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Impact of Climate Change on Agricultural Trade and Food Security in ECOWAS

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ACPC
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Abstract

This paper investigates the impact of climate change on agricultural trade flows inside and outside the ECOWAS region. To reach its objectives, the study uses a trade module of trade cost minimization built within a bio-economic optimization model of cropland allocation. The results showed that the pattern of trade in ECOWAS induced by climatic factors will depend on socio-economic conditions that may prevail during the century. No specific pattern of trade flows is predicted, but there are some countries that may export food to other countries some years and may in turn become importers in other years. Furthermore, several countries may become dependent on products outside ECOWAS trade to meet their domestic food demands. The factors that may ease the cost of trade in ECOWAS on food imports may be an adjustment of the common exterior tariffs. In fact, the study showed that a trade policy that reduces the common exterior tariffs of between 5% and 10% could induce the reduction of total trade cost of about 3% to7% respectively.

Keywords: Climate change, food production, trade flows, ECOWAS

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List of Acronyms

GHG: Greenhouse Gas

FAO: Food and Agriculture Organization

ECOWAS: Economic Community of West African States

RCP: Representative Concentration Pathways

RCM: Regional Climate Model

GCM: Global Climate Model

ESM: Earth System Models

SSP: Share Socio-economic Pathways

NGO: Non-governmental Organization

EPIC: Environmental Policy Integrated Climate

GTAP: Global Trade Analysis Project

AEZ: Agro-Ecological Zone

ECT: Exterior Common Tariff

GDP: Gross Domestic Product

MIRAGE: Modeling International Relationships in Applied General Equilibrium

USAID: United States Agency for International Development

GIS: Geographic Information System

NLP: Non-Linear Program

GAMS: Generalized Algebraic Modeling Software

Introduction

The impact of climate change on agriculture is expected to be more pronounced on the African continent if nothing is done to reduce the emission of greenhouse gases (GHG) and appropriate definition of adaptation strategies (IPCC, 2014; Rosenzweig and Parry, 1994). Today, there is a consensus that mitigation in terms of reduction of GHG emissions is more of concerns of global agreements between large emitters from industrial countries. Whether these agreements are reached or not to reduce emissions in order to maintain global temperature increase below the 2^{o}C by 2100, adaption measures are to be quickly designed to reduce the impact on food security, particularly, in countries located within the tropics. Certainly, African countries have to also do what is required in emission reduction, particularly, from reforestation and investment in cleaner energy sources. Given that climate models predict an increase in temperature but random scenarios in precipitations, some countries may experience more rainfalls than others. This means that while some countries may be experiencing good crop harvest others may not.

Therefore, one of the ways to resolve food insecurity issues may be through food trade across countries. This study is focused on ECOWAS countries as a case study to understand the climate, agricultural production, food trade, and food security nexus. A previous study (Rosenzweig and Parry, 1994) has established that countries located in the northern hemisphere will be only marginally affected by climate change in terms of their ability to produce food from agriculture. Simultaneously those which are located in the southern hemisphere, particularly, those located within the tropics will suffer climate change effects on food production from agriculture. While it is proved that

countries in the south will be more affected by climate change in their ability to produce food from agriculture, some countries within the south may do better than others. Therefore, regional trade and food import from northern hemisphere may be necessary for those in the southern hemisphere to cope with climate change (Stephan and Schenker, 2008).

It is well acknowledged in the literature that adaptation of agricultural systems to climate change will require changes in current practices. These changes include deployment of new seeds that are resistant to heat through biotechnology in order to build the resilience of agricultural plant spices as well as to heat waves induced by short droughts. Other recommended changes in practices include the use of irrigation through investment in dams and water reservoirs. Whether the water for irrigation is obtained from stream flows or groundwater, significant investments in adaptation capacities are required to bring these practices into reality.

Currently, most West African countries are under-resourced to carry out such investments given that almost all governments are faced with several social challenges including investment in health, education, and basic infrastructure. Even if these investments are made to reduce water stress, the effectiveness of these measures is subject to the availability of water resources to satisfy alternative needs of water resources. Recently, many West African countries such as Ghana, Togo, and Benin were unable to supply enough electricity to meet the demand, which resulted in several days of blackouts in several parts

of these countries as a result of low level of water in Akosombo (Ghana) and Nangbeto dams due to reduction in rainfall[1].

Consequently, food trade may be critical to resolving food shortages in regions that are in deficit due to irregular rainfalls. Climate-induced dynamic comparative advantages that may arise from climate change where some countries may be temporarily net exporters of agricultural goods can be exploited to resolve food insecurity in these countries (FAO, 2015). Several arguments have been made in favor of a trade of agricultural commodities as a means of adapting to climate change (Stephan and Schenker, 2008; Bajželj et al., 2014[2]). First, trade operates as an insurance against the risk of climate change. Going by this view, trade is the means by which food availability can be preserved for regions that are affected by reduced agricultural productivity. Second, trade can spread the cost of adaptation if free trade flows are allowed.

In fact, if free trade is allowed between countries, countries that are net exporters of food may face food price increase in order to allow other food deficit regions to survive. This directly poses the question of accessibility raised in a previous study (Julia and Duchin, 2007). In fact, food can be imported but the majority of the inhabitants of the affected country may not be able to afford it. This may invariably lead to food insecurity if the

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[1] As regional dams run dry, lights go off in Togo. http://www.irinnews.org/fr/node/226281 [Accessed 04-08-2016]

[2] Bajželj, B., Richards, K. S., Allwood, J. M., Smith, P., Dennis, J. S., Curmi, E., & Gilligan, C. A. (2014). Importance of food-demand management for climate mitigation. Nature Climate Change, 4(10), 924-929.

inhabitants of the affected country hold less labour income to tackle food purchase.

The objective of this paper is to study how food trade can be a strategy to reduce food insecurity in West African countries. Specifically, this paper seeks to:

1) identify countries that are net suppliers from those that have deficit across scenarios while finding the cheapest ways to move food from excess supply countries to excess demand countries,
2) measure the impact of trade and agricultural policies within the ECOWAS zone on trade flows,
3) evaluate implications of trade flows on food security.

To reach these objectives, several research questions are to be addressed. These fundamental research questions include the following:

i. how effectively food could be moved from excess supply countries to excess demand countries?
ii. what are the implications of food trade on climate change adaptation costs minimization? and
iii. what are the food security implications of the observed trade flows?

To give tentative answers to these research questions, a bio-economic optimization model was developed for 14 West African countries. These are Benin, Burkina Faso, Cote d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, and Togo. The bio-economic model is calibrated for the land use observed in 2004 and simulated

up to the year 2100 with drivers such as crop yields and prices under various climatic and socio-economic scenarios. A trade module minimizing trade costs is then developed to detect excess supply and demand countries and move food cost effectively from excess supply countries to excess demand countries.

The remaining sections of the paper detail the methodological approaches used in the study to address the aforementioned research questions. Subsequently, the model parameterization, scenario development, and model simulation results are presented. Finally, the paper concludes in the last section with policy recommendations from the lessons learnt from the model simulation.

Materials and Methods

The study uses a bio-economic optimization model based on a representative risk-neutral profit maximizer assumption within which a food trade module is developed. The food trade module is built as a transport model that allocates food optimally from excess supply countries to excess demand countries. The model is then applied to the countries in the ECOWAS region to analyse the impact of climate change on the food system and trade. To reach the objectives of this study, several models were integrated. First, a regional climate model is used to predict temperature and precipitations from the year 2004 to 2100 with two representative concentration pathways (RCP[3] 4.5 and RCP 8.5). Second, an econometric crop simulator is used to simulate crop yields under the two RCPs.

Below in Figure 1 is the structure of the trade module:

[3] Representative Concentration Pathways (RCP)

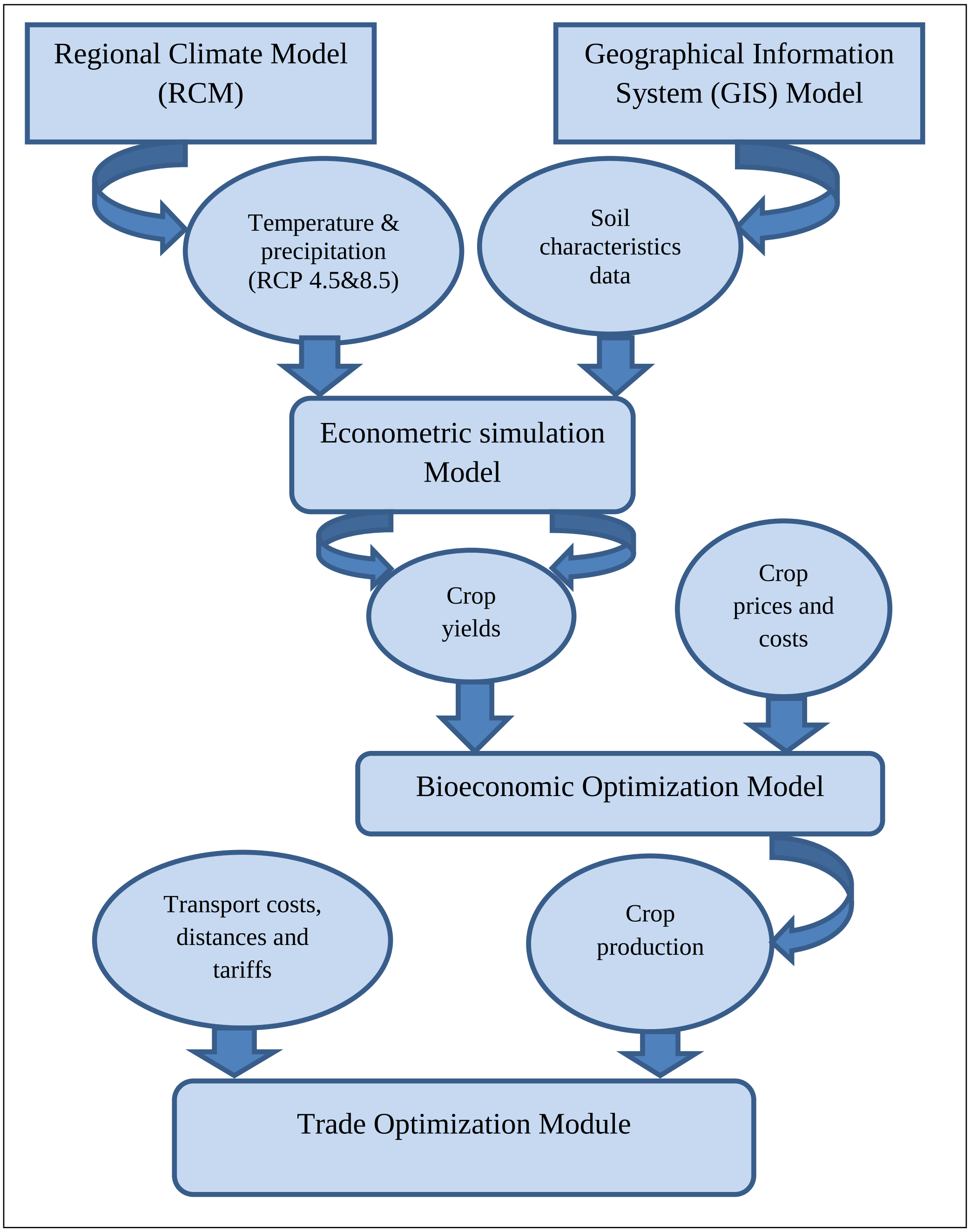

Figure 1: Structure of the Trade Module

Third, the simulated yields under the two RCPs are coupled with crop prices data projected with four socio-economic scenarios and fed into a profit-maximizing bio-economic model to predict crop, livestock land use, and production. Finally, the produced crop levels are used to predict trade flows in the ECOWAS region while taking into account transport costs and trade tariffs outside of the ECOWAS free trade zone.

Climate change and socio-economic scenarios

The climate scenarios are aimed at projecting climate variables under two representative concentration pathways (RCPs). In order to achieve this, temperature, precipitation, and evapotranspiration values are projected for the West African region from year 2004 to 2100. These climate variables are used to simulate crop yield values under RCP 4.5 and RCP 8.5. A Regional Climate Model (RCM) is the main tool used to generate baseline and climate change data for the ECOWAS region. The regional climate modeling technique consists of using initial conditions, time-dependent lateral meteorological conditions and surface boundary conditions to drive high-resolution limited area models.

The driving data is derived from CMIP5 Global Climate Models (GCMs) or Earth System Models (ESMs) and can include greenhouse (GHG) and aerosol forcing. The basic strategy is thus to use the GCMs to simulate the response of the global circulation to large-scale forcing and the RCM to (a) account for sub-GCM grid scale forcing (e.g., complex topographical features and land cover heterogeneities) in a physically-based way; and (b) enhance the simulation of atmospheric circulations and climatic variables at fine spatial scales. This technique, therefore, constitutes the most appropriate tool to

generate regional climate change data for West Africa and has been used extensively over the region (Sylla et al., 2012).

These two RCPs scenarios are coupled with four shared socio-economic pathways (SSPs). These SSPs are used to derive data to index prices and costs in the bio-economic model. The four SSPs are built on the following story lines. Two dominant forces (State Actors and Non-State Actors) interact with two policy drivers (Short-term priorities and Long-Term priorities) to form the four scenarios. In the first scenario (SSP1), State Actors are dominant meaning that strong institutions exist but the governments are short sighted by short-term gains leading to an extensive need of cash. As a result, inflation is a little above the average. In the second scenario (SSP2), State Actors are focused on long-term priorities with a slow and painful transition to sustainable development.

As a result, general price levels are well controlled with low inflation. In the third scenario (SSP3), Non-State actors such as NGOs and the civil society are mature and are in control of the state business. As a result, there is a struggle between the civil society and the private sector that is ultimately productive. In all these scenarios, the study predicted medium inflation levels. In scenario four (SSP4), non-State actors are dominant with short-sighted priorities; the institutions are weak, and the countries are not governed, and the resources of the country are used to solve crisis instead of investing in the future. As a result, inflation levels are high. Finally, the two RCP scenarios are coupled with the four SSP scenarios to build a total of eight scenarios that are used in this paper.

Crop yields simulation

Crop yields are usually simulated based on several variables (Izaurralde et al, 2006, Chang, 2002; Chanillor et al[4]. 2014; Bassu et al., 2014[5]) including, climate (temperature, precipitation, evapotranspiration, and CO_2 concentration levels), soils (three soil types are considered in this paper: clay, loam, and sand) and management types/technology (fertilizer usage, rotation, and irrigation). In the agricultural context of West Africa, most crops are grown without fertilizer use or irrigation. Thus, the yield of crops is therefore responsive to factors that include climate variables and soil types. The use of biophysical crop simulators such as EPIC is more driven by the desire to estimate environmental outcomes such as agricultural runoffs and emissions. In the context of this research, the interest lies more in the aspect of estimating the values of the crop yields without pointing out various direct environmental impacts. Consequently, an econometric yield estimation approach is used. The yield function used is drawn from a previous research (Gornott and Wechsung, 2016) and can be expressed as:

$$Y_{it} = Z_{it} CO2_t^{\delta} \left(\prod_{j=May}^{Oct} T_{ijt}^{\alpha_j}\right) \left(\prod_{j=May}^{Oct} P_{ijt}^{\beta_j}\right) \left(\prod_{k=1}^{9} S_{ik}^{\gamma_k}\right) \quad (1)$$

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[4] Challinor, A. J., Watson, J., Lobell, D. B., Howden, S. M., Smith, D. R., & Chhetri, N. (2014). A meta-analysis of crop yield under climate change and adaptation. Nature Climate Change, 4, 287-291.

[5] Bassu, S., Brisson, N., Durand, J.L., Boote, K., Lizaso, J., Jones, J.W., Rosenzweig, C., Ruane, A.C., Adam, M., Baron, C. and Basso, B., 2014. How do various maize crop models vary in their responses to climate change factors?. Global change biology, 20(7), pp.2301-2320.

Or in logarithmic terms:

$$\log(Y_{it}) = \log(Z_{it}) + \sum_{j=May}^{Oct} \alpha_j \log(T_{ijt}) + \sum_{j=May}^{Oct} \beta_j \log(P_{ijt}) + \sum_{k=1}^{9} \gamma_k \log(S_{ik}) + \delta \log(CO2_t) \quad (2)$$

where i and t are respectively the agro-climatic and soil zones index, and time index; Z_{it} is the technological progress; T_{ijt} is the monthly main temperature; P_{ijt} is the monthly main precipitation; S_{ik} is the soil characteristics, and $CO2_t$ is the CO_2 concentration in the atmosphere at the time t.

The dynamic of the technological progress[6] is given by

$$\log(Z_{it}) = 0.06 * \left(\frac{t}{1+t}\right)^{60} + 0.98 * \log(Z_{it-1}) + U_{it}\ ;\ \ Z_{i0} = 1 \quad (3)$$

Where U_{it} is a white noise with a truncated normal distribution$\aleph(0, 0.005, [0, +\infty[)$?[7]

The bioeconomic profit maximization model

The bio-economic model is designed as an optimization problem where the representative farmer maximizes a discounted profit of choosing among seven cropping systems (McCarl and Spreen, 1980, Egbendewe-Mondzozo, 2011). These include paddy rice, cereals (maize, sorghum, and millet), vegetable-fruits-nuts (banana, cassava, plantain, potato, sweet potato, and yam), oil-seeds (beans, cashew nuts, cowpea, groundnut, and soybean), sugarcane, cotton and indigenous crops (cocoa, coffee, and sesame), as into the Global

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[6] The idea behind the technological progress is yield can increase by 1% each year. To avoid non-stationary process, technological change is captured by equation 3.

[7] Refer to Atewamba (in press) for details on crop yields simulations.

Trade Analysis Project (GTAP) classification of crops and four (4) livestock types mainly cattle, sheep, chicken and others. The land unit used in the model is based on dividing the West Africa region into 39 agro-climatic zones (ACZs) within which three types of land quality (loam, clay, and sand) are overlaid. This leads to a total of 84 land units or agro-climatic and soil zones (ACSZs) over which the representative farmer maximizes profits. To get back from ACSZs to country units, we overlaid country limits into the ACSZs and used area weights to estimate country level production. The model wa then calibrated using positive mathematical programing method (Howitt, 1994). The calibrated model helps define agricultural land penetration rate of plus and minus one percent (%) each for five years which is used to constrain land allocation dynamically with crop yields under the two RCPs scenarios. Production costs and prices are projected under each SSP scenario by indexing the year 2004 values. The model predicts land allocation from 2010 to 2100 with five (5) years' steps (Lokonon et al. 2016). The total output computed is then passed to the trade module to predict trade flows based on climate change driven dynamic comparative advantages.

The trade module

This is a dynamic transportation model in which food is being moved from countries that are net suppliers to countries that are net in demand. Let $x_{c,i,j,t}$ be the quantity of crops c to be moved from country i to country j in time period t. The excess supply in country i is given as $a_{c,i,t}$ and the excess demand in country j is given as $b_{c,j,t}$. Let $Dist_{i,j}$ be the distance from country i to country j and γ is the unit transport cost. If $imp_{c,i,t}$ is the import from

outside ECOWAS free trade zone and δ_c is the common exterior tariff (ECT) parameter by crop c then the transport model could be written as:

$$\underset{x_{c,i,j,t}\,;\,imp_{c,i,t}}{\text{MIN}} \sum\nolimits_c \sum\nolimits_i \sum\nolimits_j \sum\nolimits_t \left(x_{c,i,j,t} \times \gamma \times Dist_{i,j} + \delta_c \times imp_{c,i,t}\right) \quad (1)$$

Subject to:

$$\sum\nolimits_j x_{c,i,j,t} \leq a_{c,i,t}, \forall c, i, t \quad (2)$$

$$\sum\nolimits_i x_{c,i,j,t} + imp_{c,j,t} \geq b_{c,j,t}, \forall c, j, t \quad (3)$$

$$x_{c,i,j,t} \geq 0;\ imp_{c,i,t} \geq 0\ , \forall c, i, j, t \quad (4)$$

The objective function (i) consists of choosing shipment quantity and outside ECOWAS zone imports, such that total trade cost is minimized. The constraints (ii) stipulate that the total shipments must be less or equal to the available supply. Constraints (iii) express the fact that total shipments plus imports must be greater or equal to the excess demands. Constraints (iv) are the requirement that shipment and imports must be positive.

Trade module parameterization

Crop production levels

The trade module takes as given crop production levels from the bio-economic optimization model. These production levels are considered as the estimates of the total supply available from domestic ECOWAS producers. The model allows imports from outside the ECOWAS zone, namely the rest of Africa, Europe, Asia, and the Americas. All imports from outside ECOWAS zone is subject to the exterior common tariff (ECT). Recall that total production levels were calibrated to the 2004 production levels. Only four crop types (paddy rice, cereals, vegetables & fruits and oil & Seeds) were studied as traded crops. Note that for all these crops, ECOWAS countries usually do not allow free trade, but could accept to sell the excess supply to a member country that is in need. Other three crop types (i.e. sugarcane-sugar bees, cotton, and cocoa-coffee-sesame) are not included in the module because they are mostly cash crops that are exported outside the ECOWAS zone.

Crop demand

Total demand for crops is computed using constant elasticity demand functions of the form $A \times f(Price, GDP)$ where prices and gross domestic products (GDP) vary across the four socio-economic scenarios. The scale parameters A are calibrated for each crop and each country based on 2004 as the base year. The demand quantity data was obtained from Food and Agriculture Organization (FAO, 2015). Price and income elasticity values are drawn from the Modeling International Relationships in Applied General Equilibrium (MIRAGE) Model (Decreux and Valin, 2007). To make these demands dynamic, the demand functions here indexed to the average yearly population growth of 3.5% and income elasticity growth rates spanning 3% to

8.5% every five years are assumed. The elasticity dataset is only available for some individual countries and a group of countries of the region.

As a consequence, the individual countries considered in the study are Benin, Burkina Faso, Cote d'Ivoire, Ghana, Guinea, Nigeria, Senegal, and Togo. These countries (Gambia, Guinea-Bissau, Liberia, Mali, Niger, and Sierra Leone) were grouped under the label "other ECOWAS" countries. After calibration and projection of the demands, the difference with total production is calculated to estimate excess demands $b_{c,j,t}$ and excess supply $a_{c,i,t}$ from each country up to 2100. The value of γ which is the average cost in US$ per ton/km is set at 75.2 cents. Data was obtained from a USAID report on transport costs to West Africa countries (USAID, 2012). The parameter $Dist_{i,j}$ which is the distance between countries' capital cities was calculated using geographic information system (GIS) on an ECOWAS map. The parameter δ_c which includes exterior common tariff rates of ECOWAS countries is taken from the ECOWAS report (ECOWAS, 2006). Given the nonlinearities in the demand functions, the trade module is solved using a nonlinear program (NLP) in GAMS software (McCarl et al., 2014[8]).

[8] McCarl, B.A., Meeraus, A., van der Eijk, P., Bussieck, M., Dirkse, S., Steacy, P. and Nelissen, F., 2014. McCarl GAMS user guide. 2012-01-12)[2012-12-30]. http://www. gams. com/docs/bigdocs/GAM-SUsersGuide. pdf.

Model Results and Discussion

The strategy adopted in presenting the outputs of this study is to show the impact of climate change under RCP 4.5 and RCP 8.5 on food crop trade flow by focusing on the changes in the trade flow relatively to the baseline without climate change for each socio-economic scenario. The RCP 8.5 is the business as a usual scenario whereas the RCP 4.5 is the mitigation scenario.

The baseline scenario

The baseline scenario describes a counterfactual situation where climate change effects are assumed to be absent. This scenario is driven by yields simulated under the assumption that climate conditions today remain the same until the end of the century. Trade is then defined in terms of its potential given the excess demand and the excess supply for crops that are computed across countries. The model then tries to find the minimum costs of shipping food from countries with excess produce to those in short supply (or deficient). The results of this baseline scenario vary across crops and shared socio-economic pathways (SSPs are used to simulate prices across the century).

Paddy rice is traded from Guinea and Nigeria to other countries under SSP1 across the century. The trend of trade flow is not uniform across time but could be increasing for some years and be decreasing in other years. The importing countries of paddy rice originating from Guinea are Ghana, Togo, and Other ECOWAS countries; whereas countries importing from Nigeria are all the remaining countries in ECOWAS except Guinea. No paddy rice trade is predicted under the SSP2 scenario. Under SSP3 scenario, only Ghana is predicted to import paddy rice from Nigeria between 2050 and 2080. Under

SSP4, many more countries such as Cote d'Ivoire, Ghana, Guinea, and Togo become exporters of rice for some years.

Cereals are traded under SSP1 only from Burkina Faso to Nigeria all across the century with varying trends. A similar pattern of trade is observed under SSP2 but the exports ended in 2030. Under SSP3, a similar trade flow is observed but the exports ended in 2060. Contrary to the limited trade flows under the previous SSPs, trade flow increases under SSP4 with cereal exports originating from all countries except Cote d'Ivoire, Ghana, Guinea, and Togo.

Vegetables-fruits-and-nuts (VFN) are traded under SSP1 from Cote d'Ivoire, Ghana, Guinea, Nigeria, Senegal and Togo to other countries. However, some exporting countries become importing countries for some years during the century. Under SSP2 only two countries (Cote d'Ivoire and Senegal) export some quantities of VFN to Guinea in 2010). Under SSP3, Cote d'Ivoire extends her exports to Nigeria as well till the year 2020. Also, Senegal extends her exports to Nigeria and Togo till the years 2010 and 2020 respectively. Many more countries will be exporting fruits under SSP4. In fact, under this SSP, countries such as Benin, Ghana, Cote d'Ivoire, Guinea, Togo and other ECOWAS countries are predicted to export VFN to Burkina Faso to meet the overwhelming demand expressed in that country until the year 2080.

Oilseeds trade under SSP1 occurs from Republic of Benin, Burkina towards Cote d'Ivoire, Ghana, and Guinea from the year 2080 till 2100. Trade under SSP2 occurs between 2030 and 2050. Many more countries (Burkina Faso, Cote d'Ivoire, Ghana, Nigeria and other ECOWAS) are predicted to export oilseeds to countries such as Republic of Benin, Senegal, and Togo which are in high demand for these crops. Under SSP3, trade occurs mainly during the

last half of the century and the exporting countries are Benin, Burkina Faso, Nigeria and other ECOWAS countries. The excess demand countries are all the studied countries except Benin, Burkina Faso, and other ECOWAS countries. No trade of oil-seeds has been observed under the SSP4 scenario.

This simulation of trade without climate change is the baseline that is compared against the simulations under climate change scenario RCP 4.5 and 8.5 to assess the impact of climate change on trade flow in the ECOWAS region.

Impact of climate change on paddy rice trade

The impact of rice trade flows from baseline under the RCP 4.5 is presented in Table 1. Relatively to the baseline without climate change, the model predicts the socio-economic conditions -SSP1-that rice may be traded from Cote d'Ivoire to Burkina Faso and Ghana from 2090 to the end of the century. Some other countries such as Guinea and Nigeria may have their trade to other countries reduced or increased but without any consistent pattern. With the socio-economic conditions -SSP2-, Nigeria may experience a decrease of its trade to Ghana from 2050 to 2080 and an increase thereafter. The model predicts no rice trade within the zone with the socio-economic conditions-SSP3. With the socio-economic conditions -SSP4-, trade resumes from Cote d'Ivoire, Ghana, Guinea and Togo to other countries but without any specific pattern. The trade flow under the business as usual climate change scenario -RCP 8.5- is presented in Table 2. With the socio-economic conditions -SSP1, Cote d'Ivoire may still trade rice to Burkina from the years 2090 to the end of the century and to Ghana till the year 2070. Trade originating from other countries such as Guinea and Nigeria might continue with an increase or a

decrease from the baseline but without any specific pattern. There would be no rice trade within this zone (SSP2) whereas with the socio-economic conditions -SSP3-, Nigeria will continue rice trade to Ghana from the middle of the century until 2080 but with reduced volume relatively to baseline. With the socio-economic conditions -SSP4-, the trade will continue from the exporting countries (Cote d'Ivoire, Ghana, Guinea and Nigeria) to the other countries but without any specific patterns.

Table 1: Rice trade flow changes from baseline under RCP 4.5

		2020	2030	2040	2050	2060	2070	2080	2090	2095	2100
SSP1: Cash, Control & Calories											
Cote d'Ivoire	Burkina Faso	0.0	0.0	0.0	0.0	0.0	0.0	0.0	572.6	1478.7	1865.2
Cote d'Ivoire	Ghana	0.0	0.0	0.0	0.0	0.0	0.0	0.0	555.6	452.3	416.4
Guinea	Senegal	0.0	0.0	0.0	-1.0	0.0	-1.0	-0.5	-0.9	-1.0	-1.0
Guinea	Togo	0.0	0.0	0.0	-1.0	0.0	0.0	0.1	-0.2	-0.2	-0.3
Guinea	Other ECOWAS	-1.0	-1.0	-0.4	1135.2	1.6	1150.6	991.4	0.0	0.0	0.0
Nigeria	Benin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.1	-0.1
Nigeria	Burkina Faso	0.0	0.0	0.0	-0.8	0.0	0.0	-0.1	-0.3	-0.6	-0.7
Nigeria	Cote d'Ivoire	0.0	0.0	-1.0	0.0	-0.1	-0.3	16.2	-1.0	-1.0	-1.0
Nigeria	Ghana	-1.0	-0.4	0.1	0.1	0.1	0.2	0.2	-1.0	-1.0	-1.0
Nigeria	Senegal	0.0	0.0	-1.0	1086.9	-0.1	809.7	140.7	0.0	0.0	0.0
Nigeria	Togo	0.0	0.0	-1.0	0.6	-0.9	-0.4	0.0	0.0	0.0	0.0
Nigeria	Other ECOWAS	-1.0	-1.0	0.0	-0.3	0.0	0.0	0.0	0.0	0.0	0.0
SSP2: Self-determination											
Nigeria	Ghana	0.0	0.0	0.0	-1.0	-0.6	-1.0	-1.0	976.8	4320.3	5521.2
SSP4: Save Yourself											
Cote d'Ivoire	Burkina Faso	0.0	0.0	-0.6	0.0	0.2	88.8	0.0	0.0	0.0	0.0
Cote d'Ivoire	Ghana	0.0	0.0	50.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ghana	Burkina Faso	0.0	0.0	0.0	-0.4	-0.2	-0.2	0.0	-0.7	-1.0	0.0
Guinea	Senegal	-1.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Guinea	Togo	-1.0	3.2	-0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Guinea	Other ECOWAS	11.0	-1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nigeria	Benin	-1.0	0.1	0.0	0.0	0.0	0.0	0.1	-0.4	-0.7	-1.0
Nigeria	Burkina Faso	-1.0	0.0	0.3	4.5	0.0	0.0	0.0	0.0	0.0	0.0
Nigeria	Cote d'Ivoire	-1.0	9.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nigeria	Ghana	0.2	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nigeria	Togo	0.0	-1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nigeria	Other ECOWAS	0.3	836.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Togo	Burkina Faso	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	-1.0

Table 2: Rice trade flow changes from baseline under RCP 8.5

		2020	2030	2040	2050	2060	2070	2080	2090	2100
					SSP1: Cash, Control & Calories					
Cote d'Ivoire	Burkina Faso	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1004.3	2590.0
Cote d'Ivoire	Ghana	0.0	0.0	0.0	0.0	0.0	126.1	292.5	513.3	222.3
Guinea	Senegal	0.0	0.0	0.0	-1.0	0.0	-0.3	-0.5	-1.0	-1.0
Guinea	Togo	0.0	0.0	0.0	-1.0	0.0	428.6	0.0	-0.2	-0.4
Guinea	Other ECOWAS	-1.0	-0.7	-0.2	1347.1	1.2	850.8	457.9	0.0	0.0
Nigeria	Benin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.1
Nigeria	Burkina Faso	0.0	0.0	0.0	-0.4	0.0	0.0	0.0	-0.4	-1.0
Nigeria	Cote d'Ivoire	0.0	0.0	-1.0	-0.1	-0.5	-1.0	-1.0	-1.0	-1.0
Nigeria	Ghana	-1.0	0.1	0.1	0.1	0.1	-0.1	-0.4	-1.0	-1.0
Nigeria	Senegal	0.0	0.0	-1.0	1080.2	-0.2	0.0	0.0	0.0	0.0
Nigeria	Togo	0.0	0.0	-1.0	0.5	0.1	-1.0	0.0	0.0	0.0
Nigeria	Other ECOWAS	-1.0	-0.9	0.3	-0.4	0.0	0.0	0.0	0.0	0.0
					SSP3: Civil Society to the Rescue?					
Nigeria	Ghana	0.0	0.0	0.0	-1.0	-1.0	-1.0	-1.0	0.0	0.0
					SSP4: Save Yourself					
Cote d'Ivoire	Burkina Faso	0.0	0.0	-1.0	-1.0	-1.0	0.0	342.7	241.7	747.0
Cote d'Ivoire	Ghana	0.0	0.0	-0.3	0.0	25.7	132.5	76.4	221.0	44.0
Cote d'Ivoire	Togo	0.0	0.0	0.0	0.0	-1.0	0.0	0.0	0.0	0.0
Ghana	Burkina Faso	0.0	0.0	0.0	-1.0	-1.0	-1.0	-1.0	-1.0	0.0
Guinea	Ghana	74.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Guinea	Senegal	-1.0	-1.0	-1.0	-0.9	472.6	401.1	320.2	245.9	251.2
Guinea	Togo	-1.0	0.0	-1.0	2.2	164.9	171.3	175.7	183.5	185.7
Guinea	Other ECOWAS	-1.0	1.6	727.0	556.8	21.2	0.0	0.0	0.0	0.0
Nigeria	Benin	-1.0	-1.0	-0.6	0.3	0.5	0.7	0.9	1.2	1.9
Nigeria	Burkina Faso	-1.0	-1.0	-1.0	43.4	1108.1	1065.1	672.1	717.8	153.0
Nigeria	Cote d'Ivoire	-1.0	-1.0	353.8	165.9	0.0	0.0	0.0	0.0	0.0
Nigeria	Ghana	-1.0	1.7	333.0	249.0	154.8	89.7	0.0	0.0	0.0
Nigeria	Senegal	0.0	0.0	605.5	151.2	0.0	0.0	0.0	0.0	0.0
Nigeria	Togo	0.0	-1.0	154.6	0.0	0.0	0.0	0.0	0.0	0.0
Nigeria	Other ECOWAS	-1.0	338.8	326.5	0.0	0.0	0.0	0.0	0.0	0.0
Togo	Burkina Faso	0.0	0.0	0.0	0.0	0.0	-0.9	0.0	0.0	-1.0

Impact of climate change on cereal trade

The impact of climate change scenario RCP 4.5 on cereal trade with various socio-economic assumptions is presented in Table 3. With the socio-economic scenario-SSP1- a clear pattern of trade flow has emerged with a few exceptions. In fact, positive trade volumes of cereals may flow respectively from Burkina Faso to Cote d'Ivoire, Guinea, and Togo; from Nigeria to Benin, Ghana and Togo; from Senegal to Guinea and Togo; from other ECOWAS countries to Cote d'Ivoire, Guinea, and Nigeria. The results also showed that most of the trade will occur from the middle to the end of the century and only a few trade transactions will occur at the beginning of the century. With the socio-economic scenario-SSP2- only Burkina Faso will be trading positive volumes of cereals to Nigeria from 2020 to 2040.

However, under the socio-economic scenario-SSP3- trade of positive volumes of cereals will flow from Burkina Faso to Nigeria during the entire century. With the socio-economic scenario-SSP4- Benin will enter into cereal exporting countries but a less consistent trade pattern will emerge from this scenario. Under the climate change scenario, RCP 8.5, the predicted trade flow from baseline with various socio-economic conditions is presented in Table 4. With the socio-economic scenario-SSP1- the previous trade pattern observed under RCP 4.5 is replicated with changes in trade volumes. With the socio-economic scenario-SSP2- only Burkina Faso will be trading cereals to Nigeria but trade volumes have increased with this RCP scenario while the consistent decline of the trade from baseline is observed with the socio-economic scenario-SSP3. The more consistent decline of trade volumes relatively to the baseline is also observed with the socio-economic scenario-SSP4.

Impact of climate change on Vegetable-Fruit-and-Nut trade

The impact of climate change under RCP 4.5 on VFN relatively to the baseline without climate change is presented in Table 5. With the socio-economic scenario-SSP1, exports from Cote d'Ivoire to Burkina Faso at the beginning of the century will be dropping down relatively to the baseline while exports from Benin will be increasing starting from 2070 to the end of the century. The trade of VFN from Ghana, Guinea, Nigeria and Togo to the other West African countries will continue but with no clear pattern (Table 5). Under the SSP2 socio-economic scenario, there will be trading of VFN. With the socio-economic scenario-SSP3, apart from Cote d'Ivoire which would have reduced its trade to Guinea and Nigeria relatively to the baseline in 2020, Ghana and Nigeria would have increased their trade volumes to other countries staring from 2070 until the end of the century.

Table 3: Cereals trade flow changes from baseline under RCP 4.5

		2020	2030	2040	2050	2060	2070	2080	2090	2100
					SSP1: Cash, Control & Calories					
Burkina Faso	Cote d'Ivoire	0.0	0.0	0.0	488.6	1528.8	2350.7	1590.8	3513.3	4052.1
Burkina Faso	Ghana	0.0	0.0	0.0	3012.7	3895.6	4967.9	6048.1	4817.3	7565.2
Burkina Faso	Guinea	0.0	0.0	0.0	1.7	3147.7	0.0	656.3	5604.0	7212.1
Burkina Faso	Nigeria	0.4	0.2	0.4	0.1	-1.0	-0.6	-0.3	-1.0	-1.0
Burkina Faso	Togo	0.0	0.0	0.0	0.0	528.9	614.1	0.0	0.0	2097.7
Nigeria	Benin	0.0	0.0	0.0	0.0	551.3	0.0	0.0	3609.9	3932.7
Nigeria	Ghana	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2043.3	0.0
Nigeria	Togo	0.0	0.0	0.0	0.0	698.8	0.0	0.0	2499.1	1749.9
Senegal	Guinea	0.0	0.0	0.0	183.6	0.0	0.0	11.6	0.0	0.0
Senegal	Togo	0.0	0.0	0.0	0.0	0.0	754.4	0.0	783.7	0.0
Other ECOWAS	Cote d'Ivoire	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0
Other ECOWAS	Guinea	0.0	0.0	0.0	2275.1	0.0	3962.3	4237.8	943.1	0.0
Other ECOWAS	Nigeria	858.6	1345.6	76.0	0.0	0.0	0.0	0.0	0.0	0.0
					SSP2: Self-determination					
Burkina Faso	Nigeria	2.9	0.7	491.8	0.0	0.0	0.0	0.0	0.0	0.0
					SSP3: Civil Society to the Rescue?					
Burkina Faso	Nigeria	0.2	0.3	0.6	3.7	5324.4	3207.6	642.4	109.0	186.3
					SSP4: Save Yourself					
Benin	Cote d'Ivoire	48.3	0.0	0.0	0.0	1688.3	554.2	0.0	0.0	0.0
Benin	Ghana	0.0	0.0	45.8	0.0	0.0	0.0	0.0	0.0	0.0
Benin	Guinea	0.0	1.1	4.3	1.8	-1.0	2.2	606.4	847.1	1680.3
Benin	Nigeria	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Benin	Togo	0.0	-0.1	-1.0	0.0	0.0	0.0	361.0	52.2	0.0
Burkina Faso	Cote d'Ivoire	0.0	0.0	-1.0	-1.0	-1.0	-1.0	-0.2	-0.2	-0.5
Burkina Faso	Ghana	751.4	-0.1	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
Burkina Faso	Guinea	198.7	-0.2	-0.9	-1.0	0.1	-1.0	-1.0	-0.9	-1.0
Burkina Faso	Nigeria	-0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Burkina Faso	Togo	0.0	0.0	5505.2	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0

Nigeria	Benin	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	-1.0	-1.0
Senegal	Togo	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other ECOWAS	Cote d'Ivoire	-1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other ECOWAS	Ghana	-1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other ECOWAS	Guinea	-0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other ECOWAS	Nigeria	-1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other ECOWAS	Togo	-1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 4: Cereals trade flow changes from baseline under RCP 8.5

		2020	2030	2040	2050	2060	2070	2080	2090	2100
					SSP1: Cash, Control & Calories					
Burkina Faso	Benin	0.0	0.0	0.0	0.0	789.7	0.0	0.0	0.0	0.0
Burkina Faso	Cote d'Ivoire	0.0	0.0	0.0	676.2	1896.1	0.0	934.8	3519.6	4201.8
Burkina Faso	Ghana	0.0	0.0	0.0	3050.0	4031.1	5019.8	6075.9	5012.8	7325.6
Burkina Faso	Guinea	0.0	0.0	0.0	0.0	594.0	816.7	816.1	5378.2	8159.4
Burkina Faso	Nigeria	0.5	0.2	0.5	-0.1	-0.7	0.0	-0.2	-1.0	-1.0
Burkina Faso	Togo	0.0	0.0	0.0	333.0	560.5	0.0	0.0	0.0	0.0
Nigeria	Benin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3615.0	4146.6
Nigeria	Ghana	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1861.7	426.6
Nigeria	Togo	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2587.4	3985.8
Senegal	Guinea	0.0	0.0	0.0	0.0	0.0	219.3	0.0	0.0	0.0
Senegal	Nigeria	0.0	64.8	20.2	0.0	0.0	0.0	0.0	0.0	0.0
Senegal	Togo	0.0	0.0	0.0	294.9	839.3	0.0	0.0	700.6	0.0
Other ECOWAS	Cote d'Ivoire	0.0	0.0	0.0	366.9	0.0	0.0	0.0	0.0	0.0
Other ECOWAS	Guinea	0.0	0.0	0.0	2473.4	2583.6	2874.6	4111.0	1170.0	0.0
Other ECOWAS	Nigeria	1692.9	2301.4	1195.6	0.0	0.0	0.0	0.0	0.0	0.0
					SSP2: Self-determination					
Burkina Faso	Nigeria	3.2	2.5	809.7	0.0	0.0	0.0	0.0	0.0	0.0
					SSP3: Civil Society to the Rescue?					
Burkina Faso	Nigeria	-1.0	-1.0	-1.0	-1.0	0.0	0.0	0.0	0.0	0.0
					SSP4: Save Yourself					
Benin	Guinea	0.0	-1.0	-1.0	-1.0	-1.0	-1.0	0.0	0.0	0.0
Benin	Nigeria	-1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Benin	Togo	0.0	-1.0	-1.0	0.0	0.0	0.0	0.0	0.0	0.0
Burkina Faso	Cote d'Ivoire	0.0	0.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
Burkina Faso	Ghana	0.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
Burkina Faso	Guinea	0.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
Burkina Faso	Nigeria	-1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Burkina Faso	Togo	0.0	0.0	0.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
Nigeria	Benin	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	-1.0	-1.0
Senegal	Togo	-1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other ECOWAS	Cote d'Ivoire	-1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other ECOWAS	Ghana	-1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Other ECOWAS	Guinea	-1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other ECOWAS	Nigeria	-1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other ECOWAS	Togo	-1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 5 : Vegetables-Fruits-and-Nuts trade flow changes from baseline under RCP 4.5

		2020	2030	2040	2050	2060	2070	2080	2090	2100
				SSP1: Cash, Control & Calories						
Benin	Burkina Faso	0.0	0.0	0.0	0.0	0.0	151.6	7266.7	5588.0	6866.6
Cote d'Ivoire	Burkina Faso	-1.0	-0.2	-0.1	-0.3	-1.0	0.0	0.0	0.0	0.0
Cote d'Ivoire	Ghana	-1.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cote d'Ivoire	Guinea	0.0	0.0	0.0	0.0	0.0	-1.0	0.0	0.0	0.0
Cote d'Ivoire	Nigeria	3273.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cote d'Ivoire	Senegal	0.0	0.0	0.0	0.2	-0.1	-0.3	-0.4	-0.4	-0.4
Cote d'Ivoire	Togo	0.0	0.0	0.0	1346.6	-0.3	-0.7	-0.9	-0.6	-0.5
Cote d'Ivoire	OtherECOWAS	0.0	0.0	0.0	-1.0	-1.0	0.0	0.0	0.0	0.0
Ghana	Burkina Faso	0.0	0.0	-0.3	0.3	0.3	0.0	-0.3	-0.2	-0.2
Ghana	OtherECOWAS	0.0	0.0	0.0	0.0	0.0	-1.0	0.0	0.0	0.0
Guinea	Nigeria	257.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Guinea	Togo	0.0	0.0	0.0	-1.0	0.0	0.0	0.0	0.0	0.0
Guinea	OtherECOWAS	-1.0	0.3	-0.2	0.0	0.0	0.0	0.0	0.0	0.0
Nigeria	Benin	-1.0	0.2	0.6	0.2	-0.3	-1.0	-1.0	-1.0	-1.0
Nigeria	Burkina Faso	-1.0	0.1	2.1	0.0	0.0	0.0	0.0	0.0	0.0
Nigeria	Senegal	0.0	22.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Nigeria	Togo	0.0	116.7	3.0	-1.0	0.0	0.0	0.0	0.0	0.0
Nigeria	OtherECOWAS	-1.0	-0.3	-0.1	0.0	0.0	0.0	0.0	0.0	0.0

Senegal	OtherECOWAS	-0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Togo	Burkina Faso	-1.0	-0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SSP3: Civil Society to the Rescue?										
Cote d'Ivoire	Guinea	-0.9	0.0	0.0	0.0	0.0	0.0	9471.9	0.0	0.0
Cote d'Ivoire	Nigeria	-1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ghana	Burkina Faso	0.0	0.0	0.0	0.0	0.0	0.0	34533.7	0.0	0.0
Ghana	Guinea	0.0	0.0	0.0	0.0	0.0	10542.2	4996.0	14248.6	0.0
Nigeria	Burkina Faso	0.0	0.0	0.0	0.0	0.0	0.0	76359.2	12204.7	0.0
Nigeria	Cote d'Ivoire	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28816.4	4291.3
Nigeria	Ghana	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	124.8
Nigeria	Guinea	0.0	0.0	0.0	0.0	0.0	1287.4	0.0	13586.7	43117.1
Nigeria	Nigeria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nigeria	Senegal	0.0	0.0	0.0	0.0	0.0	272.7	13893.8	23088.9	37787.7
Nigeria	Togo	0.0	0.0	0.0	0.0	0.0	0.0	26683.8	0.0	0.0
Nigeria	OtherECOWAS	0.0	0.0	0.0	0.0	0.0	20795.5	21720.2	38347.6	51431.8
SSP4: Save Yourself										
Benin	Burkina Faso	-1.0	-0.3	-0.3	-0.1	0.3	0.1	-0.1	-0.1	-0.1
Cote d'Ivoire	Burkina Faso	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ghana	Burkina Faso	-0.2	0.1	0.8	0.5	-1.0	0.0	0.0	0.0	0.0
Nigeria	Benin	388.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Togo	Burkina Faso	-0.3	-0.1	-0.2	0.0	-0.6	-1.0	0.0	0.0	0.0

Table 6: Vegetables-Fruits-and-Nuts trade flow changes from baseline under RCP 8.5

		2020	2030	2040	2050	2060	2070	2080	2090	2100
					SSP1: Cash, Control & Calories					
Benin	Burkina Faso	0.0	0.0	0.0	0.0	0.0	952.7	8723.0	11444.1	14771.7
Cote d’Ivoire	Burkina Faso	-1.0	-0.8	-0.4	-0.2	-1.0	0.0	0.0	0.0	0.0
Cote d’Ivoire	Ghana	-1.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cote d’Ivoire	Guinea	0.0	0.0	27.4	0.0	0.0	-1.0	0.0	0.0	0.0
Cote d’Ivoire	Nigeria	2473.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cote d’Ivoire	Senegal	0.0	0.0	0.0	0.1	-0.1	-0.4	-0.5	-0.5	-0.4
Cote d’Ivoire	Togo	0.0	0.0	0.0	1453.6	-0.3	-0.7	-1.0	-0.8	-0.7
Cote d’Ivoire	OtherECOWAS	0.0	0.0	0.0	-0.5	-1.0	0.0	0.0	0.0	0.0
Ghana	Burkina Faso	0.0	0.0	-1.0	0.2	0.3	-0.1	-0.3	-0.4	-0.4
Ghana	OtherECOWAS	0.0	0.0	0.0	0.0	0.0	-1.0	0.0	0.0	0.0
Guinea	Nigeria	60.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Guinea	Togo	0.0	0.0	0.0	-1.0	0.0	0.0	0.0	0.0	0.0
Guinea	OtherECOWAS	-1.0	-0.4	-1.0	0.0	0.0	0.0	0.0	0.0	0.0
Nigeria	Benin	-1.0	-1.0	1.0	0.2	-0.3	-1.0	-1.0	-1.0	-1.0
Nigeria	Burkina Faso	-1.0	0.1	5.7	0.0	0.0	0.0	0.0	0.0	0.0
Nigeria	Senegal	0.0	56.6	64.7	0.0	0.0	0.0	0.0	0.0	0.0
Nigeria	Togo	0.0	0.0	5.9	-1.0	0.0	0.0	0.0	0.0	0.0
Nigeria	OtherECOWAS	-1.0	0.7	0.9	0.0	0.0	0.0	0.0	0.0	0.0
Senegal	Nigeria	-0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Senegal	OtherECOWAS	-1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Togo	Burkina Faso	-1.0	-0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
					SSP3: Civil Society to the Rescue?					
Cote d’Ivoire	Guinea	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cote d’Ivoire	Nigeria	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
					SSP4: Save Yourself					
Benin	Burkina Faso	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
Cote d’Ivoire	Burkina Faso	-1.0	2089.0	1626.6	0.0	0.0	0.0	0.0	0.0	0.0

Cote d’Ivoire	Nigeria	52.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cote d’Ivoire	Senegal	0.0	0.0	100.5	176.0	252.1	300.3	311.4	335.3	404.9
Cote d’Ivoire	Togo	0.0	0.0	1768.0	2021.6	2288.0	2546.5	2788.8	3074.3	3367.7
Ghana	Burkina Faso	-1.0	-0.7	2.4	5.7	11.0	8847.4	8815.4	8725.7	8579.8
Guinea	Burkina Faso	0.0	379.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Guinea	Nigeria	366.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Guinea	Senegal	0.0	25.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Guinea	OtherEcowas	0.0	627.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nigeria	Benin	0.0	0.0	6909.3	7238.9	7604.4	7988.4	8337.2	8644.3	8903.5
Nigeria	Burkina Faso	0.0	3710.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Togo	Burkina Faso	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	0.0	0.0	0.0

Finally, with the socio-economic scenario-SSP4, more decline in trade of vegetable-fruits-and-nuts is observed going from Benin, Cote d’Ivoire, Ghana, and Togo to Burkina Faso and to Benin. Under the RCP 8.5, the trade flow changes of VFN from baseline is presented in Table 6. With the socio-economic scenario-SSP1, Republic of Benin is seen as exporting VFN to Burkina starting from 2070 to the end of the century. Exports from Cote d’Ivoire, Ghana, Nigeria and Togo have followed some increases and some decreases relatively to the baseline. With the socio-economic scenario-SSP3, results showed exports from Cote d’Ivoire to Guinea and Nigeria will decrease by the year 2020. However, under the socio-economic scenario-SSP4, exports from Cote d’Ivoire to Nigeria, Senegal, and Togo will increase consistently relatively under the baseline scenario. A similar increase in trade is observed from Nigeria to Benin. Consistent declines in trade relatively to the baseline are observed from Benin to Burkina Faso and from Togo to Burkina Faso.

Impact of climate change on oil-seeds trade

The impact of climate change under RCP 4.5 on the trade of oilseeds trade from baseline without climate change is presented in Table 7. With the socio-economic scenario-SSP1, trade of oil-seeds from Benin and Burkina to Ghana, Guinea, and Cote d'Ivoire showed that export of produce has been declining towards the end of the century. The only exception is the increase of trade from Benin to Guinea in the year 2100. Under the socio-economic scenario-SSP2, oilseed export will either increase or decrease at the beginning of the century but without any specific pattern. With the socio-economic scenario-SSP3, oilseeds trade is projected to increase in some years (e.g. Burkina Faso to Togo in 2050 & 2060) and decreased for other years (Benin to Ghana in 2080) without any specific pattern. No change in oilseeds trade from baseline with the socio-economic scenario-SSP4.

Table 7: Oil-seeds trade flow changes from baseline under RCP 4.5

		2020	2030	2040	2050	2060	2070	2080	2090	2100
					SSP1: Cash, Control & Calories					
Benin	Cote d'Ivoire	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.2
Benin	Ghana	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.9
Benin	Guinea	0.0	0.0	0.0	0.0	0.0	0.0	-0.9	-1.0	2051.5
Burkina Faso	Guinea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0
					SSP2: Self-determination					
Burkina Faso	Nigeria	0.0	81.4	-1.0	0.0	0.0	0.0	0.0	0.0	0.0
Cote d'Ivoire	Nigeria	0.0	344.6	-0.5	-1.0	0.0	0.0	0.0	0.0	0.0
Ghana	Nigeria	0.0	47.0	-0.9	0.0	0.0	0.0	0.0	0.0	0.0
Nigeria	Benin	25.3	-1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Senegal	Togo	0.0	80.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OtherECOWAS	Benin	0.0	275.1	-1.0	0.0	0.0	0.0	0.0	0.0	0.0
OtherECOWAS	Ghana	0.0	0.0	179.2	0.5	-1.0	0.0	0.0	0.0	0.0
OtherECOWAS	Guinea	0.0	3.5	-1.0	-1.0	0.0	0.0	0.0	0.0	0.0
OtherECOWAS	Nigeria	0.0	682.3	8.8	-0.4	0.0	0.0	0.0	0.0	0.0
					SSP3: Civil Society to the Rescue?					
Benin	Cote d'Ivoire	0.0	0.0	0.0	0.0	0.0	0.0	0.0	935.8	0.0
Benin	Ghana	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	0.0	0.0
Benin	Guinea	0.0	0.0	0.0	0.0	-1.0	-1.0	431.7	658.7	0.0
Benin	Nigeria	0.0	0.0	0.0	0.0	0.0	13.0	0.0	-1.0	142.0
Benin	Togo	0.0	0.0	0.0	0.0	-1.0	-0.4	0.3	0.0	723.2
Burkina Faso	Cote d'Ivoire	0.0	0.0	0.0	0.0	0.0	0.0	7.4	0.0	0.0
Burkina Faso	Ghana	0.0	0.0	0.0	0.0	8.1	-1.0	417.7	721.7	0.0
Burkina Faso	Guinea	0.0	0.0	0.0	12.7	23.0	-1.0	-1.0	111.4	0.0
Burkina Faso	Nigeria	0.0	0.0	0.0	0.0	0.0	266.4	0.0	-1.0	239.0
Burkina Faso	Togo	0.0	0.0	0.0	220.9	121.3	0.0	0.0	0.0	0.0
Cote d'Ivoire	Benin	0.0	0.0	0.0	0.0	28.9	0.0	0.0	0.0	0.0
Cote d'Ivoire	Guinea	0.0	0.0	0.0	0.0	98.5	0.0	0.0	0.0	0.0
Cote d'Ivoire	Nigeria	0.0	0.0	0.0	0.0	119.5	0.0	0.0	0.0	0.0
Nigeria	Benin	0.0	0.0	0.0	43.9	0.0	0.0	0.0	0.0	0.0
Nigeria	Ghana	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	80.6	0.0
Nigeria	Senegal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	103.4	0.0
Nigeria	Togo	0.0	0.0	0.0	0.0	0.0	0.0	-0.3	942.9	0.0

Senegal	Togo	0.0	0.0	0.0	0.0	63.6	92.7	0.0	0.0	0.0
OtherECOWAS	Cote d'Ivoire	0.0	0.0	0.0	0.0	0.0	247.9	0.0	-1.0	2.3
OtherECOWAS	Ghana	0.0	0.0	0.0	0.0	0.0	138.3	0.0	-1.0	-0.1
OtherECOWAS	Guinea	0.0	0.0	0.0	0.0	0.0	270.2	0.0	-1.0	-0.1
OtherECOWAS	Nigeria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	-1.0
OtherECOWAS	Senegal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	0.1
OtherECOWAS	Togo	0.0	0.0	0.0	0.0	0.0	19.4	0.0	-1.0	1208.0

Table 8: Oil-seeds trade flow changes from baseline under RCP 8.5

		2020	2030	2040	2050	2060	2070	2080	2090	2100
		SSP1: Cash, Control & Calories								
Benin	Cote d'Ivoire	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Benin	Ghana	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.9
Benin	Guinea	0.0	0.0	0.0	0.0	0.0	0.0	-0.9	-1.0	0.0
		SSP2: Self-determination								
Burkina Faso	Nigeria	0.0	58.6	-1.0	0.0	0.0	0.0	0.0	0.0	0.0
Cote d'Ivoire	Nigeria	0.0	362.4	-0.6	-1.0	0.0	0.0	0.0	0.0	0.0
Ghana	Nigeria	0.0	42.0	-0.9	0.0	0.0	0.0	0.0	0.0	0.0
Nigeria	Benin	8.3	-1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OtherECOWAS	Benin	0.0	260.0	-1.0	0.0	0.0	0.0	0.0	0.0	0.0
OtherECOWAS	Ghana	0.0	0.0	220.9	0.6	-1.0	0.0	0.0	0.0	0.0
OtherECOWAS	Guinea	0.0	0.7	-1.0	-1.0	0.0	0.0	0.0	0.0	0.0
OtherECOWAS	Nigeria	0.0	942.0	7.0	-0.6	0.0	0.0	0.0	0.0	0.0
OtherECOWAS	Senegal	0.0	181.1	-1.0	0.0	0.0	0.0	0.0	0.0	0.0
OtherECOWAS	Togo	0.0	65.3	-1.0	0.0	0.0	0.0	0.0	0.0	0.0
		SSP3: Civil Society to the Rescue?								
Benin	Cote d'Ivoire	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	0.0	0.0
Benin	Ghana	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	0.0	0.0
Benin	Guinea	0.0	0.0	0.0	0.0	-1.0	-1.0	0.0	0.0	0.0
Benin	Nigeria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	0.0
Benin	Togo	0.0	0.0	0.0	0.0	-1.0	-1.0	0.0	0.0	0.0
Burkina Faso	Cote d'Ivoire	0.0	0.0	0.0	0.0	0.0	0.0	-0.9	0.0	0.0
Burkina Faso	Ghana	0.0	0.0	0.0	0.0	0.0	-1.0	0.0	0.0	0.0
Burkina Faso	Guinea	0.0	0.0	0.0	0.0	0.0	-1.0	-1.0	0.0	0.0

Burkina Faso	Nigeria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	0.0
Cote d'Ivoire	Ghana	0.0	0.0	84.8	2.9	0.0	0.0	0.0	0.0	0.0
Cote d'Ivoire	Nigeria	245.5	254.9	92.7	0.0	0.0	0.0	0.0	0.0	0.0
Ghana	Nigeria	50.5	26.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Guinea	Nigeria	25.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nigeria	Ghana	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	0.0	0.0
Nigeria	Togo	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	0.0	0.0
OtherECOWAS	Cote d'Ivoire	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	-1.0
OtherECOWAS	Ghana	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	-1.0
OtherECOWAS	Guinea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	-1.0
OtherECOWAS	Nigeria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	-1.0
OtherECOWAS	Senegal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	-1.0
OtherECOWAS	Togo	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	0.0
				SSP4: Save Yourself						
Cote d'Ivoire	Senegal	98.5	104.6	110.9	117.2	36.8	131.2	85.1	48.5	0.0
Cote d'Ivoire	OtherECOWAS	135.4	105.8	72.6	57.2	115.2	0.0	0.0	0.0	0.0
Ghana	Burkina Faso	0.0	0.0	0.0	0.0	83.4	89.1	94.3	76.3	26.5
Ghana	Senegal	0.0	0.0	0.0	0.0	86.2	0.0	51.7	38.4	0.0
Guinea	Senegal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	56.0	27.7
Guinea	Togo	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1
Nigeria	Benin	217.4	216.9	215.9	213.7	213.2	212.6	210.5	206.4	201.0
Nigeria	Burkina Faso	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	74.2
Nigeria	Cote d'Ivoire	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.9
Nigeria	Senegal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	123.4
Togo	Burkina Faso	66.3	69.9	73.7	77.8	0.0	0.0	0.0	20.9	0.0

The impact of climate change under RCP 8.5 on oilseeds trade from baseline without climate change is presented in Table 8. Under the socio-economic scenario-SSP1, oilseeds trade from Benin to Cote d'Ivoire increased in the year 2100 while trade from Benin to Guinea declined between the years 2080 and 2090. With the socio-economic scenario-SSP2, oil-seeds trade flows changed during the first half of the century but without any specific pattern. With the socio-economic scenario-SSP3, oilseeds trade from Cote d'Ivoire to Ghana and Nigeria increased (Table 8). A similar pattern is observed from Ghana to Nigeria and vice-versa. Trade from other countries declined or remained steady relatively to the baseline. Finally, with the socio-economic scenario-SSP3, oilseeds trade remained steady or increased from baseline. The exporting countries are Cote d'Ivoire, Ghana, Guinea, Nigeria and Togo.

Sensitivity to exterior common tariff

Ceteris-paribus, if the demand for food continues to increase due to population and economic growth, ECOWAS countries may continuously be in need of food importation from outside the ECOWAS region until the end of the century. The comparison between the baseline total trade costs and the two climate change scenarios trade costs (Table 9) showed that trade costs increased with the socio-economic conditions-SSP3 and -SSP4 under RCP 8.5 because of the intensity of outside zone food imports driven by the need to adapt to climate change. These adaptation costs may be reduced through the decrease of the exterior tariff. Here we assume both a reduction of 5% and 10% of the tariffs and evaluate the impact on total trade costs under the RCP 8.5. The results of the two sensitivity analyses are presented in Table 10.

Table 9: Percent trade cost differences from baseline

	SSP1	SSP2	SSP3	SSP4
Baseline	10565447	59186317	35773588	273.61219
RCP 4.5	8857.48	54044690	12879351	270.03937
Difference	-1.00	-0.09	-0.64	-0.01
RCP 8.5	13789.29	52780709	54534409	24053103
difference	-1.00	-0.11	0.52	87908.47

Table 10: Sensitivity in ECT decrease under RCP 8.5

	SSP1	SSP2	SSP3	SSP4
5% decrease				
Original	13789.3	52780709	54534409	24053103
New	13749	52592467	54340235	23985026
Change	-0.003	-0.004	-0.004	-0.003
10% decrease				
Original	13789.3	52780709	54534409	24053103
New	13708.8	52404226	54146062	23916950
Change	-0.006	-0.007	-0.007	-0.006

Table 11: Outside ECOWAS rice import changes from baseline under RCP 4.5 and SSP1

	2020	2025	2030	2035	2040	2045	2050
Benin	0.0	0.0	0.0	0.0	0.0	643.9	0.0
Burkina Faso	0.0	0.0	0.0	0.0	0.0	0.2	3.7
Cote d'Ivoire	0.2	0.2	0.2	1.0	806.9	0.0	0.0
Ghana	710.9	494.9	0.0	0.0	0.0	0.0	0.0
Guinea	181.0	38.6	0.0	0.0	0.0	0.0	0.0
Nigeria	433.8	0.0	0.0	0.0	0.0	0.0	0.0
Senegal	0.0	0.0	0.0	0.0	0.4	0.0	0.0
Togo	0.1	0.1	0.1	259.1	287.4	0.0	0.0
Other ECOWAS	0.4	1.6	26.2	2203.2	259.4	0.0	0.0

We find from the sensitivity analysis that a decrease in the ECT by 5% will reduce the adaption costs under RCP 4.5 by an amount between 0.3 to 0.4 percent depending on the SSP scenarios. A further decrease to 10% in the ECT will reduce the adaptation costs under RCP 4.5 by an amount between 0.6 and 0.7 percent depending on the SSP scenarios.

Implications for food security in the ECOWAS

Many West African countries will continue to import food from outside the ECOWAS region given that demands are rising more than what the ECOWAS production zone can cover. For instance, rice import changes from baseline originating from outside ECOWAS under RCP 8.5 with SSP1 are presented in Table 11. This shows that with climate change, food imports from outside ECOWAS might increase for some countries. These results are consistent with the results found by Rosenzweig and Parry (1994) under various climate change scenarios. The notion of food security is thus multidimensional. These dimensions include the availability of food (supply) which may combine domestic production and imports from outside sources, the accessibility of food and the security/quality of food. The definition that was agreed upon at the World Food Summit in 1996 is that food security exists when people at all times, have physical and economic access to sufficient safe and nutritious food to meet their dietary needs and food preferences for a healthy and active life (Pinstrup-Anderson, 2009).

While the part related to dietary need and food preferences could be addressed at a household level, this study is beyond the scope of household analysis. It is a regional assessment of the ability of each country to meet its demand

originating from either inside or outside the ECOWAS zone. So what could be said in terms of food security at this point is more related to the food availability which measures the physical availability of food. The physical availability will be met as long as the countries outside ECOWAS, particularly those that are located in the northern hemisphere are not significantly affected by climate change. And it has been shown that the northern hemisphere will not suffer significantly from climate change in terms of its ability to produce food (Rosenzweig and Parry, 1994). Therefore, the question that remains is accessibility/affordability issues which depend on the marginal values of imports outside of ECOWAS. For instance, under RCP 8.5 and with SSP1 the marginal values of rice import are given in Figure 1. These values show how expensive importing food resources from outside ECOWAS could become over time.

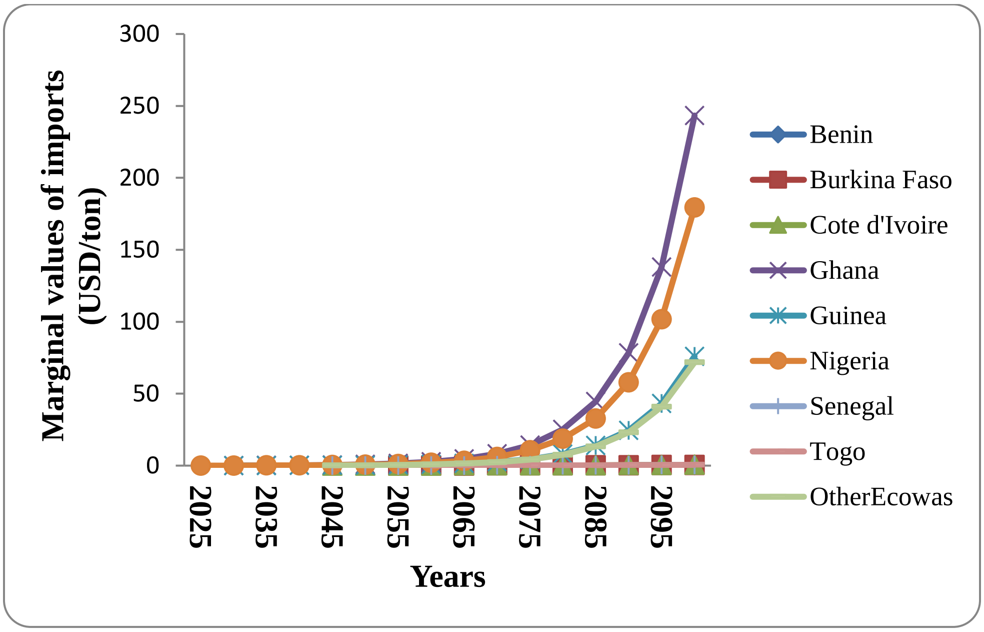

Figure 1: Marginal value of food imports

Conclusion

This study looked at the potential impact of climate change scenarios that included a baseline scenario without climate change, a business as usual scenario (RCP 8.5) and a mitigation scenario (RCP 4.5) on trade flows in the ECOWAS region. Crop production under these climate change scenarios has been evaluated with four hypothetical shared socio-economic pathways (SSPs). These socio-economic scenarios are used to drive prices and costs dynamically in the crop production process.

The results suggest that the impact of climate change on crop trade flows will depend on crop types, climate change, and socio-economic scenarios that are being considered. We find that trade within ECOWAS may be limited due to supplier shortages but no clear pattern has emerged in terms of the net exporters and the net imported. Some countries that are net exporters for some years may become net importers some other years. Therefore, reliance on food imports outside ECOWAS will be the key to foster food availability in the ECOWAS zone. Since the ECOWAS zone might be net importers of food, all imports will then be subject to the exterior common tariffs established in 2015. We then ran trade policy scenarios of 5 to 10% decrease in the ECT. The sensitivity results showed that these policy measures may reduce adaptation cost about 3-7% under the RCP 8.5. However, change in the ECT will not have any significant impact on the trade flow apart from reducing the cost of trade. This fact is due to the model structure which is built for meeting the need of food demand both from inside zone and outside zone imports.

The implications of trade flows observed under the climate change scenarios in terms of food security have been discussed to show that as long as

ECOWAS countries have the opportunity to import food from outside regions including Europe, Asia, Australia, Americas and others African countries, the question of food availability will be resolved. In fact, previous studies have already shown that climate change may affect food supply within the tropics but the possibility of food import from the northern hemisphere may be a way to adapt to climate change effects (Rosenzweig and Parry, 1994). The question of whether people will be able to have economic access to food or whether the food imported will be safe or not is not addressed in this research. Therefore, food will be available as long as there are possibilities of imports outside the ECOWAS.

Finally, this study implies that more efforts are to be put into agricultural production within the ECOWAS zone. These include investment in agricultural research, extension services, irrigation equipment and biotechnology to improve inside ECOWAS production of food. In addition, in the study, we assumed that demand is heavily influenced by the population which grows at 3.5% in average throughout the century.

However, it is possible that population growth may decline before we reach the end of the century to levels already seen in the developed countries. Therefore, the demand projections might be overestimated. Furthermore, the structure of our model which takes prices exogenously has been a limiting factor. Future model building efforts are to be oriented towards price endogenous model that completely accounts for food supply outside the ECOWAS zone. These efforts may improve the results of this analysis. A future research that considers all the available arrays of adaptation measures,

including irrigation, biotechnology and other sustainable methods of crop yield increase could be undertaken.

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