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Modelling Climate Change, Agricultural Trade and Food Security in ECOWAS

Labintan Adeniyi Constant

UNITED NATIONS UNIVERSITY
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Economic Commission for Africa
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By:

Labintan Adeniyi Constant

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Preface

The following is the documentation on the IAM exercise to assess the spatial impact of climate change on agricultural production, trade flows and food security in the ECOWAS region. The report contains model structure, model input, output and linkage between different models. It aims to help users on how to use the model and compute results for Analysis.

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General Introduction

There are no doubts that those extreme events such as drought and flood will affect livelihoods in Sub-Sahara Africa (SSA), which includes the ECOWAS Region. This is widely acknowledged by several studies, which explored the impact of climate change across regions (FAO 2009; FAO, 2010; IPCC, 2014). Most analyses have concluded that the region is likely to be the most vulnerable to climate change due to the fact that the economies of these countries as agriculture depends primarily on rainfall. Agriculture is the region's key economic driving sector and the main employment generation source. In addition, the sector contributes to foreign currency mobilization. It has been predicted that the region's' crop productivity will change significantly with some disparity among crop varieties. Claudia et al., (2010) using IMPACT model found that in the Gulf of Guinea, by the year 2020, the yield of rice and maize will increase by 1.80 and 2.40% respectively, while the yield of sugarcane, cassava, and sweet potatoes will decrease by 0.50, 11.94 and 15.90% respectively. According to the same authors, following the region's growing population and structural changes, the region's cereal demand will increase from 145MT to 175 Mt while the demand for animal products will increase from 8MT to 22MT between 2000 and 2050. This changes coupled with climate change will transform the region into a net food importer for only cereal crops. As a result, food commodity prices of maize, wheat, and rice will increase by 34, 36 and 48% respectively between the year 2000 and 2050. Given the number of undernourished and food insecure people in the region, this number will be expected to increase due to the reduction in domestic food supply , increase in food prices and low household income.

Indeed, given the disparity among the production systems, agricultural performance, agricultural policies and technology adoption of different countries, the impact of climate change will significantly vary among countries. Consequently, a disaggregated impact assessment is needed. In order to achieve this, Nelson et al., (2010) explored the impact of climate change among ECOWAS countries. This is illustrated in Tables 1 to 4 below.

Analysis of Tables 1a, b and c showed that some countries will experience increase in their grain production while others will experience a decrease in their grain production. According to these results, millet and sorghum

production will increase in Burkina Faso, Mali, Niger, and Nigeria respectively, while in Rep. of Benin, Cote d'Ivoire, Ghana, and Nigeria maize production will increase. This means some countries will have a more comparative advantage for certain crops compared to others and this can be used to cope with the negative impact of climate change and hence, build resilience. However, the full potentials of this production need to be assessed given the non-heterogeneity in climate distribution and climate change patterns among and within the country production system, agro-climatic Zones (ACZs) and River Basin. This will reduce the uncertainty in estimation and integration of a country's agricultural policy in order to capture real changes and appropriated farming behaviour.

In a related development, the proposed Integrated Assessment Modelling (IAM) proposed a robust modelling framework, which takes into account the spatial and temporal distribution of climate change impact on agricultural land, water resources and the response of farmers to these changes. The IAM is constituted of a land allocation model named ECOWAS Water Allocation Model (ECOLAND), an hydro-economic model named ECOWAS Water Allocation Model (ECOWAT) and a modified version of MIRAGE trade model named ECOWAS Trade Model (ECOTRAD). The integration of the various models is soft linkage with a different scenario to allow the user to assess climate change impact on agricultural production system, agricultural trade flows, and food security and also assess their nexus with development policy. The flexibility allows the user to use a scenario from the model or build a scenario from other models. The details are illustrated in the following chapters

Table 1: Changes in Millet Output in ECOWAS under Output in ECOWAS under the baseline scenario, 2010 and 2050

Country	2010 Yield (MT/ha)	2010 Area (thousands of ha)	2010 Production (MT)	2050 Yield (MT/ha) Min	2050 Yield (MT/ha) Max	2050 Area (thousands of ha) Min	2050 Area (thousands of ha) Max	2050 Production (MT) Min	2050 Production (MT) Max
Benin	0.75	48	36	2.21	2.35	80	85	180	198
Burkina Faso	0.83	1,369	1,142	2.34	2.62	1,669	1,760	3,992	4,539
Côte d'Ivoire	0.55	95	52	1.65	1.75	143	152	237	267
Gambia	1.29	102	132	2.85	2.92	156	166	447	485
Ghana	0.78	211	166	1.68	1.74	333	354	562	616
Guinea	0.77	19	14	2.45	2.54	16	17	40	44
Guinea-Bissau	1.49	31	46	2.77	2.93	48	52	134	151
Mali	0.67	1,726	1,149	2.17	2.54	2,067	2,204	4,641	5,408
Niger	0.46	5,964	2,737	1.23	1.51	6,190	7,915	9,188	10,570
Nigeria	1.31	5,555	7,299	3.12	3.23	5,580	5,895	17,727	19,010
Senegal	0.51	831	425	1.39	1.42	1,267	1,358	1,758	1,922
Sierra Leone	1.14	8	9	2.52	2.61	8	8	20	22
Togo	0.81	62	51	1.82	1.93	78	83	145	160

Table 2: Changes in Sorghum under the baseline scenario, 2010 and 2050

Country	2010 Yield (MT/ha)	2010 Area (thousands of ha)	2010 Production (MT)	2050 Yield (MT/ha) Min	2050 Yield (MT/ha) Max	2050 Area (thousands of ha) Min	2050 Area (thousands of ha) Max	2050 Production (MT) Min	2050 Production (MT) Max
Benin	0.90	211	190	1.96	2.06	375	385	739	787
Burkina Faso	1.02	1,594	1,632	1.86	2.08	1,952	1,981	3,638	4,109
Côte d'Ivoire	0.62	107	67	1.25	1.29	167	171	210	219
Gambia	1.64	25	41	3.51	3.59	41	42	144	151
Ghana	0.95	369	352	2.04	2.09	631	647	1,290	1,342
Guinea	0.63	10	6	1.40	1.43	8	8	11	12
Guinea-Bissau	0.99	27	27	1.97	2.05	45	46	89	93
Mali	0.86	983	846	2.70	3.03	1,142	1,176	3,142	3,517
Niger	0.46	2,329	1,075	1.19	1.42	2,724	3,360	3,847	4,241
Nigeria	1.15	8,412	9,675	2.04	2.13	9,947	10,145	20,336	21,617
Senegal	0.79	188	149	1.74	1.77	315	323	550	571
Sierra Leone	1.91	10	20	2.83	2.88	14	14	39	41
Togo	1.16	236	274	2.32	2.45	321	329	747	803

Table 3: Changes in Maize Output in ECOWAS Under the baseline scenario, 2010 and 2050

Country	2010			2050					
				Yield (MT/ha)		Area (thousands of ha)		Production (MT)	
	Yield (MT/ha)	Area (thousands of ha)	Production (MT)	Min	Max	Min	Max	Min	Max
Benin	1.08	748	810	1.87	2.08	886	929	1,660	1,911
Burkina Faso	1.41	458	646	2.20	2.61	408	424	900	1,105
Côte d'Ivoire	1.11	745	824	1.98	2.09	787	825	1,601	1,661
Gambia	1.93	16	31	2.55	2.73	17	18	43	48
Ghana	1.52	825	1,255	2.44	2.59	945	990	2,311	2,538
Guinea	1.15	138	159	2.14	2.29	161	168	344	386
Guinea-Bissau	1.90	16	31	2.03	2.15	18	19	37	41
Mali	1.39	381	531	2.31	2.61	304	313	703	803
Niger	0.78	4	3	1.57	1.69	1	2	2	3
Nigeria	1.29	4,696	6,070	1.74	1.90	4,405	4,829	7,664	9,181
Senegal	1.98	132	263	2.76	2.90	144	151	398	439
Sierra Leone	1.92	10	20	2.98	3.10	10	11	30	33
Togo	1.11	477	531	1.78	2.01	318	334	567	661

Table 4: Number of undernourished under the baseline scenario, 2010 and 2050

Country	2010	2050					
		Pessimistic		Baseline		Optimistic	
		Min	Max	Min	Max	Min	Max
Benin	423	741	794	520	554	375	404
Burkina Faso	1,047	1,439	1,462	1,159	1,180	866	887
Côte d'Ivoire	740	851	904	500	541	222	254
Gambia	48	59	60	28	29	6	7
Ghana	836	977	1,057	620	683	365	417
Guinea	420	526	555	312	334	127	145
Guinea-Bissau	102	92	96	65	68	0	2
Liberia	312	365	384	295	310	61	72
Mali	7,817	8,410	8,720	6,325	6,596	4,338	4,587
Nigeria	884	915	946	605	631	313	337
Niger	1,398	2,821	2,846	2,485	2,506	1,757	1,776
Senegal	449	388	400	169	178	13	21
Sierra Leone	242	450	462	227	236	108	116
Togo	254	274	296	168	185	80	94

ECOLAND - Land Allocation Model

Introduction

The land allocation model (or ECOLAND) is a dynamic intertemporal and spatial ECOWAS whole farm model. It is a modified version of the "AGRESTE" whole farm model (Kutcher and Scandizzo, 1981). The representative risk-neutral and profit maximization agent operates in an agro-climatic zone (ACZ) as units and there are 39 of these. The farming system is characterized by seven (7) cropping systems mainly paddy rice (pdr); cereal (gro), vegetable –fruit-nuts (av_f); oil seeds (osd); sugarcane-sugarbeet (c_b), fibers (pfb) and indigenous crops (ocr). This is akin to the Global Trade Analysis Project (GTAP) classification of crops and four (4) livestock breeding systems mainly cattle, sheep, chicken and others.

The model aims to estimate the corresponding land allocation for each agricultural crop and a group of crops in each given ACZ from year 2004 up to year 2100 with respect to climate change. It uses the theory of representative risk-neutral farm agent producing food crop and rearing livestock. In this model, agricultural crops and livestock activities that are appropriate are considered for each of these ACZs. The farm agent objective is to optimize the farming profit. This is illustrated by Max (yfarm), where yfarm is the sum of income made from crop production, and livestock minus all production costs such as cropping activity cost, labour cost definition, working capital requirements, veterinary costs, and technology adoption costs. However, the profit maximization is subject to resource constraints. This includes arable land, labour, fertilizer, seeds, and other relevant input and their costs. The decision-making of the economic agent will consist of adequately allocating available resources to sustain the business of farmers. Thus, the estimation of the appropriate land use in each ACZ and how it will perform under the whole farm model.

Model Overviews

Description

The model is an ACZ unit based model. Each ACZ input data relative to the year 2004 is located in the workbook called ***"ECOLANDNEW.XLX"***, which was linked to another file called ***ECOCALIB.GMS.*** The latter performs the optimization for the baseline. As for the simulation data (from year 2010 to 2100), twelve workbooks were used and some of these are ***"ECOLANDNEW45SSP1-ECOLANDNEW45SSP4, ECOLANDNEW85SSP1 - ECOLANDNEW85SSP4, ECOLANDNEWSSP1 - ECOLANDNEWSSP4"***. Indeed, the model included two climate- change scenarios (Representative

Concentration Pathways-RCPs 4.5 and 8.5), and four socio-economic scenarios (Share Socio-economic Pathways-SSPs) (Vervoort *et al.*, 2013). Each RCP was combined with the SSP files. Consequently, there were eight (8) scenarios with climate change and four additional scenarios without climate change. For example, ***ECOLANDNEW45SSP1*** refers to the combination of the RCP4.5 with the SSP1 and ***ECOLANDNEWSSP4*** is relative to SSP1 without accounting for climate change.

Model Data

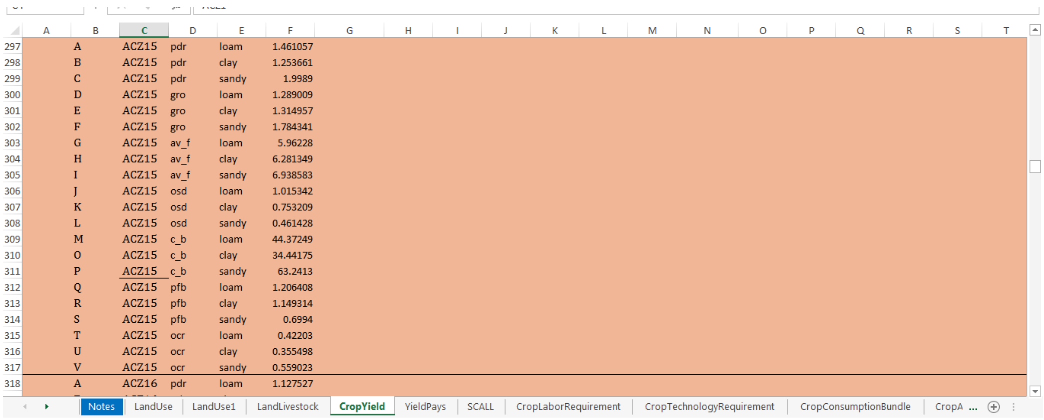
Data used were from several sources, and these included desk review and collection of socio-economic data. Indeed, socioeconomic parameters used in the modeling were from e.g., Louhichi *et al*(2013); Louhichi & Paloma(2014); Lokonon *et al*(2015); Yilma(2006); Kutcher & Scandizzo(1981); Paloma *et al.*(2012). Other sources include World Development Institute Database and the Food and Agriculture Organization (FAO) database. The base year data is 2010 while projection has been made up to 2100.

Climate data:

The ECOLAND climate data was represented by cropping yield. This was defined for three (3) levels following three (3) RCP scenarios. However, crop yield data were obtained from AQUA-CROP model, which uses climate and crop management data (AQU-CROP, 20xxx). ECOLAND climate data are linked to crop yields. This was defined for two (2) levels following two (2) RCP scenarios. However, crop yields can be simulated also through AQUA-CROP model, which needs climate data and crop- management data, or this may be calibrated through a multi-regression approach (econometric

approach) using climate data and economic data. Figure 1 illustrates crop yields data for the ACZ15 regarding the baseline.

Figure 1. Crop Yield input data



	A	B	C	D	E	F
297		A	ACZ15	pdr	loam	1.461057
298		B	ACZ15	pdr	clay	1.253661
299		C	ACZ15	pdr	sandy	1.9989
300		D	ACZ15	gro	loam	1.289009
301		E	ACZ15	gro	clay	1.314957
302		F	ACZ15	gro	sandy	1.784341
303		G	ACZ15	av_f	loam	5.96228
304		H	ACZ15	av_f	clay	6.281349
305		I	ACZ15	av_f	sandy	6.938583
306		J	ACZ15	osd	loam	1.015342
307		K	ACZ15	osd	clay	0.753209
308		L	ACZ15	osd	sandy	0.461428
309		M	ACZ15	c_b	loam	44.37249
310		O	ACZ15	c_b	clay	34.44175
311		P	ACZ15	c_b	sandy	63.2413
312		Q	ACZ15	pfb	loam	1.206408
313		R	ACZ15	pfb	clay	1.149314
314		S	ACZ15	pfb	sandy	0.6994
315		T	ACZ15	ocr	loam	0.42203
316		U	ACZ15	ocr	clay	0.355498
317		V	ACZ15	ocr	sandy	0.559023
318		A	ACZ16	pdr	loam	1.127527

Source: ECOLAND

Climate describes the physical characteristics of each ACZ and these are mainly:

- ET_0 : This is the Evapotranspiration specific to crop growing zone;
- Rain: Rain represents the daily Rainfall data collected from reference stations covering the ACZ;
- Temperature;
- CO_2: This defines the level of Carbon dioxide in the atmosphere;
- GDD: The growing degree day is defined as the length of a crop's growing period.
- Soil textures

Soil textures are mainly sandy, loam and clay land which are the commonly found in the region.

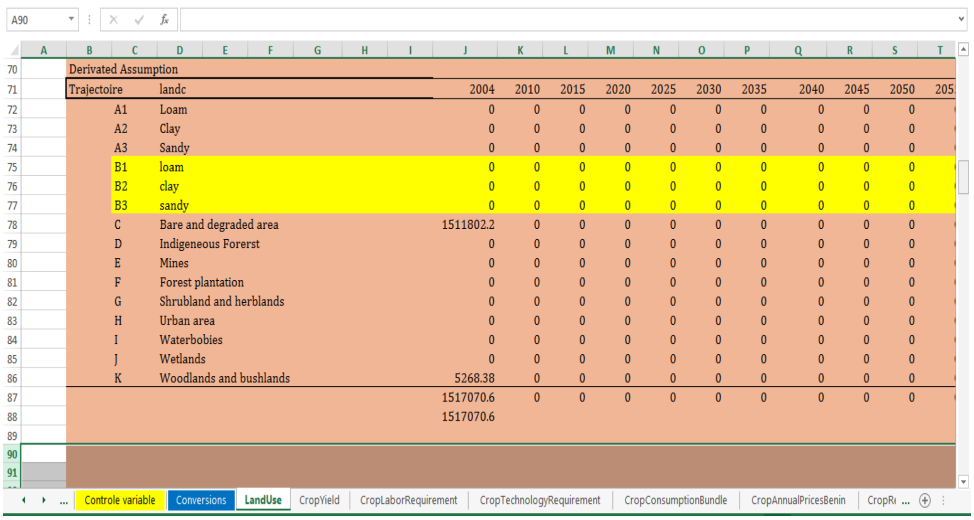
Environmental Data

The environmental data used included:

i) Annual land use Change (AFOLU)

The annual land use change called AFOLU and included 11 basic categories such as agricultural land (food crops and livestock), indigenous forest land (protected land), bare and degraded land, mining (industrial), urban land (settlement land), shrub-land, water-bodies, and wetland. This is illustrated in Figure 2. However, given the dynamics of land use change (LULUCF), the 11 land use categories are interrelated. For instance, urban land expansion may reduce arable land availability in favour of settlement land use. Similarly, soil erosion and agricultural land degradation may increase the size of bare land. In addition, changes in available soil textures mainly sandy, loam and clay land will affect cropping land allocation and perhaps the availability of other land use.

Figure 2. Annual land use change per ACZ



Derivated Assumption

Trajectoire	landc	2004	2010	2015	2020	2025	2030	2035	2040	2045	2050	205
A1	Loam	0	0	0	0	0	0	0	0	0	0	
A2	Clay	0	0	0	0	0	0	0	0	0	0	
A3	Sandy	0	0	0	0	0	0	0	0	0	0	
B1	loam	0	0	0	0	0	0	0	0	0	0	
B2	clay	0	0	0	0	0	0	0	0	0	0	
B3	sandy	0	0	0	0	0	0	0	0	0	0	
C	Bare and degraded area	1511802.2	0	0	0	0	0	0	0	0	0	
D	Indigeneous Forerst	0	0	0	0	0	0	0	0	0	0	
E	Mines	0	0	0	0	0	0	0	0	0	0	
F	Forest plantation	0	0	0	0	0	0	0	0	0	0	
G	Shrubland and herblands	0	0	0	0	0	0	0	0	0	0	
H	Urban area	0	0	0	0	0	0	0	0	0	0	
I	Waterbobies	0	0	0	0	0	0	0	0	0	0	
J	Wetlands	0	0	0	0	0	0	0	0	0	0	
K	Woodlands and bushlands	5268.38	0	0	0	0	0	0	0	0	0	
		1517070.6	0	0	0	0	0	0	0	0	0	
		1517070.6										

Source: ECOLAND

ii) Land requirement for Livestock feeding alternative (ha/head) (projected up to 2100).

Indeed, livestock breeding requested their feeding using cropping output such as grain. This is complemented by grassing which also contributed to additional land use for livestock activities.

Economics Data:

The economic data used include:

i) *Crops labour requirement ($/ha)*

This is the amount of labour allocated to each cropping system (man/day/ha).

ii) *Crop technology requirement ($/ha)*

This is relative to the cost of adopted cropping technology. This includes equipment (heavy machinery), seed, bullock, and fertilizer).

iii) Crop consumption

The representative farm considered in the model consumes a share of his total crop production to feed his family and sells the remaining output in the market. This consumption constitutes a level of household consumption and depends on their food consumption demand. Based on adequacy and appropriateness of their food consumption for meeting their dietary demand, three levels of household food consumption are defined and these are: (i) for low consumption, (ii) for more adequate and appropriated food consumption and (iii) is for highly better- off class.

iv) Crop consumption cost ($ per bundle)

This defines the corresponding cost of food consumption for each consumption bundle.

v) Crop prices

Crop prices are market prices are exogenous. Here crop prices are from another model and are projected from the base year of 2004 to 2100.

vi) Crop revenue

Crop revenue is the crop profitability per ha. The value depends on sales prices and the cost of production. This is projected from the base year of 2004 to 2100, and this is from another model (ECOWAT).

vii) Livestock labour requirement

Livestock breeding requirement which is the amount of labour per head. This is expressed in man-day per head.

viii) Livestock feeding alternative ($ per head)

This is the feeding cost of each livestock breeding system from grassing or other alternative feeding sources.

ix) Livestock prices ($, annual projection up to 2100)

Livestock prices are producer prices per ACZ. The value is projected from the base year of 2004 to 2100.

x) Veterinary cost ($ per year)

This includes the various cost of health treatment of livestock breeding.

xi) Family labour (man-month per year)

This is the projected value of farming family labour allocation.

xii) Family wage rate ($ per month per year)

The family labour use can also be remunerated following their time allocation in farming activities. This is projected from the base year of 2004 to 2100.

xiii) Farming population

Farming population is the total number of people directly involved in agricultural activities from land preparation to harvesting.

xiv) Temporal wage rate

This is relative to the wage rate for hired labour that is supposed to work temporarily on the farm.

xv) Permanent wage rate

This is relative to the wage rate for hired labour that is supposed to work permanently on the farm.

xvi) Working capital requirement ($)

It accounts for the total amount available for farming activities.

Model Results

The model outputs per ACZ were generated by running the ***ACZ.gms*** module of the ECOLAND model using COINIPOPT solver (Fig 3). Once ACZ land allocation was generated, the spatial-temporal land allocation per Basin and per country were then computed using basin and country land allocation per cropping and livestock system.

The model provides a useful output such as the spatial-temporal distribution of agricultural land availability, cropping and livestock land allocation and farming output per agro-climatic zone, per basin and per country. It also provides intertemporal agricultural production per agricultural unit, per basin and per ECOWAS country up to year 2100. This is illustrated in Figure 5 below. Country Land allocation and production are computed from the folder ***Country*** using ***production.gms*** while basin output is computed in folder **Basin** using ***Basin.gms.***

Figure 3. Land Allocation per Cropping System and per ACZ

Land Allocation Outputs

Trajectoire	Description	Notes			2004	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100
A1			crop-02	clay	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
A2			crop-05	clay	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
A3			crop-10	clay	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
A1			crop-15	clay	9.0909091	9.0909	9.0909	9.0909	9.0909	9.0909	9.0909	9.090909	9.0909	9.0909	9.0909	9.0909	9.0909	9.0909	9.0909	9.0909	9.0909	9.0909	9.0909	9.0909
A2			crop-16	clay	7.1428571	7.1429	7.1429	7.1429	7.1429	7.1429	7.1429	7.142857	7.1429	7.1429	7.1429	7.1429	7.1429	7.1429	7.1429	7.1429	7.1429	7.1429	7.1429	7.1429
A3			crop-17	clay	1148.2302	1148.2	1148.2	1148.2	1148.2	1148.2	1148.2	1148.23	1148.2	1148.2	1148.2	1148.2	1148.2	1148.2	1148.2	1148.2	1148.2	1148.2	1148.2	1148.2
A1			crop-19	Loam	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222
A2			crop-19	clay	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036
A3			crop-02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A1			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A2			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A3			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A1			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A2			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A3			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A1			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A2			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A3			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A1			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A2			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A3																								
B1			Cattle	loam	-9146469	-9E+06	-9E+06	-9E+06	-9E+06	-9E+06	-9E+06	-9146444	-9E+06	-9E+06	-9E+06	-9E+06	-9E+06	-9E+06	-9E+06	-9E+06	-9E+06	-9E+06	-9E+06	-9E+06
B2			Cattle	sandy	-4355461.4	-4E+06	-4E+06	-4E+06	-4E+06	-4E+06	-4E+06	-4355450	-4E+06	-4E+06	-4E+06	-4E+06	-4E+06	-4E+06	-4E+06	-4E+06	-4E+06	-4E+06	-4E+06	-4E+06
B3			Cattle	clay	-871092.28	-871090	-871090	-871090	-871090	-871090	-871090	-871089.9	-871090	-871090	-871090	-871090	-871090	-871090	-871090	-871090	-871090	-871090	-871090	-871090
B1			Sheep	loam	9093465.9	9E+06	9E+06	9E+06	9E+06	9E+06	9E+06	9093466	9E+06	9E+06	9E+06	9E+06	9E+06	9E+06	9E+06	9E+06	9E+06	9E+06	9E+06	9E+06
B2			Sheep	sandy	16781578	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	16781578	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07
B3			Sheep	clay	82667.871	82668	82668	82668	82668	82668	82668	82667.87	82668	82668	82668	82668	82668	82668	82668	82668	82668	82668	82668	82668
B1			Chicken	loam	-8102732.4	-8E+06	-8E+06	-8E+06	-8E+06	-8E+06	-8E+06	-8102732	-8E+06	-8E+06	-8E+06	-8E+06	-8E+06	-8E+06	-8E+06	-8E+06	-8E+06	-8E+06	-8E+06	-8E+06
B2			Chicken	sandy	-4766313.2	-5E+06	-5E+06	-5E+06	-5E+06	-5E+06	-5E+06	-4766313	-5E+06	-5E+06	-5E+06	-5E+06	-5E+06	-5E+06	-5E+06	-5E+06	-5E+06	-5E+06	-5E+06	-5E+06
B3			Chicken	clay	-1429894	-1E+06	-1E+06	-1E+06	-1E+06	-1E+06	-1E+06	-1429894	-1E+06	-1E+06	-1E+06	-1E+06	-1E+06	-1E+06	-1E+06	-1E+06	-1E+06	-1E+06	-1E+06	-1E+06
B1			Others	loam	4168341.1	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4168341	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06
B2			Others	sandy	5210426.4	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5210426	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06
B3			Others	clay	1042085.3	1E+06	1E+06	1E+06	1E+06	1E+06	1E+06	1042085	1E+06	1E+06	1E+06	1E+06	1E+06	1E+06	1E+06	1E+06	1E+06	1E+06	1E+06	1E+06
C	Bare and degraded area				1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222
D	Indigeneous Forerst				1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222
E	Mines				1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222	1222

Notes / Controle variable / Level(Scenarios) / Conversions / ACZ1 / ACZ2 / ACZ3 / ACZ4 / ACZ5 / ACZ6 / ACZ7 / ACZ8 / ACZ9 / ACZ10 / ACZ11 / ACZ12 / ACZ13 / ACZ14

ady Calculate

Sources: ECOLAND

Model Calibration

First, the economic-mathematical programming model should be calibrated before being used for climate change impact simulation. The model calibration adopted consists of reproducing observed data for the baseline year of 2004. This means reproducing or obtaining the close value of observed land allocation for various crops per land use in the year 2004. For the calibration, we rely on the traditional Positive Mathematics Programming(PMP approach (Howitt, 1995), which utilize extensive literature (e.g., Egbendewe-Mondzozo *et al.*, 2015; Egbendewe-Mondzozo *et al.*, 2011; Heckelei *et al.*, 2012). The PMP is popularly used in regional bio-economic models (Howitt, 1995; Rohm & Dabbert, 2003). One strength of the PMP calibration approach is that the model's solution is closer to observed reality (Kanellopoulos *et al.*, 2010). The usual three steps of the PMP approach are followed during the calibration procedure (Howitt, 1995; Kanellopoulos *et al.*, 2010). First, a raw linear programming model is run to understand the model behaviour without calibration. We found that only vegetables and fruits (i.e. bananas, cassava, plantains, potatoes, sweet potatoes, and yam) are grown in all ACZs. Second, we re-ran the simulation model, in which land use was constrained by the observed countries' crop land for year 2004 in order to replicate the observed crop land for the same year at country level. Finally, the shadow prices from the second step were used to calculate the coefficients of the marginal yield functions, which were then used to calibrate the model as a nonlinear quadratic optimization model under the assumption of a decreasing linear marginal yield. Following this calibration procedure, the model was able to predict cropland allocation at country level for the year 2004 with an average percentage deviation of 13.9%, which is within the acceptable range in modelling farmer behaviour (Hazell & Norton, 1986; Howitt, 1995).

In line with the results of Egbendewe-Mondzozo *et al.* (2015), this study assumes a land penetration rate of ± 2% each year to constrain cropland allocation dynamically in the simulations taking into account the fact that the total crop land use cannot be based on greater than the available arable land. This allows for the adaptation of the static nature of the traditional PMP approach in a dynamic context with more realistic levels of acreage over time. It is important to note that this approach does not allow the model to capture extreme climatic events in the short run. This is because many farmers in the ECOWAS region consume their own produce (Seo *et al.*, 2009), hence, there may not be a significant shift in acreage patterns in the short run. Therefore, the calibration approach is consistent with observed rigidity in acreage expansion in the short run. A similar calibration approach is used for livestock production in the ECOWAS region. The optimization of the calibration model is performed using ***ECOCALIB.GMS*** and ***ECOCALIBB.GMS***. ***ECOCALIB.GMS*** refers to the first and second steps of the PMP approach and ***ECOCALIBB.GMS*** **which** is relative to the third step using the first and second steps and rely on CBC solver, while the third step uses CONOPT[1] solver. ***ECOCALIBRAW.GMS*** is used to run the raw linear programming model, so it may be seen as the first step of the PMP approach.

[1] CONOPT is a solver for large-scale nonlinear optimization (NLP) developed and maintained by ARKI Consulting & Development A/S in Bagsvaerd, Denmark

Model Structure

Notations

c *is the list of selected crops . This includes pdr(Paddy rice), gro (Cereal), av_f (Vegetable), osd (Oil seeds), c_b (Sugarcane), pfb (Fiber crop) and ocr (Crop nec).*

p *refers to cropping system such as pdr , gro , av_f , osd , c_b , pfb , ocr.*

r *refers to livestock category mainly cattle, sheep, chicken, and others.*

s *characterizes all land use types mainly loamy , clay and sandy.*

Sc(s) *is for croplands (loamy, clay, sandy).*

dr *is for family consumption bundle alternatives respectively one , two and three.*

km *is the adopted technology. It includes equipment, fertilizer, seeds and bullock.*

ps(p,s) *is the process land possibilities.*

tm *is crop growing months respectively Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov and Dec.*

ty *is the time scale of a 5 year- period from 2010 with the base year of 2004.*

Parameters

The model parameters included land management data, livestock management data, crop management data, labour consumption data and other production costs (Table 5).

Table 5***: Description of ECOLAND Parameters***

Parameter	***Definition***	***Units***
landc(s,ty)	*Land data*	*Ha*
rations(r,ty	*Livestock ration Feeding alternative*	*$ USD per head*
lio(s,r)	*Land requirements for livestock feeding alternative*	*Ha per head*
labor(p,tm)	*Labour requirement for cropping*	*man-day per ha*
llab(tm,r)	*labour requirement for livestock*	*man-days per*

	feed	*head*
cbndl(c,dr)	*Consumption bundles*	*Tons per bundle*
crev(c,ty)	*Crop revenue*	*USD per ha*
price(c,ty)	*Crop prices*	*USD per kg*
ravg(c)	*Average crop revenue*	*USD per ha*
prdev(c,ty)	*Price deviation for crops*	*USD per tons*
yield(p,c,s,ty)	*Crop yields*	*Kg per ha*
techc(p,km)	*Cropping technology requirements*	*USD per ha*
fwage(tm,ty)	*Family reservation wage rate*	*USD per tons*
twage(tm,ty)	*Temporal labour wage*	*USD per man/months*

Table 5***: Description of ECOLAND Parameters (cont'd)***

Parameter	***Definition***	***Units***
vsc(dr,ty)	*Value of self-consumption*	*USD/bundle*
famlab(tm,ty)	*Family labour*	*Man equivalence work*
lprice(r,ty)	*Livestock prices*	*Ha per head*
vetpr(r,ty)	*Cost of veterinary services*	*USD per head*
landcost(ty)	*Land cost per ha*	*USD/ha*
wcbar	*Working capital*	*USD*
phi	*Risk factor*	*USD per ha*
dpm		*Man/day/month*
pwage	*Permanent labour wage rate*	*USD per ha*
prdev(c,ty)	*Price deviation for crops*	*USD per tons*
yield(p,c,s,ty)	*Crop yields*	*Kg per ha*
techc(p,km)	*Cropping technology requirements*	*USD per ha*
fwage(tm,ty)	*Family reservation wage rate*	*USD per tons*
twage(tm,ty)	*Temporal labour wage*	*USD per tons*

Sources: ECOLAND

Variables

The model variable defines cropping and livestock production behaviours data. This includes production factors such labour and land as well as intermediate inputs such as fertilizers. This is illustrated in Table 6 below.

Table 5 ***: Description of ECOLAND Variables***

Variable	***Definitions***	***Units***
xcrop(p,s,ty)	*Cropping activities*	*Ha*
xliver(r,ty)	*Livestock activity on feed techniques*	*Head*
xlive(r,ty)	*Livestock production*	*Head*
lswitch(s)	*Land downgrading*	*Ha*
xprod(c,ty)	*Crop production*	*Ton*
cons(dr,ty)	*On- farm consumption*	*Ton*
sales(c,ty)	*Crop sales*	*Ton*
flab(tm,ty)	*Family labour*	*Man-days*
tlab(tm,ty)	*Temporal labour*	*Man-days*
rationr(ty)	*Livestock rations requirement*	*$ USD*
pdev(ty)	*Positive price deviations*	*$ USD*
ndev(ty)	*Negative price deviations*	*$ USD*
yfarm(ty)	*Farm income*	*$ USD*
Revenue (ty)	*From crop and livestock sales*	*$ USD*
cropcost(ty)	*Cropping activities*	*$ USD*
labcost(ty)	*Labour cost-including family*	*$ USD*
vetcost(ty)	*Veterinary services cost*	*$ USD*
landcost(ty)	*Total land cost*	*$ USD*

Source: Made by Author

Equations

The model equations are the modified version of the whole farm model developed by Kutcher and Scandizzo, (1981):

i) Objective Function

$$Max\sum_{ty} Yfarm(ty)$$

$$Yfarm = \sum_{ty,dr}[revenue + vsc(dr,ty)*cons(dr,ty) - lab\cos t(ty) - rationr(ty) - vet\cos t(ty) - crop\cos t(ty) - tot\cos t(ty) - phi*(pdev(ty)+ndev(ty))/card(ty)]$$

ii) Constraints

a) ***Land Balance (land Availability)***

$$\sum_{ty}(\sum_{p} xcrop(p,s,ty) + \sum_{sp} ldp(s,sp)*lswish(sp) + \sum_{r} lio(s,r)*xliver(r,ty) \leq \sum_{ty} landc(s,ty)$$

b) ***Livestock Balance***

$$\sum_{ty,r} xlive(r,ty) = \sum_{ty,r} xliver(r,ty)$$

c) ***Livestock Requirement***

$$\sum_{ty} rationr(ty) = \sum_{ty,r} rations(r,ty)*xliver(r,ty)$$

d) ***Crop(s) Material Balance***

$$\sum_{ty}(\sum_{s,p} yield(p,c,s,ty)*xcrop(p,s,ty))/1000 = \sum_{ty}(sales(c,ty) + \sum_{dr} cbdl(c,dr)*cons(dr,ty))$$

e) ***On Farm Consumption***

$$\sum_{ty,dr} cons(dr,ty) = \sum_{ty} n(ty)$$

f) ***Crop production Definitions***

$$\sum_{ty} xprod(c,ty) = \sum_{ty}(\sum_{p,s} yield(p,c,s,ty) * xcrop(p,s,ty)) / 1000$$

g) ***Labour Supply/ Demand Relation***

$$\sum_{ty}(\sum_{p,s} labor(p,tm) * xcrop(p,s,ty) + \sum_{r} llab(r,tm) * xliver(r,ty) = \sum_{ty}(flab(tm,ty) + tlab(tm,ty) + dpm * plab)$$

h) ***Crop price Deviation***

$$\sum_{c} prdev(c,ty) * sales(c,ty) = pdev(ty) - ndev(ty)$$

i) ***Revenue***

$$revenue = \sum_{ty,r} lprice(r,ty) * xlive(r,ty) + 1000 * \sum_{ty,c} price(c,ty) * sale(c,ty))$$

j) ***Cropping Cost***

$$\sum_{ty} crop\cos t(ty) = \sum_{ty}\sum_{p,s} p\cos t(p) * xcrop(p,s,ty)$$

k) ***Labour Cost***

$$\sum_{ty} lab\cos t(ty) = \sum_{ty,tm}[fwage(tm,ty) * flab(tm,ty) + twage(tm,ty) * tlab(tm,ty)] / dpm + pwage * plab$$

l) ***Land Cost***

$$to\cos t(ty) = (\sum_{p,s} xcrop(p,s,ty) + \sum_{r} lio(s,r) * xliver(r,ty)) * land\cos t$$

m) ***Working Capital Requirement***

$$\sum_{ty}(crop\cos t(ty) + rationr(ty) + vet\cos t(ty) + [\sum_{tm} twage(tm,ty) * tlab(tm,ty)] / dpm + pwage * plab + \sum_{p,s} xcrop(p,s,ty) + \sum_{r} lio(s,r) * xliver(r,ty)) * land\cos t(ty)) = wcbar$$

n) ***Veterinary cost***

$$\sum_{ty} vet\cos t(ty) = \sum_{ty} vetpr(r,ty) * xlive(r,ty)$$

Model Integration

Indeed in ECOLAND model (Fig 4), crop yield and cropping systems water requirement are exogenous variables. These are output from crop model called AQUA-CROP. Thus, the yield obtained as output from AQUA-CROP model is directly linked respectively to levels 1 and 2 in ECOLAND, and this is for each ACZ. For example, the ACZ1, in Figure 4 below while the overview of the concept is illustrated in the Figure 5below.

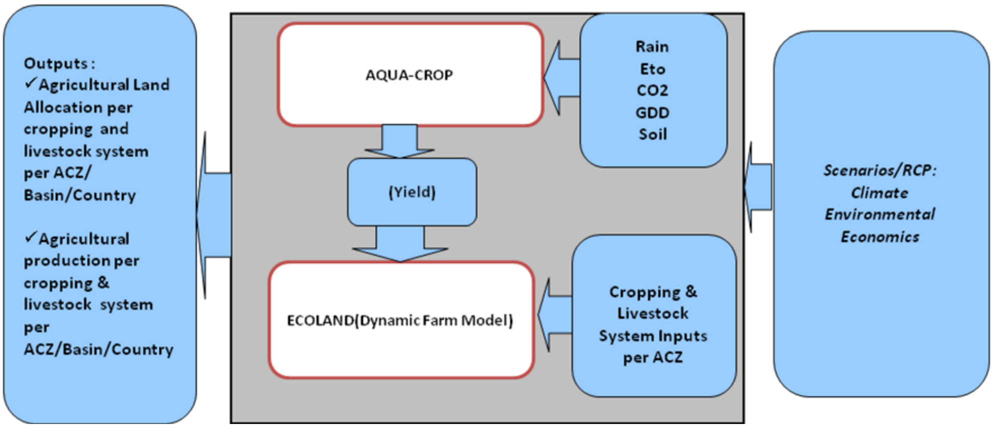
Figure 4. Snaphot of Aqua-Crop- ECOLAND linkage

Crop yield(per ha)

Type	*Description*		2004	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055
1	pdr	A	2	2.2	2.5	2.6	2.5	1	0.98	0.5	0.5	0.5	0.5
1	pdr	B	2.3	2.5	2.6	2.8	3	2	2	1.3	2	2	2
1	pdr	C	3	3.5	3.8	4	4	3	3	2.98	3	3	3
1	gro	D	3.2	2.3	2.5	3	2	4	2.2	3	4	4	4
1	gro	E	3.9	4	5	5.1	8	5	4	5	5	5	5
1	gro	F	2	3	6	6	2	6	1	6	6	6	6
1	av_f	G	3	5	7	7	3.5	7	1	1	7	7	7
1	av_f	H	4	6	8	6	5	5	4	3	2	2	2
1	av_f	I	6	6.8	9	9	6.4	9	5	4	9	9	9
1	osd	J	10	12	12.5	13	9	10	8	5	10	10	10
1	osd	K	11	13	13.5	13	10	11	7	9	9	9	9
1	osd	L	12	14	14.1	15	10	12	9	8	8	8	8
1	c_b	M	13	15	15.2	15	11	13	10	9	9	9	9
1	c_b	O	14	15	15.03	16	8	14	13	10	10	10	10
1	c_b	P	15	16	16.1	17	10	15	12	12	12	12	12
1	pfb	Q	16	16.7	16.9	17	12	16	12	14	14	14	14
1	pfb	R	17	17.8	18	18.1	16	17	14	16	16	16	16
1	pfb	S	18	18.5	19	19.4	12	18	11	14	14	14	14
1	ocr	T	19	19.3	20	21	7	19	12	9	9	9	9
1	ocr	U	20	20	21	21.1	18	20	14	8	8	8	8

Source: ECOLAND

Figure 5. Overview of ECOLAND-Aqua-Crop Model Integration



Source: Made by Author

GAMS Programming

The model GAMS code is available at UNU-INRA. This can be obtaining if formal inquiry is addressed to UNU-INRA.

ECOWAT Hydro-Economic Model

Introduction

The ECOWAT is a spatial-temporal Hydro-economic model. The model takes into account water end user's consumption behaviour, production system characteristics and countries sharing similar catchment physical characteristics and water -management planning infrastructure. This is a very useful information for assessing how countries and the farming system will respond to climate change. This approach will also contribute to decision- making for selection of better climate change adaptation strategies and interaction between the adaptation policies of different countries. The model is a modified version of hydro-economic model according to Frankward (2010). The model considers four (4) wateruser's . This includes agriculture sector mainly crops

and livestock; household; hydro-power production and recreation water users for five of the major Basin system (i.e. the Niger Basin, Senegal Basin, Volta Basin, Gambia Basin and Lake Chad. It should be noted that the ECOWAS or (West African) region is characterized by trans-boundary Catchment. The model has included two cropping seasons of rainfall season starting from March to September and drought season starting from October to February and during the latter, the fields are irrigated. This is to capture the tradeoff of water usage between rainfed cropping system and irrigation system. The model is set up with time scale up to the year 2100. The model aims to optimize the total benefit of water usage in each catchment. This is expressed by MaxTot_ben_v(p,s) where Tot_ben_v(p,s) is basically the sum of the benefits of basin related water usage activities. This includes:

- ✓ Ag_ben_v(use,y,t,p,s) for agricultural benefit ;
- ✓ ben_s(res,y,t,p)for recreation benefit ;
- ✓ m_ben_v(use,y,t,p,s) for livestock breeding benefit ;
- ✓ Energy_ben(res,hydro,t,p,s) for hydro-electricity benefit ;and
- ✓ U_benefit_uV(use,y,t,p,s) for household water usage benefit .

The model computes optimal output such as inter-temporal **crop revenue, crop price, cropping land allocation** and **water allocation** in decision-making to maximize catchment water usage benefit among end users.

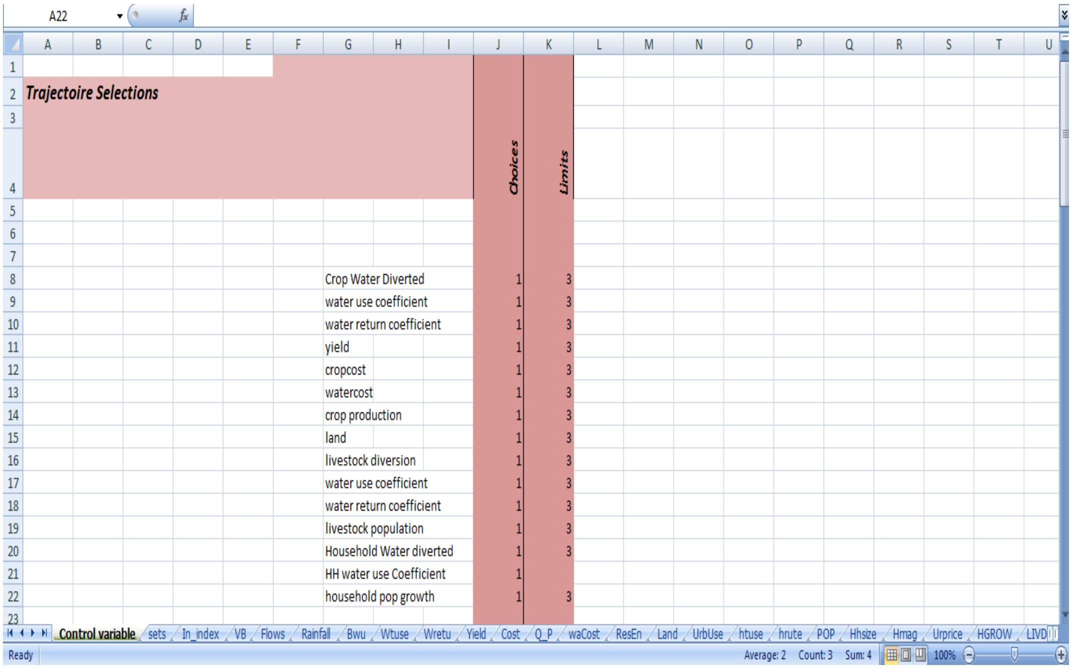
Model Overviews

Description

The model is a catchment based model. For each catchment, it uses a catchment input data named ***"Basinname.B.xls"*** which is linked to a GAMS programming code called ***watmodel.gms.*** The ***"Basinname.B.xls"*** is an excel workbook made of ***29 excel sheets*** describing the catchment *geometry and end user of water data*. For example, for Niger Basin, input data are included in ***NigerB.xls***. This is illustrated in *Figure 6* below where:

Control *variable is scenario definition sheet*
Sets *include notation and definitions;*
In _Index *is the link option between NigerB.xls and watmodel.gms;*
VB *contain basin geometry table and reservoir linkage;*
Flows *define Volta basin inflows data;*
Rainfall *defines rainfall data;*
Bwu *contains agricultural crop water diverted data;*
Wtuse *describes agricultural water- use efficiency;*
Wretu *describes the level of water return into the basin system after crop irrigation;*
Yield *contains crop yield data per ACZ;*
Cost *defines crop production cost per ACZ;*
Q_p *defines crop total production per ACZ;*
Wcost *defines cropping system water cost per ACZ;*
ResEn *defines hydro-energy data base;*
Land *defines land use database per ACZ;*
UrbUse *defines household water usage data include in both urban and rural household per ACZ;*
Htuse *contains urban water efficiency per ACZ;*
Hrute *expresses the level of household water return into the basin per ACZ;*
Pop *defines household population per ACZ;*
Hhsize *defines household size per ACZ;*
Hmag *household water spending per per ACZ;*
Urprice *defines household water price;*
HGROW *defines household population growth per ACZ;*
LIVD *expresses livestock water diverted per ACZ;*
mtuse *livestock industry water- use efficiency per ACZ;*
mretu *contain data on livestock breeding water return per ACZ;*
mpop *contains livestock population per ACZ;*
Qm *contains livestock production for the base year per ACZ;*
MGROW *contains information on livestock population growth per ACZ;*

Figure 6. Description of Basin inputs notebook



Trajectoire Selections

	Choices	Limits
Crop Water Diverted	1	3
water use coefficient	1	3
water return coefficient	1	3
yield	1	3
cropcost	1	3
watercost	1	3
crop production	1	3
land	1	3
livestock diversion	1	3
water use coefficient	1	3
water return coefficient	1	3
livestock population	1	3
Household Water diverted	1	3
HH water use Coefficient	1	
household pop growth	1	3

Source: ECOWAT Model

Model Data

Model inputs are per ACZ and are related to climate, economies, and environments. This includes climate data, cropping system inputs, livestock breeding inputs, hydro-electricity production data and household water usage data.

Climate data:

Here, climate data are mainly physical data and describe the catchment hydrology:

i) Rainfall

This is the quantified amount of precipitation in the selected catchment. It is expressed in m^3. This is the evapotranspiration in selected catchment

ii) Flow

This is a function of rainfall, sub-catchment area, the runoff and level of ground water recharge. This is expressed in the following equation:

$$source\_p(\inf low, y, t, s) = (P * S - ETo) - Rainoff \pm Grw$$

Where:

P *is the rainfall*

S *: the area of each sub-catchment (inflow)*

is the evapotranspiration

iii) Grw *is ground water recharge*

Cropping system

i) Crop water use per agro-climatic zone

Crop water use is a share of diverted water from inflow source which is used really by planting material during the growing period. This is expressed by:

$$Bu(use,\ j,t,z) = wtuse(use,t,z)*\sum_{divert}(ID\_ud(use,divert)*Bu(divert,\ j,t,z))$$

ii) Wtuse (use,t,z) water use coefficient per agro -climatic zone

This represents crop water use efficiency. It may vary by ACZ depending on farmer's water usage.

iii) Water return

One water is diverted from sources and the crop water requirement is met; the remaining water is returned into the system. This is expressed by

$$Bu(return,\ j,t,z) = wretu(use,t,z)*\sum_{return}(ID\_ud(return,divert)*Bu(divert,\ j,t,z))$$

iv) Wretu (return,t,z) water return coefficient per agro-climatic zone
v) Yield_p(use,j,k,z) Crop Yield tons per acre (proportional to ET when technology varies)
vi) Price_p(j) Crop Prices ($ per ton)
vii) Cost_p(use,j,k,z) Crop Production Costs ($ per acre)
viii) wcost_p(use,j,k,z) crop water cost($ per acre)
ix) Q_p(use,j,z) crop production
x) price_elast(j) crop prices elasticity
xi) landrhs_p(use,y,z) land in production

Household

i) mu_use_base_p(i,l,t,z) base water delivery (acre feet/hh/year)
ii) htuse(use,t,z) hh water use coefficient
iii) hretu(return,t,z) hh water return coefficient
iv) pop(use,l,t,z) urban and rural pop (1000s of households)
v) Hhsize(use,l,t,z) hh size
vi) hhgrowth(use,l,y,t,z) hh pop annual growth rate

vii)p_elasticity_p(use,l,t) price elasticity of demand for water
viii) mu_price_base_p(use,l,t,z) base year hh water price ($ per acre foot)
ix) AC_uuse0_p(use,l,t,z) base year marginal cost of supply.

Livestock

i) mbase_p(i,m,t,z) total livestock pop water demand (divert+use+return)100m3 /m/month
ii) mtuse(use,t,z) water use coefficient
iii) mretu(return,t,z) water return coefficient
iv) mgrowth(use,m,y,t,z) growth rate
v) Q_m(use,m,z) base year production
vi) price_elast_m (m) price elasticity
vii) p_m observe price
viii) cost_m(use,m,y) production cost
ix) mpop(use,m,t,z) monthly base year population

Hydro-power & Recreation

i) z0_p (res) initial reservoir levels at stock nodes
ii) zmax_p(res) maximum reservoir capacity
iii) MBe_p(res) coefficient for reservoir based recreation
iv) bhh(res) hydro reservoirs
v) Bpower_p(res,t) slope in power price / month
vi) hydro_price (res,t) hydro-electricity prices energy_prot_p (y,s,t) energy production

Model Results

Once the model input data are completed for the catchment, the model is run using non-linear programming option **CONOPT** as a solver. The obtained results are listed in a notebook namely **“*Basinname.B.ww_Basin*”.** This is illustrated in **Figure 7** below where

Bu_p *describes crop water consumption per ha;*

M_price_v_p *expresses crop prices;*

Tag_prof_v_p *defines cropping system total profitability for the whole catchment;*

Ag_prof_v_p *defines cropping system profitability per user. Here end users are trans-boundary countries;*

Production_v_p *is the cropping system production per ACZ;*

Tacre *expresses the land allocation per end user;*

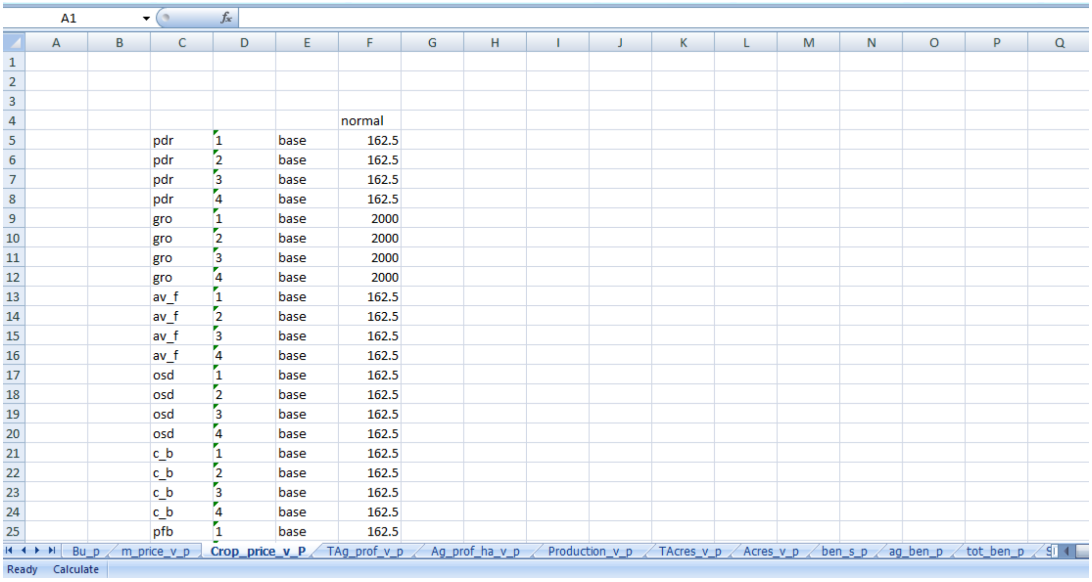
Acre *expresses the land allocation per cropping system technology (rainfall and irrigated crops) and per end user;*

Ben_s_p *is the benefit of water end users per nodes;*

Ag_ben_p *is the agricultural benefit;*

Tot_ben_s *is the total benefit of water usage by all end users for the whole catchment.*

Figure 7. Model Results per Catchment



A1

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1																	
2																	
3																	
4						normal											
5			pdr	1	base	162.5											
6			pdr	2	base	162.5											
7			pdr	3	base	162.5											
8			pdr	4	base	162.5											
9			gro	1	base	2000											
10			gro	2	base	2000											
11			gro	3	base	2000											
12			gro	4	base	2000											
13			av_f	1	base	162.5											
14			av_f	2	base	162.5											
15			av_f	3	base	162.5											
16			av_f	4	base	162.5											
17			osd	1	base	162.5											
18			osd	2	base	162.5											
19			osd	3	base	162.5											
20			osd	4	base	162.5											
21			c_b	1	base	162.5											
22			c_b	2	base	162.5											
23			c_b	3	base	162.5											
24			c_b	4	base	162.5											
25			pfb	1	base	162.5											

Bu_p / m_price_v_p / Crop_price_v_P / TAg_prof_v_p / Ag_prof_ha_v_p / Production_v_p / TAcres_v_p / Acres_v_p / ben_s_p / ag_ben_p / tot_ben_p

Ready Calculate

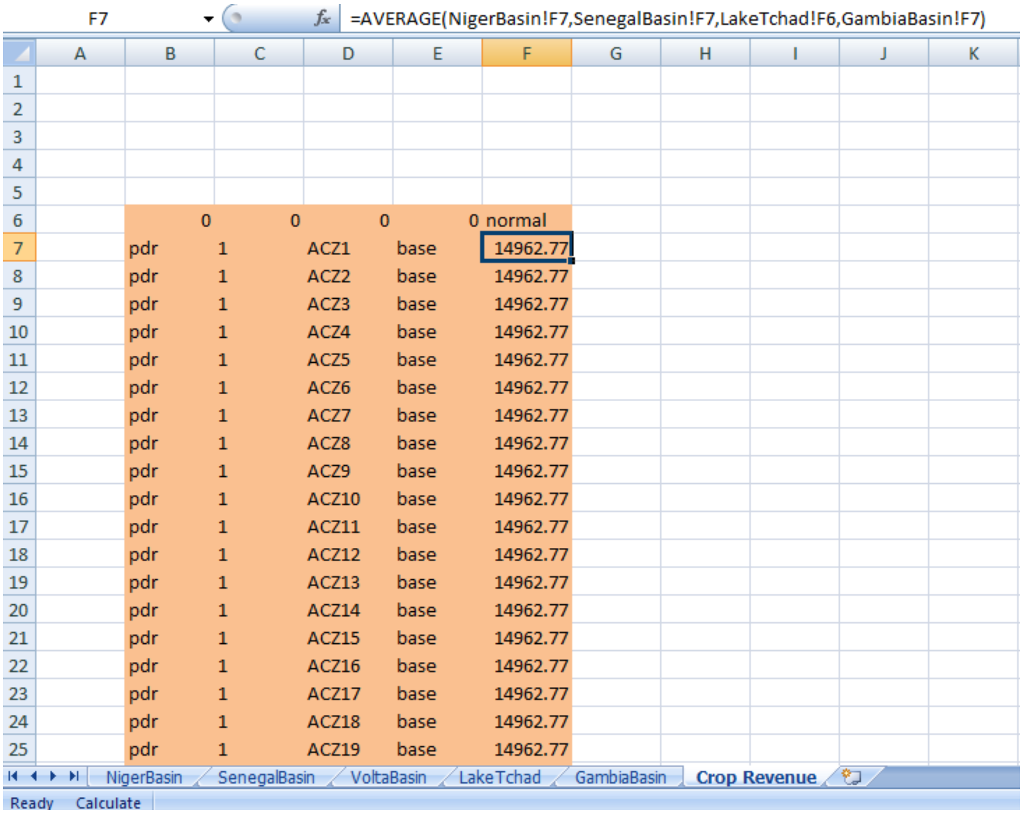
Source: ECOWAT model

Model Aggregated Output

Using the methods of what was evaluated for the Niger Basin, similar methods were used to perform the simulation for each catchment. Thus, ***crop revenue and crop prices per ACZ*** are computed from the base year of 2004 up to 2100 (Fig 8). This is computed in excel notebook namely ***"aggregate.xls"*** where:

Niger Basin *contains all aggregated output for Niger Basin*
Crop revenue *is the aggregated cropping system revenue per ACZ for the ECOWAS region.*

Figure 8. Output of ECOWAT Model



F7 =AVERAGE(NigerBasin!F7,SenegalBasin!F7,LakeTchad!F6,GambiaBasin!F7)

	A	B	C	D	E	F
6		0	0	0	0	normal
7		pdr	1	ACZ1	base	14962.77
8		pdr	1	ACZ2	base	14962.77
9		pdr	1	ACZ3	base	14962.77
10		pdr	1	ACZ4	base	14962.77
11		pdr	1	ACZ5	base	14962.77
12		pdr	1	ACZ6	base	14962.77
13		pdr	1	ACZ7	base	14962.77
14		pdr	1	ACZ8	base	14962.77
15		pdr	1	ACZ9	base	14962.77
16		pdr	1	ACZ10	base	14962.77
17		pdr	1	ACZ11	base	14962.77
18		pdr	1	ACZ12	base	14962.77
19		pdr	1	ACZ13	base	14962.77
20		pdr	1	ACZ14	base	14962.77
21		pdr	1	ACZ15	base	14962.77
22		pdr	1	ACZ16	base	14962.77
23		pdr	1	ACZ17	base	14962.77
24		pdr	1	ACZ18	base	14962.77
25		pdr	1	ACZ19	base	14962.77

NigerBasin / SenegalBasin / VoltaBasin / LakeTchad / GambiaBasin / Crop Revenue

Ready Calculate

Model Calibration

Calibrating ECOWAT consists of reproducing ***cropping diverted water***, ***crop prices, and agricultural land use per cropping system, agricultural benefit,*** and ***crop revenue*** for the years 2004, 2010 and 2014 respectively.

Model Structure

Notation and definition

inflow(i) *is catchment inflows*
river(i) *is gauge stations located on inflows*
divert(i) *is water diverted node*
return(i) *is water return node*
use(i) *is water usage countries*
rel(i) *is reservoir*
hydro (i) *is hydro-electricity reservoir*
u *Stocks--location of important nodes*

t *monthly time*
ts *rainfall season*
ts2 *Irrigation season*
y *year*
j *cropping system*
l *Household groups*
k *crop type (rainfall versus irrigation)*
p *policy*
s *scenario*
m *livestock category*
z *agro- climatic zone*
tlast (y) *terminal period among all years above*
tfirst(y) *first year*
slast (t) *terminal month any year*
sfirst(t) *first month any year*
tn (t) *off rainfall season*
tn2 (t) *off irrigation season for the second crop*
timelast (y,t) *last year and last month;*

Model parameters

Indeed, the model ECOWAT parameters include basin geometry data, which describe the connection between the basin inflows; list of the reservoirs and

their physical characteristics; base year data of water end users. This includes diverted water for cropping system, livestock production, energy production and recreation; their respective water usage efficiency coefficient (Table ***7)***.

Table 6 : ***Description of ECOWAT model parameters***

Parameter	**Definition**	**Units**
Bv_p(I,river)	Basin Geometry	Not applicable
Bd(inflow, divert)	Wet Table	Not applicable
Blv_p(rel, res)	Links reservoir stocks to downstream release flows	Not applicable
Inflows(inflow,y,t,p,s)	Basin Inflows	Acre feet/second
Bu(use,j,t,z)	Crop Water diverted	Acre feet/ha
Wtuse(use,t,z)	Water use coefficient	Not applicable
Wretu(return,t,z)	Water return coefficient	Not applicable
yield_p(use,j,k,z)	Crop yield	t/ha
cost_p(use,j,k,z)	Cost of production	$ USD
wcost_p(use,j,k,z)	Cost of water	$ USD
Q_p(use,j,t,z)	Crop production	t
Price_elast(j)	Price elasticity	Not applicable
Source_p (inflow,y,t,p,s)	Inflows	Acre feet/second
Zo_p(res)	Initial Reservoir capacity t	
Zmax_p(res)	Maximum Reservoir Capacity	
MBe_p(res)	Recreation Benefit	
Bhh(res)	Hydro-reservoir	
Bpower_p(res,t)	Slope in power prices	
Hydro-price(res,t)	Hydro-electricity prices	$ USD
Energy_prot_p(y,s,t)	Energy production	Kwht
Landrh_p(use,y,z)	Land in Production	ha

Table 7 ***: Description of ECOWAT model parameters (cont'd)***

parameters	Definition	Units
Mu_use_base_p(I,l,t,z)	Household base water delivery	Acre feet/hh/year
htuse	Household water use efficiency	Not applicable
hrtu	Household water use return coefficient	Not applicable
pop	Living population	peoples
Hhsize	Household size	people
P_elasticity_p	Urban water demand elasticity	$ USD/acre feet/hh/year
Mu_price_base	base year household water price	$ USD/hh
AC_uuse0_p	base year marginal cost of supply	$ USD/hh
hhgrowth	household population annual growth rate	Not applicable
mbase_p	total livestock population water demand	Acre feet
mtuse	livestock water use coefficient	Not applicable
mretu	livestock water return coefficient	Not Applicable
mpop	livestock monthly base year population	head
Q_m	base year livestock production	head
price_elast_m	price elasticity of livestock demand	$ USD/head
p_m	observed livestock price	$ USD
cost_m	livestock production cost	$ USD
mgrowth	growth rate of livestock population	Not applicable

Model Variables

Following the model objective, which is to optimize water end users' benefit for each catchment, model variables are variables describing inter-temporal water consumption behaviour and profitability of each end user. This included land use in production, cultivated land per cropping system, reservoir capacity,

agriculture and livestock profitability and consumer's surplus, as well as trend in urban water consumption (Table 8).

Table 8 ***: Description of ECOWAT variables***

Variables	Definition	Units
land_v (use, y,t,z,p,s)	Land in Production	ha
Acres_v (use,j,k,y,t,z,p,s)	Area under Cultivation	ha
X_v (i, y,t,p,s)	Water flows	Acre feet /second
ben_f_v (use, y,t,p,s)	Water economic benefit by user	
Ben_s_v (res, y,t,p,s)	Water economic benefit by reservoir	$ USD
Ag_ben_j_v (j,y,t,p,s)	Agricultural water usage benefit	$ USD
T_ag_ben_v (p,s)	Total Agricultural Benefit by nodes	$ USD
Con_surp_v (j, y,t,p,s)	Agricultural Consumer surplus	
Ag_prof_ha_v (use,j,k,y,t,z,p,s)	Agricultural profitability	$ USD
Ag_Ben_v (use, y,t,p,s)	Agricultural Benefit by nodes	$ USD
Production_v (use,j,k,y,t,z,p,s)	Crop production	
Crop_price_v (j, y,t,p,s)	Crop price	$ USD
U_con_sur_u_v (use,y,t,p,s)	Urban total consumer surplus	$ USD
U_Price_u (l,y,t,p,s)	Urban water prices	$ USD/hh
U_Rev_u_v (use,y,t,p,s)	Urban Revenue	$ USD
U_benefit_u_v (use,y,t,p,s)	Urban total benefit	$ USD
U_Rev_u_v (use,y,t,p,s)	Urban Revenue	$ USD

Table 9 *: Description of ECOWAT variables (contd).*

Variables	Definition	Units
mCon_surp_v (m, y,t,p,s)	Livestock consumer surplus	$ USD
m_prof_m_v (use,m,y,t,p,s)	Livestock profitability	$ USD
m_production_v(m,y,t,p,s)	Livestock production	$ USD
m_price_v (m, y,t,p,s)	Crop prices	$ USD
m_Ben_v (use, y,t,p,s)	Livestock benefit	$ USD
tot_ben_v (p,s)	Total user benefit	$ USD
tot_ben_base_normal_v	Total base economic benefit	$ USD
Z_v(res,y,t,p,s)	Reservoir water stock	$ USD
Reservoirs_h_v(res, y,t,p,s)	Reservoir height	$ USD
Energy_ben_v (res,hydro,y,t,p,s)	Hydro-electricity benefit	$ USD
hydro_price_v (res,hydro,y,t,p,s)	Hydro-price	$ USD/Kwht
energy_prod_v (res,hydro,y,t,p,s)	Energy production	Kwht

Model Equation

The model equations were a modified version of AMUDARYA Basin hydro-economic model proposed by Frankward and Shokhrukh-Mirzo Jalilov (2011)

Objective function

$$MaxTot\_ben\_v(p,s)$$

Where:

$$Tot\_ben\_v(p,s) = \sum_{use,y,t} (df(y)*ag\_ben\_v(use,y,t,p,s) + \sum_{res,y,t} df(y)*ben-s\_v(res,y,t,p,s) + \sum_{use,y,t} df(y)*m\_ben\_v(use,y,t,p,s) +$$
$$\sum_{res,hydro,y,t} df(y)*bhh(res,hydro)*energy\_ben(res,hydro,y,t,p,s) + \sum_{use,y,t} df(y)*U\_benefit\_u\_v(use,y,t,p,s) +$$

$df(y) = 1/(1+0.5)^{ord(y)}$ Where $df(y)$ is annual discount factor

Tot_ben_v(p,s) is the total benefit of water usage in each catchment. This is basically the sum of all the basin related water usage activities benefit and these are ag_ben_v(use,y,t,p,s) for agricultural benefit; ben_s(res,y,t,p,s) for recreation benefit (include tourism); m_ben_v(use,y,t,p,s) for livestock ;energy_ben(res,hydro,y,t,p,s) for hydro-electricity benefit and U_benefit_uV(use,y,t,p,s) for household water usage benefit . The total benefits are subject to constraints such as: water & land availability, water end users' demand, economic factors (population, prices, cost of production etc...). Given the social value of water, the model included discounting rate to account for the valuation of the future time scale benefit. This is expressed as follows.

$$df(y) = 1/(1+0.5)^{ord(y)}$$

Constraints are expressed as follows

- ***Land block***

Land in production

$$\sum_{j,k,z} Acres\_v(use, j, k, y, t, z, p, s) \le \sum_{z} land\_v(use, y, t, z, p, s)$$

Rainfall land

$$\sum_{z} Acres\_v(use, j, first, y, t, z, p, s)\$ts(t) = \sum_{z} Acres\_v(use, j, first, y, mar, z, p, s)$$

Irrigated land

$$\sum_{z} Acres\_v(use, j, \mathrm{sec}ond, y, t, z, p, s)\$ts2(t) = \sum_{z} Acres\_v(use, j, first, y, oct, z, p, s)$$

- ***Hydrology block***

Source nodes

$$X\_v(\inf lows,y,t,p,s)=source\_p(\inf low,y,t,s)$$

Hydrologic mass balance

$$X\_v(river,y,t,p,s)=\sum_{\inf low} Bv\_p(\inf low,river)*X\_v(\inf low,y,t,p,s)+\sum_{riverp} Bv\_p(riverp,river)*X\_v(riverp,y,t,p,s)+$$

$$\sum_{divert} Bv\_p(divert,river)*X\_v(divert,y,t,p,s)+\sum_{return} Bv\_p(return,river)*X\_v(return,y,t,p,s)+\sum_{rel} Bv\_p(rel,river)*X\_v(rel,y,t,p,s)$$

Divert

$$X\_v(divert,y,t,p,s)\le\sum_{\inf low} Bd\_p(\inf low,divert)*X\_v(\inf low,y,t,p,s)+\sum_{river} Bd\_p(river,divert)*X\_v(river,y,t,p,s)+$$
$$\sum_{divertp} Bd\_p(divertp,divert)*X\_v(divertp,y,t,p,s)+\sum_{return} Bd\_p(return,divert)*X\_v(return,y,t,p,s)+\sum_{rel} Bd\_p(rel,divert)*X\_v(rel,y,t,p,s)$$

Use

$$X\_v(use,y,t,p,s)=\sum_{j,k,z}(Bu(use,j,k,z)*Acres\_v(use,j,k,y,t,z))+\sum_{l,z} mu\_use\_base(use,l,t,z)*(1+hhgrowth(use,l,y,t,z)+$$
$$\sum_{m,z} mbase\_p(use,m,t,z)*(1+mgrowth(use,m,y,t,z)$$

Starting reservoir mass balance

$$z\_v(res,y,t,p,s)=zo(res)+\sum_{rel} Blv\_p(rel,res)*X\_v(rel,y,t,p,s)$$

Reservoir mass balance accounting

$$z\_v(res,y,t,p,s)=\sum_{y2,t2} z\_v(res,y2,t2,p,s)+\sum_{rel} Blv\_p(rel,res)*X\_v(rel,y,t,p,s)$$

Reservoir height

$$reservoirs\_h\_v(res,y,t,p,s)=\exp(-1.81263)*z\_v(res,y,t,p,s)$$

- ***Energy Block***

Energy production

$$energy\_prod\_v(res,hydro,y,t,p,s) = (1/1000000)*reseroirs\_h\_v(res,y,t,p,s)*(1/2.6297)*X\_v(hydro,y,t,p,s)*9.8*0.75*24*(365/12)$$

- ***Economics Block***

Agricultural Benefits

$$Ag\_Ben\_v(use,y,t,p,s) = \sum_{j,k} Ag\_prof\_ujt\_v(use,j,k,y,t,p,s)$$

$$Ag\_prof\_ujt\_v(use,j,k,y,t,p,s) = \sum_{z} Ag\_prof\_ha\_v(use,j,k,y,t,z,p,s)*Acres\_v(use,j,k,y,t,z,p,s)$$

$$Ag\_prof\_ha\_v(use,j,k,y,t,z,p,s) = [crop\_price\_v(j,y,t,p,s)*yield\_p(use,j,k,z) - \cos t\_p(use,j,k,z) - w\cos t\_p(use,j,k,z)]$$

$$crop\_price(j,y,t,p,s) = b0\_p(j) + b1\_p(j)*\sum_{k} T\_production\_v(j,k,y,t,p,s)$$

$$T\_production(j,k,y,t,p,s) = \sum_{use,z} production\_v(use,j,k,y,t,z,p,s)$$

$$production\_v(use,j,k,y,t,z,p,s) = Acres\_v(use,j,k,y,t,z,p,s)*yield\_p(use,j,k,z)$$

b1_p (j) intercept by country and crop

$$b1\_p = \Pr ice\_p(j)/(\sum_{use,z} Q\_p(use,j,z)*(1/price\_elast(j))$$

delta_p_p(j) price change

$$delta\_p\_p(j) = -b1\_p(j) * \sum_{use,z} Q\_p(use, j, z)$$

b0_p (j) slope

$$bo\_p(j) = price\_p(j) * delta\_p\_(j)$$

Household benefit

$$U - benefit\_u\_v(use, y, t, p, s) = U\_cons\_sur\_u\_v(use, y, t, p, s) + U\_\mathrm{Re}v\_u\_v(use, y, t, p, s)$$

$$U\_cons\_sur\_u\_v(use, y, t, p, s) = 0.5 * \sum_{l,z} U\_B0\_p(l,t) - U\_price(l,t,p,s)] * u\_use\_p(use,l,t,z) * (1 + hhgrowth(use,l,t,z))$$

$$U\_\mathrm{Re}v\_u\_v(use, y, t, p, s) = \sum_{l,z} U\_price\_u(l, y, t, p, s) * u\_use\_p(use,l,t,z) * (1 + hhgrowth(use,l,y,t,z))$$

$$U\_price\_u(l, y, t, p, s) = U\_B0\_p(l,t) + U\_B1\_p(l,t) * [\sum_{use,z} u\_use\_p(use,l,t,z) * (1 + hhgrowth(use,l,y,t,z))]$$

slope_p(l,t) change in price

$$slope\_p(l,t) = \sum_{use,z} (mu\_price\_base\_p(use,l,t,z) / [p\_elasticity\_p(use,l,t) * u\_use\_p(use,l,t,z)])$$

pmax_p (l,t) maximum (choke) price

$$p\max - p(l,t) = \sum_{use,z} mu\_price\_base\_p(use,l,t,z) + u\_use\_p(use,l,t,z) * (-slope\_p(l,t))$$

U_B1_p (l,t) slope of price

$$U\_B1\_p(l,t) = [2 / (uuse\_p(l,t)^2] * [\sum_{use,z} MNB\_uuse0\_p(use,l,t,z) * u\_use\_p(use,l,t,z) - TNB\_uuse0\_p(l,t)]$$

U_B0_p (l,t)   intercept of price

$$U\_B0\_p = \sum_{use,z}(MNB\_uuseo\_p(use,l,t,z) + AC\_uuse0\_p(use,l,t,z)) - U\_B1\_p(l,t)*uuse\_p(l,t)$$

Livestock Benefit

$$m\_Ben\_v(use,y,t,p,s) = \sum_{m} m\_prof\_ujt\_v(use,m,y,t,p,s)$$

$$m\_prof\_ujt\_v(use,m,y,t,p,s) = m\_prof\_m\_v(use,j,k,y,t,z,p,s)*\sum_{z} mpop(use,m,y,t,z,p,s)*(1+mgrowth(use,m,y,t,z))$$

$$m\_prof\_m\_v(use,m,y,t,z,p,s) = [m\_price\_v(m,t,p,s)*yield\_p(use,j,k,z) - \cos t\_p(use,m,z)]$$

$$m\_price(m,y,t,p,s) = m\_b0\_p(m) + m\_b1\_p(m)*m\_production\_v(m,y,t,p,s)$$

$$m\_production(m,y,t,p,s) = \sum_{use,z} mpop(use,m,y,t,z,p,s)*(1+mgrowth(use,m,y,t,z))$$

m_b1_p   (m) intercept

$$m\_b1\_p = \text{P}\_m(m)/(\sum_{use,z} Q\_m(use,m,z)*(1/price\_elast\_m(m))$$

m_b0_p   (m) slope)

$$m\_bo\_p(m) = p\_m(m)*delta\_m\_p(m)$$

delta_m_p(m) price change

$$delta\_m\_p(m) = -m\_b1\_p(m)*\sum_{use,z} Q\_m(use,m,z)$$

Hydro-electricity Benefit

$$energy\_ben\_v(res, hydro, y, t, p, s) = energy\_prod\_v(res, hydro, y, t, p, s) * hydro\_price(res, t)$$

Recreation Benefit

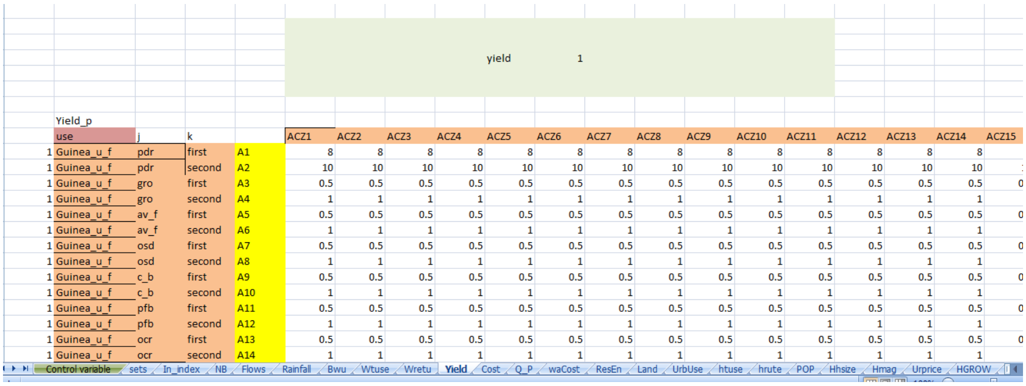
$$Ben\_s\_e(res, y, t, p, s) = MBe\_p(res) * z\_v(res, y, t, p, s)$$

Model Integration

ECOWAT-AQUA-CROP Model Integration

Indeed in ECOWAT model, crop yield and cropping systems water requirement are exogenous variables. These are output from crop model such as AQUA-CROP model. Thus, the obtained yield output and crop water diverted from AQUA-CROP are directly linked to the level 1 data in ECOWAT, and this was conducted for each basin. For example, the results from the Niger Basin are illustrated in Figures 9 and 10 while the overview of the concept is presented in Figure 11 below.

Figure 9. Overview of Aqua-Crop- ECOWAT linkage for crop yield

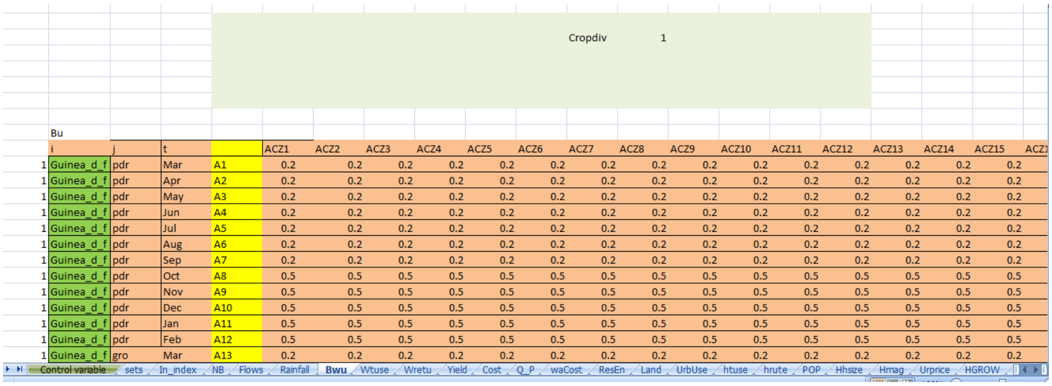

yield 1

Yield_p

	use	j	k		ACZ1	ACZ2	ACZ3	ACZ4	ACZ5	ACZ6	ACZ7	ACZ8	ACZ9	ACZ10	ACZ11	ACZ12	ACZ13	ACZ14	ACZ15
1	Guinea_u_f	pdr	first	A1	8	8	8	8	8	8	8	8	8	8	8	8	8	8	
1	Guinea_u_f	pdr	second	A2	10	10	10	10	10	10	10	10	10	10	10	10	10	10	1
1	Guinea_u_f	gro	first	A3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0
1	Guinea_u_f	gro	second	A4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
1	Guinea_u_f	av_f	first	A5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0
1	Guinea_u_f	av_f	second	A6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
1	Guinea_u_f	osd	first	A7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0
1	Guinea_u_f	osd	second	A8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
1	Guinea_u_f	c_b	first	A9	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0
1	Guinea_u_f	c_b	second	A10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
1	Guinea_u_f	pfb	first	A11	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0
1	Guinea_u_f	pfb	second	A12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
1	Guinea_u_f	ocr	first	A13	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0
1	Guinea_u_f	ocr	second	A14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

Source: ECOWAT Model

Figure 10. Overview of Aqua-Crop- ECOLAND linkage for crop water diverted



Cropdiv 1

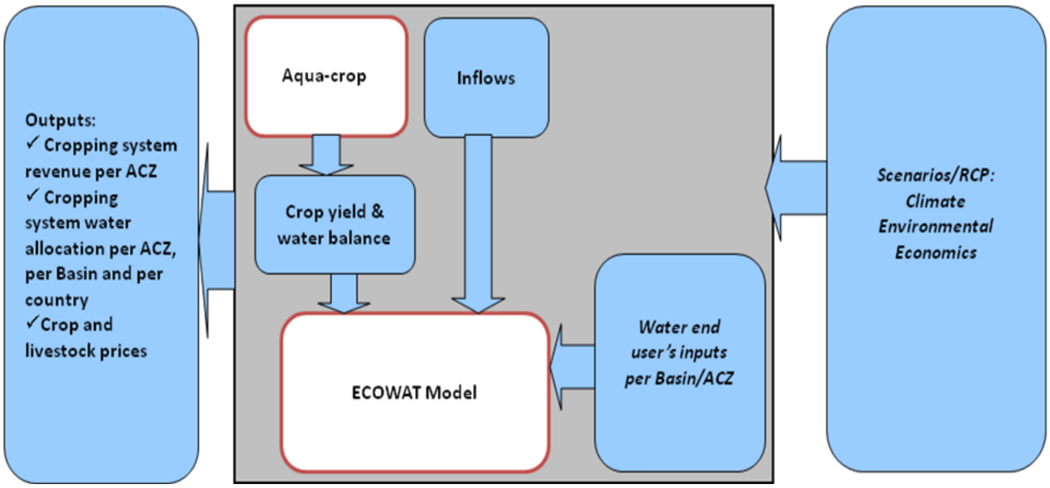
Bu

	i	j	t		ACZ1	ACZ2	ACZ3	ACZ4	ACZ5	ACZ6	ACZ7	ACZ8	ACZ9	ACZ10	ACZ11	ACZ12	ACZ13	ACZ14	ACZ15	ACZ1
1	Guinea_d_f	pdr	Mar	A1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	
1	Guinea_d_f	pdr	Apr	A2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	
1	Guinea_d_f	pdr	May	A3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	
1	Guinea_d_f	pdr	Jun	A4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	
1	Guinea_d_f	pdr	Jul	A5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	
1	Guinea_d_f	pdr	Aug	A6	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	
1	Guinea_d_f	pdr	Sep	A7	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	
1	Guinea_d_f	pdr	Oct	A8	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
1	Guinea_d_f	pdr	Nov	A9	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
1	Guinea_d_f	pdr	Dec	A10	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
1	Guinea_d_f	pdr	Jan	A11	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
1	Guinea_d_f	pdr	Feb	A12	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
1	Guinea_d_f	gro	Mar	A13	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	

Control variable / sets / In_index / NB / Flows / Rainfall / Bwu / Wtuse / Wretu / Yield / Cost / Q_P / waCost / ResEn / Land / UrbUse / htuse / hrute / POP / Hhsize / Hmag / Urprice / HGROW

Source: ECOWAT model

Figure 11. Overview of the ECOWAT model



Source: Made by Authors

ECOLAND-ECOWAT Models Integration

ECOLAND and ***ECOWAT*** integrating modelling is made throught variables commonly present in both models. Both model share some similar socio-economic variables. Indeed, exogenous variables in ECOLAND model have ***cropped revenue, crops prices, and livestock prices*** while in ECOWAT model, they are ***agricultural land availability and livestock population***.

However, ***agricultural land availability*** and ***livestock population*** *are the* output of ECOLAND, while ***revenue, crop prices,*** and ***livestock prices*** are the output of ECOWAT. Thus, the integration consists of linking ECOLAND selected output value as input in ECOWAT at first scenario level and vice versa. This is illustrated in *Figures 12-15 and* the conceptualized framework is presented in *Figure16* below.

Figure 12. Linkage of crop price in ECOLAND from crop prices data

Crop annual Prices														
Type	Description		2004	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055
1	pdr	A	1.1	1.2	1.3	1.5	1.6	1.7	1.8	1.9	2	2	2
1	gro	B	1.9	2	2.1	2.3	2.4	2.5	2.6	2.7	2.8	2.8	2.8
1	av_f	C	3	3.1	3.2	3.5	3.6	3.7	3.8	3.9	4	4	4
1	osd	D	1.2	1.3	2	2.1	2.2	2.3	2.4	2.5	2.6	2.6	2.6
1	c_b	E	0.9	1	1.5	1.6	1.7	1.8	1.9	2	3	3	3
1	pfb	F	6	7	8	8.1	8.2	8.3	8.4	8.5	9	9	9
1	ocr	G	4	4.1	4.3	4.4	4.5	4.6	4.7	4.8	5	5	5

Source: ECOLAND model

Figure 13. Linkage of crop revenue in ECOLAND from crop revenue data

Crop revenue													
Type	Description		2004	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055
1	pdr	A	14962.765	14912	14983	15577	7988	7228	5923	6738	7221	7221	7221
1	gro	B	9225.8903	9225.4	9236.3	9228.6	2265	2067	1499	1903	1901	1901	1901
1	av_f	C	-675	-675	-675	-675	470	621	605	518	519	519	519
1	osd	D	-675	-675	-675	-675	1146	1380	1357	1702	1560	1560	1560
1	c_b	E	-675	-675	-675	-675	320	351	310	322	294	294	294
1	pfb	F	-675	-675	-675	-675	200	189	129	167	150	150	150
1	ocr	G	-675	-675	-675	-675	140	110	160	183	188	188	188

Source: ECOLAND model

Figure 14. Linkage of livestock price in ECOLAND from livestock price data

Livestock prices													
Type	lprice		2004	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055
1	Cattle	A	200	230	260	290	300	301	310	312	313	313	313
1	Sheep	B	250	251	252	253	253	254	255	256	257	257	257
1	Chicken	C	25	26	27	28	29	30	31	32	33	33	33
1	Other	D	15	16	17	18	19	20	21	22	23	23	23

Source: ECOLAND model

Figure 15. Linkage of Livestock Population in ECOWAT from Livestock

landhs																			
use	y	ACZ1	ACZ2	ACZ3	ACZ4	ACZ5	ACZ6	ACZ7	ACZ8	ACZ9	ACZ10	ACZ11	ACZ12	ACZ13	ACZ14	ACZ15	ACZ16	ACZ17	ACZ18
Guinea_u_f	1	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	366
Guinea_u_f	2	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	366
Guinea_u_f	3	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	366
Guinea_u_f	4	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	366
Guinea_u_f	5	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	366
Guinea_u_f	6	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	366
Guinea_u_f	7	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	366
Guinea_u_f	8	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	366
Guinea_u_f	9	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	366
Guinea_u_f	10	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	366
Guinea_u_f	11	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	366
Guinea_u_f	12	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	366
Guinea_u_f	13	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	366
Guinea_u_f	14	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	366
Guinea_u_f	15	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	366
Guinea_u_f	16	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	366
Guinea_u_f	17	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	366
Guinea_u_f	18	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	366
Guinea_u_f	19	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	3666	366

Bwu / Wtuse / Wretu / Yield / Cost / Q_P / waCost / ResEn / **Land** / UrbUse / htuse / hrute / POP / Hhsize / Hmag / Urprice / HGROW / LIVD / mtuse / mreturn / mpop / Qm / MGROW

Source: ECOWAT Model

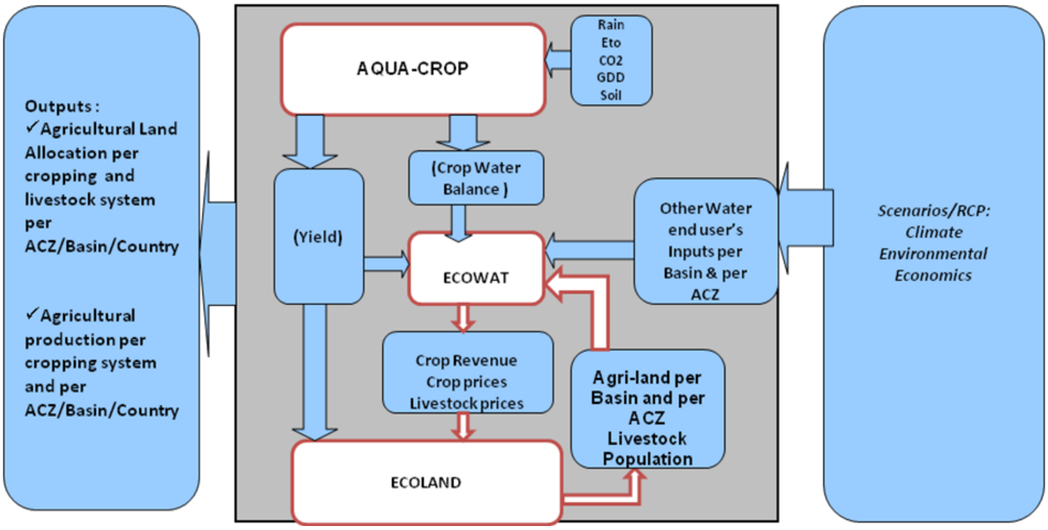
Figure 15: Linkage of Livestock Population in ECOWAT from Livestock Population Growth Data (cont'd)

	use	m	y	t	ACZ1	ACZ2	ACZ3	ACZ4	ACZ5	ACZ6	ACZ7	ACZ8	ACZ9	ACZ10	ACZ11	ACZ12	ACZ13	ACZ14	ACZ15	ACZ16
A1	Guinea_u	Cattle	1	Jan	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.0
A2	Guinea_u	Cattle	1	Feb	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.0
A3	Guinea_u	Cattle	1	Mar	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.0
A4	Guinea_u	Cattle	1	Apr	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.0
A5	Guinea_u	Cattle	1	May	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.0
A6	Guinea_u	Cattle	1	Jun	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.0
A7	Guinea_u	Cattle	1	Jul	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.0
A8	Guinea_u	Cattle	1	Aug	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.0
A9	Guinea_u	Cattle	1	Sep	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.0
A10	Guinea_u	Cattle	1	Oct	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.0
A11	Guinea_u	Cattle	1	Nov	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.0
A12	Guinea_u	Cattle	1	Dec	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.0
A13	Guinea_u	Cattle	2	Jan	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.0
A14	Guinea_u	Cattle	2	Feb	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.0
A15	Guinea_u	Cattle	2	Mar	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.0
A16	Guinea_u	Cattle	2	Apr	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.0
A17	Guinea_u	Cattle	2	May	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.0
A18	Guinea_u	Cattle	2	Jun	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.0
A19	Guinea_u	Cattle	2	Jul	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.0
A20	Guinea_u	Cattle	2	Aug	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.0
A21	Guinea_u	Cattle	2	Sep	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.0

Bwu / Wtuse / Wretu / Yield / Cost / Q_P / waCost / ResEn / Land / UrbUse / htuse / hrute / POP / Hhsize / Hmag / Urprice / HGROW / LIVD / mtuse / mreturn / mpop / Qm / **MGROW**

Source: ECOWAT Model

Figure 16. Conceptualization of AQUACROP-ECOLAND-ECOWAT model Integration



Source: Made by Authors)

Gams Programming

The Model GAMS code is available at UNU-INRA. This can be obtained with formal inquiry sent to UNU-INRA.

ECOTRADE -Trade Model

Introduction

The ECOWAS region trade model so-called ECOTRAD was developed using the MIRAGE model (Yvan and Hugo, 2007). It is a sequence dynamic recursive CGE model. The model accommodates the GTAP8 Africa database to the MIRAGE model given the difference of nomenclature. In ECOTRAD, using gtapagg the world is disaggregated into 19 regions. These includes nine ECOWAS countries namely Benin, Burkina-Faso, Ivory-coast, Ghana, Guinea, Nigeria, Senegal, Togo and rest of ECOWAS countries; one region for the Rest of Sub-Sahara Africa; one region for Middle East and Northern Africa(MENA);; one region each for respectively Oceania, East -Asia , South-East Asia, South Asia, North America , Latin America , Europe ,and the Rest of the World.

In addition, the sectors were disaggregated into 31 economics sectors of which 12 agricultural sectors, 12 industrial sectors and seven (7) services sectors. For the purpose of food security analysis, food crops includes agricultural crops and process food. .

The model has been adjusted to include the ECOWAS Common External Tariff policy (CET) for the Business as Usual (BAU) scenarios. It aims to assess the impact of occurring changes in respectively cropping land allocation, cropping water allocation and in domestic supply of agricultural commodities on agricultural trade flow and national food security. It is an economy-wide impact assessment and provides useful output for decision-making on how to improve trade and food security in ECOWAS countries.

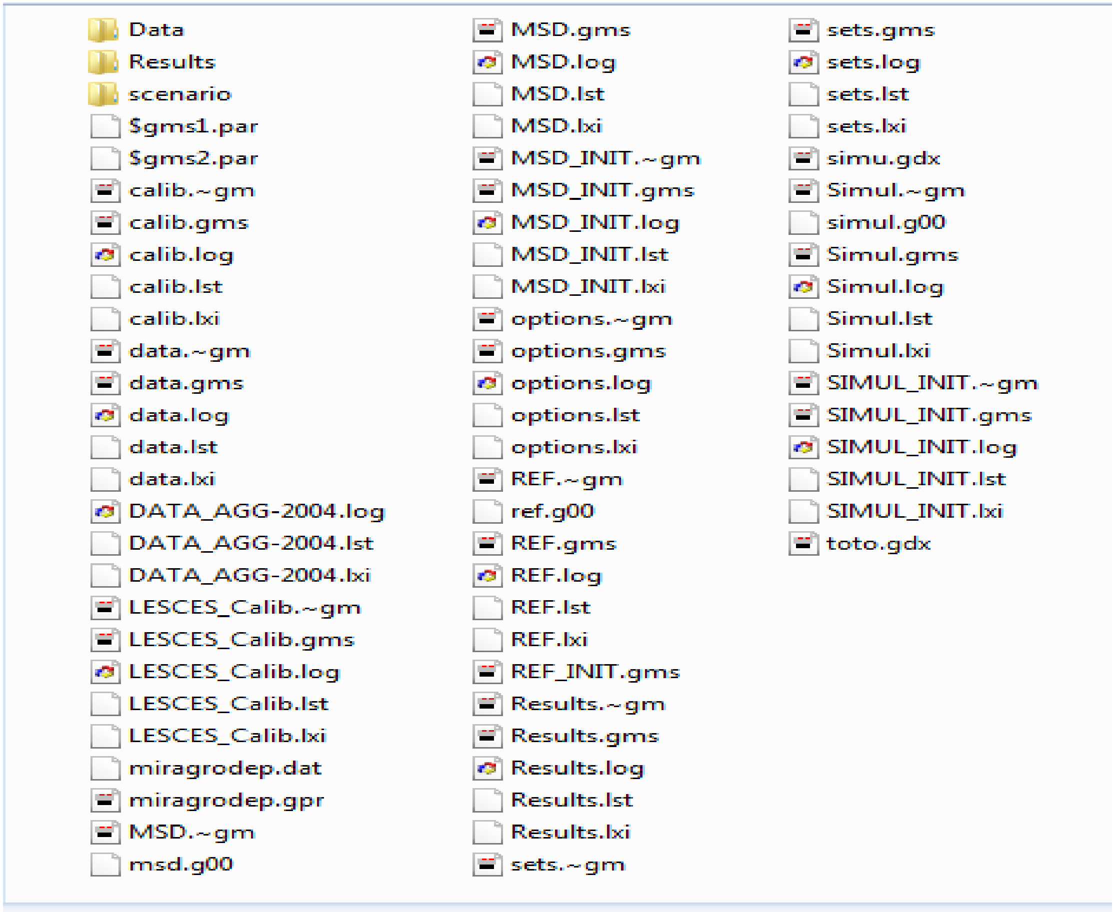
Model Overview

Description

The model is made of 3 main folders respectively ***Data; Scenarios and Results*** and 11 main Gams files respectively ***SET.gms; Data.gms; Calib.gms; MDS_INIT.gms; MDS.gm; Option.gms; REF_Init.gms; REF.gms; Simul_INIT.gms; Simul.gms and Results.gms.*** This is illustrated in Figure 17 below where:

Data: Contain the model input data***;***
Scenarios: contain the model scenarios data;
Results: contain the model output after simulation;
SET.gms: define the model notation information
Data.gms: run for adjustments, aggregation of model input data
Calib.gms: run for model data calibration
MDS_INIT.gms: initialization of model variable and parameters
MDS.gm: BAU computation
Option.gms: Model option definition such as time horizon
REF_Init.gms: Reference scenario definition
REF.gms: reference scenario computation
Simul_INIT.gms: simulation of BAU
Simul.gms: Model simulation
Results.gms:

Figure 17. ECOTRADE Input files



Source: ECOTRAD MODEL

Model Data

The model data basically includes base year data ***DATA1_AGG-2004.gdx*** computed using basedata2004.gdx data. However, basedata2004.gdx is built using GAgg8 platform. In doing so, the step of computing basedata2004.gdx using GAgg8 is as follows:

First, install ***GAgg81Afry04*** on your C: / drive.

Open ***GTAPAgg,*** after go to **View**/**Change** regional aggregation. From this section, there are 42 regions which are aggregated into 19 regions. These include Rep. of Benin, Burkina-Faso, Ivory-coast, Ghana, Guinea, Nigeria, Senegal, Togo and the rest of ECOWAS countries for ECOWAS region. One region for the Rest of Sub-Sahara Africa (Botswana, Cameroun, Ethiopia, Kenya, Madagascar, Mozambique, Mauritius, Malawi, Namibia, Rwanda ,Tanzania, Uganda, South Africa, Zambia, Zimbabwe, Rest of Eastern Africa, Rest of Central Africa, Rest of Southern Africa) ; MENA(Middle Est-North Africa); Oceania; East -Asia ; South-East Asia; South Asia; North America ; Latin America ; Europe -27 (27 countries in Europe) and the Rest of the Word (the Rest of World and the Rest of Europe).

Once this is done, the new aggregation is saved using save ***aggregation scheme to file.***

The similarity method is used for sectoral aggregation using ***View/Changes sectoral aggregation. Existing 57 old sectoral aggregations are aggregated into*** sectoral 31 sectors. This include 12 agricultural sectors namely paddy rice; wheat; cereal; vegetable –fruits-nuts; oil seeds; sugarcane-sugarbeet ; fibers and other indigenous crops ; livestock; animal product nec ; forestry and fishery, 12 industrial sector’s mainly meat; other meat products; raw milk; Processed food; Vegetable oil; Dairy products ; Processed rice; Sugar; other food products ; beverage and tabocco; extracted oil and other industries; seven

(7) service sectors mainly water; electricity; public administration/defense/education/health/defense and other services.

The aggregated input is then created by running ***Create aggregated database** (Figure 18)**.* In the generated files two important files are extracted and these are: BaseData.har and Default.prm respectively which are the base year data and the parameters database. Indeed, GAMS cannot read HAR files directly. However, it is easy to convert them to GDX files. Create a new project in your GTAP8 working directory, where the HAR files are stored. Then create a new GAMS file, which may be named HAR2GDX.gms and which contains only two lines:

$CALL har2gdx basedata2004.har basedata2004.gdx

$CALL har2gdx parameters2004.har parameters2004.gdx

Other input data ***are ELAST_PAR.gdx***, ***VAL_PAR.gdx***, prices elasticity and income elasticity; and ***DATA.gdx*** which contains exogenous parameters such as populations and GDP growth.

Thus, using ***DATA_AGG-2004.gms,*** the model base year on 2004 input data is generated and this is called ***DATA1_AGG-2004.gdx.***This includes sets and parameters listed below. Sets are***:***

Agr: *all agricultural commodities definition;*
AgrTot: *All agricultural sectors include food sector;*
ENDW_COMM: all endowment commodities mainly land, capital, natural resources, and skill and unskilled labour;
GTAP_I: *GTAP sectors;*
GTAP_R: *GTAP regions;*
Icp*: perfect competition commodities;*
L_1*: Skill labour;*
MAP_I*: sectoral mapping between GTAP and ECOTRAD sector;*
MAP_R*: Region mapping between GTAP and ECOTRAD region;*
Nord: *Developed regions;*
Prod_comm: *produced commodities;*
Reg: *GTAP regions;*
Scareland: *Scarcity land regions;*
Simple: *import demand tree;*
TRAD_COMM: *trade commodities;*
Transporation: *transport sectors;and*
Unchanged: *GTAP tariffs,*

Figure 18. ECOTRAD Model Data Aggregation

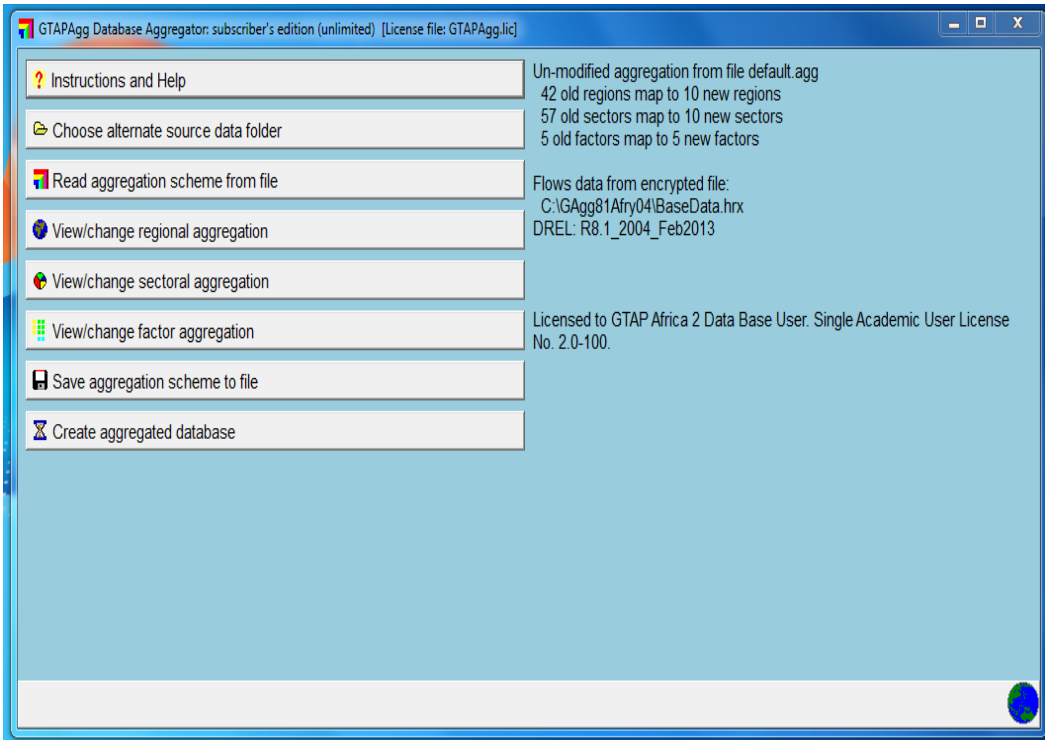


Figure 18: ***ECOTRAD Model Data Aggregation (cont'd)***

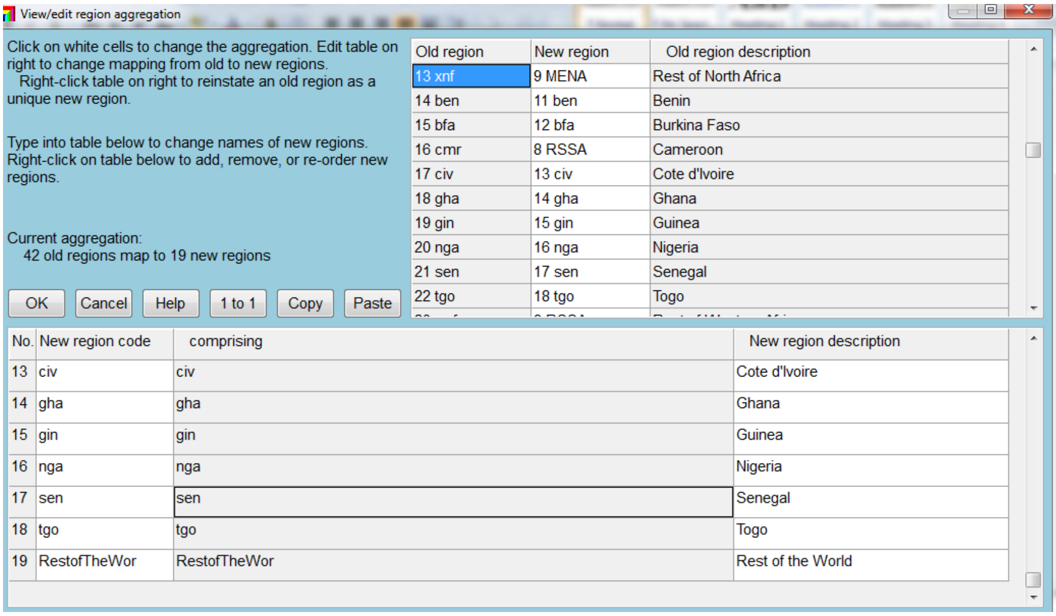
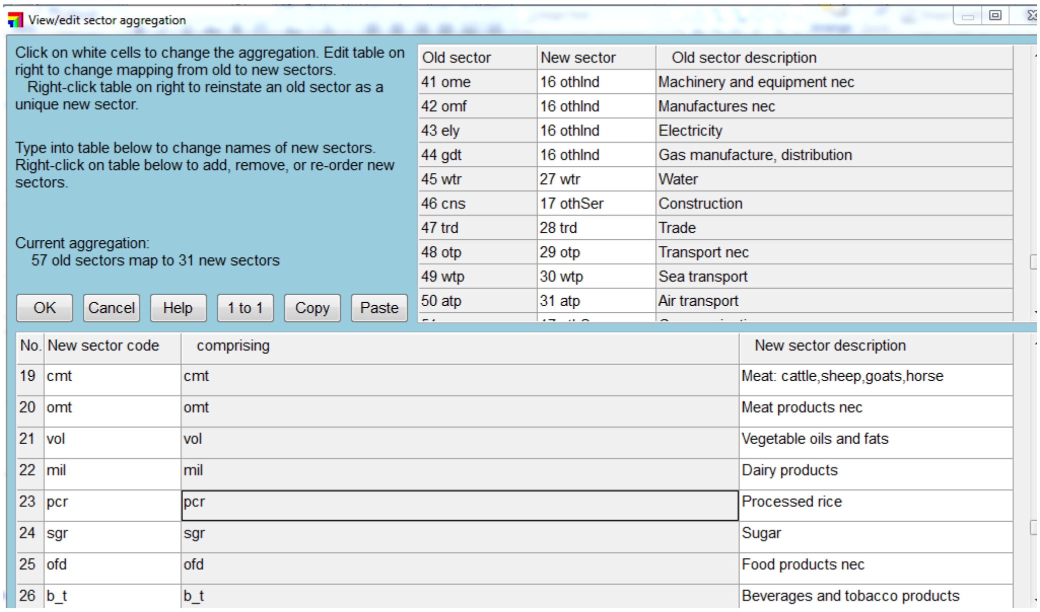


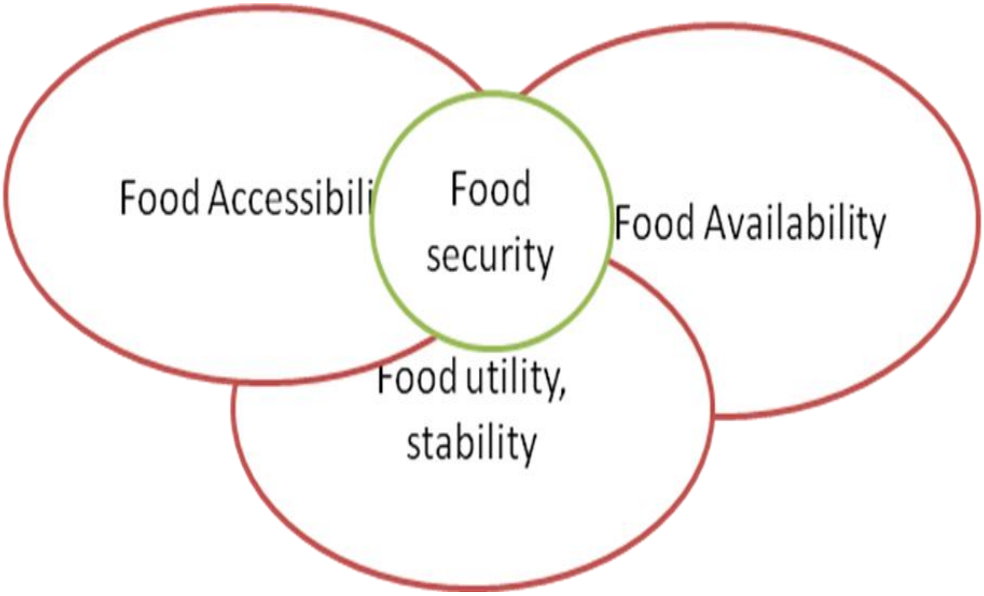
Figure 18: ***ECOTRAD Model Data Aggregation (cont'd)***



Model Output

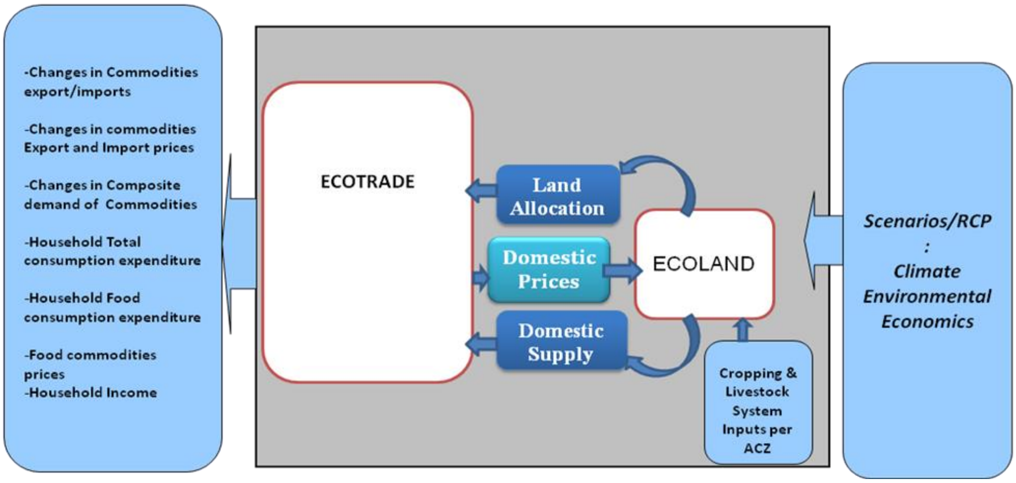
These are variables for accessing the impact of climate change on trade flows and food security. However, following the world food summit of 1996, food security was addressed only if the food is available, accessible and of adequate quality to meet people's dietary demands. This is illustrated in Figure 19. In addition, food security can be assessed at national and household levels. Given the complexity, food security assessment is a multiple disciplinary task. Here, the impact assessment looks at food security at the national level. The availability is most likely to depend on the supply side. This is subject to both domestic and imported food products. As determinant variables, total food production, ***VALDEMTOT=*** Total food demand and household final consumption of various food products are used as a proxy to quantify food availability. While, accessibility is on the demand side of the management. Food prices and household wages will be the determinants for improving food access. These are quantified by two variables which are ***PCCN (Price of final consumption)*** and ***WLtreel (Household Real wage).*** Regarding the nutritional matter, food quality is essential. Meanwhile, addressing people's dietary demand requests adequate and healthy food products. However, considering ECOTRAND as a single model, there is no possibility of setting household food utility and stability constraints. This constitutes one of the limitations in assessing food security at country/household level using trade model. Trade model alone is not sufficient for the impact assessment. Nonetheless, the land allocation model ECOLAND does include food consumption bundle information. Indeed, food consumption bundle provides useful information on quantity and quality of food consumed in meeting the dietary demand. Thus, to capture this dimension of food security it is then important to link the ECOTRAD and ECOLAND models. The ECOLAND & ECOTRAD linkage is illustrated in Figure 20.

Figure 19. Conceptualization of Food Security.



Source: Made by Authors

Figure 20. Overview of ECOTRADE model



Source: Made by Authors

Model Calibration

The Calibration of ECOTRAD consists of using the Model inputs data to compute and reproduce the value of intermediate consumption quantities and prices; the quantities and prices values of factors of production (capital, labour and natural resources); quantities and prices of value added and final demand of commodities for the base year of 2004.

Model Structure

Notation and Definition

Region:

This includes Benin.(ben), Burkina.(bfa), Ivory.(civ), Ghana.(gha), Guinea.(gin), Nigeria (nga),Senegal.(sen),Togo.(tgo),RWA.(xwf),EASIA.(EAsia),SEASIA.(SEAsia) ,SASIA.(SoutAsia), NAmerica. (North America), LAmerica. (Latin America), EUROPE. (EU27), MENA. (MiddleEast,egy,mar,tun,xnf), RSSA.(bwa,cmr, eth,ken, mdg, moz, mus, mwi, nam,rwa,tza, uga, zaf, zmb, zwe,xec,xsc,xcf,xac), OCEANIA. (Oceania), RoW. (Rest of TheWor ,RestEurope).

Time: from year 2004 to 2100

J is used for definition of sectors. These are mainly agricultural, industries, services and administrative sectors listed by pdr(paddy rice), wht(wheat), gro(cereal),v_f(vegetable), osd(oil seed), c_b(sugarcane/sugarbeet), pfb(plant & fiber); ocr(crop nec); ctl(cattle,sheep,goat); oap(animal products), rmk(raw milk), wol, frs(fruits), fsh(fish), cmt(meat products), omt(meat products nec); vol(vegetable); mil(dairy products), pcr(processed rice); sgr(sugar); ofd(food products nec);b_t(beverage & tabacco);ely(electricity); wtr(water); oil(oil); osg(public administration/defense/education/health) ; othInd(coal,gas,textile, wearing apparel, leather, woods, paper& publishing, petroleum,chemical, rubber, plastic, mineral, ferrous, metal, motor& vehicule, transport,mineral); othSer(eletronic, machinery and equipment, manifacture, gas manifacture,construction, trade, transport nec, sea transport, air transport, communication, financial services, insurance ,business services nec, recreations & other services, dwellings)

agr(J) : all agricultural commodities respectively pdr,wht,gro,v_f, osd c_b, pfb, ocr,ctl,oap, rmk, wol,frs,fsh.
BUS(J): private industries are pdr,wht, gro, v_f, osd, c_b, pfb, ocr, ctl, oap,rmk, wol,frs, fsh, cmt,omt,vol, mil,pcr,sgr, ofd, b_t ,ely,wtr, oil, othInd.(coa,gas,tex, wap, lea, lum, ppp, p_c,crp, nmm, i_s, nfm, fmp, mvh, otn,omn), othSer.(ele, ome, omf, gdt,cns, trd, otp, wtp, atp, cmn, ofi, isr ,obs, ros, dwe)
PUB(J): public industries are government administrations and services sectors defined by osg
F Production factors: these are Skilled labour (slab) , Unskilled Labour(ulab) , Capital (cap), Land (land) and Natural resources (natr).
L(F) : Labour categories include slab and ulab.
K(F) : Capital categories cap, land and natr .

Model Parameters

The model parameters are detailed in Table 9 and the ECOTRAD variables in Table 10.

Table 10 *: ECOTRAD Model Parameters*

parameters	*Definitions*
a(i,r,s)	Investment scale coefficient
a_C(i,r)	Household consumption coefficient
a_CNTER(i,r)	Total intermediate consumption scale coefficient
a_D(i,r)	Local demand scale coefficient (CES - Demand same quality zone)
a_H(i,r)	Skilled labour coefficient (CES - Capital skilled labour)
a_IC(i,j,r)	Intermediate consumption scale coefficient (CES - Intermediate consumption)
a_IMP(i,r,s)	Import scale coefficient (CES - Total imports)
a_invf(i,r,s)	Share parameters for reinvestment

	strategy
a_K(i,r)	Capital coefficient (CES - Capital skilled labour)
a_KG(i,r)	Capital good scale coefficient (CES - Total investment)
a_L(i,r)	Unskilled labour coefficient (CES or CD - Value added)
a_M(i,r)	Total import demand scale coefficient (CES - Demand same quality zone)
a_Q(i,r)	Capital-skilled labour aggregate coefficient (CES or CD- Value added)
a_RN(i,r)	Natural resources coefficient (CES or CD- Value added)
a_TE(i,r)	Land coefficient (CES or CD - Value added)
a_Tr(Transport,i,r,s)	Share of each mode in every trade flow
a_TrSupply(Transport,r)	Share of each region in the world transport production
a_U(i,r)	Same quality demand scale coefficient (CES - Total demand)
a_V(i,r)	Different quality demand scale coefficient (CES - Total demand)

Table 9: ***ECOTRAD Model Parameters (cont'd)***

parameters	***Definition***
a_VA(i,r)	Value added scale coefficient
alpha	Elasticity of investment to return on capital
b_Lt(Ltype,r,Simul)	Labour scale coefficient (CET - Total unskilled labour supply)
b_TE(i,r)	Land scale coefficient (CET - Total land supply)
c_T(Transport)	Scale coefficient (Cobb-Douglas - merchandise transportation)
cmin(i,r)	Minimal consumption (LES-CES)
ech(i,r)	Scale parameter (Cobb-Douglas - Value added)
epa(r)	Saving rate
K_(i,r,s)	Capital of year t-1
pondC(i,s)	Share of commodity i in total consumption
Delta(r)	Capital depreciation
Pop_ag(PopType,r,temps	Population aggregated at the regional level used in the model
sigma_ARM(i)	Armington elasticity (CES Domestic Import)
sigma_C(r)	Household consumption elasticity of substitution
sigma_CAP(j)	Capital-skilled labour elasticity (CES - Capital skilled labour)
sigma_IC	Intermediate consumption elasticity (CES - Intermediate consumption)
sigma_IMP(i)	Import elasticity (CES - Total imports)
sigma_INVF	Elasticity reinvestment
sigma_KG	Capital good elasticity (CES - Total investment)
sigma_L	Labour elasticity (CET - Total unskilled labour supply)
sigma_TE	Land elasticity (CET - Total land supply)

sigma_Tebar(r)	Total land supply elasticity
sigma_VA(j)	Value added elasticity (CES second level)
sigma_VAR(i)	Variety elasticity (CES - Bilateral trade or Domestic demand**)**

Table 9: ***ECOTRAD Model Parameters (cont'd)***

AdvDDO (i,r,s)	Ad valorem component of duty tax rate (benchmark)
AdvDD(i,r,s,temps,simul)	Ad valorem component of duty tax rate
subfO(f,i,r)	Rate of factor-based subsidies (ad volume benchmark)
subf(f,i,r,Temps,Simul)	Rate of factor-based subsidies (ad volume)
taxAMFO(i,r,s)	Export tax equivalent to MFA quotas (benchmark)
taxAMF(i,r,s,Temps,Simul)	Export tax equivalent to MFA quotas
taxccO(i,s)	Final consumption tax rate (benchmark)
taxcc(i,s,Temps,Simul)	Final consumption tax rate
taxEXPO(i,r,s)	Export tax rate from r to s (benchmark)
taxEXP(i,r,s,Temps,simul)	Export tax rate from r to s
taxiccO(i,j,s)	Intermediary consumption tax rate (benchmark)
taxicc(i,j,s,Temps,Simul)	Intermediary consumption tax rate
taxkgcO(i,s)	Capital good tax rate (benchmark)
taxkgc(i,s,Temps,Simul)	Capital good tax rate
taxPO(i,r)	Production tax rate (benchmark)
taxP(i,r,Temps,Simul)	Production tax rate
TPI(i,r,s,temps,simul)	One plus tariffs

t1	Initial year
ITOTO(i,s)	Investment in commodity i
PRODTOTO(i,r)	Value of production at market price
VTAXEXPO(i,r,s)	Tax on export in value
VDDO(i,r,s)	Duty tax in value
PFOBO(i,r,s)	FOB prices
ICOMP(i,j,s)	Intermediary consumptions at market price
COMP(i,s)	Final consumption at market price
KGOMP(i,s)	Capital good consumption at market price
EVFK(i,r)	Capital return
VTAXAMFO(i,r,s)	MFA quota equivalent tax

Model Variables

Table 11 ***: ECOTRAD Model Variables***

Variables	*Definition*
Intermediate inputs	
Y(j,r,Temps,simul)	Production per firm
PY(j,r,Temps,simul)	Marginal cost
VA(j,r,Temps,simul)	Value added
PVA(j,r,Temps,simul)	Price of value added
CNTER(j,r,Temps,simul)	Intermediate consumption by sector j
PCNTER(j,r,Temps,simul)	Price of intermediate consumption by sector j
PGF(r,Temps,simul)	Total factor productivity
Value Added	
Q(j,r,Temps,simul)	K-H bundle
PQ(j,r,Temps,simul)	Price of K-H bundle
L(j,r,Temps,simul)	Unskilled labour
PL(j,r,Temps,simul)	Price of unskilled labour
WLt(Ltype,r,Temps,simul)	Rate of return to unskilled labour
Lt(Ltype,r,Temps,simul)	Unskilled labour

PLind(r,Temps,simul)	Real price for urban unskilled labour (Lewis' hypothesis)
TE(j,r,Temps,simul)	Land use
PTE(j,r,Temps,simul)	Price of land
WTE(j,r,Temps,simul)	Rate of return to land
RN(j,r,Temps,simul)	Natural resources
PRN(j,r,Temps,simul)	Price of natural resources
Aggregate capital & labor	
H(j,r,Temps,simul)	Skilled labour
PH(j,r,Temps,simul)	Price of skilled labour
WH(r,Temps,simul)	Rate of return to skilled labour
K(j,r,s,Temps,simul)	Capital stock invested by r in s
KTOT(j,r,Temps,simul)	Capital stock
PK(i,s,Temps,simul)	Price of capital
WK(i,s,Temps,simul)	Rate of return to capital
Mobile factors	
Lbar(r,Temps,simul)	Total unskilled labour supply
TEbar(r,Temps,simul)	Total land supply
Hbar(r,Temps,simul)	Total skilled labour supply
WLbar(r,Temps,simul)	Shadow price of unskilled labour
WTEbar(r,Temps,simul)	Shadow price of land

Table 12 ***: ECOTRAD Model Variables (cont'd)***

Variables	*Definitions*
Kbar(r,Temps,simul)	Total capital stock
WKbar(r,Temps,simul)	Shadow price of capital
Final demand	
BUDC(r,Temps,simul)	Budget devoted to final consumption
AUX(r,Temps,simul)	Utility function
P(r,Temps,simul)	Shadow price of utility
C(i,r,Temps,simul)	Final consumption
PC(i,r,Temps,simul)	Price of final consumption
Intermediate Consumption	
IC(i,j,r,Temps,simul)	Intermediate consumption of good i by sector j
PIC(i,j,r,Temps,simul)	Price of intermediate consumption good i for sector j
Capital Good	
INV(j,r,s,Temps,simul)	Investment by r in s
B(r,Temps,simul)	Scale coefficient for investment by region r
INVTOT(s,Temps,simul)	Total investment in region s
PINVTOT(s,Temps,simul)	Price of investment in region s
KG(i,s,Temps,simul)	Capital good consumption of good i in regions
PKG(i,s,Temps,simul)	Price of capital good consumption of good i in region s
Geographic Origin	
DEMTOT(i,s,Temps,simul)	Total demand for good i
PDEMTOT(i,s,Temps,simul)	Shadow price of total demand for good i
D(i,s,Temps,simul)	Demand for domestic good i
PD(i,s,Temps,simul)	Shadow price of demand for domestic good i
M(i,s,Temps,simul)	Imports by s from its quality zone
PM(i,s,Temps,simul)	Shadow price of imports by s from

	its quality one
DEM(i,r,s,Temps,simul)	Bilateral trade from r to s (volume)
PDEM(i,r,s,Temps,simul)	Shadow price of bilateral trade from r to s
DEMA(i,r,s,Temps,simul)	Bilateral trade from r to s (volume) Ag
PDEMA(i,r,s,Temps,simul)	Shadow price of bilateral trade from r to s

Table 13 *: ECOTRAD Model Variables (cont'd)*

Variables	*Definitions*
Income	
RECPROD(i,r,Temps,simul)	Production tax receipts
RECDD(i,r,Temps,simul)	Tariff revenues
RECCONS(i,r,Temps,simul)	Consumption tax receipts
RECEXP(i,r,Temps,simul)	Export tax receipts
RECTAX(r,Temps,simul)	Fiscal tax receipts
REV(r,Temps,simul)	Disposable income for final demand and investment
SOLD(r,Temps,simul)	Current account surplus without FDIs for region r
PIBMVAL(Temps,simul)	World gross domestic product (value)
GDPVOL(r,Temps,simul)	Gross domestic product (volume)
Merchandise transportation	
TRADE(i,r,s,Temps,simul)	Trade
Tr(i,r,s,Temps,simul)	Transport demand by export
PTr(i,r,s,Temps,simul)	Price of transport by export
TrMode(j,i,r,s,Temps,simul)	Transport demand by export per mode
TrSupply(j,r,Temps,simul)	Supply of international transportation by region r
WorldTr(j,Temps,simul)	World supply of international transportation
PTrMode(j,Temps,simul)	Price of transport per mode
PCIF(i,r,s,Temps,simul)	CIF price
Taxes & duties	
DD(i,r,s,Temps,simul)	Import duties
PIndC(r,Temps,simul)	Price Index

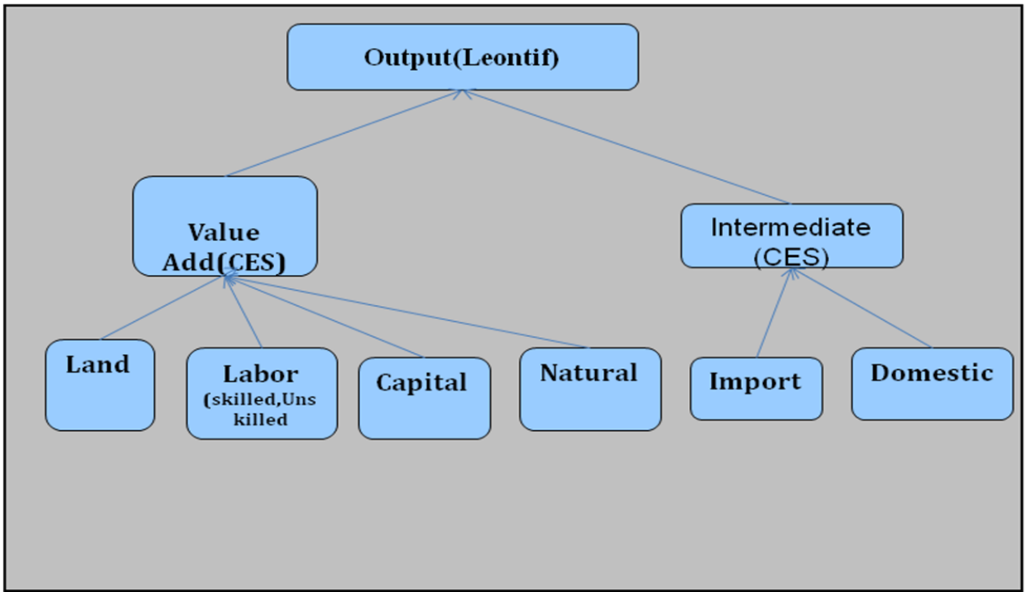
Model equations

The equations of the model are summarized in the appendix. In what follows, we present the structure of production, the commodity flows, and the model shocks.

Structure of Production

The production technology is a Leontif production function characterized by five (5) production factors (Capital, Unskilled, Skilled, Land and Natural Resources). This is expressed by the Figure below. We have three Agents (government, household, firm). The firm produced the mean of production using composite intermediate input substitute to value added based on endowment commodities. This is illustrated in Figure 21.

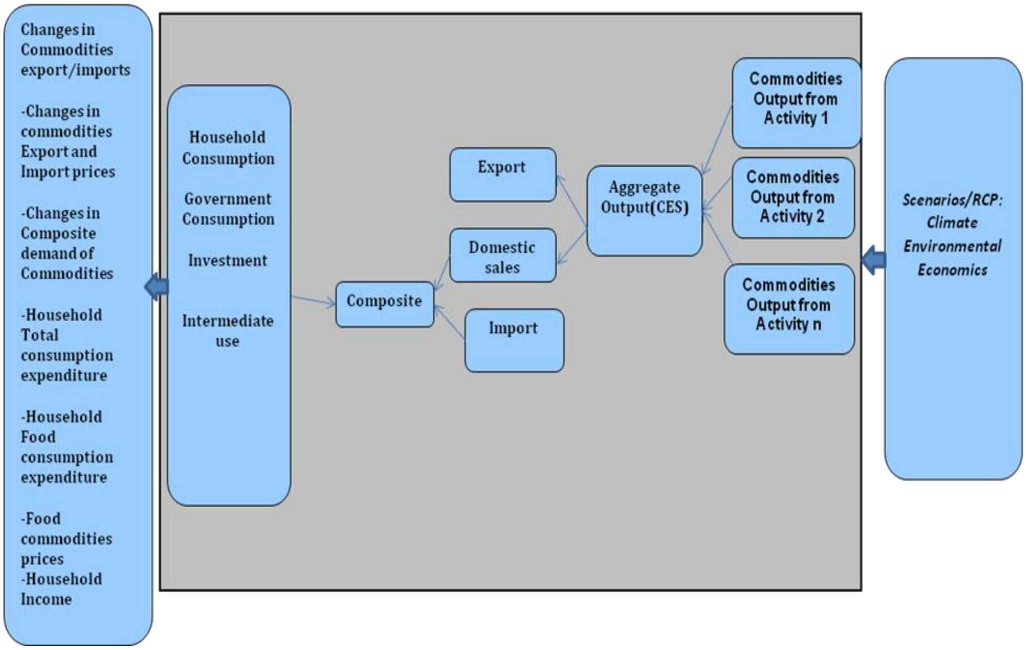
Figure 21. Structure of Production



Commodity Flows

Each sector of the economy in each region produces an aggregated output. A part of this output is supplied to the domestic market and the remains are exported. The domestic supply is then substituted to imported commodities to form composite aggregated goods. The composite commodities are used for various purposes such as intermediate inputs for firm production, household consumption, and government consumption. The Government collects various taxes, consumes and invests in the economy. We are in an open and competitive economy where household income is from labour and Capital. Capital accumulation is subject to land, capital, and natural resources. This is illustrated in Figure 22 below.

Figure 22. Commodity Trade Flows



Source: Made by Authors)

Model Shocks

For the impact assessment and following the structure of supply and demand, three main shocks are implemented in the model.

❖ ***Reference Scenarios***

This refers to the Business as Usual (BUA) scenario. It defines the normal trend with the implementation of ECOWAS common tax policy (CET). This is explicitly expressed by:

$$taxEXPend(i,r,s,temps,sim) = (1 - ctax(i,r,s,temps-1)) * RECEXP.l(i,r,temps-1,sim)$$

Where $ctax(i,r,s,temps-1)$ are changes in the value of applied tax?

❖ ***Changes in agricultural land allocation***

Indeed, climate change will affect agricultural arable land and perhaps reduce the land area used for this purpose. The reduction of agricultural land will obviously induce changes in land allocation per cultivated crops. Following the model production structure, the land is considered as a production factor. In the model, all factors of production are substituted using a Constant Elasticity of Substitution (CES) relation. Changes in agricultural land allocation will induce changes in ***aggregated output*** which is the mean change in agricultural domestic output production. Thus, following commodity flows, changes in domestic supply in return will affect the quantity and ***prices of commodities imported, exported and consumed***. The impact of occur changes in agricultural crops land allocation is implemented in the model through the following equation:

$$TE.l(j,r,temps,sim) = (1 - chland(j,r,temps-1)) * TE.l(j,r,temps-1,sim)$$

Where

$chland(j,r,temps-1)$ is the percentage changes in agricultural land allocation per agricultural commodity, and

$TE.l(j, r, temps, sim)$ is the size of allocated land per cropping system.

- ***Changes in agricultural water allocation.***

Indeed, following the model production structure, water is considered as an intermediate input. Intermediate inputs play a key role in aggregated output production. Climate change will affect water availability and perhaps water allocation among end users. This is assessed through the water allocation model namely ECOWAT. The impact of changes in agricultural water allocation is expressed by the following equation

$$IC.l(j, j, r, temps, sim) = (1 - cwater(i, j, r, temps)) * IC.l(i, j, r, temps, sim)$$

Where:

$cwater(i, j, r, temps)$ is changes in water usage per agricultural commodity and per region and $IC.l(i, j, r, temps, sim)$ is water usage. Water is an intermediate input in the model

- ***Changes in the domestic supply of agricultural commodities.***

Changes in domestic production are combined effects of changes in cropping system yield and land allocation obtained from land allocation model. In the model, the induced changes in domestic output are implemented by the following equation:

$$Y.l(j, r, temps, sim) = (1 - cpro(j, r, temps - 1)) * Y.l(j, r, temps - 1, sim);$$

Where

$cpro(j, r, temps - 1)$ is changes in domestic agricultural commodities' production and $Y.l(j, r, temps, sim)$ is the level of domestic agricultural firm production.

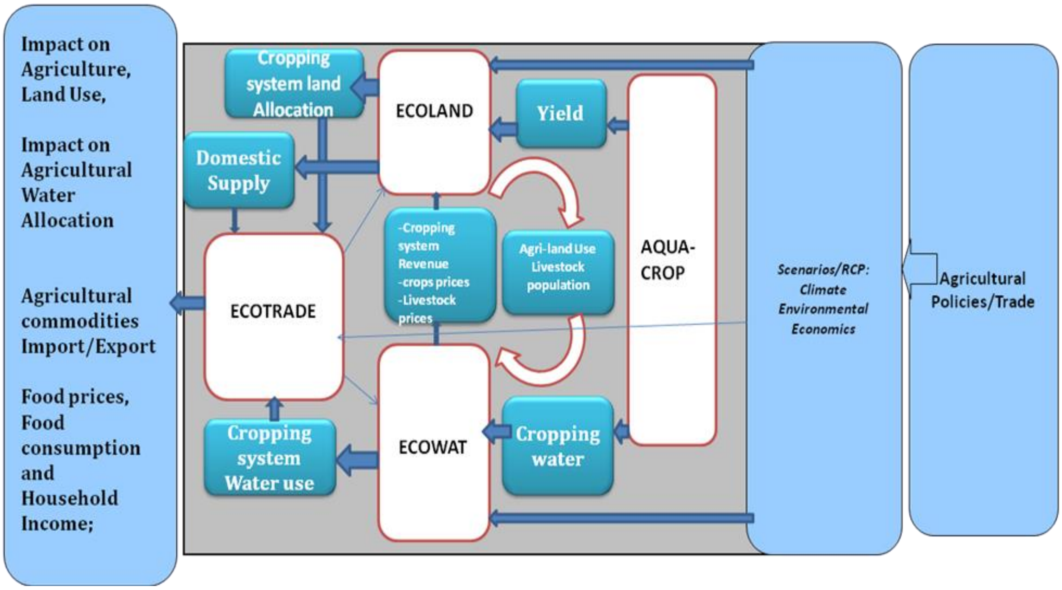
AQUACROP-ECOLAND-ECOWAT-ECOTRAD Models Integration

For the comprehensive impact assessment of climate change impact on food security and trade flows, this section presents the overview of integrating the crop model (AQUA-CROP) with the land Allocation model (ECOLAND), the water allocation model (ECOWAT) and the trade model (ECOTRAD). This is done through soft-link. Thus, AQUA-CROP estimates crop yield data under various climate 3 majors' trajectories. The first two trajectories are made of 2 Representative Concentration Pathways (RCP) define by IPCC namely RCP4.5 and RCP8.5 while the third trajectory define climate change adaptation strategy policy scenario. Thus, for each scenario, the obtained yield is in turn used in ECOLAND as previously described. It should be recalled

that ECOLAND model estimates the cost-effectiveness of land size that should be allocated to each cropping system and as well as the domestic crop supply under a different scenario. In the model, *crop prices, crop revenue and livestock prices* are taken as exogenous variables or parameters. These variables are outputs from the hydro-economic model (ECOWAT). In ECOWAT, *crop water requirement, land allocation, and livestock population* are key inputs, which are generated from AQUA-CROP and ECOLAND as outputs. Therefore, ECOLAND and ECOWAT are linked through interchanging *crop prices, crop revenue and livestock prices, as well as through land allocation data (Fig 29).*

ECOTRAD, a modified version of MIRAGE World Trade Model communicates with ECOLAND and ECOWAT. This communications is via land use as changes and crop water allocation. These changes are exogenous in ECOTRAD and derive from ECOLAND and ECOWAT. Further, ECOTRAD generates price data that enters ECOLAND and ECOWAT as parameters. This is also illustrated in ***Figure 23*** below.

Figure 23. Overview of AQUACROP-ECOLAND-ECOWAT-ECOTRAD Models Linkage



Source: Made by Authors)

GAMS Programming

The model GAMS code is available at UNU-INRA. This can be provided for needed person if formal inquiry is addressed to UNU-INRA.

Conclusion

It is commonly recognized that climate change constitutes a veritable threat to African development and particularly to ECOWAS countries. However, despite many attempts to quantify the impact of climate in the region's key development pillars such as agriculture, trade, and food security, very limited work has been done to evaluate the spatial and temporal distribution of the impact of climate change and fully integrate the nexus between production and consumers' patterns. This could reduce uncertainty in obtaining the results of impact assessment of climate change and improve decision-making.

Therefore, to assess the impact of climate change on agricultural production, the proposed Integrated Assessment framework has attempted to incorporate the spatial and temporal changes which is caused by climate change on farming production system as well as the inputs (i.e. quantities and prices). This includes quantities and prices of land, water resources, fertilizers, labour, technology and the like. In addition, the framework has included the nexus linkage between resources end users. These are illustrated in both the dynamic land allocation model (ECOLAND) and the hydro-economic model (ECOWAT).

However, to assess the impact of climate change on agricultural commodity trade and food security, the proposed framework has incorporated the intra-market linkage between ECOWAS countries and the Rest of the World and fully integrated the multiple dimension of food security definition. This includes the condition of food availability, food accessibility, food utilization and stability. Given the limitation of using trade model as a single model set to analyse the impact of climate change on agricultural trade and food security, the framework offers the possibility to fully integrate the trade model (ECOTRAD) with ECOLAND and ECOWAT.

By implementing this, the framework requested intensive data but fully incorporated spatial and temporal producers, consumers and market behaviours information for robust analysis and improved decision-making options to enhance adaptation policies in boosting the region's resilience to climate change.

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MATE MASIE

"What I hear, I keep"-Symbol of wisdom, knowledge and understanding.

NEA ONNIMNO SUA A, OHU

"He who does not know can know from learning, -Symbol of life-long education and continued

NYANSAPO

"Wisdom knot" – Symbol of wisdom, ingenuity, intelligence and patience.

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