on providing semi-quantitative estimates for scenario variables and model inputs, in close collaboration with the modelling teams. Stakeholders also crafted scenario names that give some hint to the nature of the scenarios.

Self-Determination is a scenario where state actors dominate development and agendas are focused on the long-term. *Cash, Control, Calories* is a scenario where state actors dominate development and with a myopic agenda setting. *Civil Society to the Rescue?* is a scenario with non-state actors dominating regional development with a long-term strategic agenda. *Save Yourself* is a scenario where non-state actors dominate the regional development and their focus is on the short-term. While each scenario describes the future to 2050, in the scenarios where governance is focused on the shorter term, we see that governments focus on short-term priorities, this does not mean that the scenarios are themselves shorter. Instead, throughout the time period of these scenarios, short-term concerns are given priority. This results in a relative lack of investment in long-term projects and short cycles of growth and investment in other areas, making developments in the two scenarios with this characteristic more unstable. Longer narratives of the CCAFS scenarios can be found in Appendix A.

Although the CCAFS regional scenarios development process has focused its objectives around policy engagement and planning, facilitators of the process have been participants of the SSP development community. In particular, IIASA has been an active member of the SSP development process, first through the development of the scenarios and their narratives (O'Neill et al. 2014; O'Neill et al. 2015), and then by modeling the future economic and demographic quantitative change for each pathway (Kc and Lutz 2014) needed for integrated-assessment models (IAM). As such, it follows that the SSPs and the CCAFS can be linked in a practical way since both scenarios have moved in a parallel direction in terms of scenarios development *process*: participatory, end-state oriented (Vervoort et al. 2014; O'Neill et al. 2014); *focus*: socio-economic development with an uncertainty of future climate leading to challenges for adaption; and consistent sources for quantitative drivers of future change (O'Neill et al. 2015; Vervoort et al. 2014; Herrero et al. 2014)(Zurek and Henrichs 2007). We have followed the methods suggested by Van Ruijven et al (2014) for downscaling and using the global SSPs for regional impact, adaptation, and vulnerability (IAV) studies which include using the SSPs as a boundary condition and developing nested regional storylines that would be internally consistent within the

global framework. In the sections that follow we present the outcomes of the downscaling of SSPs within the regionally appropriate storylines of the CCAFS scenarios.

Using the unique link between the CCAFS regional scenarios developed with stakeholders and quantified by economic models in the plausibility space of the SSPs, we can offer regionally appropriate and climate independent regional RAPs (Figure 2). These regional RAPs provide feedback to the global RAPs as well as provide consistency for downscaled scenarios. To some extent, field level and subnational economic impact analysis has begun to integrate the agricultural technology trends from global economic models (Antle et al. 2015).

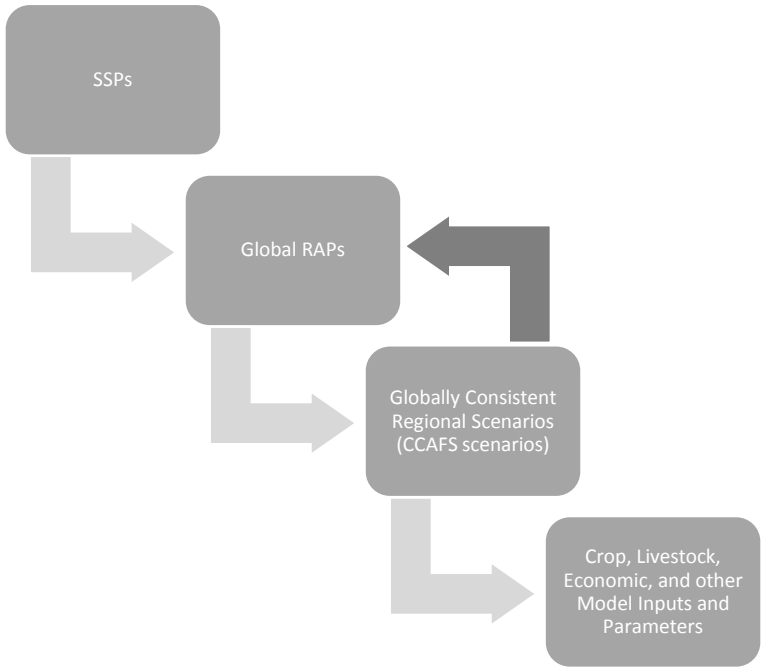


Figure 2 Globally consistent regional scenarios adapted from Figure 4 in (Valdivia et al. 2015)

2.2 Quantified CCAFS Scenarios Drivers

The quantification process of the regional scenarios has two parts: 1) interpretation of the stakeholder semi-quantitative indicators, into numerical values to be used as drivers in both models; and 2) running the models over the time period with the drivers for each scenario and examining the model results for consistency using the scenarios storylines and the semi-quantitative indicators. The drivers included in the quantification include population, GDP, technological improvements in crop and livestock yields, farm input costs. We have translated the semi-quantitative indicators into model drivers by using the socioeconomic drivers of the SSPs as a starting point for CCAFS scenarios and made a critical comparison between the

stakeholder-generated scenarios and the SSPs(O'Neill et al. 2014; O'Neill et al. 2015; Kc and Lutz 2014; Chateau and Dellink 2012). Table 1 presents the full set of semi-quantitative indicators and note which indicators serve as a model input or model output; they have been grouped into categories consistent with those presented by O'Neill et al (2015). The mapping of indicators to SSP indicators can be found in Appendix B. In the following paragraphs, we present the drivers of change used by the models in the quantification of CCAFS scenarios nested within and bounded by the SSP drivers

Table 1 Semi-quantitative Indicators of Interest for West Africa Scenarios Stakeholders

Demographics/Human Development	Economy & Lifestyle/ Policies & Institutions	Environment and Natural Resources/ Technology
Population Growth/Urbanization+, *	Gross Domestic Product+, *	Terrestrial species biodiversity indicator+, *
Women with higher education*	Percent population in poverty*	Marine species biodiversity indicator * Forest cover++, *
Access to health care*	Dietary Diversity++, *	Yields for rainfed crops+, *
Access to potable water* Equity*	Farmer input prices+ Transportation infrastructure	Yields for irrigated crops+, *
Prevalence of malaria*	Existence of social protection schemes; percent population covered *	Area for rainfed arable land++, *
	Number of community based organizations * Corruption index *	Area for irrigated arable land++, * Livestock yield change+, *
	Crime rates	Livestock numbers++
	Reports of contaminated food/ food borne diseases; aflatoxins *	Water Availability for Agriculture+, *

+ indicates this indicator was translated from semi-quantitative information into values used as a model input

++ indicates that this indicator is was evaluated in the context as a model output

* indicates that this indicator aligns to a qualitative element of the SSPs (O'Neill et al. 2015)

2.2.1 GLOBIOM and IMPACT

Integrating the regional qualitative stories developed by stakeholders into models, can offer an idea of how regional changes, such as population growth, can affect something else that may seem unrelated, such as the expansion of cropland. GLOBIOM and IMPACT are partial-equilibrium models that use the underlying assumptions of relationships between prices, supply, and demand of products at the initial year of the time period (2000 for GLOBIOM, 2005 for

IMPACT) and examine how changes in certain drivers change the relationship in the future. As global models, GLOBIOM and IMPACT examine future development of, not only the region, but of the rest of the world, creating globally-consistent regional scenarios. The model outputs from the scenarios modeled by GLOBIOM may prove useful as an input for additional modeling of regional RAPs because it considers multiple management systems, or *technologies*, the biophysical environment of production, or *climates*, and the *socioeconomic* context of the region (Antle et al. 2015). IMPACT has a long history of using in scenario analysis of alternative futures in the global agriculture system, and with recent modeling improvements has expanded the commodities and countries that can be directly analyzed. Table 2 presents the main similarities and differences about the both models used for quantifying the scenarios.

Table 2 GLOBIOM and IMPACT comparison (Source: Authors)

	GLOBIOM	**IMPACT**
Economic Sector	Agriculture sector including crops, livestock, bioenergy, and forestry	Agriculture sector including crops, ag. processing, and livestock
Time Horizon	2000–2050/2100	2005-2050
Role of Markets	Regional markets linked through global markets determine supply and demand	Global markets determine supply and demand
Geography	Global representing 30 country/regions	Global representing 159 country/regions
Resolution of Production side	Bottom-up approach at detailed gird-cell level (>10,000 worldwide) (4 crop production systems and 8 livestock production systems)	320 food production units (intersection of national and hydrological boundaries) (2 crop production systems and 8 livestock production systems)
Commodities	30 agricultural commodities (18 crops, 5 forest products, 7 livestock products, 9 bioenergy products)	60 agricultural commodities (39 crops, 6 livestock, 15 processed goods)
Environment	GHG accounting, irrigation water use, and endogenous land-use change	Hydrology, water basin management of irrigation water, exogenous and endogenous cropland area expansion
Climate Change	Represented by EPIC crop model	Represented by DSSAT crop models and linked hydrology models

2.2.2 Crop productivity

Technical progress in crop production is represented in both models through an increase in crop yields. As a starting point for the future projections of crop yields, we have used an econometric

estimate of the relationship between crop yields and GDP per capita assumptions of the SSPs (Herrero et al. 2014). The SSP crop yield projections used as a starting point then consider the scenario narratives on agricultural productivity both for scenario-specific storylines as well as crop-specific productivity. Historically, increases in production within the region have come from expansions in cropland area rather than through significant yield improvements (Byerlee, Stevenson, and Villoria 2014; Hillocks 2002). The exogenous change yield improvements would have on domestically produced calories are presented in Figure 3 for the CCAFS scenarios and *SSP2*, for Western Africa as well as globally. Yields, being exogenous drivers and not model outputs, do not represent the transitions between low-input low-yielding crop systems to high-input, high-yield crop systems or reallocation of crop production to highly productive land or crop types, the yield gap between Western Africa and the global average will remain a challenge for the agricultural system even in the scenario with the highest investment in agriculture, *Self-Determination.*

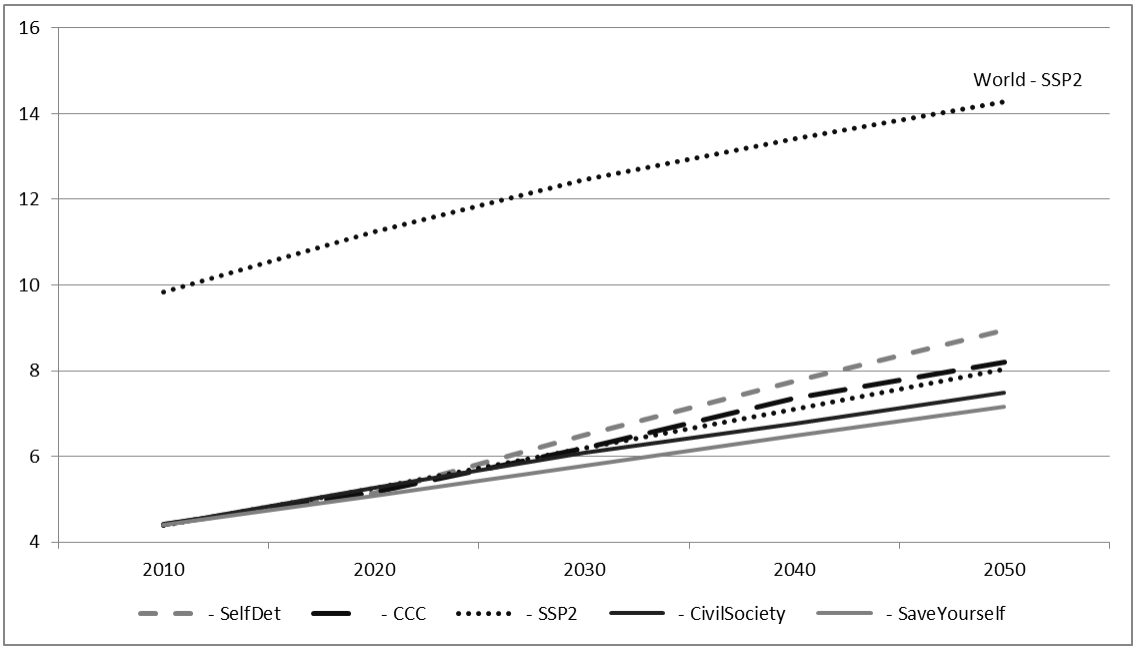


Figure 3 Aggregate Exogenous Crop Yields (gigacalories per ha) for Western Africa by scenario and for *SSP2* and global *SSP2* average (Source: Authors)

2.2.3 Livestock productivity

Sub-Saharan Africa has been the focus of a recent foresight study to examine the potential of the region to meet a growing demand for livestock products, through transitions from extensive land based systems to mixed crop-livestock systems and also yield improvements by feed utilization(Herrero et al. 2014). The suggested actions (intensifying pastoral systems while also protecting pastoralist and protecting animal health) echo those made in the West African

assessment of livestock by the Sahel West African Club Secretariat and OCED (Kamuanga et al. 2008).

To model the productivity of the livestock sector, we use the conversion efficiency of livestock product per unit of feed projections, as presented in *African Livestock Futures* (Herrero et al 2014), for the SSPs as a starting point for the regional scenarios and further developed the pathways using the narratives and semi-quantitative drivers. Investment in ruminant production due to the growing demand result in a yield improvements in *Self-Determination*, while in *Cash, Control, Calories* the focus is on dairy production and monogastric production in the early decades. In *Civil Society to the Rescue?* meat demand drives the investments from private sector and social entrepreneurs. Little investment is made for livestock or veterinary services in the *Save Yourself* scenario resulting in relatively insignificant yield improvements.

2.2.4 Socioeconomic development

Economic development and population growth are essential elements in the models, and when combined give per capita income a critical factor in determining food demand (Valin et al. 2014). We compared the socioeconomic and demographic developments for the region guided by the scenario narratives and the semi-quantitative logic and directions of changes as presented in Palazzo et al. (2014) for the CCAFS scenarios over the same time period for the SSPs as quantified by the SSP developers (Kc & Lutz 2014; O'Neill et al. 2014; Dellink et al. 2015). In West Africa, the population of the region grows from 300 million in 2010 to between almost 600 million in *Self-Determination* or 800 million in *Save Yourself*. GDP per capita increases across all scenarios, but by 2050 all remain lower than the regional SSP projections. *Cash, Control, Calories* initially sees the largest increase, but its GDP development is unstable, and it begins to slow and actually declines slightly after 2040 –reflecting the short-termism of the scenario. Per capita GDP is highest in *Self-Determination* by 2050. *Civil Society to the Rescue?* experiences a steady and consistent increase in per capita GDP, albeit not a particularly large one over time. Per capita GDP in *Save Yourself* increases the least of the scenarios over the time period and follows cycles of growth and recession, which represents unstable economic development. Appendix D provides more details on the macroeconomic development of the region

2.2.5 Cropland Area Expansion

GLOBIOM models the competition for land endogenously, meaning that sectors compete for land based on the value of the land for production of wood products, crops, and livestock grazing, as well as the cost and suitability associated with converting the land to other uses (Havlík et al. 2014). To harmonize the quantitative modeling results, cropland area expansion as modeled by GLOBIOM was used as an input into IMPACT. Within IMPACT, the distribution of crop area by crop type and management system, in this case irrigated or rainfed cropland area, remained endogenous. Cropland expands in the region nearly 55% in SSP 2 by 2050, with expansion in *Cash, Control, Calories* and *Self-Determination* increasing less (4% and 9% less,

respectively) and *Save Yourself* and *Civil Society to the Rescue*? increasing slightly more (4% and 2% more).

2.2.6 Regional integration

The state and potential for economic integration within Africa and the ECOWAS community has been scrutinized and estimated (United Nations 2009; UNCTAD 2012) and the effects of regional integration as it pertains to food security have also been examined by quantitative modeling (Dijk 2011) The degree to which regional integration efforts are succeeding within agriculture highlight the challenges facing the region, where competing national interests and standards often clash with competing international donor initiatives (Rohrbach, Minde, and Howard 2003).

Simson and Tang (2013) suggest that shocks in the agricultural supply chain, stemming from conflicts or climate change, are one of the most important causes of food insecurity in the ECOWAS region. Conflicts are highlighted in each of the scenarios, however, the lack of strong state governments combined with short-term priority setting, in *Save Yourself* give this scenario the most potential for food insecurity. Limitations in the trade of both the inputs to and products of agriculture can have profound effects on food security (Baldos and Hertel 2015; Mosnier et al. 2014). The CCAFS scenario narratives consider the challenges to regional integration, which have been brought into the quantitative modeling of GLOBIOM through impacts in the farm input costs (Appendix C).

2.2.7 Development outside of Western Africa

To examine the impact of the scenarios assumptions within the region, the global context was assumed to follow the same trend of population and economic growth in each of the scenarios. The rest of world, in this case, faces the population and economic development of the *SSP2*: Middle of the Road where, by 2050, the global population reaches 9.2 billion people (Kc and Lutz 2014). The global average GDP per capita is expected double to reach around 16,000 USD by 2050. As discussed earlier, the climate impacts on crop yields are also applied globally. The impacts of climate change on agriculture will be worse for some regions (Nelson et al. 2010; Leclère et al. 2014; Mosnier et al. 2014). Without considering the potential climate impacts to the regions outside of Western Africa, we would underestimate the total climate change impacts, both the local effects as well as the effects on regions from which Western Africa imports

2.2.8 Climate change impacts

West Africa is highly dependent on agriculture, predominantly rainfed agriculture, which at the mercy of a changing climate, making the region particularly vulnerable. The strictly biophysical impacts on crop production due to changes in climate have been examined extensively within the model intercomparison communities of AgMIP and ISI-MIP through globally-gridded crop models (GGCM) (Müller & Robertson 2014). For West Africa, the analysis of impacts through crop models as well as through empirical study find that the negative impacts of climate change

on agriculture are robust, though the magnitude of impact remains uncertain (Jalloh et al. 2013; Sultan et al. 2013; Roudier et al. 2011; Müller 2011; Müller et al. 2011; Müller & Robertson 2014). These studies stress the role of temperature change and of carbon fertilization in the region, and highlight the challenge to produce meaningful scientific projections from studies with significant methodological differences(Müller et al. 2011).

Climate impacts are applied to the crop yields in the models as relative differences in crop growth from simulations in GGCMs using conditions of future climates from GCM models (Leclère et al. 2014; Mosnier et al. 2014; Nelson et al. 2014; Müller and Robertson 2014). The impacts of CO2 fertilization on crop yields is included the EPIC (Environmental Policy Integrated Climate model) crop modeling simulations used within GLOBIOM, while IMPACT does not consider these impacts (Appendix F). The scientific community has yet to reach an agreement on the whether the potential benefits from increases in CO2 can be taken up and used crops, especially if temperature and precipitation reduce crop yields, but taken together the yields from GLOBIOM and IMPACT can show the potential range of the biophysical and economic impacts on crop yields from climate change.

3. Results

The CCAFS scenarios, developed by stakeholders and then modeled with GLOBIOM and IMPACT, help to create a complete picture of the changes over time and among the scenarios in terms of socio-economic and agricultural development for Western Africa and also offer a regionally appropriate elaboration of SSPs, which can be useful for future regional adaptation and mitigation research. The quantified scenarios as they are presented here have been used by policy makers to test policy options under possible futures. First we will present the mapping of the CCAFS scenarios to the SSP scenarios, then we highlight the impacts of the scenarios on improving food security, the regional supply of crop and livestock products and impacts on the environment including land use change.

3.1 CCAFS scenarios in the Context of the SSPs

In *Self-Determination*, where strong state actors focus on long-term issues, semi-quantitative indicators align closely with *SSP1: Sustainability* in nearly all qualitative elements describing the SSP narrative, such as investments in productivity and extension services, increased education and health and sanitation services, regulations to reduce deforestation, and effective social protection schemes. A key difference is that investments are estimated to be lower in this scenario due to a lack of financial support from outside of the region and a reliance on regional resources.

Save Yourself, where action is not taken by the weak and unstable governments, but by CSOs in an emergency response manner, and by the private sector acting with short-term profitability interests, mirrors the low-income country narrative of *SSP4: Inequality* and an overall global narrative of *SSP3: Regional Rivalry*, of low technology development for the agriculture sector

and food security issues due to growing inequality and high population growth. The key difference is that this West Africa scenario sees more instability in its development, where the SSPs represent more gradual change.

Civil Society to the Rescue?, where weak governments are replaced with strong CSOs tackling food security with a long-term focus, together with strategic investments by a more socially conscious private sector, is most closely represented by *SSP2: Middle of the Road*, where some actions for protection lead to a decline in deforestation rates, and modest productivity and commercialization benefits fall to those who already have capacity rather than inducing a transformation of small-holders, and moderate increases in education and health issues largely taken up by CSOs with private sector support. Ultimately, in this scenario, the lack of government support and coordination means that non-state ambitions are only partially achieved.

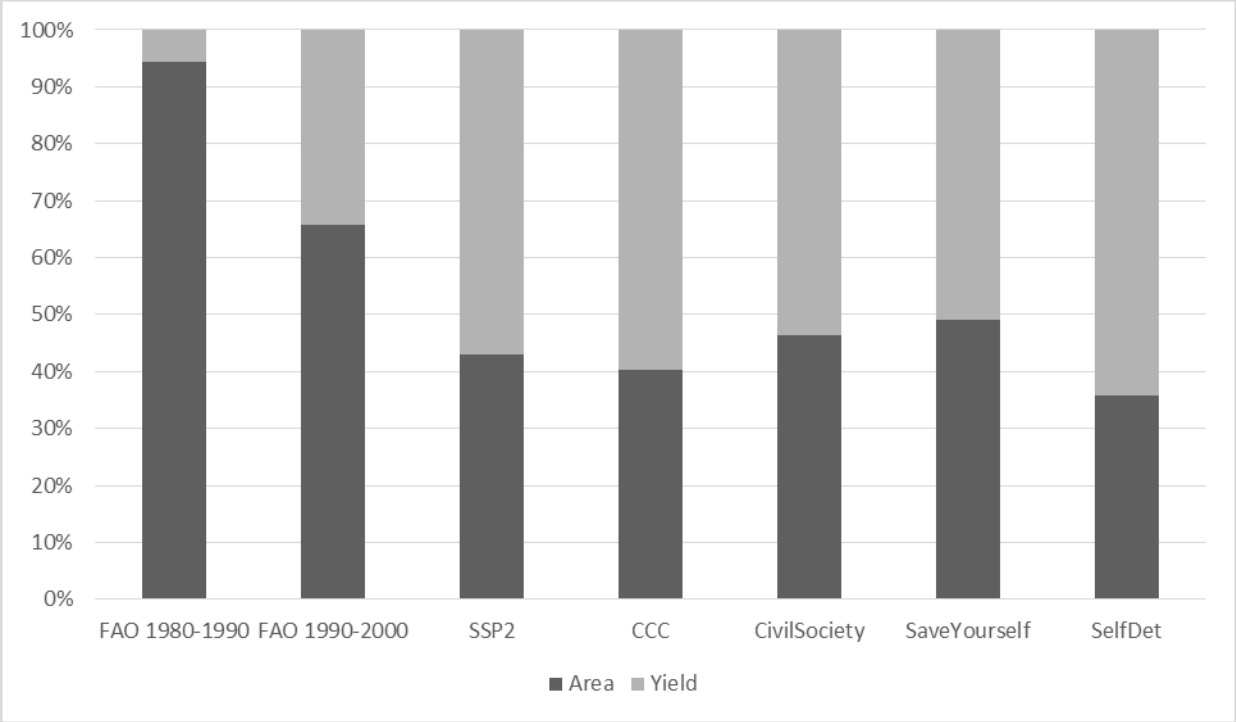
The short-sighted prioritization of governments interested in maintaining power in the *Cash, Control, Calorie*s scenario, create an highly urbanized, high economic growth scenario, which drive reactive investments in education and health services, (similar to *the SSP5: Fossil-fueled Development*). The difference with SSP5 is that in this scenario, investment cycles are short, creating unstable development throughout the scenario period.

3.2 *Quantified CCAFS Scenarios*

3.2.1 Agricultural Production

Agricultural production currently accounts for about a quarter of the region's GDP, but was as high as 35% in the 1980s (World Bank Development Indicators, 2015). West Africa, as a region, is the leader, or among the top global producers of cassava, millet, sorghum, and oil palm (FAOSTAT, 2015). In particular, the sorghum, millet, and cassava production in the region accounts for nearly 20, 27, and 41 percent of the total global production, respectfully. Historically, increases in production within the region have come from expansions in cropland area rather than through significant yield improvements (Byerlee et al. 2014; Hillocks 2002). In the CCAFS scenarios, this historical trend continues in the *Save Yourse*lf and *Civil Society to the Rescue?* scenarios, where the share of the average annual growth rate in production from 2000-2050 is split or nearly split between crop area expansion and yield improvements (Figure 4).

Figure 4 Share of source of production growth based on the rate of growth, area is cropland area expansion and yield is increase in the aggregate crop yield in tons per hectare



Source: FAOSTAT 2015, (left side); GLOBIOM model results (right side).

Overall, crop production in the region increases from 2010 to 2050 for all scenarios, with *Self-Determination* having the highest levels of crop production and *Save Yourself* having the least growth in crop production. The development of crops in the region remains of particular importance to the global production by 2050, especially for millet, cassava, and sorghum. A more detailed look on the regional agricultural production under the scenario futures can be found in Appendix E.

3.2.2 Livestock Production

The development of the livestock sector in Western Africa, of which contributions to the national GDP range from 10%-15% (Kamuanga et al. 2008), depend on not only the overall productivity in the region to meet the growing demand but also supporting the transformation of livestock systems from pastoral to mixed systems, where more productive livestock both graze and consume feed crops. In the CCAFS scenarios, the investments in livestock production nearly double the total livestock output of dairy and ruminant and monogastric meat for *Cash, Control, Calories* and *Self-Determination*. Although there is little investment in the livestock sector (aside from the dairy sector) in *Save Yourself* and limited investment in *Civil Society to the Rescue?*, the scenarios still see an annual increase of total livestock production of around 2%.

While the increase in both ruminant and monogastric meat is largest for Self Determination (closely followed by *Cash, Control, Calories*), *Save Yourself* has the least productive livestock sector of the scenarios, but still the scenario sees huge expansion in the dairy sector. While the per capita demand for dairy is the lowest in *Save Yourself,* due to large growth in population, the

total dairy demand is highest, driving the growth in supply, although most of the demand for dairy is met with imports.

3.2.3 Climate change effects on crop yields

Examining impacts on the most important crops to the region (cassava, millet, sorghum, and maize) shows us that the average trend holds despite one of the GCM climate models (MIROC) producing conditions that crop models show is generally more favorable (Figure 5). Historically, cassava has been planted in the region because of its hardiness in periods of drought and pest and disease resistance in an effort to reduce periods of food insecurity (Hillocks 2002). Despite its hardiness, the impact of climate change on cassava yields is considerable and when compared to a climate neutral future, although GLOBIOM and IMPACT differ on their assessment of the climate impacts (high/low compared to the climate neutral future for each model, -2%/-20% and +3%/-1%, respectively), due to the nature of the crop models used to simulate the yield effects. IMPACT uses the DSSAT (Decision Support System for Agrotechnology Transfer) crop modeling suite developed by the University of Florida (Hoogenboom et al 2012, Jones et al 2003), where cassava is not modeled explicitly but instead IMPACT assumes the effects from climate change on potato yields mimic those of cassava. The climate effects on maize are negative for both models though the magnitude of effects is stronger for IMPACT than GLOBIOM. The climate impacts on millet may seem inconsistent since they range from -18% to +23%, however, four out of the five GCM models used to model the crop effects find negative climate impacts which is consistent with other assessments under varied climatic conditions using Western Africa specific crop models (Sultan et al. 2013). For both models, the negative climate impacts on aggregate crop yields in the *Self-Determination* scenario, which has the highest exogenous yield improvements, are in most cases, still greater than the yields for the three other scenarios without climate impacts, suggesting that adaptation measures and investments taken in the present can have impacts to lessen the impacts of future climate change.

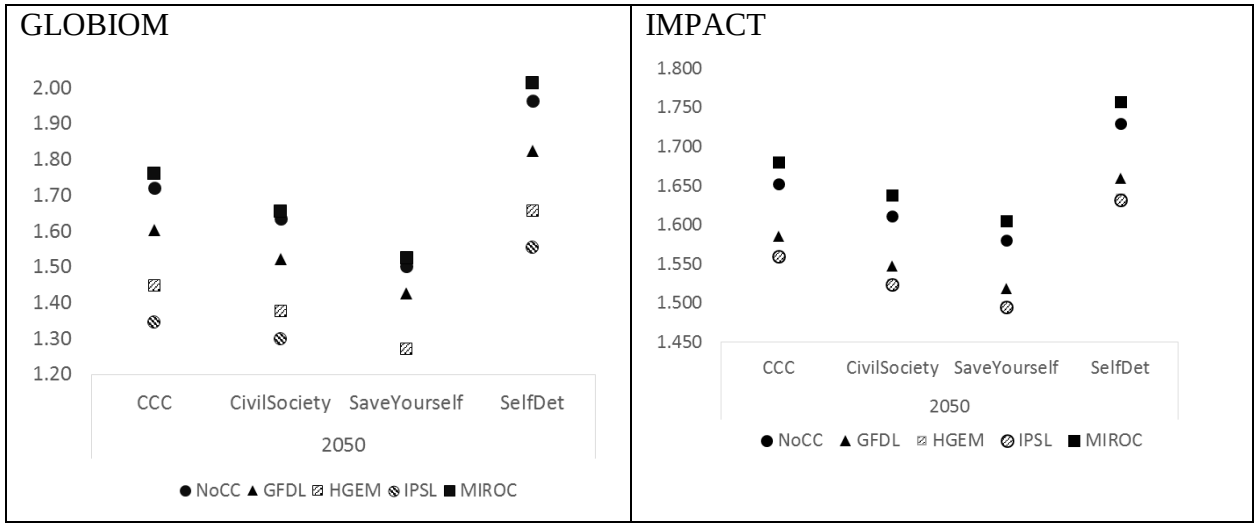


Figure 5 Relative change in average crop yields compared to 2010 yields as modeled by GLOBIOM and IMPACT for the CCAFS Western Africa Scenarios with and without the

climate change effects on crop growth included (note: the y-axis is not the same for both models
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3.2.4 Kilocalorie availability and food demand

Kilocalorie availability per capita per day is one of the most commonly used indicators used to measure food security, which considers the total food products demanded by a region and translates the quantity of product to calories. Both models employ a double-log demand system to model consumer food demand, considering both a dynamic adjustment to demand based on income growth as well as a demand response based on prices (Valin et al. 2014). As the income per capita increases over the time period in all scenarios, food demand, and kilocalories available, increase in the region (Figure 1Figure 6). *Self-Determination* sees the greatest improvement in food security due to the long-term prospective and high economic growth. *Cash, Control, Calories*, with a relatively large increases in the GDP per capita, sees a limited increase in the food security, due to the nature of markets within the region. Food security remains a challenge for the region in *Save Yourself* due to the relatively low economic growth and high population growth and failing state of the region's agriculture. The SSP mirror of *Save Yourself*, SSP3, was also found to present challenges for the food security in Africa in other quantitative assessments. (Hasegawa et al. 2015). In terms of the diet composition, the scenarios with the highest economic growth and largest investment in livestock productivity, *Cash, Control, Calories* and *Self-Determination,* have the largest consumption of meat products. *Civil Society to the Rescue?* and *Save Yourself* have a larger increase in the per capita demand for cassava and other tubers than in the other scenarios, which follows with the socio-economic status of the scenarios, as cassava is a staple food crop typically consumed less with rising incomes.

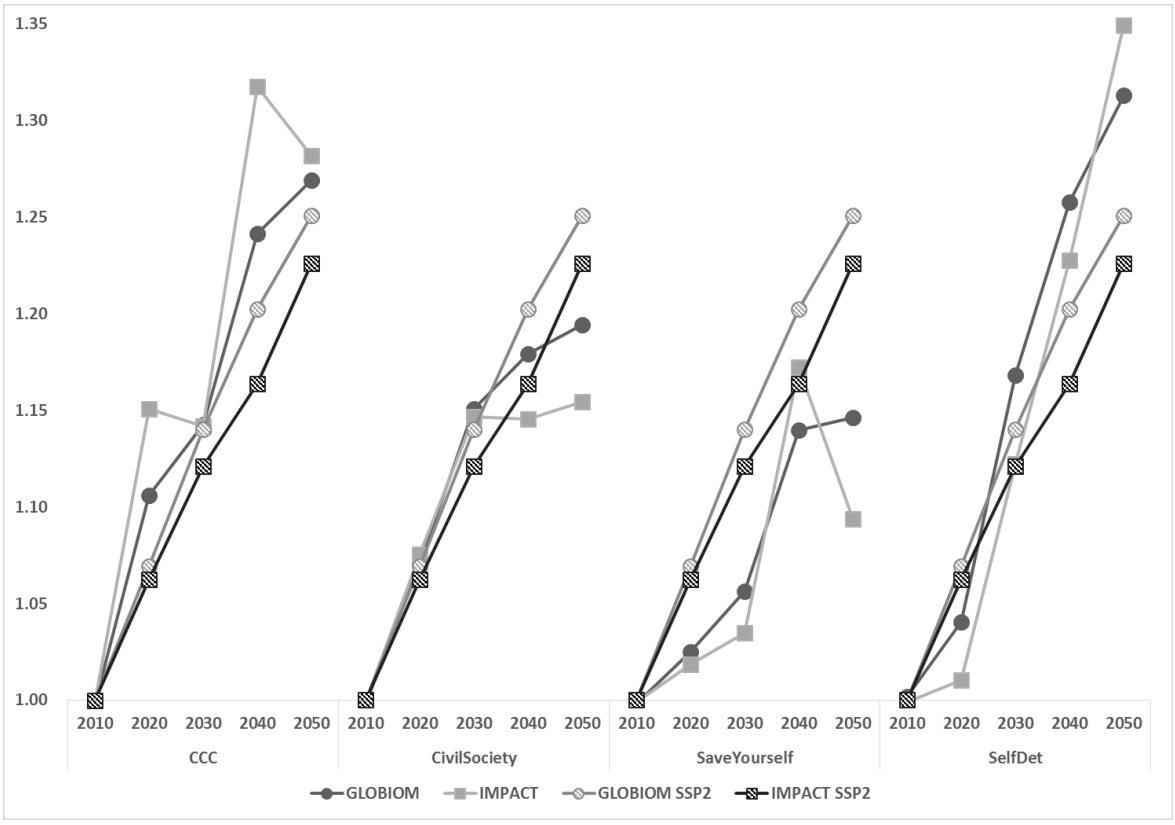

Figure 6 Kilocalorie availability per capita per day as modeled by GLOBIOM (circles) and IMPACT (squares) for Western Africa CCAFS scenarios compared to *SSP2* and indexed to year 2010 values

3.2.5 Prices and Net Trade

The regional price for crops increase over time for both *Save Yourself* and *Civil Society to the Rescue?* (+6% and +4% higher in 2050 than in 2010). By 2050, prices decrease in *Cash, Control, Calories* and *Self-Determination* sees an overall decline (-2% and -4% lower in 2050 than in 2010).

Dairy prices remain relatively stable and by 2050 decrease (-3%) in all the scenarios. Prices for monogastric meat, excluding eggs, increase the most in *Save Yourself* and *Civil Society to the Rescue?*, but the focus and investment in the monogastric industry in *Cash, Control, Calories* keeps the price from increasing as is seen in the other scenarios. Keeping producer input costs low and improvement in crop yields provide more feed for monogastrics in the *Self-Determination* scenario keeping the price from increasing more than 2% by 2050 despite the growing per capita demand which triples from 2010 to 2050.

Despite the large share of production in region, in all the scenarios by 2050, cassava becomes imported, with imports equaling between 12% and 18% the production in the region. Cassava is

primarily seen as a staple food crop and is consumed less as incomes rise, while it is also utilized as livestock feed making it an important crop due to a growing demand for meat products from rising income. It is no surprise then that among the scenarios the share of cassava used for livestock feed accounts for 68% of the demand for *Self Determination*, due to growing incomes and meat demand, and only 26% for *Save Yourself*.

Expressed as a share of the regional production, net imports of crop products by 2050 are as large as 16%/29% (*Cash, Control, Calories*) and as little as 12%/22% (in *Self-Determination*) of the total crop production, in GLOBIOM and IMPACT respectively. Although GLOBIOM and IMPACT model results agree that imports of all livestock products increase in the region over time, there is no agreement in the scenario about which products will have the greatest imports as a share of regional production.

3.2.6 Development outside of Western Africa

By 2050, socioeconomic growth in rest of the world increases demand for and production of agricultural products by 42% for crop products and 65% for livestock products. In 2010, South Asia, China, and South America were the largest consumers of crop products, but by 2050, South Asia and all of Africa will see the largest growth in demand for both crop and livestock products. South America (including Brazil) will become the largest producer for crop and livestock products, followed by South Asia. In terms of food security outside the region, kilocalorie consumption improves in nearly all regions, with India and the rest of South Asia calorie consumption increasing 15% and 23%, and Eastern and the rest of Sub-Saharan Africa calorie consumption increasing 31% to 37% by 2050.

3.2.7 Cropland Expansion and Land use Change

To understand how the development of the agriculture sector in each scenario will affect the land use we identified where the cropland and grassland expansion occurs: within Western Africa, outside the Western Africa but within Sub-Saharan Africa, and in the rest of the world. GLOBIOM endogenously models the global demand for land by considering the main users of land. Increases in food demand are met either through productivity increases or though expansion of crop and grassland. Demand not met by regional production will be met by increased production from outside the region. Shifting agricultural expansion outside the region highlights possible unintended environmental effects.

Globally, agricultural area expands more than 11% in *SSP2* by 2050 and there is relatively little difference when comparing the *Middle-of-the-Road SSP2* scenario among the CCAFS scenarios. The difference in agricultural area between the scenarios to a savings of 6.2 million ha (*Self-Determination*) or an expansion of 2.6 million ha *(Save Yourself*) globally by 2050 compared to *SSP2*. The Green Revolution, where the adoption of improved seeds increased agriculture output worldwide, is credited with saving at least twice as much land over forty years in developing countries from being converted to agricultural land (Stevenson et al. 2013).

Within Western Africa, the total forest area and natural land converted to agricultural land is slightly higher in *Self-Determination* than in the other CCAFS scenarios suggesting that the market conditions and large agricultural productivity gains increase the profitability and may incentivize expanding crop and grassland, in what is known as Jevon's paradox (Alcott 2005; Byerlee, Stevenson, and Villoria 2014). However, the regional level hides the true global land sparing in *Self-Determination* (Figure 4). When compared to the average conversion of natural land in the other CCAFS scenarios, *Self-Determination* saves almost 3.64 ha outside the region for every 1 ha converted within the region. Shifting the share of production growth from area expansion to yield improvements is an indication that the region may be increasing the profitability in *Self-Determination* In *Save Yourself*, where the regional agriculture sector struggles and the lack of regional integration keeps farm input prices high, less land is used for agriculture in the region by 2050, but at the expense of additional agricultural area converted outside the region. Similarly, the relative land sparing that occurs globally in *Cash, Control, Calories* and *Civil Society to the Rescue?*, comes from a large decrease in agricultural area of Western Africa (2.8 million ha and 1.7 million ha respectively), but an increase of nearly that much area in the rest of the world (Figure 7).

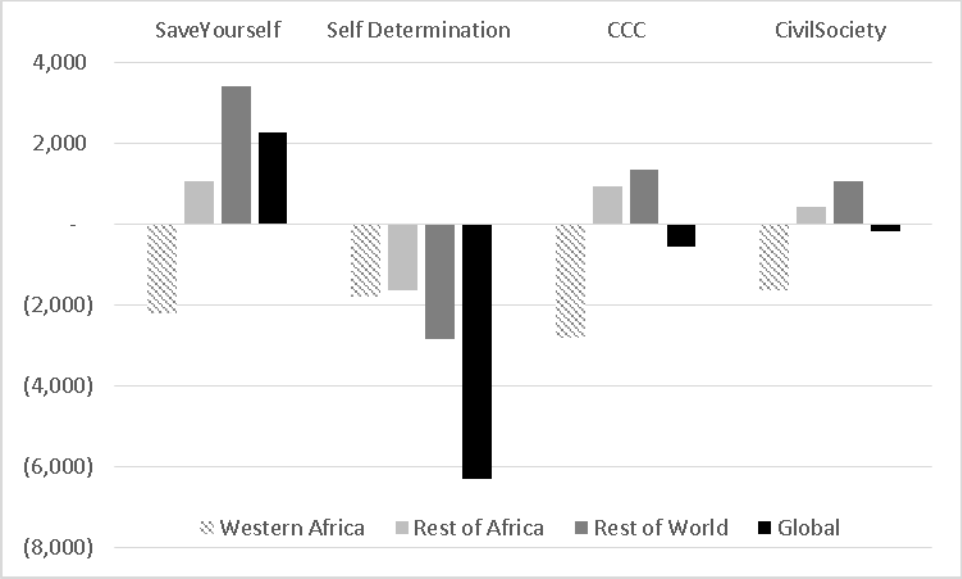

Figure 7 Difference in total land conversion from 2010-2050 compared to *SSP2* (M ha) Note: negative values imply land savings compared to *SSP2*

3.3 Using the West Africa scenarios for policy guidance

A primary purpose for the scenarios discussed in this paper is to use them for national and regional policy guidance (Vervoort et al. 2014). In such processes, a close collaboration with decision-makers results in the design of a process in which the regional scenarios are downscaled to the national level and to the concerns of a specific plan or policy. In an inclusive process that involves state and non-state actors, including those responsible for the policy and those who are

most likely to be affected by it, the future scenarios offer multiple, challenging contexts in which to test draft plans and policies, providing recommendations for improved strategies which are then integrated. Examples of such use of the regional scenario are as follows:

- In Burkina Faso, members of the public and private sector and local experts gathered in July 2015 to use the West Africa scenarios to develop and test the country's new National Plan for the Rural Sector for Burkina Faso (PNSR) and to identify research priorities needed to help the plan succeed (https://ccafs.cgiar.org/blog/using-future-scenarios-design-policy-and-research-together-burkina-faso#.VfF4shGqpBd). The quantified CCAFS scenarios were useful for adding regional context to the country level scenarios developed by drafters of the PNSR.

- The CCAFS scenarios have helped guide and inform district- and national level policy processes in Ghana by facilitating an understanding of the factors that may pose challenges to local development such as population growth, urbanization, and government policies. (https://ccafs.cgiar.org/blog/scenarios-help-guide-discussions-what-ghana%E2%80%99s-future-could-look#.VfF4ZRGqpBd)

- Informed by these national-level processes, a collaboration with ECOWAS and other research partners has been set up to use the regional scenarios for ECOWAS-level priority setting, notably with the current process of new reshape of the ECOWAS common agricultural policy to meet the new challenges facing West Africa agriculture (ECOWAP+10).

4. Discussion and conclusion

The focus of the SSPs have been on global pathways and dynamics offering limited insights at national and regional levels. The quantified socioeconomic storylines of the SSP have been provided at the national and sub-national levels, but insights into the impacts and drivers of plausible future regional developments has been lacking – and this is especially the case for the West African region. This scenarios exercise offers one of the first sets of globally-consistent, stakeholder-generated regional scenarios connected to the SSPs, and is the first stakeholder-generated RAPs set for West Africa.

The region is a key level at which to develop scenarios – because it allows for a connection to the global level while still relevant to regional economic bodies like ECOWAS, as well as to national governments and are easy to connect to global scenarios assessments (Zurek and Henrichs 2007). Scenarios that provide plausible developments of the agricultural system at the regional level can also provide appropriate and necessary inputs for more disaggregated impact assessment (Antle et al. 2015; Valdivia et al. 2015). Additionally, linking the scenarios between levels allows policy makers to address issues within their decision contexts. The policy guidance examples mentioned in section 3.3 show that the scenarios bridge global, regional and national (even sub-national) levels while at the same time linking research on contextual changes in West

Africa directly with policy development, in a process that can be replicated -with case-specific adaptations- across the region. The fact that the scenarios focus strongly on actor interactions and priorities has made them both strategically relevant to decision-makers, and imaginable at national and sub-national levels.

The scenarios also offer the opportunity to reflect on the potential agricultural, food security, and climate futures of the ECOWAS region as well as its socio-economic developments. Results from this paper provide specific information that could guide ECOWAS in its effort to forging informed policy framing for the regional agricultural sector. In the future, food security may pose a challenge when population grows rapidly and is coupled with stagnate or unstable economic growth. In the scenarios, long term priority setting that focuses on economic growth increases food availability, however, the quantitative models are not yet equipped to model income inequality or urban and rural poverty.

Conversion of forest and other natural lands to agricultural land occurs in all the scenarios presented here; in futures without significant productivity gains, agricultural production increases through extensification, following the historical trend, to meet growing demand, and in futures where investments are directed at improving agricultural yields of crops and livestock or increasing market access, the additional converted area is more profitable and productive. The expansion of agricultural area must be examined in the global context, because improvements in the returns to land in West Africa that increase region's competitiveness within Africa may reduce potential land use change on a global scale.

Climate change is likely to have a negative effect on both crop yields and grassland productivity, and the lack of investment in crop productivity may exacerbate the challenges of climate change. Since the region has historically seen production growth through expansion of cropland area rather than through yield improvements, this poses a major future challenge for improving food security as well as the in the protection of the forest and biodiverse areas.

Although the agricultural sector faces low crop yields, the region produces and will continue to produce a significant share of the global production for a selection of crops. Large shares of these crops are consumed within the region, but trade in these crops continues to be important in the future. Cassava is presently a staple food crop in the region and will continue to serve as a vital crop for the region, both for food consumption and, under changing diet preferences due to increasing incomes, as livestock feed. Despite strides to improve productivity, the region's agricultural sector may not be able keep up with the growing regional and global demands and for many crops competitiveness may decline with the region seeing an increase in the share of imports relative to the region's overall production, cassava included.

Some of the semi-quantitative indicators fell outside the scope of the applicability for the quantitative modeling, such as indicators regarding equity, health, and human services, but it was useful to consider them in a semi-quantitative session for policy guidance purposes. Exploring

how these policies would look within a modeling exercise may provide a useful tool for policy makers.

Finally, using existing quantitative models does have drawbacks as models have been designed based on the present and past, rather than on qualitatively different futures, and therefore there are limits in terms of how diverse futures can be captured. There is also a risk on the policy side: quantitative scenarios of the future can easily and wrongfully be interpreted as forecasts with predictive value. Therefore, the presentation of quantitative results from the CCAFS scenarios process involves highlighting the limitations and assumptions of the models and shows that depending on the model as well as the scenario, very different futures arise.

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