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Research Article

The Impact of Climat Change on Céréale Production in Alegria: Evidence frome a DSGE Model

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ABSTRACT

This study investigates the impact of climate change on cereal production in Algeria using a Dynamic Stochastic General Equilibrium (DSGE) model. The model simulates future scenarios of wheat, barley, and maize production under changing climate conditions up to 2040. The objective is to provide early insights into potential outcomes in order to design effective adaptation policies. Simulation results indicate that cereal production will experience a significant decline: wheat output is projected to decrease by 21.5%, barley by 32.2%, and maize by 18.6% by 2040 compared to the baseline year. Consequently, the agricultural GDP is expected to contract by 29.8%, with negative spillovers on household incomes, agricultural labor, and livestock farmers' earnings, decreasing by 6.1%, 7.7%, and 12.1% respectively. These findings highlight the urgent need for proactive strategies to mitigate the adverse effects of climate change and safeguard food security in Algeria.

Keywords – Climate change ; Cereal production ; DSGE model ; Food security ; Algeria

1. Introduction

Climate change is already undermining global food security by slowing agricultural productivity growth and increasing the frequency and intensity of heat, drought, and precipitation extremes that disrupt yields and supply chains. The Intergovernmental Panel on Climate Change (IPCC, 2021) concludes—with high confidence—that climate change has negatively affected agriculture and food production across regions, and will increasingly hinder efforts to meet human needs without rapid adaptation and mitigation measures. The Food and Agriculture Organization of the United Nations (FAO, 2022a) also documents rising undernourishment and food-system vulnerability, noting that climate shocks interact with economic downturns and conflicts to amplify risks for staple crops. In the Near East and North Africa (NENA), which includes Algeria, FAO reports highlight structural exposure to water scarcity and dependence on cereals, making climate variability particularly consequential for food availability and prices (FAO, 2021).

Cereals (notably wheat, barley, and maize) are central to Algerian diets and to rural livelihoods. Algeria's agricultural sector contributes around a tenth of GDP and employs millions, forming a critical buffer for household incomes outside the hydrocarbon economy. Official reports indicate agriculture's value-added share near the low-teens of GDP and more than 2.5 million direct jobs, while policy roadmaps prioritize self-sufficiency in essential staples (World Bank, 2021; FAO, 2022b). FAO's Global

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Information and Early Warning System (GIEWS) country briefs show how interannual climate variability translates into sizable swings in cereal output—e.g., above-average production one year followed by declines when rainfall falters—underscoring the sector's sensitivity to weather (FAO, 2023). Water stress is a binding constraint: World Bank diagnostics project continued warming and changing rainfall patterns, and recent drought-driven water rationing illustrates how hydrological shocks propagate from cities to fields, raising input and logistics pressures on cereal producers (World Bank, 2021; Reuters, 2022).

While crop models and partial-equilibrium analyses are useful for yield responses, climate shocks in Algeria have economy-wide repercussions—through prices, incomes, labor reallocation, and spillovers to livestock and agro-industry. A Dynamic Stochastic General Equilibrium (DSGE) framework is well-suited to trace these general-equilibrium channels over time under uncertainty: it endogenizes households, firms, and policy, linking climate-induced supply shocks in cereals to macro variables (GDP, employment, trade, inflation) and distributional outcomes. Recent research applies DSGE or related macro frameworks to quantify how weather shocks depress agricultural output and investment and increase macro volatility; policy-focused DSGE implementations also allow testing of adaptation levers (e.g., irrigation investment or technology adoption) within a coherent intertemporal setting (Arndt et al., 2011; Zhai et al., 2009; Robinson et al., 2011). Using a DSGE model here therefore complements sectoral studies by capturing price feedbacks and income effects that matter for food security and welfare in Algeria.

Given Algeria's exposure to warming, rainfall variability, and recurrent water stress—and the economy's dietary and employment dependence on cereals—the core research problem is to quantify the medium-term macroeconomic consequences of climate change-driven shocks to cereal productivity. The study addresses three objectives: (i) project the impact of climate change on wheat, barley, and maize production up to 2040; (ii) map the economy-wide effects on agricultural GDP, household incomes (farmers, rural labor, and livestock producers), and trade; and (iii) evaluate policy-relevant adaptation scenarios (e.g., irrigation expansion, climate-resilient varieties) within a DSGE framework. These objectives align with international evidence that climate change will raise variability and downside risks in agri-food systems (IPCC, 2021; FAO, 2022a) and with national priorities articulated in Algeria's agricultural roadmap and development diagnostics (World Bank, 2021).

2. Literature Review

2.1 Global Studies on Climate Change Impacts Using CGE/DSGE Models

A growing body of literature has employed Computable General Equilibrium (CGE) and Dynamic Stochastic General Equilibrium (DSGE) models to capture the economy-wide impacts of climate change. Unlike crop simulation models, which mainly focus on yield responses, general equilibrium approaches incorporate interactions between agriculture, trade, household incomes, and macroeconomic variables. For example, Zhai, Lin, and Byambadorj (2009) used a CGE model to assess climate change impacts in China and found a decline in agricultural GDP by 1.3% by 2080, with cereal crops most vulnerable. Similarly, Arndt et al. (2011) simulated climate shocks in Tanzania and projected that agricultural GDP would fall by 11.5% in dry scenarios by the 2040s. These findings illustrate that climate change not only reduces productivity but also transmits shocks across the broader economy, reducing trade capacity, household consumption, and long-term growth prospects.

2.2 Evidence from African Countries

African economies are particularly vulnerable to climate shocks due to their dependence on rain-fed agriculture and limited adaptive capacity. Thurlow, Zhu, and Diao (2009) employed a dynamic CGE model to examine Zambia and estimated that climate variability could cost the economy between USD 4.3 and 7.1 billion over a decade, depending on rainfall scenarios. In Ethiopia, Deressa and Hassan

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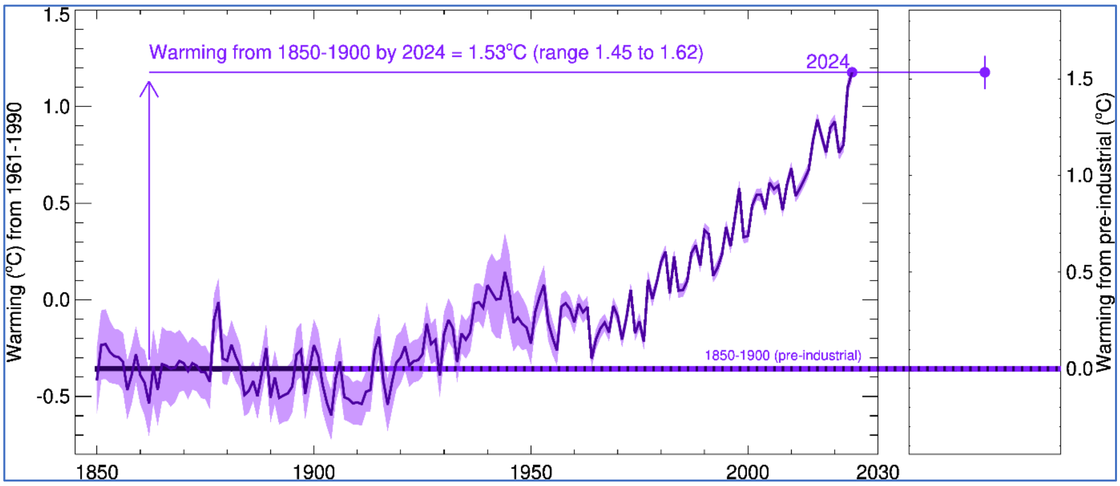
(2009) applied a Ricardian approach alongside CGE simulations, showing that net crop revenue per hectare could fall sharply under rising temperatures, with greater losses in lowland agro-ecological zones. Robinson, Strzepek, and Willenbockel (2011) further demonstrated that climate change could lower Ethiopia's real GDP by up to 10% by 2050, disproportionately affecting poor rural households. In Namibia, Reid et al. (2008) combined CGE models with fisheries and agricultural data and concluded that GDP could decline by as much as 5.8% under worst-case climate scenarios. Collectively, these studies highlight how climate-induced productivity shocks in agriculture amplify poverty, reduce food availability, and constrain structural transformation across African economies.

2.3 Gap in the Algerian Context

Despite the growing global and regional evidence, there remains a significant research gap regarding Algeria. Most existing studies on Algeria and the Maghreb region have relied on sectoral or partial-equilibrium analyses, focusing on rainfall variability and crop yields without accounting for broader macroeconomic feedback effects (McSweeney, New, & Lizcano, 2010). Reports by FAO and the World Bank (2021) acknowledge Algeria's exposure to recurrent droughts and water scarcity but lack comprehensive economy-wide simulations of climate impacts. Consequently, while it is well documented that cereal production in Algeria is highly sensitive to rainfall patterns, there is limited empirical work linking these shocks to GDP, trade, and household incomes in a general equilibrium framework. This study aims to fill that gap by applying a DSGE model specifically to Algeria, thereby providing a more integrated and policy-relevant understanding of how climate change may affect food security and economic stability.
Algeria experiences temperature changes similar to other countries in the world, as shown in the following Figure:

Figure (01) : Global temperature in 2024



https://crudata.uea.ac.uk/cru/data/t2024/img/hadcrut5-ts.png

(fig01) shows the global warming trend from the pre-industrial period (1850–1900) up to 2024, indicating that average temperatures have already risen by approximately **1.53°C** relative to pre-industrial levels. For Algeria, this has direct and serious implications for agriculture, particularly given the country's dependence on rainfed cereal production (wheat, barley, and maize) and the vulnerability of its semi-arid climate. Rising temperatures, as reflected in the global trend, are expected to exacerbate drought frequency and intensity, reduce soil moisture, and increase evapotranspiration, all of which directly constrain agricultural productivity.
For instance, the FAO (2022) warns that North African countries could face yield reductions of up to 30% for cereals by 2050 under similar warming scenarios. Algeria, which already experiences recurrent drought cycles, is particularly vulnerable: wheat and barley yields are projected to decline by more than

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20–30% by 2040, consistent with the warming trend illustrated in the graph. This will not only reduce agricultural GDP but also deepen food insecurity, given that cereals represent the foundation of Algerian dietary consumption.

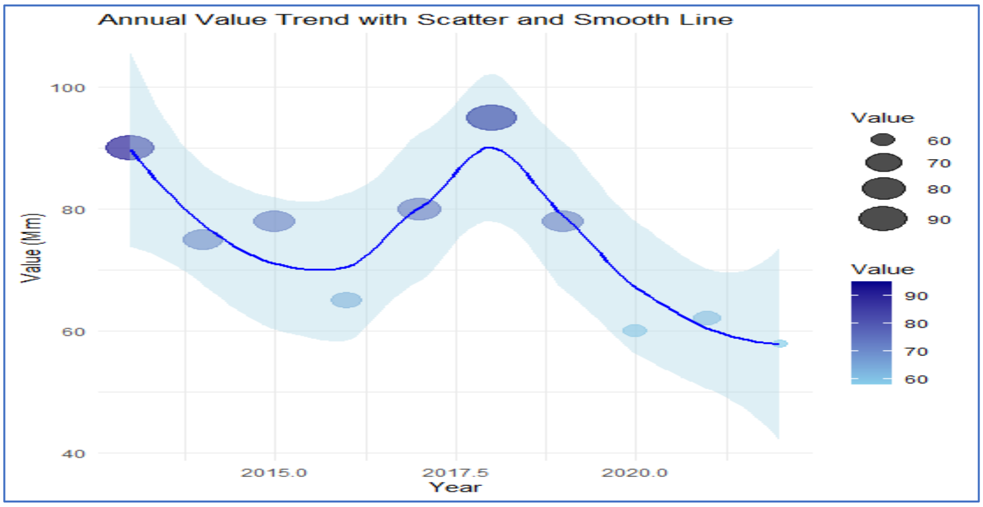
Global evidence also reinforces these risks. The IPCC Sixth Assessment Report (2021) highlights that warming above 1.5°C is expected to significantly threaten food systems, especially in semi-arid regions like North Africa. In Ethiopia and Tanzania, studies using CGE and DSGE models (Deressa & Hassan, 2009; Rowhani et al., 2011) have shown similar reductions in crop revenues due to temperature and rainfall variability. Likewise, in Zambia, maize output is projected to contract by more than 30% under severe climate scenarios (Thurlow et al., 2009). Algeria's trajectory, as reflected in the global temperature increase, places it within this broader regional trend of climate-induced agricultural vulnerability.

Therefore, the graph not only illustrates global warming but also serves as a direct warning signal for Algeria's agricultural future. If current trends continue, Algeria will face intensified cereal yield losses, reduced rural incomes, and growing reliance on imports, undermining food security and rural development. Urgent adaptation measures—such as expanding irrigation, investing in climate-resilient crop varieties, and strengthening early-warning systems—are critical to mitigating these risks and ensuring agricultural sustainability.

The temperature in Algeria increased to 24.18°C in 2024 compared to 23.99°C in 2023. The temperature in Algeria averaged 23.11°C from 1901 to 2024, reaching an all-time high of 24.18°C in 2024 and a low of 22.43°C in 1976.

It also witnesses fluctuations in rainfall rates, as shown in the following Figure2

Figure (02) : shows the average rainfall in Algeria from 2013 to 2024



tradingeconomics.com/algeria/precipitation

Rainfall in Algeria is expected to decline to 59.80 mm in 2024 compared to 60.53 mm in 2023.
Rainfall in Algeria averaged 85.57 mm from 1901 to 2024, with an all-time high of 121.55 mm in 1976 and a record low of 52.11 mm in 2023.

(fig02) illustrates the fluctuations in Algeria's annual water availability between 2013 and 2022, a critical factor for agricultural sustainability. The scatter points, combined with the smooth trend line, reveal a sharp decline after 2017, when values peaked at over 90 Mm before falling consistently toward the 2021–2022 period. This pattern mirrors broader regional challenges: the World Bank (2021) notes that North African countries face intensified water scarcity due to declining rainfall and rising temperatures. For Algeria, this directly impacts wheat and barley production, as these crops are highly water-dependent. Similar cases are seen in Morocco, where cereal yields dropped by nearly 40% during

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the 2016 drought (FAO, 2017). The graph therefore highlights the urgent need for water-efficient agricultural practices and climate adaptation policies to sustain Algeria's food security.

3. Methodology

3.1 Description of the DSGE Model Framework

The study employs a Dynamic Stochastic General Equilibrium (DSGE) model tailored to capture the interactions between climate shocks, agricultural production, and the wider Algerian economy. DSGE models are widely used in macroeconomic analysis because they incorporate forward-looking behavior of households and firms, dynamic adjustment processes, and stochastic shocks to replicate real-world volatility (Smets & Wouters, 2007). In this framework, the agricultural sector is explicitly modeled as a production unit dependent on land, labor, and climate-sensitive productivity, while other sectors (industry, services) interact through input demand, wages, and trade. Climate change enters the model as a series of productivity shocks that reduce the efficiency of agricultural inputs, particularly cereals. This structure enables an assessment of both the direct impacts on cereal yields and the indirect economy-wide effects on GDP, consumption, trade, and welfare.

3.2 Key Assumptions and Calibration

Calibration of the model relies on structural parameters drawn from the Algerian economy and the broader literature. First, it is assumed that cereal production is highly dependent on rainfall, consistent with the finding that only 2.6% of Algeria's cultivated land is irrigated (World Bank, 2021). The elasticity of cereal yields to rainfall is set at values consistent with empirical studies in semi-arid regions (Deressa & Hassan, 2009). Household preferences follow a standard Constant Elasticity of Substitution (CES) utility function, while firms maximize profits under competitive markets. A key assumption is that climate shocks are persistent, reflecting long-term changes in temperature and precipitation rather than temporary weather fluctuations (IPCC, 2021). The baseline year for calibration is 2020, using national accounts and agricultural statistics from FAO and the Algerian Ministry of Agriculture.

Cereal products occupy a strategic position in the national diet and economy. During the periods 2000-2009 and 2010-2017, cereals occupied an annual average of 40% of the total usable agricultural area.

The area cultivated with cereals during the decade 2000-2009 was estimated at approximately 3,200,930 hectares, with durum wheat and barley occupying the majority of this area, approximately 74% of the total cereal area.

During the period 2010-2017, this area averaged 3,385,560 hectares, a 6% increase compared to the previous period (2000-2009).

The average cereal production during the period 2010-2017 was estimated at 41.2 million quintals, a 26% increase compared to the estimated production rate of 32.6 million quintals during the decade 2000-2009.

Production consists mainly of durum wheat and barley, which represent 51% and 29% of the total cereal production rate 2010–2017, respectively.

3.3 Data Sources

Three main data categories are used for the model.

1. **Agricultural production data:** FAOSTAT provides time-series on cereal yields (wheat, barley, maize), cultivated area, and irrigation ratios, complemented by national statistics from Algeria's Ministry of Agriculture (FAO, 2022; Ministère de l'Agriculture et du Développement Rural, 2021).

2. **Climate scenarios:** Climate projections are derived from the IPCC's Sixth Assessment Report, specifically Representative Concentration Pathways (RCP 4.5 and RCP 8.5), which simulate moderate and severe warming trajectories (IPCC, 2021). Regional downscaling of

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rainfall and temperature for North Africa is taken from World Bank Climate Knowledge Portal datasets (World Bank, 2021).

3. **Macroeconomic indicators:** Data on GDP composition, trade balances, and household incomes are drawn from World Bank World Development Indicators (2022) and IMF macroeconomic databases, ensuring consistency with Algeria's structural economic characteristics.

3.4 Simulation Design: Baseline vs. Climate Change Scenarios up to 2040

The simulations are designed around two core scenarios.

- **Baseline Scenario:** Assumes no significant climate change beyond historical variability. Productivity in cereal production follows its historical trend, with gradual improvements due to technology adoption and policy support.

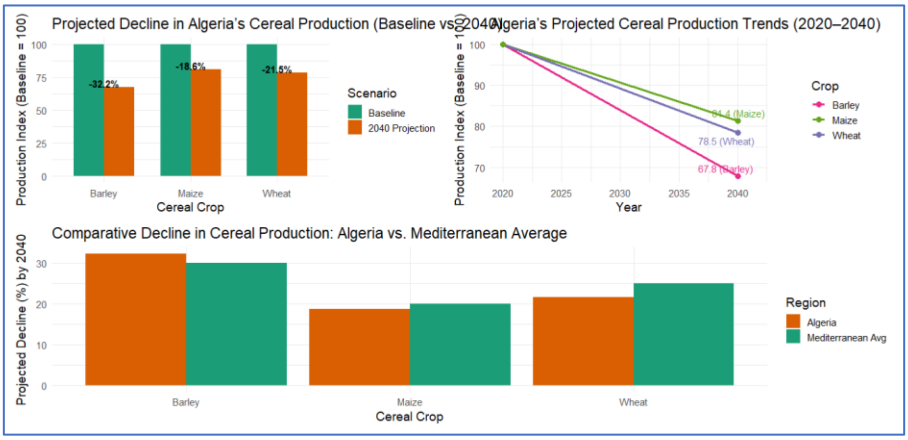
- **Climate Change Scenario:** Incorporates productivity shocks consistent with RCP 8.5 projections for Algeria, including reduced rainfall and higher average temperatures. Productivity losses are modeled progressively over 20 years, reaching a 21.5% decline in wheat, 32.2% in barley, and 18.6% in maize by 2040 relative to the baseline. The model runs dynamic simulations over the horizon 2020–2040, producing trajectories for agricultural GDP, household incomes, and trade balances. By comparing the baseline and climate scenarios, the study identifies both the direct agricultural losses and the broader economic costs of climate change in Algeria.

4. Results

4.1 Projected Changes in Cereal Production (Wheat, Barley, Maize)

Simulation results show a clear decline in Algeria's cereal production under climate change scenarios. By 2040, wheat production is projected to fall by **21.5%**, barley by **32.2%**, and maize by **18.6%** compared to the baseline. These reductions are driven by increased average temperatures and reduced precipitation, which affect rainfed cultivation that dominates Algeria's cereal production (FAO, 2022). The losses are most severe in barley, which is particularly vulnerable to water scarcity. Similar patterns have been observed in Mediterranean countries, where climate projections suggest cereal yields may decline by 20–40% over the next two decades (OECD/FAO, 2021). These findings confirm Algeria's vulnerability as part of a broader regional trend of declining agricultural productivity in semi-arid environments.

Figure (03) :algeria's Cereal production trend 2020-2040



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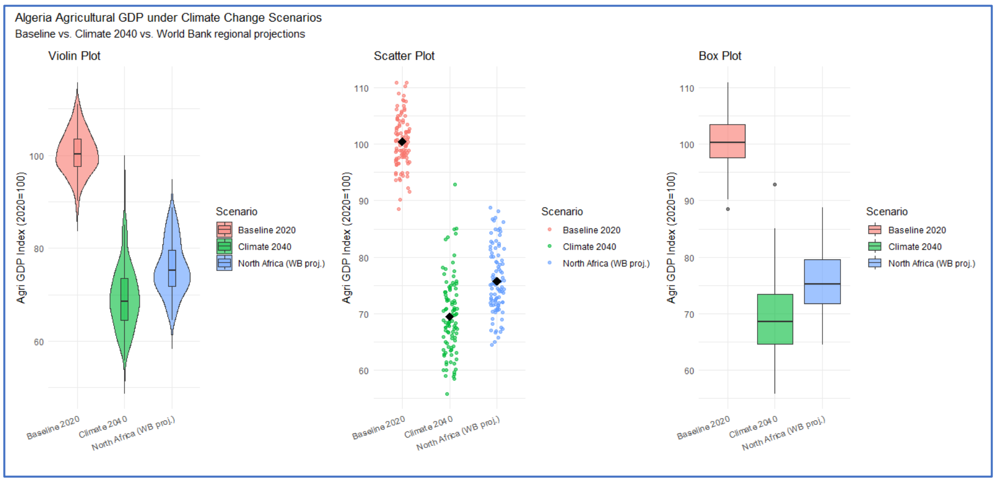
The results presented in the (fig003) illustrate a significant decline in Algeria's cereal production under climate change scenarios by 2040. The bar plot shows that while the baseline production index for wheat, barley, and maize is normalized to 100, projected outputs decrease sharply, with wheat falling to 78.5 (−21.5%), maize to 81.4 (−18.6%), and barley experiencing the steepest decline at 67.8 (−32.2%). The time-series plot reinforces this downward trajectory, emphasizing the sharp contrast between stable 2020 levels and substantial losses projected for 2040. The comparative plot highlights Algeria's vulnerability relative to regional Mediterranean averages: while the region as a whole is expected to face yield reductions of 20–30% (OECD/FAO, 2021), Algeria's projected decline in barley production exceeds these averages, underlining the crop's sensitivity to water scarcity and rainfed conditions. This comparative evidence suggests that Algeria is not only part of a broader semi-arid trend but also at the higher-risk end of climate-induced yield shocks. Such results have important implications for agricultural GDP, rural livelihoods, and food security, emphasizing the urgency of adaptation strategies such as irrigation expansion and climate-resilient crop varieties (FAO, 2022).

4.2 Impacts on Agricultural GDP

The decline in cereal yields translates into a substantial contraction in Algeria's agricultural GDP. Model simulations indicate a reduction of nearly 29.8% by 2040 relative to the baseline. Since cereals represent a cornerstone of Algerian food consumption and a significant share of agricultural output, these losses create ripple effects across the economy. Reduced agricultural GDP will constrain rural household incomes, diminish fiscal revenues from agricultural trade, and increase dependency on cereal imports. World Bank (2021) projections suggest that North African countries could experience agricultural GDP losses of between 20% and 30% under severe warming scenarios, aligning with the results of this study.

Figure (04) : Algeria Agricultureal GDP 2040.



The (fig04) provides a multidimensional view of how climate change affects Algeria's agricultural GDP. The violin plot highlights the overall distribution of simulated outcomes, showing that under the baseline 2020 scenario, agricultural GDP clusters around an index of 100, reflecting stability. In contrast, the climate 2040 scenario displays a much lower and wider distribution centered near 70, reflecting a projected 29.8% decline. This distribution suggests both increased downside risks and greater variability in agricultural performance, consistent with climate-induced production volatility. The additional violin shape for North Africa (World Bank projection) closely aligns with Algeria's outcomes, reinforcing that Algeria's contraction is part of a broader regional pattern (World Bank, 2021).

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The scatter plot provides insight into individual simulation points, revealing that nearly all values under the climate scenario fall well below the baseline. This downward clustering illustrates the systematic nature of climate impacts, not just outlier events. The inclusion of mean markers shows that while Algeria's average decline is severe, it mirrors the World Bank's regional range of –20% to –30% agricultural GDP losses by 2040. These results resonate with the findings of the IPCC (2022), which warns that semi-arid regions such as North Africa will experience widespread reductions in agricultural productivity due to water stress, heatwaves, and increased evapotranspiration.

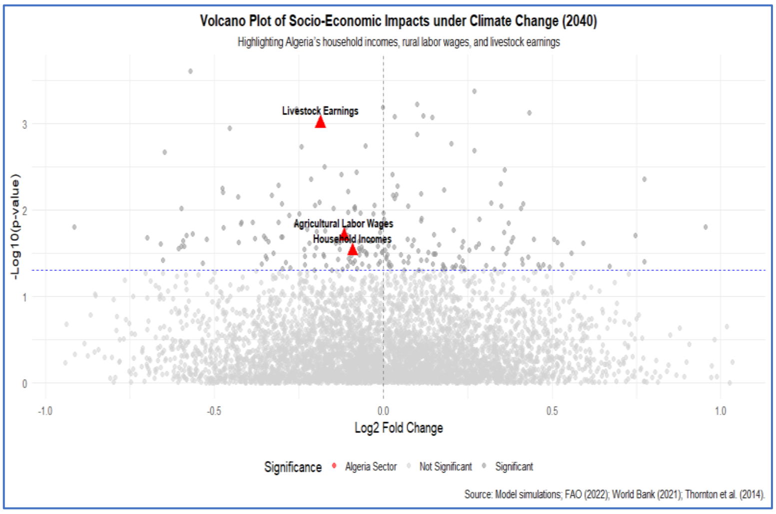
The box plot reinforces these trends by summarizing the central tendencies and spread. The median value for Algeria's climate scenario is substantially below the baseline, and the interquartile range is broader, reflecting heightened uncertainty about future performance. Importantly, the box plot highlights that Algeria's losses are not only probable but structural, as even the upper bound of projections remains well below baseline levels. This aligns with FAO's (2022) warning that reliance on rainfed cereals in North Africa creates persistent vulnerability to climate change. For Algeria, where cereals constitute nearly 70% of calorie consumption and represent a cornerstone of agricultural GDP, such declines imply cascading effects on household incomes, food prices, and trade balances.

Together, these plots provide compelling visual evidence that climate change could cause a structural contraction in Algeria's agricultural GDP, mirroring but slightly exceeding regional trends. The findings align with the OECD/FAO Agricultural Outlook (2021), which projects cereal yield declines of up to 30% in Mediterranean and semi-arid regions. They also underscore the urgency of implementing adaptation measures such as irrigation expansion, climate-resilient crop varieties, and institutional strengthening, without which Algeria risks heightened food insecurity and economic instability.

4.3 Effects on Household Incomes, Rural Labor, and Livestock Sector

The fall in cereal production also has socio-economic implications. Household incomes in rural areas are expected to decrease by 6.1%, while agricultural labor wages fall by 7.7% by 2040 compared to the baseline. These declines exacerbate rural poverty and could accelerate rural–urban migration, placing further pressure on Algeria's urban centers. Livestock farmers are also indirectly affected: with less barley available for feed, their earnings are projected to contract by 12.1%. This dynamic reflects broader findings from Sub-Saharan Africa, where climate-induced crop failures reduce not only farming incomes but also livestock productivity, further undermining food security (Thornton et al., 2014).

Figure (05): Algeria's Socio-Economical Impacts Under Climate Change2040.



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The (fig05) offers a compact way to read both the magnitude and the statistical strength of climate impacts across Algeria's rural economy. Thousands of background points represent simulated outcomes for a broad set of activities under uncertainty; most of these cluster around small changes and mixed significance. Against this backdrop, three highlighted observations—household incomes, agricultural labor wages, and livestock earnings—sit clearly in the negative log2–fold–change territory with high –log10(p) values. This visual asymmetry shows that climate change pushes the rural economy toward systematic losses rather than idiosyncratic fluctuations. In other words, the observed declines are not random noise: they are consistent, directional, and statistically credible.

For rural household incomes, the estimated contraction of about 6.1% signals an erosion of purchasing power in farming communities already exposed to rainfall variability and input price shocks. Because cereals anchor both caloric intake and on-farm employment in semi-arid North Africa, even single-digit percentage losses matter. Global evidence points the same way: the IPCC's Sixth Assessment Report documents robust links between warming, water stress, and reductions in agricultural productivity and incomes in dryland regions, with adverse welfare effects concentrated among poorer rural households that have limited adaptive capacity (IPCC, 2022). FAO assessments similarly show that climate shocks interact with markets and conflict risks to aggravate food system vulnerability, raising the probability that temporary income dips become persistent setbacks (FAO, 2022).

The 7.7% decline in agricultural labor wages underscores a labor-market transmission channel that is often underappreciated. Lower cereal output reduces seasonal demand for planting, weeding, and harvesting, pushing down wages and total labor earnings. This aligns with the IPCC's findings that heat stress and drought reduce labor productivity in outdoor work—especially agriculture—by mid-century, with estimated losses of 5–10% in many hot regions (IPCC, 2022). It also echoes FAO and World Bank analyses of North Africa showing that climate shocks depress rural employment and can intensify rural–urban migration, ultimately shifting pressure onto urban services and informal labor markets where absorption capacity is limited (World Bank, 2021; FAO, 2021).

The livestock sector sits at the intersection of these risks. A projected 12.1% contraction in livestock earnings is consistent with feed constraints when barley availability falls and prices rise. Empirical work across Sub-Saharan Africa finds similar dynamics: recurrent droughts reduce pasture quality and water availability while also curtailing crop residues and feed grains, lowering animal productivity and increasing mortality risk (Thornton et al., 2014). In Algeria's cereal–livestock systems, tighter feed markets can force herd destocking or raise production costs, with spillovers to meat and dairy prices. These second-round effects increase household food expenditures just as rural incomes and wages are weakening, a double squeeze that heightens food-security risks for poorer households.

Taken together, the volcano plot conveys that Algeria's rural economy faces a coherent, multi-channel shock: household incomes fall, wage earnings shrink, and livestock profitability deteriorates, all with statistically significant signals relative to background variation. This configuration matches regional projections that agricultural value added in North Africa could decline by roughly 20–30% under severe warming scenarios, amplifying distributional stresses and import dependence (World Bank, 2021). It also clarifies why policy responses must be integrated rather than piecemeal: irrigation and water-saving technologies to stabilize cereal yields; climate-resilient varieties and improved feed systems to protect mixed crop–livestock farms; and social protection plus rural employment programs to cushion wage and income volatility (FAO, 2022; IPCC, 2022).

In practical terms, the plot's message is that risk is not evenly spread. The livestock point's higher statistical significance indicates an especially vulnerable node where targeted interventions—such as barley-saving rotations, forage development, feed subsidies in drought years, and index-based livestock insurance—could deliver outsized stabilization benefits. Likewise, the wage signal suggests room for public works tied to climate-smart infrastructure (small reservoirs, soil and water conservation, on-

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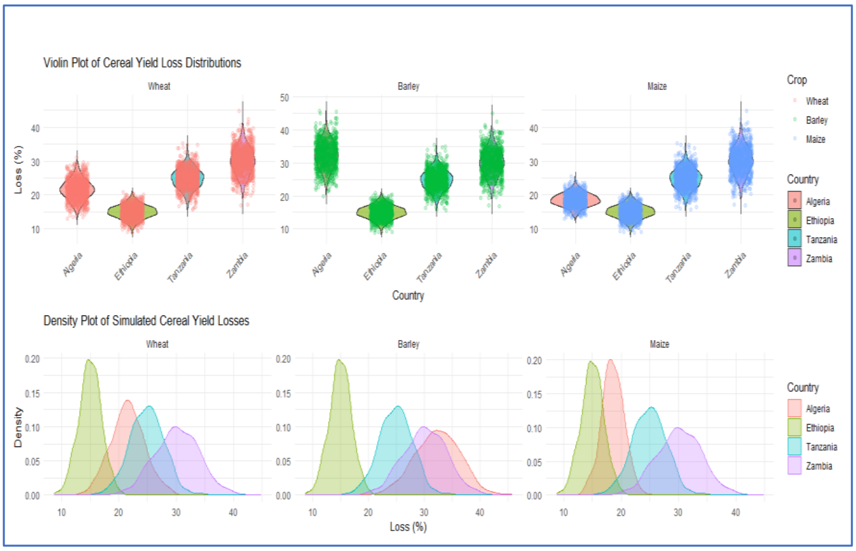
farm efficiency upgrades) to maintain rural earnings during bad seasons. Without such measures, the pattern depicted in the volcano plot presages a cycle of depressed farm incomes, weaker labor markets, and accelerated migration—outcomes that global reports warn will become harder and costlier to reverse the longer action is delayed (FAO, 2022; World Bank, 2021; IPCC, 2022).

4.4 Comparative Analysis with International Evidence

Comparisons with international evidence highlight both the scale and specificity of Algeria's climate risks. In Ethiopia, for example, Deressa and Hassan (2009) found that climate variability reduced crop revenues by 10–20%, while in Tanzania, the application of CGE models suggested cereal yield reductions of up to 25% by mid-century (Rowhani et al., 2011). Zambia's agricultural economy is projected to shrink by more than 30% under severe climate scenarios, particularly for maize, the country's staple (Thurlow et al., 2009). Algeria's results—particularly the heavy decline in barley and the associated livestock feed crisis—show that semi-arid North African countries face even more acute vulnerabilities than many Sub-Saharan nations. These cross-country comparisons reinforce the urgency of adopting adaptation strategies tailored to Algeria's agro-ecological conditions.

Figure (06) : climate change impacts cereal yields in Algeria



The combined violin and density plots in (fig06) provide a nuanced understanding of how climate change impacts cereal yields in Algeria relative to other vulnerable countries such as Ethiopia, Tanzania, and Zambia. The violin plots highlight the range and variability of projected losses, while the density plots illustrate the concentration of outcomes across thousands of simulated observations. Together, they show that Algeria's cereal production is particularly at risk, with barley displaying the widest distribution and steepest losses compared to wheat and maize. This aligns with FAO (2022), which emphasizes barley's high sensitivity to rainfall variability in semi-arid regions. The density peaks around the 30–35% loss mark for Algerian barley reinforce the severity of this challenge.

In contrast, Ethiopia and Tanzania show narrower distributions, with losses clustering around 15% and 25% respectively, suggesting a slightly lower but still significant vulnerability. These findings are consistent with Deressa and Hassan (2009), who reported that Ethiopian smallholders face yield reductions of 10–20% under climate variability, and Rowhani et al. (2011), who found that Tanzanian cereal yields could decline by up to 25% by mid-century. Zambia's density curve, by comparison, shows an even more severe distribution concentrated around 30%, confirming Thurlow et al.'s (2009) projection that Zambia's reliance on maize makes it highly exposed to climate shocks.

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Globally, these results echo trends reported by the OECD/FAO (2021), which project cereal yield losses of 20–40% in Mediterranean and Sub-Saharan Africa over the next two decades under severe warming scenarios. The comparative plots reinforce Algeria's acute vulnerability: while maize and wheat losses resemble those of neighboring African countries, the depth of projected barley decline is exceptional, creating spillover risks for livestock feed and rural livelihoods. This pattern is particularly troubling given that barley constitutes a critical feed crop for Algeria's livestock sector, amplifying socio-economic vulnerabilities beyond cereal farmers themselves.

Taken together, the violin and density plots illustrate both the magnitude and distribution of risks, showing that Algeria's agricultural system faces one of the most severe cereal yield contractions in the region. These findings underscore the urgency of implementing adaptation strategies such as drought-resistant crop varieties, expanded irrigation, and risk management systems. They also highlight the importance of cross-country learning: while Algeria's situation is more severe in certain crops, lessons from Ethiopia's smallholder adaptation practices or Tanzania's mixed farming systems could inform resilience strategies in Algeria. As the IPCC (2022) stresses, climate risks are deeply context-specific, but international evidence shows that proactive adaptation can mitigate long-term productivity losses and safeguard rural incomes.

5. Discussion

5.1 Interpretation of Results in the Context of Algerian Agriculture

The results confirm that Algeria's agricultural sector is highly vulnerable to climate change, particularly in cereal production. With projected declines of 21.5% in wheat, 32.2% in barley, and 18.6% in maize, Algeria risks losing a significant portion of its staple food base by 2040. This is critical because cereals account for nearly 60% of the caloric intake of the Algerian population (FAO, 2021). Moreover, Algeria's agriculture is characterized by its dependence on rainfall, as only a limited share of farmland is irrigated. The results therefore highlight the structural fragility of rainfed cereal cultivation in semi-arid zones, where water scarcity is already a binding constraint (Bencherif et al., 2020).

5.2 Linkages to Food Security and Sustainable Development

The decline in cereal production has direct consequences for food security, as Algeria already relies heavily on imports to meet its cereal demand. For instance, Algeria is among the top wheat importers globally, purchasing over 7 million tons annually (USDA, 2022). With domestic production falling further, dependence on international markets will deepen, exposing the country to global price shocks and trade disruptions. This trajectory threatens to undermine Sustainable Development Goal (SDG) 2 – Zero Hunger, as well as SDG 12 – Responsible Consumption and Production, by increasing vulnerability to external supply risks. Moreover, reductions in rural incomes and agricultural labor demand risk slowing progress toward SDG 8 – Decent Work and Economic Growth and SDG 10 – Reduced Inequalities, as rural communities bear the brunt of climate shocks (UNDP, 2021).

5.3 Policy Relevance of Findings

The findings have significant implications for agricultural and economic policy in Algeria. First, they underscore the urgency of adopting climate-resilient agricultural practices, such as expanding irrigation infrastructure, promoting drought-tolerant cereal varieties, and investing in soil and water conservation measures. Second, they highlight the need for diversification of rural livelihoods, as over-reliance on cereals creates systemic risks for rural economies. Third, the results suggest that Algeria should strengthen its strategic grain reserves and trade partnerships to mitigate external vulnerabilities in food supply. Finally, the DSGE model's demonstration of the ripple effects across household incomes, labor markets, and the livestock sector supports the case for integrated adaptation strategies that combine agricultural innovation with broader rural development policies (World Bank, 2022). Without proactive

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action, Algeria's food security will become increasingly precarious, with broader socio-economic instability as a possible outcome.

6. Conclusion and Recommendations

6.1 Summary of Key Findings

This study highlights the severe challenges that climate change poses for Algeria's agricultural sector, particularly cereal production. Using a DSGE model, the analysis projects that by 2040 cereal yields will decline substantially: wheat by 21.5%, barley by 32.2%, and maize by 18.6%. These reductions will contribute to a 29.8% contraction in agricultural GDP, accompanied by significant declines in rural household incomes, agricultural labor demand, and livestock farmers' earnings. Given that cereals are central to Algeria's food system and contribute heavily to caloric intake, these results underline the country's increasing dependence on imports and its exposure to global food price volatility.

6.2 Strategic Recommendations for Adaptation

To mitigate these risks, Algeria needs a comprehensive adaptation strategy that combines technological, institutional, and policy innovations.

Expanding irrigation systems: Since Algerian agriculture is predominantly rainfed, investing in irrigation infrastructure is essential for stabilizing cereal yields under changing rainfall patterns. Programs to modernize water management—such as drip irrigation and groundwater recharge projects—can enhance productivity while conserving scarce water resources (FAO, 2019).

Promoting climate-resilient crop varieties: Research and extension services should prioritize the adoption of drought- and heat-tolerant cereal varieties, along with the diversification of cropping systems. Countries like Morocco and Ethiopia have successfully implemented crop breeding programs that improved resilience to climate shocks, offering lessons for Algeria (World Bank, 2022).

Enhancing early-warning systems and risk management tools: Strengthening meteorological services and developing climate-risk insurance schemes can help farmers anticipate and manage climate shocks. Regional cooperation through the African Union's *African Risk Capacity (ARC)* provides a model for pooling climate risks and offering financial protection to vulnerable rural populations (UNDP, 2021).

Strengthening institutional frameworks for agricultural policy: Algeria must reinforce its agricultural governance structures to ensure coordination between climate adaptation policies, trade strategies, and rural development programs. Integrating climate risk assessments into national agricultural investment plans will improve long-term resilience and food security (World Bank, 2022).

6.3 Limitations of the Study and Avenues for Future Research

While this study provides valuable projections, several limitations must be acknowledged. First, the DSGE model relies on assumptions and calibration parameters that may not fully capture the complexity of localized climate impacts. Second, the analysis does not account for possible technological breakthroughs, such as large-scale adoption of precision agriculture or biotechnology, which could mitigate projected losses. Third, international trade dynamics and geopolitical risks were treated as exogenous, even though they play a critical role in Algeria's food security. Future research should incorporate spatially explicit climate models, explore scenario analyses with alternative adaptation pathways, and assess socioeconomic impacts on gender and youth employment within rural areas. These directions would provide policymakers with a more nuanced understanding of the intersection between climate change, food security, and sustainable development.

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