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Can intra-regional food trade increase food availability in the context of global climatic change in West Africa?

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Abstract This paper investigates the role of intra-regional trade on food availability within the context of global climatic change in the Economic Community of West African States (ECOWAS). To that end, the study uses a module of trade cost minimization built within a bio-economic optimization model of cropland allocation. The results show that the climate-induced trade pattern in ECOWAS depends on the prevailing socio-economic conditions during the century. No specific pattern of trade flows is predicted but several countries may become dependent on food imports outside of ECOWAS. An adjustment of the common external tariffs (CET) may reduce food import costs. Also, doubling crop yields by 2050 could significantly reduce outside dependence. Finally, actions are urgently needed to be taken to foster agricultural production in ECOWAS.

1 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 to define appropriate 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

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or not to reduce emissions in order to maintain global temperature increase below the 2 °C by 2100, adaption measures are to be quickly designed to reduce the impact on food availability, 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 stochastic patterns 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 the issue of food availability may be through food trade across countries. This study is focused on the ECOWAS countries as a case study to understand the climate, agricultural production, food trade, and food availability 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 terms of weakening their ability to produce food from agriculture; some countries within the South may do better than others. Therefore, intra-regional trade and food import from the 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 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. Consequently, intra-regional 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 trade of agricultural commodities as a means of adapting to climate change (Stephan and Schenker 2008; Bajželj et al. 2014). 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 inhabitants of the affected country hold less labor income to tackle food purchase.

The objective of this paper is to study how intra-regional food trade can be a strategy to increase food availability in West African countries. Specifically, this paper seeks to (1) identify countries that are net suppliers from those that have deficit across scenarios, (2) measure the impact of intra-regional trade and agricultural policies within the ECOWAS on trade flows, and (3) evaluate the implications of trade flows on food availability. To reach these objectives, several research questions are to be addressed. These fundamental research questions include the following: (i) which countries are in excess supply versus those that are in excess demand across scenarios? (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 Rep. of 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, production costs, 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.

2 Materials and methods

2.1 Background on food trade within and outside ECOWAS

The ECOWAS is created in 1975 (Brown 1982). There is a long history of trade within ECOWAS and between ECOWAS and its partners. Inside ECOWAS food trade has been dominated by the informal sector making it difficult to collect data. Inside ECOWAS food trade includes mainly cereals and livestock. Officially, food trade is about 1% of the total trade within ECOWAS. This number may be higher with informal trade (ENDA CACID 2012). Also, within ECOWAS trade suffers from country level policies that do not allow formal trade of cereals for food security reasons. However, in case of a food deficit, countries with excess supply can officially sell to those in need. For instance, in 2012, the country of Togo through the World Food Program (WFP) sold cereals to Niger which was affected by severe drought. Outside ECOWAS, food import accounts for 14% percent of total imports in 2012 and the main products that are imported include rice and wheat (ENDA CACID 2012).

2.2 Modeling materials

The study uses a bio-economic optimization model based on a representative risk-neutral profit maximizer assumption within which an intra-regional food trade module is developed. The food trade module is built as a classical transport model (Dantzig 1963) that allocates food optimally from excess supply countries to excess demand countries. The model is then applied to the countries in the ECOWAS to analyze intra-regional trade within the context of global climatic change. To reach the objectives of this study, several models were integrated. First, a regional climate model is used to predict temperature and precipitations from 2004 to 2100 with two representative concentration pathways (RCPs), namely RCP 4.5 which represents a medium level greenhouse gas forcing and RCP 8.5 which represents a high level greenhouse gas forcing. Second, an econometric crop simulator is used to simulate crop yields under the two RCPs based on the projected temperature and precipitations levels. Other elements including soil characteristics obtained from geographic information system (GIS) mapping were included in the yield simulation. Third, the simulated yields under the two RCPs are coupled with crop prices data projected within four socio-economic scenarios and fed into a profit-maximizing bio-economic model to predict land use as well as crop and livestock production levels. Finally, the produced crop levels are used to predict intra-regional trade flows in the ECOWAS while taking into account transport costs and trade tariffs outside of the ECOWAS free trade zone. The region has recently put in place a tariff system to handle trade outside of ECOWAS. These tariff levels are included to evaluate their effectiveness as policy instruments to stimulate outside ECOWAS trade. The complete structure of the model is shown in Fig. 1.

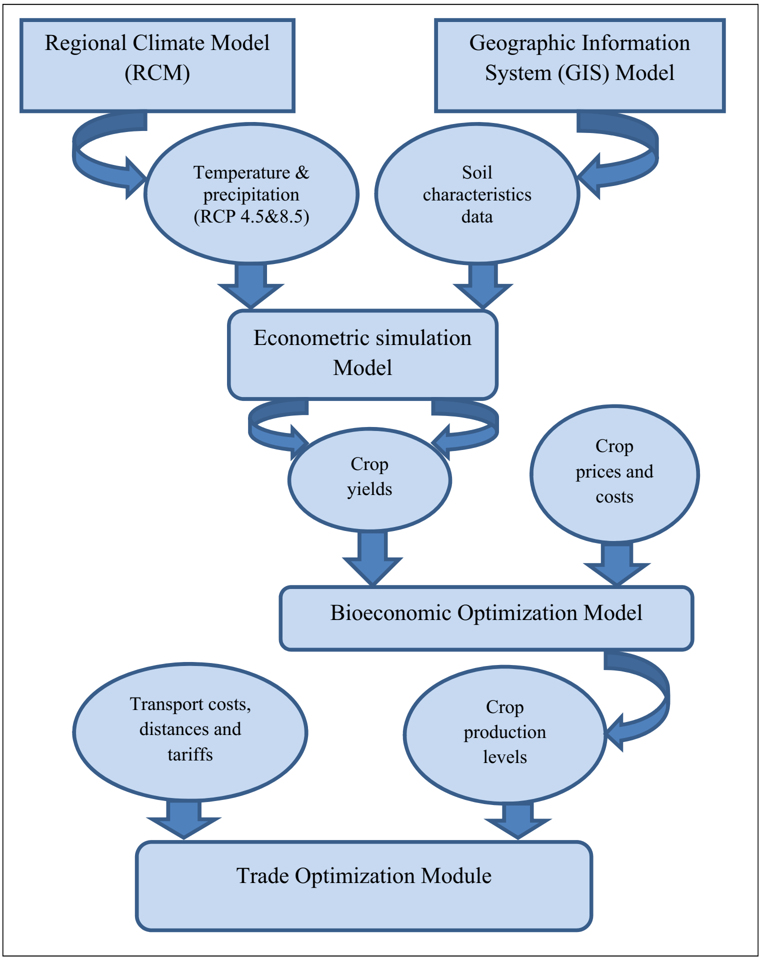

Fig. 1 Structure of the intra-regional trade model

2.2.1 Climate change and socio-economic scenarios

The climate scenarios are aimed at projecting climate variables under two RCPs. In order to achieve this; temperature, precipitation, and CO_2 concentration values are projected for the West African region from 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 ECOWAS. 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 RCP 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 (Wilkinson and Eidinow 2008; Palazzo et al. 2014, O'Neill et al. 2014; Lokonon et al. 2016). 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 slightly 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 well 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.

2.2.2 Crop yield simulation

Crop yields usually are simulated based on several variables (Izaurralde et al. 2006; Chang 2002) 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 yields are 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 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:

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

or in logarithmic terms:

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

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 mean temperature; P_{ijt} is the monthly mean 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 is given by Eq. (3) which allows a slow total factor productivity (TFP) growth rate of about 1%. This rate implies doubling crop yields only after a century. This growth rate reflects the deceptive technical change rate observed in West Africa's agriculture in recent years (Nin-Pratt et al. 2010).

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

where U_{it} is a white noise with a truncated normal distribution $\aleph(0, 0.005, [0, +\infty))$.

2.2.3 The bio-economic profit maximization model

The bio-economic model is designed as an optimization problem where the representative farmer maximizes a discounted profit (McCarl and Spreen 1980; Egbendewe-Mondzozo et al. 2011) of choosing among seven cropping systems. These include paddy rice, cereals (maize, sorghum, and millet), vegetable-fruits-nuts (banana, cassava, plantain, potato, sweet potato, and yam), oilseeds (beans, cashew nuts, cowpea, groundnut, and soybean), sugarcane, cotton, and indigenous crops (cocoa, coffee, and sesame) as in the Global 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 splitting the West African 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 is then calibrated using positive mathematical programing method (Howitt 1995). From the calibration year (2004), agricultural land penetration rate of plus and minus 1% each 5 years is defined to constrain land allocation dynamically until 2100. 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). During the calibration exercise, the

2010 data on land use were already available. Therefore, the projected values of the model are constrained within 12% absolute deviation vis-à-vis the actual 2010 data as suggested by the theory (Hazell and Norton 1986). The total output computed is then passed to the trade module to predict intra-regional trade flows based on climate change-driven dynamic comparative advantages.

2.2.4 The trade module

This is a dynamic transportation model in which food crops are being moved from countries that are net suppliers to countries that are in excess 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 per unit transport cost. If $imp_{c,\,i,\,t}$ is the import from outside ECOWAS free trade zone and δ_c is the common external tariff (CET) parameter applied to crop c, then the transport model could be written as:

$$\underset{x_{c,i,j,t};imp_{c,i,t}}{\mathrm{MIN}} \sum_c \sum_i \sum_j \sum_t \left(x_{c,i,j,t} \times \gamma \times Dist_{i,j} + \delta_c \times imp_{c,i,t} \right) \tag{4}$$

Subject to:

$$\sum_j x_{c,i,j,t} \le a_{c,i,t}, \forall c, i, t \tag{5}$$

$$\sum_i x_{c,i,j,t} + imp_{c,j,t} \ge b_{c,j,t}, \forall c, j, t \tag{6}$$

$$x_{c,i,j,t} \ge 0; imp_{c,i,t} \ge 0, \forall c, i, j, t \tag{7}$$

The objective function (4) consists of choosing shipment quantities and outside ECOWAS zone imports such that the total trade cost is minimized. The constraints (5) stipulate that the total shipments must be less or equal to the available supply. Constraints (6) express the fact that total shipments plus imports must be greater or equal to the excess demands. Constraints (7) are the requirement that shipment and imports must be non-negative.

Trade module parameterization

a. Crop production levels

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

b. 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 base year. The data on demand quantities are 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 functions are indexed to the average yearly population growth of 3.5% and income elasticity growth rates spanning from 3 to 8.5% every 5 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 Rep. of Benin, Burkina Faso, Cote d'Ivoire, Ghana, Guinea, Nigeria, Senegal, and Togo. The other countries (Gambia, Guinea-Bissau, Liberia, Mali, Niger, and Sierra Leone) were grouped under the label "other ECOWAS." 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 are 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 are calculated using geographical information system (GIS) on an ECOWAS map. The parameter δ_c which includes common external 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) with the generalized algebraic modeling software (GAMS).

3 Model results and discussion

The results focus on the impact of climate change under RCP 4.5 and RCP 8.5 relatively to the baseline without climate change for each socio-economic scenario.

3.1 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 current 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 crops from countries with excess supply to those in excess demand. The results of this baseline scenario vary across crops and shared socio-economic pathways.

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; 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 paddy rice in 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 end in 2030. Under SSP3, a similar trade flow is observed but the exports end 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 VFN under SSP4. In fact, under this scenario, countries such as Benin, Ghana, Cote d'Ivoire, Guinea, Togo, and other ECOWAS are predicted to export VFN to Burkina Faso to meet the overwhelming demand expressed in that country until the year 2080.

Oilseed trade under SSP1 occurs from Rep. 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 Rep. 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 Rep. of Benin, Burkina Faso, Nigeria, and other ECOWAS countries. The excess demand countries are all the studied countries except Benin, Burkina Faso, and other ECOWAS. No trade of oilseeds is 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.

3.2 Impact of climate change on paddy rice trade

The impact of climate change on paddy 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 under the socio-economic conditions—SSP1—that rice could 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 could have reduced or increased trade flows to other countries 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 within ECOWAS countries paddy rice trade 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.

Trade flows under the climate change scenario—RCP 8.5—are presented in Table 2. With the socio-economic conditions—SSP, Cote d'Ivoire may still trade rice to Burkina Faso from the year 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

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 and 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 and 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 − 0.1	Benin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	− 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

the baseline but without any specific pattern. There is no prediction within zone rice trade with the socio-economic conditions—SSP2—whereas with the socio-economic conditions—SSP3, Nigeria is predicted to 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 is predicted to continue from the exporting countries (Cote d'Ivoire, Ghana, Guinea, and Nigeria) to the other countries but without any specific patterns.

3.3 Impact of climate change on cereal trade

The predicted impact of climate change scenario RCP 4.5 on cereal trade with various socio-economic assumptions is presented in supplementary material (Table 3). With the socio-economic scenario—SSP1, a clear pattern of trade flows 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 to Cote d'Ivoire, Guinea, and Nigeria. The results also show that most of the predicted trade may 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 is predicted to 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 may flow from Burkina Faso to Nigeria during the entire century. With the socio-economic scenario—SSP4, Benin may enter into cereal exporting countries but a less consistent trade pattern emerges from this scenario.

Under the climate change scenario, RCP 8.5, the predicted trade flow change from baseline with various socio-economic conditions is presented in supplementary material (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 is predicted to be trading cereals to Nigeria but trade volumes have increased with this RCP scenario, while a consistent decline of trade from baseline is observed with the socio-economic scenario—SSP3. A more consistent decline of trade volumes relatively to the baseline is also observed with the socio-economic scenario—SSP4.

3.4 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 supplementary material (Table 5). With the socio-economic scenario—SSP1, exports from Cote d'Ivoire to Burkina Faso at the beginning of the century are predicted to be dropping down relatively to the baseline while exports from Benin are 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 continues but with no clear pattern (refer to supplementary material Table 5). Under the SSP2 socio-economic scenario, there are 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 are predicted to increase trade volumes to other countries starting from 2070 until the end of the century. Finally, with the socio-economic scenario—SSP4, more decline in trade of VFN is observed going from Benin, Cote d'Ivoire, Ghana, and Togo to Burkina Faso and to Benin.

Under the RCP 8.5, trade flow changes in VFN from baseline are presented in supplementary material (Table 6). With the socio-economic scenario—SSP1, Rep. of Benin is exporting

VFN to Burkina Faso starting from 2070 to the end of the century. Exports from Cote d'Ivoire, Ghana, Nigeria, and Togo follow some increases and some decreases relatively to the baseline. There is no trade of VFN within ECOWAS with the socio-economic scenario—SSP2. With the socio-economic scenario—SSP3, results show that exports from Cote d'Ivoire to Guinea and Nigeria are predicted to decrease in the year 2020. However, under the socio-economic scenario—SSP4, exports from Cote d'Ivoire to Nigeria, Senegal, and Togo are predicted to increase consistently relatively to the baseline. 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.

3.5 Impact of climate change on oilseed trade

The impact of climate change under RCP 4.5 on intra-regional trade of oilseeds from baseline without climate change is presented in supplementary material (Table 7). With the socio-economic scenario—SSP1, trade flows of oilseeds from Benin and Burkina Faso to Ghana, Guinea, and Cote d'Ivoire show 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 is predicted to either increase or decrease at the beginning of the century but without any specific pattern. With the socio-economic scenario—SSP3, oilseed trade is predicted to increase in some years (e.g., Burkina Faso to Togo in 2050 and 2060) and decrease for other years (Benin to Ghana in 2080) without any specific pattern. There is no change in oilseed trade from baseline with the socio-economic scenario—SSP4.

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

3.6 Sensitivity to the common external tariffs

Ceteris paribus, if the demand for food continues to increase due to population and economic growth, ECOWAS may continuously be in need of food imports from outside the ECOWAS until the end of the century. The comparison between the baseline total trade costs and the two climate change scenarios trade costs (supplementary material Table 9) shows that trade costs increase 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 external 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 supplementary material (Table 10).

We find from the sensitivity analysis that a decrease in the CET by 5% could reduce the adaptation costs under RCP 8.5 by an amount between 0.3 to 0.4% depending on the SSP scenarios. A further decrease to 10% in the CET could reduce the adaptation costs by an amount between 0.6 and 0.7% depending on the SSP scenarios.

3.7 Sensitivity to yield increase

Asia and Latin America have tripled their crop production between 1960 and 2000 (Sanchez 2010). Several scientists believe that Africa can also improve food quantity and quality (Sanchez and Swaminathan 2005). To evaluate the importance of yield increase in adapting to climate change, a sensitivity analysis to doubling and tripling crop yields by 2050 (Ray et al. 2013) is tested. The sensitivity results indicate that doubling or tripling crop yields due to technological innovations may increase crop production and reduce significantly food imports outside of the ECOWAS.

3.8 Implications for food security in the ECOWAS

Many West African countries could continue importing food from outside the ECOWAS given that demands are rising more than what the ECOWAS production levels can cover. For instance, rice import changes from baseline originating from outside ECOWAS under RCP 8.5 with SSP1 are presented in supplementary material (Table 11). This shows that with a higher climate change scenario, 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 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-Andersen 2009). Since the part related to dietary need and food preferences is 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 ECOWAS. 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 in regard to their ability to produce food. Furthermore, 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 the 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 food import are given in supplementary material (Fig. 2). These values show how expensive importing food resources from outside ECOWAS could become over time.

4 Conclusion

This study looked at the potential impact of climate change scenarios that include a baseline scenario without climate change, a medium greenhouse gas forcing scenario (RCP 4.5), and a high greenhouse gas forcing scenario (RCP 8.5) on intra-regional trade flows in the ECOWAS. 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 across the century.

The results suggest that the impact of climate change on crop trade flows will depend on crop types, the level of greenhouse gas forcing, and socio-economic scenarios that are being considered. We find that trade within ECOWAS may be limited due to supply shortages but no clear pattern has emerged in terms of the net exporters and the net importers. Some countries that are net exporters in some years may become net importers in some other years. Therefore, reliance on food imports outside of ECOWAS may be the key to foster food availability in the ECOWAS. Since the ECOWAS might be net importers of food, all imports will then be subject to the common external tariffs established in 2015. We then ran trade policy scenarios of 5 and 10% decrease in the CET. The sensitivity results show that these policy measures may reduce adaptation costs of about 3–7% under the RCP 8.5. However, changes in the CET 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 intra-regional (inside ECOWAS) trade and outside ECOWAS imports. In addition, the model sensitivity to yield increase is evaluated. The results suggest that doubling crop yields by 2050 could significantly reduce dependence from outside food 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 imports 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 countries. These include investment in agricultural research, infrastructures, extension services, irrigation equipment, and biotechnology to improve inside ECOWAS food production. In addition, in the study, we assumed that demand is heavily driven 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 developed countries (1.5 to 2% for instance). 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 models that completely accounts for food supply modeling outside the ECOWAS. These efforts may improve the results of our current 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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References

Bajželj B, Keith SR, Allwood JM, Pete S, Dennis JS, Curmi E, Gilligan CA (2014) Importance of food-demand management for climate mitigation. Nat Clim Chang 4:924–929
Brown WV (1982) The ECOWAS: a strategy for AID support. Agency for International Development, Washington DC
Chang CC (2002) The potential impact of climate change on Taiwan's agriculture. Agric Econ 27:51–64
Dantzig GB (1963) Linear programming and extensions. Princeton University Press, Princeton
Decreux Y, Valin H (2007) MIRAGE, updated version of the model for trade policy analysis focus on agriculture and dynamics, CEPII Working Paper No 2007–15
ECOWAS (2006) ECOWAS common external tariff, list of type "B" exceptions of member states. ECOWAS commission, Abuja
Egbendewe-Mondzozo A, Swinton MS, Izaurralde C, Manowitz D, Zhang X (2011) Biomass supply from alternative cellulosic crops and crop residues: a spatially explicit bioeconomic modelling approach. Biomass Bioenergy 35(1):4636–4637
ENDA CACID (2012) L'état du commerce en Afrique de l'Ouest. Rapport annuel, Dakar
FAO (2015) Climate change and food systems: global assessments and implications for food security and trade. Food Agriculture Organization (FAO), Rome
Gornott C, Wechsung F (2016) Statistical regression models for assessing climate impacts on crop yields: a validation study for winter wheat and silage maize in Germany. Agric For Meteorol 217:89–100
Hazell PBR, Norton RD (1986) Mathematical programming for economic analysis in agriculture. Macmillan, New York
Howitt RE (1995) Positive mathematical programming. Am J Agric Econ 62(1):82–102
IPCC (2014) Climate change impacts, adaptations and vulnerability, contribution of working group 2 to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge
Izaurralde RC, Williams JR, McGill WB, Rosenberg NJ, Jakas MCQ (2006) Simulating soil C dynamics with EPIC: model description and testing against long-term data. Ecol Model 192(3–4):362–384
Julia R, Duchin F (2007) World trade as the adjustment mechanism of agriculture to climate change. Clim Chang 82:393–409
Lokonon OKB, Egbendewe-Mondzozo, A., Coulibaly, N. and Atewamba, C., 2016. Spatial implication of climate change on land allocation and agricultural production in ECOWAS. UNU-working paper
McCarl BA, Spreen TH (1980) Price endogenous mathematical programming as a tool for sector analysis. Am J Agric Econ 62(1):87–102
Nin-Pratt A, Johnson M, Magalhaes E, You L, Diao X, Chamberlin J (2010) Yield gaps and potential agricultural growth in West and Central Africa. International Food Policy Institute, Washington, D.C.
O'Neill CB, Kriegler E, Riahi K, Ebi LK, Hallegatte S, Carter RT, Mathur R, van Vuuren PD (2014) A new scenario framework for climate change research the concept of shared socioeconomic pathways. Climatic Change 122(3):387–400
Palazzo A et al (2014) Simulating stakeholder-driven food and climate scenarios for policy development in Africa, Asia and Latin America: a multi-regional synthesis, Copenhagen, Denmark: CGIAR Research Program on climate change, agriculture, CCAFS Working paper no. 109
Pinstrup-Andersen P (2009) Food security: definition and measurement. Food Security 1:5–7
Ray DK, Mueller ND, West PC, Foley JA (2013) Yield trends are insufficient to double global crop production by 2050. PLoS One 8(6):e66428
Rosenzweig C, Parry M (1994) Potential impact of climate change on world food supply. Nature 367:133–138
Sanchez PA (2010) Tripling crop yields in tropical Africa. Nat Geosci 3:299–300
Sanchez PA, Swaminathan MS (2005) Hunger in Africa: the link between unhealthy people and unhealthy soils. Lancet 365(9457):442–444
Stephan G, Schenker O (2008) International trade and the adaptation to climate change and variability. Center for European Economic Research, Discussion Paper No. 12–008
Sylla MB, Gaye AT, Jenkins GS (2012) On the fine-scale topography regulating changes in the atmospheric hydrological cycle and extreme rainfall over West Africa in a regional climate model projections. Int J Geophys 2012:981649 15 pages
USAID, 2012. Impact of road transport industry liberalization in West Africa, Technical Report
Wilkinson A, Eidinow E (2008) Evolving practices in environmental scenarios: a new scenario typology. Environ Res Lett 3:1–11