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Chapter

Biophysical and Economic Factors of Climate Change Impact Chain in the Agriculture Sector of ECOWAS

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Abstract

The chapter assesses key biophysical and economic factors of climate change impact chain in the agriculture sector of the Economic Community of West African States (ECOWAS), mainly within the decade following the launching of the Comprehensive Africa Agricultural Development Programme (CAADP) and Maputo Accord. This is done through a review of literature and analysis of data mainly from international databases. We find that land resources for agricultural production are substantial, but land degradation and land productivity are serious problems, particularly in the context of climate change. Although the region has experienced unprecedented growth, financing agricultural development is still an issue. Developing quality infrastructure and stimulating agricultural trade may provide a win-win strategy to build resilience to climate change and strengthen economic development. The economics of adaptation to climate change in the agricultural sector of ECOWAS has mainly focused on the magnitude of costs and returns on country-wide and technology-specific measures. There is a need, however, to integrate biophysical and economic factors of climate change impact chain in sound analytical frameworks to provide “multi-metric” considerations of non-monetary and nonmarket measures, risks, inequities, and behavioral biases in addressing climate change.

Keywords: agriculture, climate adaptation, CAADP, ECOWAS, land degradation, Maputo accord, climate change, infrastructure, trade, climate finance

1. Introduction

Four major agroecological zones span the Economic Community of West African States (ECOWAS) region: these are the Sahelian, Sudan Savannah, Guinea Savannah, and Forest zone. At a broader level, ECOWAS has been grouped into a Gulf of Guinea zone and a Sudano-Sahelian zone based on geographical and climatic homogeneity [1]. All the Gulf of Guinea countries have shorelines with the Atlantic Ocean. The Sudano-Sahelian zone as a whole experiences a hotter and drier climate than the Gulf of Guinea zone. The countries in the former zone are Benin, Cote d’Ivoire, Ghana, Guinea, Guinea-Bissau, Liberia, Nigeria, Sierra Leone, and Togo. Burkina Faso, Cape Verde, the Gambia, Mali, Niger, and Senegal are in the

latter zone. While the savannah spreads through both zones, the humid forest agro-ecology is mainly restricted to the Gulf of Guinea (**Figure 1**). The United Nations classified 11 of the 15 countries as least developed based on human resources, poverty level, and economic vulnerability. The exceptions were Ghana, Nigeria, Cote d'Ivoire, and Cape Verde [2]. However, because of its size, natural resources, and importance of agriculture in the economies, ECOWAS has a potential of contributing significantly to world trade, food security, and carbon storage.

Agriculture is the key sector of ECOWAS economies and the one that supports nearly 60% of the region population. The Comprehensive Africa Agriculture Development Programme (CAADP) and the declaration on agriculture and food security by the African Union commonly known as the "Maputo Accord" of 2003 promoted investment for the expansion of the area under sustainable land and water management, increased food supply and agricultural research, and technology dissemination in sub-Saharan Africa and the adoption of a policy of allocating at least 10% of annual national budgets to agriculture and attainment of 6% annual growth in the agriculture sector. The achievement of these goals is under threat from climate change, bearing in mind that the vulnerability of countries in ECOWAS to climate change is among the highest in the world [4]. Therefore, a critical challenge facing the region is how to feed an expected population of around 600 million by 2050 while simultaneously reducing and responding to climate change. There is a growing number of studies analyzing how agricultural production and commodity markets need to be adjusted to promote interregional balance in agricultural production and food security in response to climate change [5–9]. However, the uncertainties with regard to climate change impacts on agriculture remain considerable, and climate change impacts on food security are even less clear. The development of appropriate adaptation and mitigation measures to respond to or combat climate change is dependent on the knowledge of the climate change impacts as well as the nature and trends of the climate change impact chain factors.

The objective of this chapter is to broadly assess at the regional and zonal levels key biophysical and economic factors of the climate change impact chain in

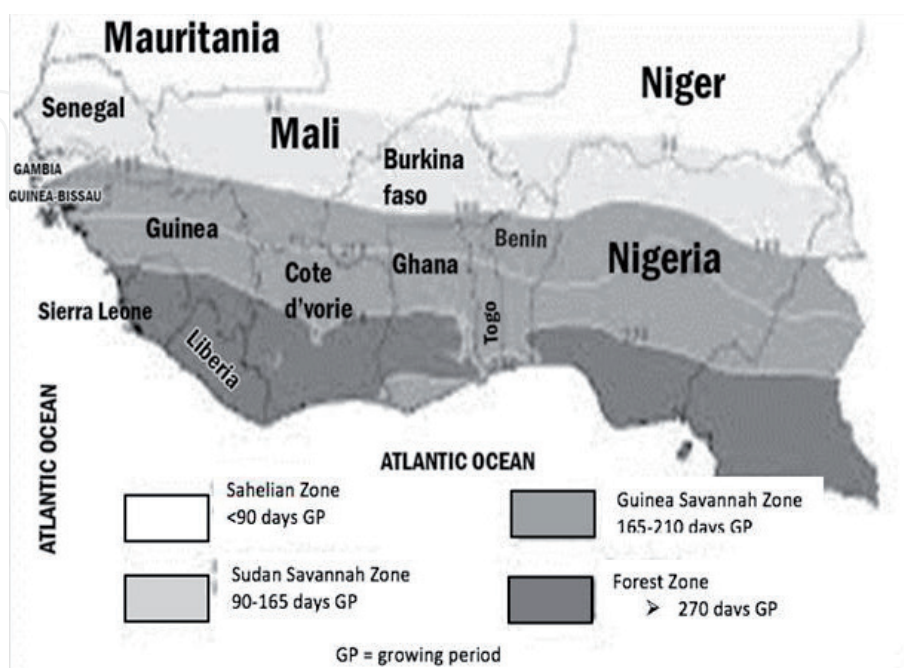


Figure 1. Location of ECOWAS member states. Source: Adapted from [3].

ECOWAS, especially within a decade after the CAADP and the Maputo Accord, and the economics of adaptation in the crop's subsector. The assessment consists of an analysis of data from international databases and sources and information from other studies. Country national level data on land use, crop production, and yield for 2003 and 2013 are taken mainly from FAO and the World Bank databases and sources. Sums, means, ranges, and percentages are computed.

The remainder of the chapter is organized as follows. In Section 2, we underline the conceptual framework of climate change impact chain in the agriculture sector. Section 3 presents the biophysical factors, mainly land resources, land use, land degradation, and crop production. The economic factors are analyzed in Section 4, where we discussed how growth, inflation, infrastructure, and trade may shape the impacts of climate change on the agricultural sector of ECOWAS. In Section 5, we investigate the current knowledge on the economics of adaptation to climate change and raise the concern of integrating biophysical and economic factors to inform decision-making. Section 6 concludes and makes some remarks for further research.

2. Conceptual framework of climate change impact chain in the agriculture sector

The extent to which climate change affects the agriculture sector and food security depends on the flow of impacts from the environmental system to the economic system through biophysical and social systems that define the agriculture sector. The chain of climate change impacts can be conceptualized as follows (**Figure 2**).

Global warming manifests itself as increasing global mean air and ocean surface temperatures, which directly affect the local environmental system of agriculture, including climate, hydrology, and soil. Changes in the environmental system affect land use, crop yield, and production, which define the biophysical system of

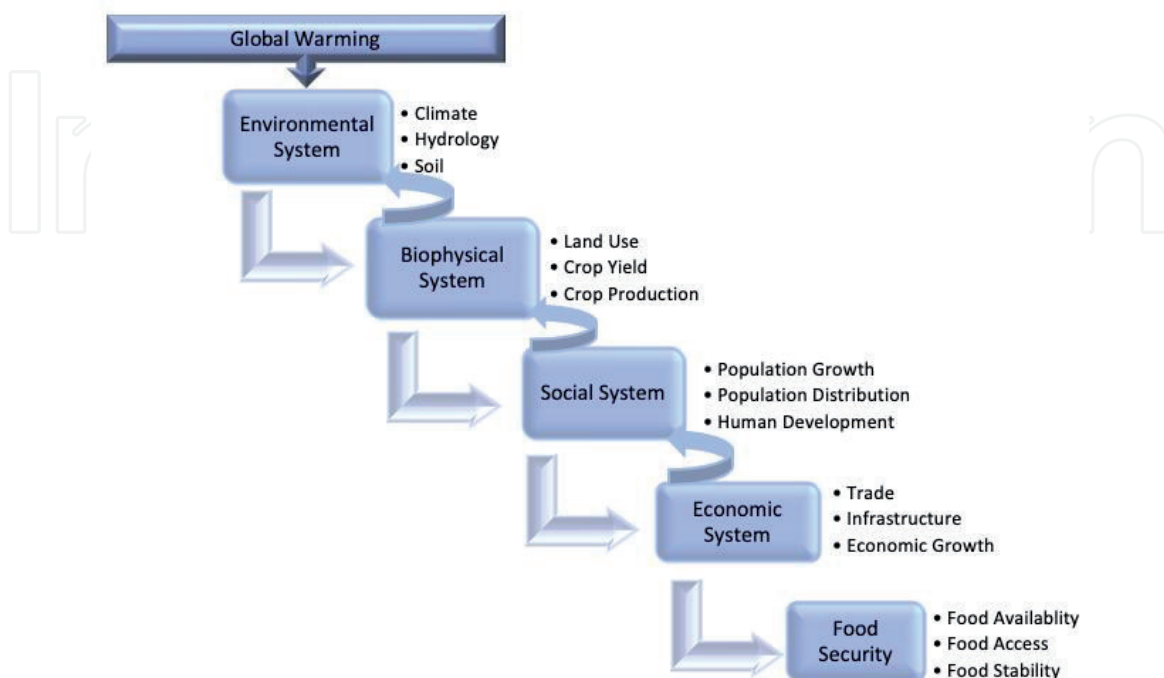


Figure 2.
Climate change impact chain in the agriculture sector.

agriculture. The social system (population growth and distribution, human development) and the economic system (economic growth, trade, infrastructure) define the adaptive capacity of the agriculture sector to manage the changes in the biophysical system in order to guarantee food availability, access, and stability for the population. The resilience of these systems to the wave of climate-induced shocks defines the extent and the magnitude of climate change impact on the agriculture and food security. Indeed, these systems can either moderate or exacerbate the wave of climate-induced shocks on agriculture and food security. For example, if the biophysical system is vulnerable to climate-induced shocks, while the economic system is resilient, then the impact of climate change on agriculture and food security will be reduced.

Mapping the climate change impact chain in the agriculture sector may allow researchers and policy makers to understand the impacts of climate change and identify opportunities and challenges to reduce these impacts on agriculture and food security. In the following sections, we will investigate the biophysical and economic systems of the climate change impact chain in the agriculture sector of ECOWAS.

3. Biophysical factors: land resources, land use, land degradation, and crop production

3.1 Land resources, land use, and land degradation

The total surface area of ECOWAS is 504 million hectares made up of 207 million hectares in the Gulf of Guinea and 297 million hectares in the Sudano-Sahelian [10]. Total cultivable land area for the 15 ECOWAS countries is 196 million hectares out of which 130 million hectares were in the Gulf of Guinea and 66 million hectares in the Sudano-Sahelian zone [1]. Information on land use in 2003 and 2013 are shown in **Table 1**; some aspects were discussed by [11] who concluded that the situation is, in general, deteriorating.

The proportion of protected lands increased in both the Gulf of Guinea and Sudano-Sahelian zones probably indicating responsiveness by governments to global concerns for the preservation of natural resources. This contrasts with a decrease from 19.5 to 13.8% over the same period in protected lands in high-income countries [9, 13]. Lands under arable plus permanent crops were 31.8 and 9.7% in the Gulf of Guinea and Sudano-Sahelian zones, respectively, in 2003 and 33–11% in 2013. Land under arable crops increased to a much greater extent in the Sudano-Sahelian than the Gulf of Guinea. Overall, land under arable crops in ECOWAS increased by 7.3%. Area under permanent crops increased more in the Sudano-Sahelian than in the Gulf of Guinea, with an average increase of 10.5% for ECOWAS. Arable land plus permanent crop lands as a proportion of total land was almost the same in 2003 and in 2013 in the Gulf of Guinea. In the Sudano-Sahelian, there was a small increase from 9.7 in 2003 to 11.3% in 2013. For ECOWAS as a whole, it was 18.7% in 2003 and 20.2% in 2013.

These findings suggest a high proportion of land reserves for agricultural production and variability between zones. However, it would have been more meaningful to express arable plus permanent croplands as a percentage of cultivable land, but the definition of cultivable land lacks clarity. According to [1] “cultivable area is an area of land potentially fit for cultivation. This term may or may not include part or all of the forests and rangeland. Assumptions made in assessing cultivable land vary from country to country. In this (FAO) survey, national figures have been used whenever available, despite possible large discrepancies in computation methods.”

Land use	Gulf of Guinea	Sudano-Sahelian	ECOWAS	Gulf of Guinea	Sudano-Sahelian	ECOWAS
	2003	2003	2003	2013	2013	2013
Protected land (percentage of total land)						
Mean	4.8	7.4	5.7	18.5	13.3	16.8
Range	0.7–11.4	2.3–11.6	0.7–11.6	2.4–27.1	4.4–24.2	2.4–27.1
Arable crop land (ha × 1000)						
Total	51,367	28,371	79,738	52,434	33,106	85,540
Range	270–35,000	47–14,050	47–35,000	300–34,000	55–16,800	55–34,000
Permanent crop land (ha × 1000)						
Total	14,257	322	14,579	15,685	427	16,112
Range	130–6450	2–145	2–6450	165–6500	4–150	4–6500
Arable + permanent crop land (percentage of total land)						
Total	31.8	9.7	18.74	33.0	11.3	20.2
Range	6.4–45.9	5.0–30.5	5.0–45.9	7.3–52.2	5.4–44.5	5.4–52.2
Forests (ha × 1000)						
Total	52,903	22,336	75,239	47,717	20,436	68,153
Range						
Forests (percentage of total land)						
Total	25.6	7.5	15.0	23.1	6.9	13.5
Range	7.9–74.7	1.0–45.4	1.0–74.7	4.2–71.1	0.9–43.3	0.9–71.1
Carbon stocks in forests (million t)						
Total	5874	834	6708	5264	770	6034
Range	38–1841	3.7–352	3.7–1841	20–1839	3.9–336	3.9–1839

Source: Author's calculations from [10–12].

Table 1.

Land use: areas under arable and permanent crops and carbon storage in forests in ECOWAS.

Research is therefore needed on reliably estimating cultivable land to facilitate the assessment of key factors controlling climate change impacts.

Area under forests declined at the rate of 9.8 and 8.5% in the Gulf of Guinea and Sudano-Sahelian, respectively. Overall, there was a 9.4% decline in area under forests in ECOWAS over 10 years (**Table 1**). The decline in the Sudano-Sahelian zone may, however, not be uniform because the conversion of biomass into forest has taken place in the Sudano-Sahelian zone [15]. The increase in arable area and decrease in area under forests in ECOWAS associated with the release of carbon to the atmosphere would contribute to land degradation.

The estimated carbon stocks in forests of ECOWAS (**Table 1**) were substantial (6708 million t in 2003 and 6034 million t in 2013) but significantly greater in the Gulf of Guinea, where forests predominate, than the Sudano-Sahelian. The variation of carbon stocks with agroecosystems as measured in the field and laboratory [16] showed that for mangrove ecosystems, roots and soil together accounted for about 86% of the total ecosystem carbon stocks (463 and 1382 Mg C ha⁻¹ in the low mangroves of semiarid Senegal and in the tall mangroves of humid Liberia, respectively).

ECOWAS countries have experienced significant land degradation [15, 17]. Based on land area data of the World Bank [10, 14] and areas of degraded land [17], it is estimated that up to 644,000 km² (31%) of lands in the Gulf of Guinea and 1,124,000 km² (38%) of lands in the Sudano-Sahelian zone and 1,768,000 km² (35%) of lands in ECOWAS were severely to very severely degraded by 2000. Nkonya et al. [18], however, reported a lower but still important rate of 19% of lands excluding deserts for Niger. The primary causes of land degradation in ECOWAS are deforestation, agriculture, conversion of grasslands to croplands, and overgrazing [18, 19]. Deforestation in ECOWAS is associated with slash and burn agriculture as well as with fuelwood, charcoal, and timber production to meet basic livelihood needs of small-holder farmers and boost incomes of commercial enterprises. Moussa et al. [19] estimate that more than 60% of carbon dioxide emission in Africa is due to deforestation and land degradation. Land reclamation to combat degradation is therefore a climate change adaptation option requiring financing by governments and their international development partners.

3.2 Crop production

The FAO database on crop production is available on the basis of country and not on farming systems or agroecological zones (AEZ). Nevertheless, it is well known that millet and sorghum are the traditional cereals of the Sudano-Sahelian, and maize, the roots and tubers, and tree crops are mainly cultivated in the Gulf of Guinea. With the development and release of new varieties of crops and changing climate, the distribution of these crops across ECOWAS is changing. Rice cultivation is becoming ubiquitous throughout the region as the urban population and demand for rice increase.

The production and yield of the major food and cash crops—rice, maize, millet and sorghum grains, cassava and yam tubers, groundnut (unshelled), cotton lint, coffee green berries, cocoa beans and palm oil—for the Gulf of Guinea and the Sudano-Sahelian zones are shown in **Tables 2–4**; along these lines:

3.2.1 Annual crops: cereals

The production and yield of rice in the Gulf of Guinea zone increased by 99 and 17%, respectively; for the Sudano-Sahelian zone, the corresponding values were 113 and 24%. The production of maize in the Gulf of Guinea zone rose by 53%, but yield declined by 4%. The production and yield of millet in the Gulf of Guinea zone declined by 78 and 45%, respectively. In the Sudano-Sahelian, zone production increased by 9%, but yield declined by 3%. For sorghum, production and yield in the Gulf of Guinea decreased by 31 and 14%, respectively; contrary to this, production and yield increased by 54 and 8%, respectively, in the Sudano-Sahelian zone.

3.2.2 Annual crops: roots and tubers and groundnut

The production of cassava in the Gulf of Guinea zone increased by 37%, but yield declined by 19%. In the Sudano-Sahelian zone, production and yield increased by 12 and 42%, respectively; this was a desirable case of yield increasing substantially over time. The production of yam in the Gulf of Guinea increased by 27%, but yield decreased by 25%. Similarly, the production in the Sudano-Sahelian zone increased by 157%, but yield declined by 29%. The large increase in yam production in the Sudano-Sahelian may indicate evolving farming systems because yam was traditionally a major crop in the humid areas of ECOWAS. In the Gulf of Guinea,

	Production (×1000 t)		Yield (t ha ⁻¹)	
	2003	2013	2003	2013
Rice (paddy)				
Gulf of Guinea	5912	11,739	1.48	1.73
Range	54.2–3116	209.7–4823	0.83–2.31	1.25–3.30
Sudano-Sahelian	1344	2863	2.35	2.91
Range	20.5–938.2	69.7–1978	1.77–3.10	1.05–6.28
ECOWAS	7256	14,602	1.59	1.88
Maize				
Gulf of Guinea	8878	13,577	1.50	1.44
Range	16–5203	7.3–8423	1.00–2.24	0.49–2.15
Sudano-Sahelian	1569	3504	1.59	1.97
Range	2.2–665.5	5.8–1636	0.38–2.28	0.18–2.59
ECOWAS	10,447	17,081	1.51	1.52
Millet				
Gulf of Guinea	6765	1474	1.32	0.72
Range	10–6260	18.1–910	0.65–1.38	0.61–1.29
Sudano-Sahelian	5938	6464	0.59	0.58
Range	120.3–2745	93.8–2922	0.48–1.09	0.41–0.94
ECOWAS	12,703	7938	0.84	0.60
Sorghum				
Gulf of Guinea	8768	6079	1.13	0.98
Range	10–8016	26.9–5300	0.55–1.16	0.67–1.35
Sudano-Sahelian	3115	4792	0.65	0.70
Range	30.1–1610	30.4–1880	0.27–1.13	0.37–1.11
ECOWAS	11,883	10,871	0.95	0.83

Source: [11, 13].

Table 2.
Cereal production in ECOWAS.

production and yield of groundnut declined by 10 and 28%, respectively. In the Sudano-Sahelian, production and yield increased by 50 and 1%, respectively.

3.2.3 Zonal effects on crop production and yield

Crop production was higher in the Gulf of Guinea than the Sudano-Sahelian zone, with Nigeria being the highest producer in ECOWAS of rice, maize, sorghum, cassava, yam, and groundnut in both 2003 and 2013. World Bank [20] also reported higher crop production in the humid and subhumid AEZs than the semiarid zone. The greater proportion of the humid and subhumid zones is within the Gulf of Guinea zone, and this may explain in part why production of the major crops was higher in this zone. The average yield of rice, maize, and yam in the Sudano-Sahelian zone was, however, higher than the average yield of these crops in the Gulf of Guinea zone in both years. Thus, the highest yield of rice in 2003 and 2013 was reported for Niger, and that of maize in 2003 was for Senegal, and in 2013 it was

	Production (×1000 t)		Yield (t ha ⁻¹)	
	2003	2013	2003	2013
Cassava				
Gulf of Guinea	55,647	76,215	10.28	8.37
Range	38–36,304	23–47,407	5.86–15.2	3.52–18.27
Sudano-Sahelian	344	384	6.86	9.75
Range	3.4–181.7	4.1–156.1	2.17–17.90	1.36–19.97
ECOWAS	55,991	76,599	10.25	8.37
Yam				
Gulf of Guinea	41,017	52,197	10.45	7.83
Range	20.5–29,697	21.5–35,618	8.67–12.11	6.61–16.78
Sudano-Sahelian	67	171	12.36	8.77
Range	31–35	79.2–91.6	12.01–12.80	5.86–20.63
ECOWAS	41,084	52,368	10.45	7.83
Groundnut				
Gulf of Guinea	4056	3664	1.34	0.97
Range	4.3–3037	6.5–2475	0.60–1.53	0.64–1.24
Sudano-Sahelian	1316	1979	0.77	0.78
Range	92.9–440.7	0.28–677.5	0.49–0.89	0.49–1.38
ECOWAS	5372	5643	1.13	0.89

Source: [11, 13].

Table 3.
Cassava, yam, and groundnut production in ECOWAS.

for Mali. In both years, the highest yield of cassava was reported for Niger and that of yam in both years for Mali. These findings are relevant in exploring how climate change may impact production and productivity differently, in various parts of ECOWAS, and how this knowledge can be exploited for improved food security and poverty alleviation.

3.2.4 Changes in crop production and yield over time

The production of rice, maize, cassava, yam, and groundnut increased between 2003 and 2013, but that of millet and sorghum decreased. In contrast to this positive change in production, yields of millet, sorghum, cassava, yam, and groundnut decreased, and although those of rice and maize increased slightly in ECOWAS as a whole, yields were low and well below their potentials. Increases in crop production in ECOWAS are generally more closely related to the area harvested than to yield per unit area [22]. Lipton et al. [23] reported yields of 1.01 t ha⁻¹ for rice, 0.78 t ha⁻¹ for maize, 0.56 t ha⁻¹ for millet, 0.76 t ha⁻¹ for sorghum, and 7.63 t ha⁻¹ for cassava in Western Africa for 1961–1963. These levels, compared to those shown in **Tables 2** and **3**, indicate only modest increases over four to five decades from a very low baseline. Thus, the evidence is that while crop production increased, the boosting of crop yields (productivity), a major concern of CAADP and the Maputo Accord did not take place during the period under review. This finding should be of serious concern given that the Consultative Group on International Agricultural

	Production (×1000 t)		Yield (t ha ⁻¹)	
	2003	2013	2003	2013
Coffee green				
Gulf of Guinea	192.3	172.6	0.37	0.21
Range	0.06–140.0	0.07–103.7	0.2–1.7	0.14–2.48
Sudano-Sahelian		0.062		0.21
ECOWAS	192.3	172.7		0.76
Cocoa beans				
Gulf of Guinea	2263	2696	0.49	0.48
Range	0.1–1352	0.12–1449	0.17–0.68	0.14–0.86
ECOWAS	2263	2696	0.49	0.48
Cotton lint				
Gulf of Guinea	573	368		
Range	1.8–172	1.4–133.5		
Sudano-Sahelian	447	422		
Range	0.18–259.7	0.19–280		
ECOWAS	1020	790		
Palm oil				
Gulf of Guinea	1528	1638		
Range	4.9–1022	6–880		
Sudano-Sahelian	9	17		
Range	2.5–6	3–13.7		
ECOWAS	1537	1655		

Source: authors calculations from [11, 13].

Table 4.
Perennial and cash crop production in ECOWAS.

Research (CGIAR) centers in collaboration with the National Agricultural Research and Extension Systems (NARES) have developed and released high-yielding, pest- and disease-resistant crop varieties with associated improved crop and soil management practices over the past three to four decades and increase in crop yields is recognized as a major step toward poverty reduction and food security [23]. The impacts of climate change on agriculture have reinforced the need for achievement and maintenance of high crop yields as an adaptation measure both by small-scale and large-scale investors.

3.3 Perennial and cash crops

Data for coffee, cocoa, and palm oil (from oil palm) were available almost exclusively for the Gulf of Guinea zone where they are mainly cultivated. For coffee, in the Gulf of Guinea zone, production and yield decreased by 10 and 45%, respectively. Production of cocoa increased by 19%, while yield decreased by 3%. Cote d'Ivoire in 2003 and 2013 was the highest producer in ECOWAS of coffee green berries and cocoa beans. Like for annual crops, yields of cocoa and coffee were well below potentials, and their improvement should be a sector development priority

for governments. Production of palm oil increased by 7% in the Gulf of Guinea and 96% in the Sudano-Sahelian zone (data only for Gambia and Senegal), but the production of cotton lint in the Gulf of Guinea and Sudano-Sahelian zone declined by 36 and 6%, respectively. This contrasts with the 7.3% per annum increase in cotton production between 1980 and 2006 in West Africa reported by [21]. Mali in 2003 and Burkina Faso in 2013 were the highest producers of cotton lint in ECOWAS. Data were not available on yield of palm oil and cotton.

4. Economic factors: GDP, inflation, infrastructure, and trade

The vulnerability of the ECOWAS agricultural system to climate change depends partly on certain economic factors such as income, price level, labor productivity, transportation, communication, innovation, and trade, which define ECOWAS' adaptive capacity to external shocks, including climate change. The greater the adaptive capacity of ECOWAS, the lower its vulnerability to climate change, particularly in the agricultural sector.

4.1 Growth, inflation, and capital formation

After several years of strong economic growth, ECOWAS faced a small increase in 2016 of 0.5%. It rebounded in 2017 to 2.5% and was projected to 3.8% in 2018 and 3.9% in 2019. Countries' performance varied, but because Nigeria, Cote d'Ivoire, Ghana, and Senegal contribute to about 90% of the regional gross domestic product (GDP), their patterns largely shape regional ones. In 2003, agriculture was the dominant sector in ECOWAS (about 40% of GDP), but services contributed most to GDP in Liberia and Sierra Leone soon after the end of their civil wars which devastated the agriculture sector; however, agriculture remains dominant in 2013 [24].

GDP per capita increased by 31.3% in ECOWAS, 34.8% in the Gulf of Guinea, and 26.9% in Sudano-Sahelian between 2003 and 2013 (**Table 5**), indicating an increase in standard of living. Furthermore, consumer prices almost double during the same period, threatening the positive effect of the increased income. Changes in the productive capacity of ECOWAS captured by the gross capital formation represented a larger share of the GDP in 2013 than 2003. The same trend is observed in the Gulf of Guinea and Sudano-Sahelian zones. Agricultural labor productivity increased by 22% between 2003 and 2013 in ECOWAS, while it decreased by 18% in Sudano-Sahelian zone. This may be explained partly by an increase in fertilizer consumption in ECOWAS and in both agroecological zones (**Table 5**).

Financing adaptation and mitigation are an important component of building resilient of the agricultural sector to climate change in ECOWAS. As observed in the previous paragraph, increasing income per capita, investment, and labor productivity are an indication that further economic efficiency in production may be realized in ECOWAS to support the financing of mitigation and adaptation efforts for climate change. However, higher consumer prices represent a significant challenge that may offset the positive effect of an improved efficiency in production for climate finance. Furthermore climate change compounds with other pressing socioeconomic development challenges such as education, sanitation, health and infrastructure, resulting to underinvestment in agriculture in ECOWAS. As reported by AfDB [25], the agriculture sector in ECOWAS suffers from chronic underinvestment. Only Burkina Faso, Mali, Niger, and Senegal have so far raised public expenditure to 10% of GDP, the target fixed by the Maputo Declaration in 2003. The Gambia, Ghana, and Togo are on the threshold of reaching this target. Nigeria devotes 6% of GDP to agriculture and the remaining ECOWAS countries

Zone/ region	GDP per capita (constant 2010 US\$)		Consumer price index (2010 = 100)		Gross capital formation (percentage of GDP)		Agriculture, value added per worker (constant 2010 US\$)		Fertilizer consumption (kilograms per hectare of arable land)	
	2003	2013	2003	2013	2003	2013	2003	2013	2003	2013
Gulf of Guinea										
Total					144.3	165.2				
Mean	736.0	992.1	64.7	122.5	9.1–23.8	7.2–27.8	1030.9	1584.7	8.6	16.3
Range	271.0– 1426.9	383.1– 2475.9	40.8– 83.6	108.2– 156.4			420.0– 2445.3	521.5– 5041.1	0.8– 29.3	2.9– 37.2
Sudano-Sahelian										
Total					90.2	165.5				
Mean	870.1	1104.0	80.7	108.4			1215.3	996.9	7.8	12.1
Range	335.7– 2310.5	373.7– 3389.9	67.7– 85.2	105.6– 115.5	10.0– 22.3	17.8– 36.2	544.7– 1960.8	470.5– 1298.5	0.3– 10.9	0.4– 31.5
ECOWAS	789.6	1036.9	72.1	116.9	234.5	330.7	1107.7	1349.6	8.2	14.4

Source: Authors calculations from the World Bank Open Data [23].

Table 5.
Growth, inflation, and capital formation.

less than 5%. This is not surprising because in the presence of limited resources and a range of objectives, financing agricultural development issues such as climate change should involve trade-offs among multiple policy goals. Therefore, financing climate policies, programs, and plans in the agricultural sector of ECOWAS should be prioritized not only in terms of their ability to reduce the impact of climate change but also in terms of their ability to deliver some development outcomes.

4.2 Infrastructure development

Infrastructure development in ECOWAS can be analyzed in three key areas: communication, transport, and technology. The telecommunication priority is the development of a reliable and modern regional telecom broadband infrastructure including the INTELCOM II program, alternative broadband infrastructure, and submarine cables as well as the establishment of a single liberalized telecom market. By 2013, 11 coastal member states were connected to submarine cables with at least 1 new landing station, and the 3 landlocked countries (Burkina Faso, Mali, and Niger) now have at least 2 access routes to the submarine cables. This has substantially increased the percentage of people using the Internet (from 1.1% in 2003 to 9.9% in 2013) and number of subscriptions to mobile cellular (from 4 subscriptions in 2003 to 78.4 subscriptions in 2013 per 100 people). A similar trend is observed in Gulf of Guinea and Sudano-Sahelian zones.

The transport program in ECOWAS has overseen the implementation of multimodal transport infrastructure and policies to promote physical cohesion among member states and to facilitate the movement of persons, goods, and services within the community with special emphasis on increased access to island and landlocked countries. However, the transportation infrastructure is still underdeveloped and of poor quality. For example, the quality of port infrastructure was estimated at 3.9 on a scale of 7, the latter representing a well-developed and efficient

infrastructure by international standards. Rail lines decreased by 72% between 2003 and 2013. This is mainly due to a sharp decrease of rail lines in the Gulf of Guinea zone (**Table 6**).

ECOWAS countries still have a long way to go to reach the African Union's target of devoting 1% of GDP to gross domestic expenditure on research and development (GERD). Mali comes closest (0.66% in 2010), followed by Senegal (0.54% in 2010), according to the UNESCO Science Report [25]. There is a lack of researchers in ECOWAS in general. AfDB [25] highlighted that only Senegal stands out, with 361 full-time equivalent (FTE) researchers per million population in 2010, while other countries, where data was available, have less than 60. However, the number of trademark applications, as an indicator of innovation, has increased substantially between 2003 and 2013 from 1671 to 25,294. Almost all trademark applications are from the Gulf of Guinea zone (99%).

Infrastructure development is an important means to build resilience to climate change, particularly in the agricultural sector, because it also delivers vital development outcomes. We should recognize that the availability and quality of infrastructure are never substitutes to agriculture-specific policies such as an increase in fertilizer use, irrigation, and improved seeds. However, inadequate infrastructure may be a significant constraint to growth and productivity. Indeed, recent literature indicates a significant positive link between infrastructure and agricultural productivity [26]. For example, transport infrastructure provides important connectivity with growing markets and also reduces input costs and transaction costs for producers and consumers, particularly in the context of climate change. Furthermore, information acquisition costs can represent a significant obstacle, for instance, when climate and weather data are costly or difficult to access. Improvement in communication infrastructure represents an opportunity to reduce information acquisition costs, thereby strengthening farmers' responses to external shocks such as climate change.

Zone/ Region	Individuals using the Internet (percentage of the population)		Mobile cellular subscriptions (per 100 people)		Trademark applications, total		Quality of port infrastructure, WEF ^a		Rail lines (total route-km)	
	2003	2013	2003	2013	2003	2013	2003	2013	2003	2013
Gulf of Guinea										
Total					1313.0	24,888.0			4482.0	639.0
Mean	0.7	7.8	2.9	73.7			0.0	3.7		
Range	0.0– 1.4	3.1– 19.1	0.1– 7.2	55.9– 106.4	627– 686.0	14– 19332.0	0.0– 0.0	3.2– 4.5	977– 3505.0	639– 639.0
Sodano-Sahelian										
Total					358.0	406.0			0	622.0
Mean	1.6	13.1	5.8	85.4			0.0	4.1		
Range	0.2– 4.3	1.15– 37.5	0.7– 11.6	38.0– 119.9	25– 298.0	406.0– 406.0	0.0– 0.0	3.5– 4.8	0.0– 0.0	622.0– 622.0
ECOWAS	1.1	9.9	4.0	78.4	1671.0	25,294.0	0.0	3.9	4482.0	1261.0

a: 1, extremely underdeveloped, to 7, well developed and efficient by international standards).
Source: Authors' calculations from the World Bank Open Data [23].

Table 6.
Infrastructure development.

Recent literature also recognizes that innovation (technological, managerial, and institutional) in agriculture is clearly an important response for effective and equitable adaptation to and mitigation of climate change. As underlined by Llanto [27], innovation can enhance technology adoption, may prevent or facilitate migration of production/population, enhance trade and aid, and increase efficiency of insurance and feasibility of inventories. More importantly, innovation will be the key in moving toward climate-smart agriculture.

4.3 Trade development

ECOWAS has a huge potential for trade both in global and intra-regional terms mainly because of its large natural resource endowment, agricultural potential, and intra-regional complementarities. Trade (the sum of exports and imports of goods and services) was estimated at almost 65% of GDP in 2003 and 78% of the GDP in 2013, representing an increase of 13 points in 10 years. A similar trend is observed in Gulf of Guinea and Sudano-Sahelian zones. The export profile of ECOWAS shows little product diversity, with a heavy reliance on extractive products (e.g., petroleum, natural gas) and a few agricultural commodities (e.g., cocoa, rubber, cotton). Agricultural raw material exports measured as a share of merchandise exports decreased by 12 points between 2003 and 2013. The decrease is substantial in Sudano-Sahelian zone (20 points) and moderate in the Gulf of Guinea zone (5 points). However, food exports measured as a share of merchandise exports increased by 19 points in the Sudano-Sahelian zone and decreased by 15 points in the Gulf of Guinea zone (Table 7). This is an indication of an improvement in the industrialization of ECOWAS and/or building of adaptive capacity to environmental and economic shocks, such as climate change.

ECOWAS imports are more diversified, with a high share of industrialized products (e.g., refined petroleum, vehicles, ships, telecommunication equipment)

Zone/ region	Trade (percentage of GDP)		Agricultural raw material imports (percentage of merchandise imports)		Agricultural raw material exports (percentage of merchandise exports)		Food imports (percentage of merchandise imports)		Food exports (percentage of merchandise exports)	
	2003	2013	2003	2013	2003	2013	2003	2013	2003	2013
Gulf of Guinea										
Total										
Mean	67.9	81.1	1.3	1.3	17.9	13.1	26.3	20.9	37.4	22.9
Range	43.3– 102.5	31.0– 131.0	0.4– 4.0	0.4– 2.8	0.0– 74.2	3.2– 49.1	15.5– 62.4	14.2– 40.3	0.0– 95.4	4.9– 38.5
Sudano-Sahelian										
Total										
Mean	60.4	72.9	2.0	1.3	29.4	9.8	28.1	27.7	32.5	51.3
Range	30.7– 98.8	61.7– 95.3	0.7– 4.3	0.4– 2.6	3.3– 79.5	0.0– 44.4	18.0– 37.6	12.1– 37.3	6.4– 85.9	8.0– 92.0
ECOWAS	64.9	77.8	1.7	1.3	23.6	11.6	27.2	24.0	34.9	35.8

Source: authors calculations from the World Bank Open Data [23].

Table 7.
 Trade development.

and food products (e.g., rice, wheat). Agricultural raw material imports measured as a share of merchandise imports decreased slightly by 0.4 points between 2003 and 2013. The same trend is observed in Sudano-Sahelian and Gulf of Guinea zones. On the other hand, food imports measured as a share of merchandise imports decreased in ECOWAS (3.2 points), Sudano-Sahelian zone (0.4 points), and Gulf of Guinea zone (5.4 points) between 2003 and 2013. ECOWAS main trading partners are highly industrialized countries such as China, India, the USA, EU countries, and Brazil, which mainly buy raw materials and sell industrialized products from/to the region. Intra-regional trade takes place, but is mainly, unreported, informal and generally considered to be well below its potential [29].

Trade is crucial for economic growth and food security, thereby representing an important controlling factor for climate change impacts in the agricultural sector [28]. Torres and van Seters [29] showed that while some countries in ECOWAS may be experiencing good crop harvest, others may not due to stochastic patterns in climate. The authors demonstrated that acreage and crop production in ECOWAS countries are sensitive to climate change and climate change will lead to a shift in land use for agricultural production within and among countries as a rational response to its impact on crop yield by farmers seeking to maximize the profit of their farm activities. A structural transformation of the agricultural sector is, therefore, inevitable to offset the negative impacts of climate change to achieve a better level of livelihood for the population. This means, therefore, that one of the ways to resolve the issue of food availability may be through food trade across countries. Several arguments have been made in favor of trade of agricultural commodities as a means of adapting to climate change [30, 31]. 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.

5. Economics of adaptation to climate change in the agriculture sector

Recent literature on the impact of future climate change on West African crop yields showed a large dispersion of yield changes ranging from -50 to $+90\%$, with the median yield loss near -11% [32]. The predicted impact is larger in Sudano-Sahelian region (-18% median response) than in the Gulf of Guinea (-13%). Roudier et al. [32] highlighted that the consistently negative impact of climate change results mainly from the temperature whose increase projected by climate models is much larger relative to precipitation change. As discussed in previous sections, the vulnerability of the biophysical system and the underdeveloped economic system of ECOWAS will exacerbate this impact on agriculture and food security. Economic analysis of adaptation in the agriculture sector of ECOWAS is still in its infancy state, and information even on costs benefit analysis of adaptation options in the agriculture sector of ECOWAS is scarce. Nevertheless, some valuable information on the magnitudes of costs and returns on a country-wide and technology-specific basis has emerged.

Butt et al. [33], through modeling studies, showed that for Mali, policy changes that result in reduction in soil productivity loss, cropland expansion, adoption of improved cultivars, and changes in trade patterns altogether, under climate change, showed an annual gain of \$252 million in economic benefits as opposed to a \$161 million loss without policy adjustment. Roudier et al. [32] examined the

benefits of climate change adaptation in agriculture for Ghana when the whole adaptation resource envelope is spent on gradual expansion of irrigated land area from 2012 onwards. The assumed upfront investment cost of irrigation is \$18,000 per ha, taking account of Ghana-specific cost estimates for recent and planned irrigation projects plus the need for complementary investment in water harvesting, etc. Under the general circulation model (GCM)/Special Report on Emissions Scenarios (SRES) of the IPCC modeling global wet scenario, the share of irrigated land rises gradually from less than 0.4 to 15% of the current total cultivated area. The resulting average annual factor productivity increase for agriculture as a whole is an additional 0.36% above baseline productivity growth. They also pointed out that this scenario can also be interpreted as representing other productivity-rising agricultural adaptation measures with a comparable yield impact per dollar spent.

It is well known that technological adaptations such as adoption of high-yielding pest and disease-resistant varieties of climate-smart varieties of cassava can double crop yields even without the use of expensive inputs (and therefore positive returns), in the immediate term. On the other hand, adaptation options in the form of soil conservation practices such as contour ridges and agroforestry require investments to pay off over longer periods, which small-scale farmers cannot afford in the typical situation of lack of long-term credit facilities by commercial banks. Persons with precarious hold on the land, such as women and strangers, are particularly constrained to make such investments. Thus, World Bank [34] reported that while farmers in Nigeria who were dependent on leased and/or communal lands expressed implicit dislike for climate-smart agriculture (CSA)-related investments, the majority with freehold titles, particularly those with registered titles, expressed positive willingness-to-accept incentives to embrace CSA and combat land degradation [35].

The following examples illustrate the nature of the investments and returns in soil management adaptation options in ECOWAS: in the Sahel of ECOWAS, stone bunds associated with shallow pits, filled with compost or manure (Zai pits), requiring 30–50 t of stones ha^{-1} and costing \$200 ha^{-1} and 150 person days of labor ha^{-1} for constructing the bunds on contours, have resulted in doubling of millet yields [36]. Bjorkemar [37] estimated the potential returns over 25 years from agroforestry, in a village in the Bombali District of Sierra Leone, as follows: \$15,470, \$135,812, \$5,427,800, and \$11,903,090 for dispersed interplanting, boundary planting, and woodlot and fruit orchard, respectively. A World Agroforestry Center study reported by [36] showed that farmer-managed natural regeneration raised millet yields from 150 to 500 kg ha^{-1} in Maradi, Niger, taking into consideration improvement in soil fertility, and increased supply of food, fodder, and firewood was at least a \$56 ha^{-1} return each year.

Analysis of the economics of adaptation to climate change is moving from a focus on efficiency, market solutions, and cost-benefit analysis of adaptation to include “multi-metric” considerations of non-monetary and nonmarket measures, risks, inequities, and behavioral biases and barriers and limits and consideration of ancillary benefits and costs for providing support to decision-makers [31]. An understanding of the controlling factors of climate change impact chain is useful as inputs to these kinds of analysis. A few studies on economics of adaptation to climate change in ECOWAS have reached such sophistication. Recently, Aklesso et al. [38] tried to integrate a number of biophysical and economic factors of climate change impact chain in order to analyze the potential of intra-regional trade in ECOWAS for increasing food availability in the context of climate change. Several models were integrated: a regional climate model to predict temperature and precipitations from 2004 to 2100 with two representative concentration pathways (RCPs); an econometric crop simulator to simulate crop yield under RCPs; a

bioeconomic optimization model to predict agricultural land allocation and crop production under RCPs; and an intra-regional food trade module built from a classical transportation model to allocate food optimally from excess supply countries to excess demand countries. The authors showed that the climate-induced trade pattern in ECOWAS depends on the prevailing socioeconomic conditions during the century, and several countries may become dependent on food imports outside ECOWAS. However, doubling crop yields by 2050 and adjusting the ECOWAS common external tariffs could significantly reduce outside dependence. Although this study attempts to investigate the link between climate change and food security in ECOWAS, more research is needed to understand how the integration of factors of climate change impact chain could affect food security and promote sustainable agricultural development in ECOWAS.

6. Conclusion

This chapter assessed key biophysical and economic factors of the climate change impact chain and the economics of adaptation in the agricultural sector of ECOWAS.

As in many developing regions, land for agricultural production in ECOWAS has increased at the expense of forest land. These changes vary, however, by agroecological zones. Furthermore, ECOWAS countries have experienced significant land degradation. The primary causes of land degradation are deforestation, agriculture, conversion of grasslands to croplands, and overgrazing. Cropping systems are generally related to agroecological zones; however, the release of new varieties of crops and changing climate is significantly changing the distribution of crops across ECOWAS. Crop production was higher in the Gulf of Guinea than the Sudano-Sahelian zone. This is partly explained by the high proportion of humid and sub-humid zones within the Gulf of Guinea. Increases in crop production in ECOWAS are more often related to the area harvested than to yield per unit area, which is the major concern of CAADP and the Maputo Accord. The boost in crop productivity expected from CAADP and the Maputo Accord did not happen between 2003 and 2013. Increasing crop yields through agricultural intensification while reducing land degradation is critical to reduce the impact of climate change in the agricultural sector of ECOWAS.

In recent years, ECOWAS has experienced an increase in income per capita, investment, and labor productivity, indicating that further economic efficiency in production may be realized. This may boost climate financing in the agricultural sector. However, further improvement in general production may not generate enough resources to address both climate change and other development challenges, particularly in the context of increasing prices. There is a need for policy makers to prioritize climate strategies that also have some development impacts. Infrastructure in ECOWAS is underdeveloped with poor quality. Although the availability and quality of infrastructure may never substitute for agriculture-specific policies such as an increase fertilizer use, irrigation, and improved seeds, infrastructure development can help build resilience to climate change. Indeed, infrastructure development provides important connectivity with growing markets and also reduces input, transaction, and information acquisition costs for farmers and other actors in the agricultural sector of ECOWAS. On the other hand, ECOWAS has a huge potential for trade both in global and intra-regional terms mainly because of its large natural resource endowment, agricultural potential, and intra-regional complementarities. However, intra-regional trade that takes place in ECOWAS is mainly informal and generally considered to be well below its potential.

In the context of insufficient financial resources to support climate adaptation actions, stimulating trade appears as an appropriate measure to preserve food availability by allowing countries with excess food production to trade with food-deficit countries.

Returns to adaptation to climate change in ECOWAS can vary widely depending on the technology with gains of up to \$252 million in economic benefits compared to \$161 loss without policy adjustment in a country in the Sudano-Sahelian zone. The economics of adaptation to climate change in the agricultural sector of ECOWAS has focused so far on the magnitude of costs and returns on a country-wide and technology-specific measures. There is a need, however, for further research to integrate biophysical and economic factors of climate change impact chain in sound analytical frameworks to provide “multi-metric” considerations of non-monetary and nonmarket measures, risks, inequities, and behavioral biases in addressing climate change.

Although important results were obtained regarding the biophysical and economic opportunities and challenges for building the resilience of the agriculture sector of ECOWAS to climate change, our study presents some limitations. For example, a detailed year-to-year trend analysis from 2003 to 2013 is not done because of the wide scope of the study (mapping), and data are not available for some parameters for some countries, and some data are not available for the same years for all variables studied. In addition, the environmental and social factors that are not covered in the study are equally important in defining the climate change impact chain in the agricultural sectors. These issues will be addressed in further research.

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