Climate change impacts across agroecological zones on agriculture in Benin: an economy-wide analysis

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Climate change impacts across PDAs on agriculture in Benin: an economy-wide analysis

Executive summary

Benin is a country with a large agricultural sector which will be strongly affected by climate change. It is experiencing these changes already. Several studies tackled the crop yield consequences of climate change. However, economy-wide and welfare effects are not consistently analysed for Benin. We carry out such an analysis, using a Computable General Equilibrium (CGE) model. On the basis of climate and plant growth projections for Benin, we simulate the effects of crop yield as well as animal productivity reduction by 2050.

Results show that climate change will affect Benin households and the economy as a whole negatively. Crop and animal husbandry production will decline significantly. As the economy of Benin is agriculture-based, this decline will result in GDP decline. Household welfare will also decline significantly, increasing food and nutrition insecurity of the poor. Effects will differ across the country in different agroecological zones.

To cope with the effects of climate change on agriculture, the government should consider investing more in research and development to identify and reinforce crop varieties that can withstand droughts and flooding, and in irrigation systems where feasible. Research could promote the development of infrastructure that can better withstand flooding and prevent the destruction of farms and herds. Prioritizing investment in vulnerable Pole of Agricultural Development (PDA) regions would help to reduce the regional disparities related to climate change. Finally, GHG emission reductions by major emitting countries would reduce the burden put on vulnerable countries such as Benin to cope with worst-case scenarios.

Impacts du changement climatique sur l'agriculture et l'ensemble de l'économie du Bénin avec différentiation des Pôles de Développement Agricole (PDA)

Résumé

Le Bénin est un pays dont le secteur agricole occupe une place prépondérante dans l'économie. Ce secteur sera fortement affecté par le changement climatique. Il subit déjà ces changements. Plusieurs études ont abordé les conséquences du changement climatique sur le rendement des cultures. Cependant, les effets sur l'ensemble de l'économie et le bien-être n'ont pas été analysés pour le Bénin. Nous avons fait une telle analyse en utilisant un modèle d'équilibre général calculable (EGC). Sur la base des projections climatiques et de croissance végétale pour le Bénin, nous avons simulé les effets de la réduction du rendement des cultures et de la productivité de l'élevage à l'horizon 2050.

Les résultats montrent que le changement climatique affectera négativement les ménages béninois et l'économie dans son ensemble. La production agricole (végétale et animale) diminuera de manière significative. L'économie du Bénin étant basée sur l'agriculture, ce déclin se traduira par une baisse du Produit Intérieur Brut (PIB). Le bien-être des ménages diminuera également de manière significative, augmentant l'insécurité alimentaire et nutritionnelle des pauvres. Les effets varieront d'un bout à l'autre du pays dans les différents Pôles de Développement Agricole (PDA).

Pour faire face aux effets du changement climatique sur l'agriculture, le gouvernement pourrait envisager d'investir davantage dans la recherche et le développement afin d'identifier et de renforcer les variétés de cultures qui peuvent résister aux sécheresses et aux inondations, ainsi que dans les systèmes d'irrigation lorsque cela est possible. La recherche pourrait promouvoir le développement d'infrastructures capables de mieux résister aux inondations et d'empêcher la destruction des fermes et des troupeaux. Donner la priorité aux investissements dans les PDA les plus vulnérables contribuerait à réduire les disparités régionales liées au changement climatique. Enfin, la réduction des émissions de gaz à effets de serre (GES) par les principaux pays émetteurs permettrait d'alléger le fardeau qui pèse sur les pays vulnérables tels que le Bénin dans l'affrontement des scénarii les plus pessimistes.

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1. Background

Benin is at significant risk from the disruptions of climate change. Since the 1970's, Benin has experienced waves of drought, floods, high winds, excessive heat, and rising sea levels (MCVDD, 2022). Furthermore, climate change is expected to continue to pose a significant threat to Benin, mainly because of its existing natural and social vulnerabilities. Adopting suitable adaptation policies is critical to hedging against these risks. Due to its essentially rain-fed nature, Beninese agriculture will remain, by 2050, subject to risks related to the spatiotemporal distribution of rainfall and other climatic factors.

Climate change has already damaged the agricultural sector through the disruption of the crop calendar; declining agricultural yields, loss of crops, disturbance of fishing and aquaculture activities, the scarcity of pastures, and intensification of transhumance. Climate change has also led to a high mortality rate among farm animals, the proliferation of waterborne diseases, and the deterioration of socio-economic infrastructure. These factors have had substantial economic repercussions on the lives of affected populations (MCVDD, 2022) One of the gravest manifestations of climate change in Benin is the reoccurring of floods, where the agricultural sector is the most affected. In 2010, Benin experienced a disastrous flood with a total damage of nearly 78.3 Billion CFA (MCVDD, 2022). More recently, in 2019 floods caused destruction of crop production, vegetables, cotton and livestock (INStaD, 2022).

Agriculture is the primary economic activity in Benin; it contributes 27% of GDP and 72% of the total value of exports. Cropping sectors produce almost 79% of the value added of the agricultural sectors while the livestock and hunting sectors produce almost 14% and the forestry and fishing sectors produce about 8% of that value added (DSA, 2022). For consistent monitoring of agricultural production across the country, its territory is divided into seven (agroecological) zones named “Pôles de Development Agricoles (PDA)” (Poles of Agricultural Development) based on agroclimatic and soil characteristics and agricultural activities. Figure 1 demonstrates the distribution of PDA in Benin, and Table 1 shows the principal characteristics of each PDA.

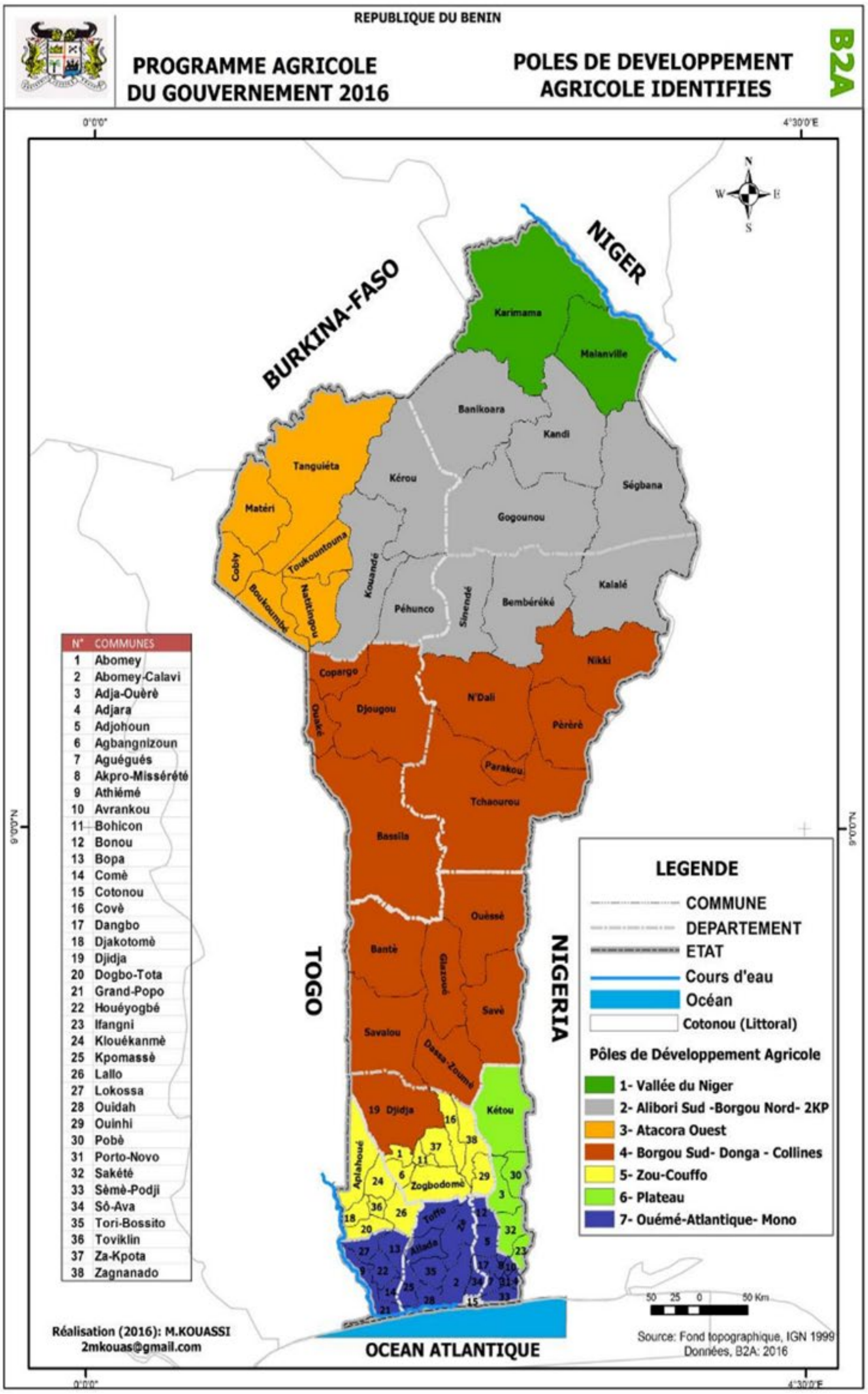

Figure 1: Agricultural Development Poles of Benin

Source: Authors' compilation based on B2A (2017).

Table 1: Key features of agroecological zones in Benin

PDA	Name	Location	Main crops activities	Main animal husbandry activities
PDA1	*Valey du Niger* (Niger valley)	Far North	Rice and vegetables	Cattle, sheep, goat, poultry
PDA2	*Alibori Sud-Borgou, Nord-2KP* (South Alibori-North Borgou-2KP)	North-centre	Cotton, maize, sorghum and Soy	Intensive cattle husbandry, sheep, goat, poultry
PDA3	*Atacora Ouest* (Atacora west)	North-west	Cotton, rice, maize, mango, beans, peanuts	Cattle, sheep, goat, poultry
PDA4	*Borgou Sud-Donga-Collines* (Borgou south-Donga, Collines)	Centre-North	Cashew, cotton, maize, rice, beans, peanuts, soy, cassava, yam & mango	Intensive cattle husbandry, sheep, goat, poultry
PDA5	Zou-Couffo	Centre-South	Citrus, mango, palm nuts, rice, maize, beans, peanuts, sylviculture	Small-scale animal husbandry
PDA6	Plateau	South-East	Palm nuts, maize, cassava, rice	_
PDA7	Oueme-Atlantic-Mono	South (coastal zone)	Pineapple, rice, vegetables, maize, cassava, palm nuts	Aquaculture and small-scale animal husbandry

Source: Authors' compilation based on B2A (2017).

Many studies have examined climate change's impact on the agricultural sector in Benin and demonstrated the negative impacts. Most studies indicate that the accumulated effect of climate change will result in a sizable reduction in agricultural output with three components: crops, livestock and fisheries. And that these effects will be differentiated across geographic zones (Hounkponou, 2015).

Previous studies have examined the economy-wide effects of climate change on Benin. For example, a study by the Ministry of the Environment and Sustainable Development (MCVDD) in 2020 used two different climatic scenarios and found that Benin's economy is likely to experience both positive and negative impacts as a result of climate change. However, to date, no economy-wide analysis has been conducted based on agroecological zones. Such analysis could provide valuable insights into the differential impacts of climate change on different regions of Benin and inform targeted policy interventions to mitigate these effects.

The government of Benin has put climate change and the improvement of resilience on the national agenda. Benin is part of the Green Climate Fund, through which it developed its national adaptation plan. More in-depth analysis is required to support the adaptation efforts of the government. There is a need to understand how specific areas and sectors are affected in order to design good adaptation policies.

The current paper aims to assess the economy-wide implications of climate change effects on agriculture considering different agroecological zones in Benin.

2. Methods

2.1 Database

We use an updated and highly disaggregated 2019 Social Accounting Matrix (SAM) based on Kinkpe *et al*. (2022), national accounts published by INStaD (2022) and additional data from

DSA-MAEP (2022a, 2022b, 2022c). Below is a brief overview of the SAM: the SAM identifies 59 activities of which 42 are agricultural. Agricultural activities are disaggregated according to the 7 PDAs.

- The SAM includes 24 factors of production
    - The labour categories skilled and unskilled are disaggregated according to gender.
    - Capital is disaggregated into agricultural and non-agricultural and land is disaggregated according to the 7 PDAs. The land of each PDA is further disaggregated into irrigated and non-irrigated.
- Households are disaggregated into rural poor and non-poor as well as urban poor and non-poor.

2.2 Model and closure rules

We use the computable general equilibrium (CGE) model STAGE (McDonald and Thierfelder 2015). A CGE model combines economic theory and numerical models to establish the impact of shocks in an economy. Real economic data is used to fit a set of equations that replicate the structure of the economy. From this framework, it is possible to simulate the effect of exogenous shocks, such as policy changes, including economy-wide interactions. The following presents a summary of the CGE model used:

- Production is structured by a three-level nest of Constant Elasticity of Substitution (CES) and Leontief production functions. At the top level, aggregate value-added, and intermediate inputs are combined using a CES function. Production factors are aggregated using CES functions at different levels, whereas the intermediate input component is aggregated using a Leontief production function (the second level). Aggregate primary factors (i.e., labour and land) are combined using CES functions (the third level).
- Producers sell their products either in the local or foreign markets, based on relative prices, as determined by a Constant Elasticity of Transformation (CET) function.
- Households supply production factors to productive activities through factor markets in exchange for wages that constitute a significant portion of their incomes. After paying taxes and making savings, households spend their income on purchasing products. Households maximise their utility subject to Stone-Geary utility functions, selecting the optimal mix of commodities and services while considering purchase prices, preferences, and income constraints.

As Benin uses a currency pegged to the Euro with a fixed parity, we apply a fixed exchange rate regime and flexible trade balance (deficit) closure. The model is savings-driven. Government savings are fixed and the household tax rate is flexible. Therefore, any policy change implemented in the model is financed through equiproportional changes in household income tax rates.

2.3 Scenarios

This study distinguishes two distinct scenarios: the reference scenario, which illustrates the economy under normal climatic conditions, and the climate change scenario, which accounts for changes in agricultural productivity induced by climate change in Benin.

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The climate change scenario is developed based on two climatic scenarios, specifically Shared Socioeconomic Pathways (SSP). These scenarios are designed by the Intergovernmental Panel on Climate Change (IPCC) to explore future trajectories for human development, energy use, and greenhouse gas emissions.

In the first scenario, SSP 126, greenhouse gas emissions are expected to decrease due to improvements in energy efficiency, renewable energy adoption, and carbon capture and storage technologies. As a result, a temperature rise of 1.8°C is projected by the end of the century. The second scenario, SSP 585 assumes increasing emissions, a growing global population, extensive use of fossil fuels, and severe climate change consequences. In this scenario, the anticipated temperature rise by the end of the century is 4.3°C.

In our climate change scenario, we determine the impacts of climate change on agriculture by 2050, considering the yield differences between the above-mentioned climatic trajectory scenarios. We estimate these impacts through a three-step process. First, we calculate annual yield growth rates for each sector under two climate scenarios using yield data provided by Potsdam Institute for Climate Impact Research (PIK). These data are produced using Inter-Sectoral Impact Model Intercomparison Project (ISIMIP2b) (Frieler *et al*., 2017; Müller *et al*., 2022). Second, we calculate the growth difference between the two scenarios by subtracting their respective annual growth rates, considering the SSP 126 scenario as the reference scenario for our calculation. This assumption implies that humans are aware of climate change and will behave rationally to reduce the future harmful effects of climate change. Finally, we calculate the compounded growth rate difference by exponentiating the growth difference to the number of years.

To consider the effects of climate change on livestock productivity, we rely on maize productivity data to mimic the changes in pasture availability. Specifically, we calculate the average changes in maize productivity in all Benin PDAs. We use that as the average change in livestock productivity as maize is from the same botanic family as most of the pasture plants. Furthermore, maize is a principal component of poultry feed.

In our CGE model, the compounded growth rate differentials are multiplied by the total factor productivity, expressing the changes in agricultural productivity due to climate change (

Activity	Changes in yield due to climate change
Cultivation of Maize in PDA2	0.96
Cultivation of Maize in PDA4	0.88
Cultivation of Maize in PDA6	0.96
Cultivation of Maize in PDA7	0.96
Cultivation of Maize in other PDAs	1.03
Cultivation of Rice in PDA1	1.02
Cultivation of Rice in PDA2	0.96
Cultivation of Rice in PDA4	0.88
Cultivation of Rice in other PDAs	0.99
Cultivation of Cassava in PDA4	0.91
Cultivation of Cassava in PDA6	0.97
Cultivation of Cassava in PDA7	1.00
Cultivation of Cassava in other PDAs	0.99
Cultivation of Yam in PDA2	0.96
Cultivation of Yam in PDA4	0.91
Cultivation of Yam in other PDAs	0.99
Cultivation of Pineapple (PDA7:99.9%, PDA4-6)	1.00

Cultivation of Fresh Vegetables and Spices in PDA1	0.94
Cultivation of Fresh Vegetables and Spices in PDA2	0.94
Cultivation of Fresh Vegetables and Spices in PDA4	0.91
Cultivation of Fresh Vegetables and Spices in PDA5	0.95
Cultivation of Fresh Vegetables and Spices in other PDAs	0.95
Other Food Crops in PDA2	0.96
Other Food Crops in PDA3	0.98
Other Food Crops in PDA4	0.91
Other Food Crops in PDA5	0.99
Other Food Crops in other PDAs	1.00
Cultivation of Cotton in PDA2	0.96
Cultivation of Cotton in PDA4	0.91
Cultivation of Cotton in other PDAs	0.99
Cultivation of Cashew in PDA2	1.26
Cultivation of Cashew in PDA4	1.06
Cultivation of Cashew in other PDAs	1.10
Cultivation of Palm nut	1.12
Cultivation of Other Agricultural Crops	0.98
Bicycle poultry husbandry	0.98
Broiler poultry husbandry	0.98
Other Animals Breeding	0.98
Raw Milk	0.98
Eggs and other Husbandry Activities	0.98

). The shock is applied to the base period SAM of 2019. The effect can thus be interpreted as the climate change impact of a pessimistic compared to an optimistic scenario occurring through the impact pathway "crop yields" on the economy of Benin in its current structure (sectoral composition, population size, income level).

3. Results

3.1 Domestic production

Error! Reference source not found. shows that changes in climatic variables suppress crop production by 6%, while livestock products drop by 0.1%. Manufacturing production decreases due mainly to a significant decrease in the agricultural sector, which is a primary intermediate input of the manufacturing sector. Decreasing agricultural production brings down the prices of production factors (Figure 4), specifically agricultural capital and labour. Consequently, fish production, including inland fisheries and aquaculture, increases by 4%.

Our analysis highlights significant variations in the impacts of climate change across different agroecological zones. As shown in Figure 3, we observe a substantial reduction in crop production in PDA2 and PDA4, largely driven by significant decreases in the production of maize, rice, vegetables, spices, and cotton (**Error! Reference source not found.**). In contrast, the growth of cassava and pineapple production is driving an increase in crop production in PDA7. For the remaining PDAs (PDA1, PDA3, and PDA5), the changes in crop production are a combination of the effects for different crops, with some experiencing production increases and others experiencing decreases.

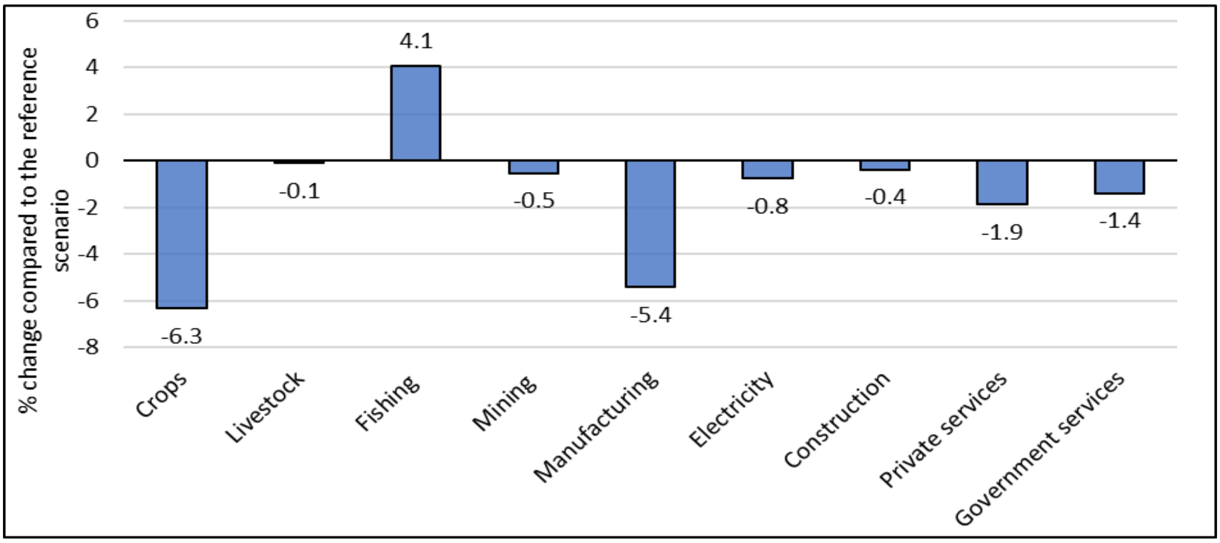

Figure 2: Effects on quantities of sectoral domestic production, % change compared to the reference scenario

Source: Authors' calculations based on simulation results.

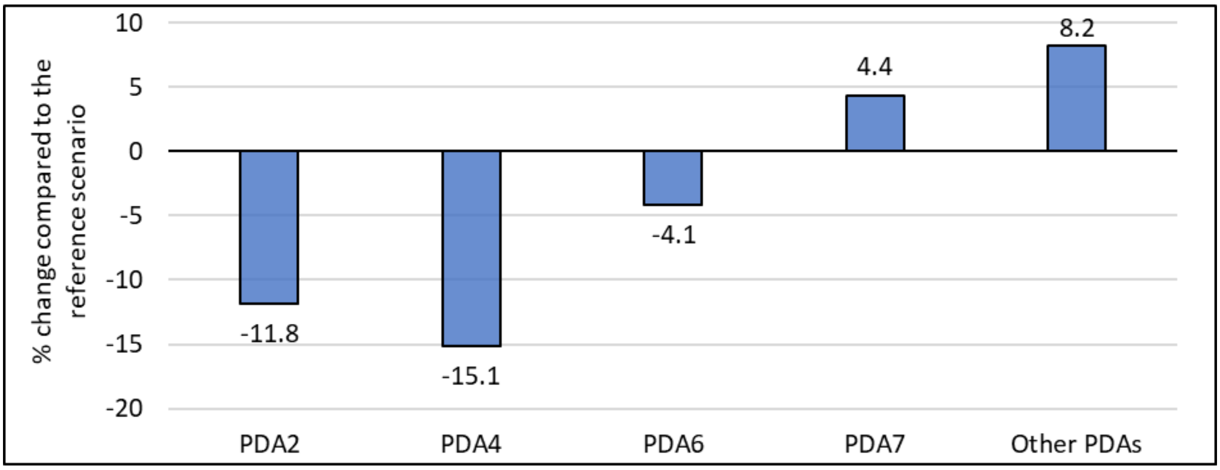

Figure 3: Effects on quantities of crop production classified according to agroecological zones, % change compared to the reference scenario

Source: Authors' calculations based on simulation results.

3.2 Factor prices

Figure 4 presents the impacts on production factor prices. It shows that prices of all factors decline, driven by the significant decrease in total production due to climate change.

The agricultural capital price drops substantially more than other factor prices. This reduction is caused by a significant decrease in cotton production, which is a capital-intensive sector due to the ginning process.

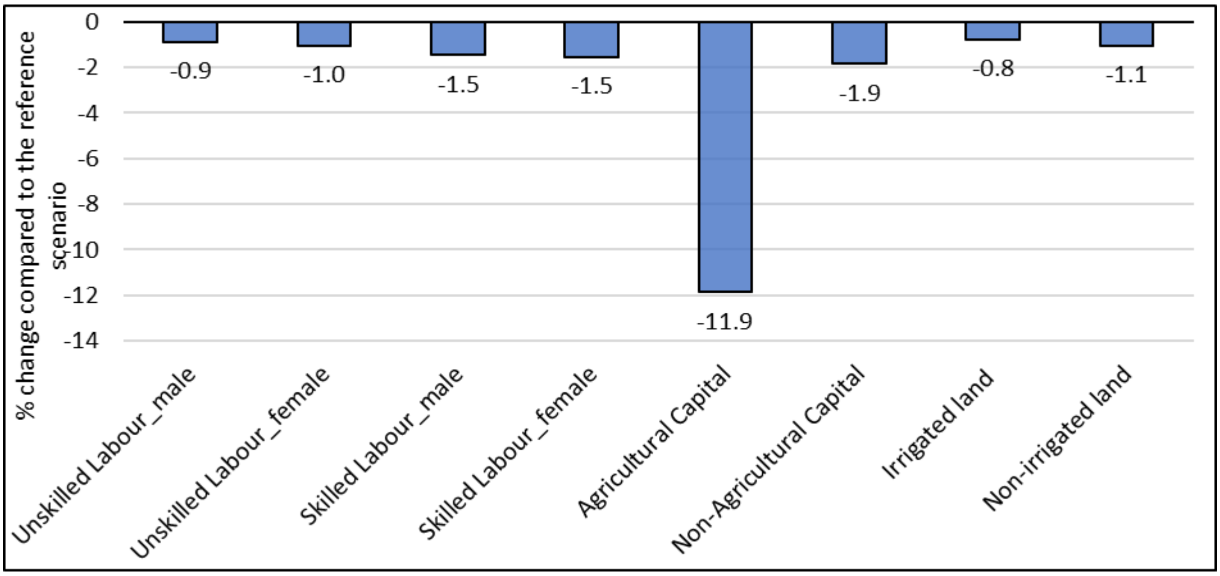

Figure 4: Effects on prices of production factors, % change compared to the reference scenario

Source: Authors' calculations based on simulation results.

Overall, land prices, irrigated and non-irrigated, decline in all agroecological zones (Figure 5), except for the PDA1. This can be explained by the slight increase in rice production in this zone. Except for the PDA4 zone, the non-irrigated land price drops more than the price of irrigated land in all zones. This result is mainly driven by the reduction in agricultural production (maize, cotton, vegetables and other food crops) using non-irrigated land. In contrast, the prices of irrigated land in the PDA4 drops more than non-irrigated land. This is driven by the increase in cashew production in this zone, which uses non-irrigated land.

3.3 Household welfare

Figure 6 illustrates the effects on household welfare. Reduction in total production due to climate change increases purchase prices of products and decreases factor prices and incomes, leading to welfare losses.

Poor households in rural and urban areas loose more compared to non-poor households. This is caused by the high share of agricultural products in poor households' consumption basket, which become more expensive than in the reference scenario. Moreover, the reduction in rural household income is higher than for urban households, driven especially by declining factor income for agricultural capital, which has a higher share in rural than in urban household income.

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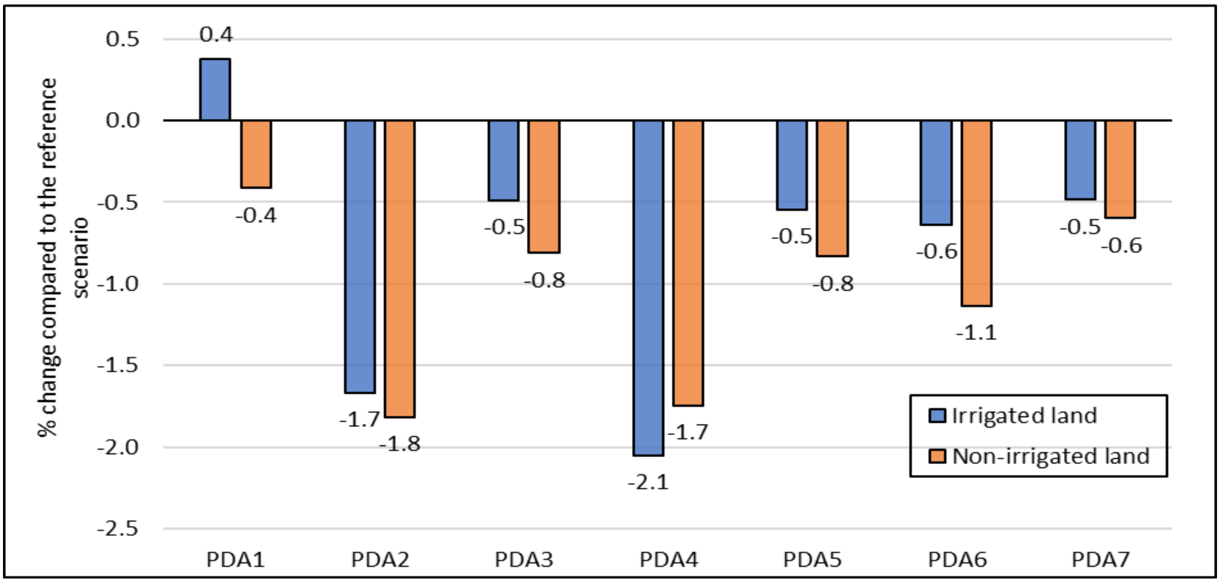

Figure 5: Effects on prices of land classified according to agroecological zones, % change compared to the reference scenario

Source: Authors' calculations based on simulation results.

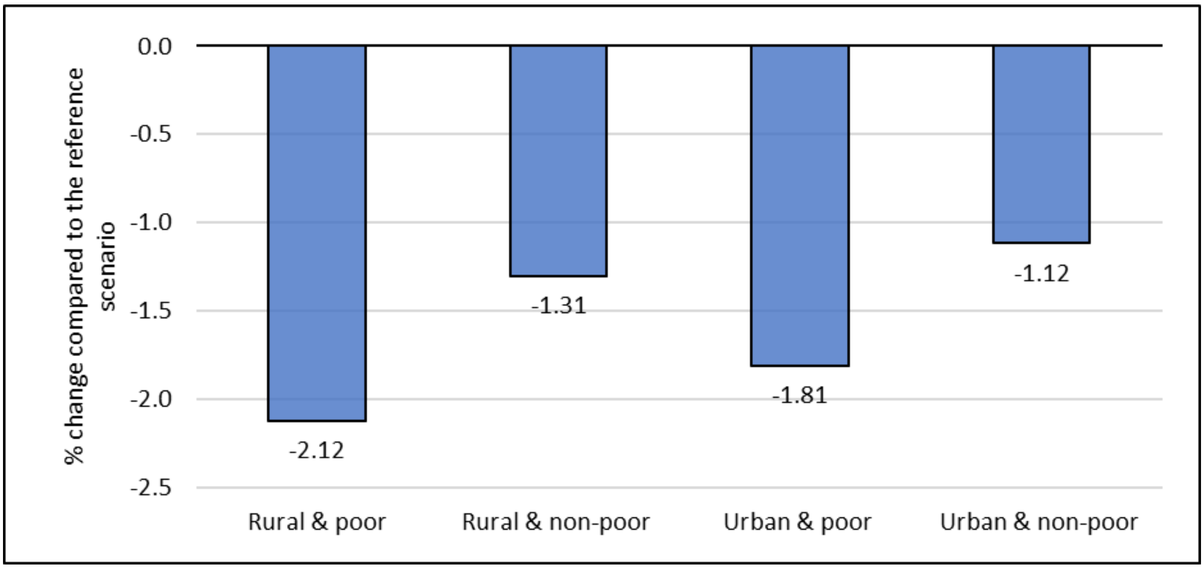

Figure 6: Effects on household welfare, Equivalent Variation (EV) as a share of household expenditure in the reference scenario

Source: Authors' calculations based on simulation results.

3.4 Macroeconomic effects

Figure 7 highlights the impact of climate change on economy-wide variables. Total production in Benin declines by 3%. This reduction translates into decreasing household consumption, driven by lower factor income and higher consumer prices of domestic products.

Total investment drops due to decreasing total demand (investment demand is a fixed share of total demand). Foreign savings (trade deficit) increase by 16% to compensate decreasing domestic savings (e.g., -6% for households).

Moreover, total exports decrease due to significant reduction in agricultural production, specifically cotton. At the same time, total imports decrease due to the reduction in total domestic demand. As a result, GDP drops.

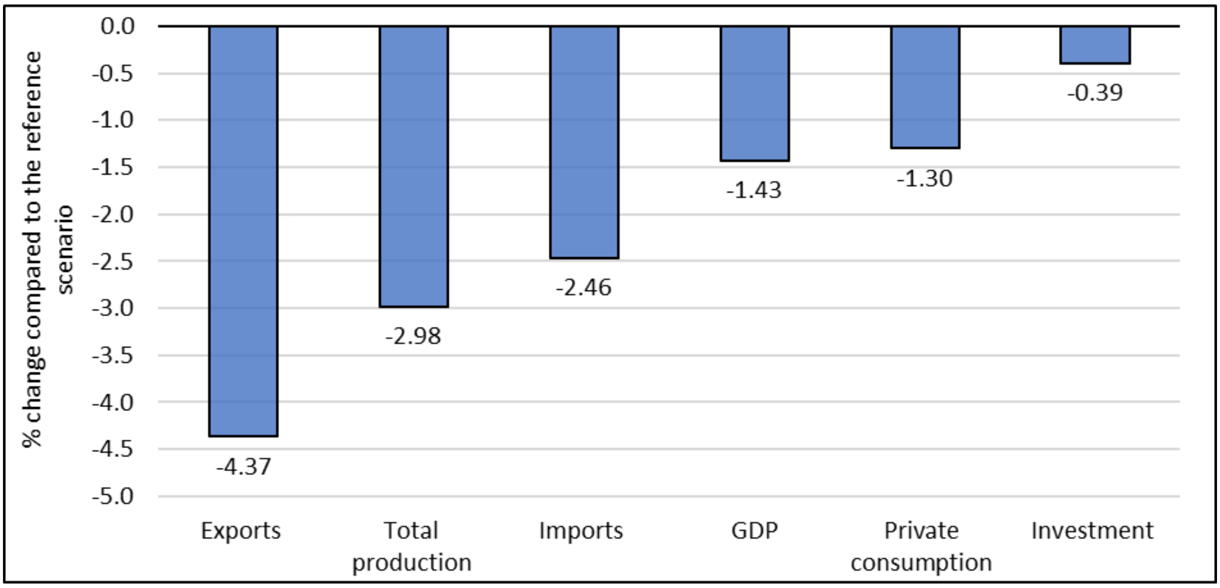

Figure 7: Effects on economy-wide indicators, % change compared to the reference scenario

Source: Authors' calculations based on simulation results.

4. Conclusion and discussion

This paper points out the vulnerability of Benin production systems and households vis-à-vis the effects if climate change. A scenario of severe compared to light climate change results in substantially lower crop productivity and production as well as animal productivity and production. As consequence, welfare of households in rural and urban areas will decline. Poor households are affected more, suffering from declining incomes as well as higher agricultural prices, which will worsen food and nutrition security. These effects would be more severe in some regions (PDAs 2, 4 and 6) than in others (PDA 1, 3, 5 and 7), pointing out regional disparities in vulnerability to climate change. The economy as a whole will be negatively affected in terms of GDP decline.

The effects of climate change on local weather conditions are uncertain and the real climate change effects may differ substantially from the simulations presented here. For crop yield projections, our work relies on state-of-the-art plant growth models. But our projections of the future productivity of animals are based on weak evidence. Especially in the drought prone northern region of the country, effects on animal stocks and livelihoods may be substantially stronger than simulated here.

Finally, we only consider the impact of climate change through agricultural yields. Other impact pathways such as increasing human heat stress or changes in the prevalence of diseases would add, but are not accounted for here.

5. Policy implications

Adaptation measures can be taken to alleviate the negative effects predicted by our simulations. The government could enhance investment in research and development to breed crop varieties which are more resistant to drought and flooding as well as related pests.

Setting up and improving suitable irrigation systems where possible would help lowering the effects of decreasing rainfall. It is important to study the irrigation potentials and suitable options for sustainable irrigation for each PDA.

To mitigate the destructive effects of flooding on farms and livestock, it is crucial to identify the regions that are most susceptible to this phenomenon and study effective adaptation mechanisms. Implementing such mechanisms in advance can safeguard farms and livestock during flooding events. One possible solution could be the construction of suitable dams, which can channel water, minimize the damage caused by floods and contribute to water storage. Paying particular attention to the PDAs with higher vulnerability would be important to control regional disparities and poverty implications resulting from climate change.

Finally, GHG emission reductions by major emitting countries would reduce the burden put on vulnerable countries such as Benin which are not emitting significantly themselves to cope with worst-case scenarios.

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Appendices

Appendix A: climate change impacts on yield across different agricultural sectors

Activity	Changes in yield due to climate change
Cultivation of Maize in PDA2	0.96
Cultivation of Maize in PDA4	0.88
Cultivation of Maize in PDA6	0.96
Cultivation of Maize in PDA7	0.96
Cultivation of Maize in other PDAs	1.03
Cultivation of Rice in PDA1	1.02
Cultivation of Rice in PDA2	0.96
Cultivation of Rice in PDA4	0.88
Cultivation of Rice in other PDAs	0.99
Cultivation of Cassava in PDA4	0.91
Cultivation of Cassava in PDA6	0.97
Cultivation of Cassava in PDA7	1.00
Cultivation of Cassava in other PDAs	0.99
Cultivation of Yam in PDA2	0.96
Cultivation of Yam in PDA4	0.91
Cultivation of Yam in other PDAs	0.99
Cultivation of Pineapple (PDA7:99.9%, PDA4-6)	1.00
Cultivation of Fresh Vegetables and Spices in PDA1	0.94
Cultivation of Fresh Vegetables and Spices in PDA2	0.94
Cultivation of Fresh Vegetables and Spices in PDA4	0.91
Cultivation of Fresh Vegetables and Spices in PDA5	0.95
Cultivation of Fresh Vegetables and Spices in other PDAs	0.95
Other Food Crops in PDA2	0.96
Other Food Crops in PDA3	0.98
Other Food Crops in PDA4	0.91
Other Food Crops in PDA5	0.99
Other Food Crops in other PDAs	1.00
Cultivation of Cotton in PDA2	0.96
Cultivation of Cotton in PDA4	0.91
Cultivation of Cotton in other PDAs	0.99
Cultivation of Cashew in PDA2	1.26
Cultivation of Cashew in PDA4	1.06
Cultivation of Cashew in other PDAs	1.10
Cultivation of Palm nut	1.12
Cultivation of Other Agricultural Crops	0.98
Bicycle poultry husbandry	0.98
Broiler poultry husbandry	0.98
Other Animals Breeding	0.98
Raw Milk	0.98
Eggs and other Husbandry Activities	0.98

Source: Authors' calculation based on data produced by ISIMIP2b model.

Appendix B: Effects on quantities of domestic crop production classified according to agroecological zones, absolute change compared to the reference scenario

	Quantity in base (million units)	Absolute change compared to the reference scenario (million units)
Maize in PDA2	6.96	-0.57
Maize in PDA4	4.08	-1.50
Maize in PDA6	2.98	-0.27
Maize in PDA7	3.28	-0.36
Maize in other PDAs	3.73	0.64
Rice in PDA1	0.99	0.08
Rice in PDA2	0.59	-0.04
Rice in PDA4	0.67	-0.23
Rice in other PDAs	0.53	0.03
Cassava in PDA4	11.80	-2.89
Cassava in PDA6	9.66	-0.25
Cassava in PDA7	10.53	0.96
Cassava in other PDAs	8.34	0.47
Yam in PDA2	10.82	1.10
Yam in PDA4	29.42	-4.02
Yam in other PDAs	4.23	0.85
Pineapple	2.68	0.42
Vegetables and Spices in PDA1	5.22	1.23
Vegetables and Spices in PDA2	6.17	-0.26
Vegetables and Spices in PDA4	11.65	-1.88
Vegetables and Spices in PDA5	15.49	0.06
Vegetables and Spices in other PDAs	2.72	-0.05
Other Food Crops in PDA2	5.30	0.08
Other Food Crops in PDA3	2.30	0.18
Other Food Crops in PDA4	6.40	-1.35
Other Food Crops in PDA5	1.90	0.17
Other Food Crops in other PDAs	0.93	0.12
Cotton in PDA2	17.87	-6.97
Cotton in PDA4	5.09	-2.67
Cotton in other PDAs	3.43	-1.14
Cashew in PDA2	1.02	0.87
Cashew in PDA4	4.24	3.44
Cashew in other PDAs	0.33	0.28
Palm nut	3.14	0.35
Other Agricultural Crops	19.79	-1.11
Total crop production	224.30	-14.21

Source: Authors' calculation based on data produced by ISIMIP2b model.