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A Computable General Equilibrium Analysis

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Water Scarcity and Improved Water Use Efficiency in Tunisia: A Computable General Equilibrium Analysis

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Abstract

Under global warming conditions, projections from the Tunisian National Institute of Meteorology indicate that Tunisia will face decreased annual rainfall and increased demand for water resources in the coming years. This research aims to quantify the potential impacts of water scarcity on the Tunisian economy, with a particular focus on the agricultural sector, which is crucial for food security and economic stability. Using a recursive dynamic Computable General Equilibrium (CGE) model, we analyse the effects of four water-related hypotheses on GDP growth, social welfare, and trade balance by 2050. Then we simulate three specific water use efficiency (WUE) scenarios—rehabilitation of water network infrastructure, modernization of irrigation systems, and the use of plant varieties with less water requirements to assess their effectiveness in mitigating water scarcity. Simulation results reveal that declining water availability significantly hampers agricultural production, adversely affecting the food processing sector and exacerbating food security concerns. These limitations lead to an increased trade balance deficit and a projected decline in GDP by 2050. In contrast, improvements in WUE partially alleviate these impacts by enhancing agricultural productivity, reducing imports, and boosting exports, which collectively improve the trade balance and stimulate GDP growth. The findings underscore the urgent need for practical actions to conserve water resources and highlight the importance of negotiating trade agreements that prioritize low-water-requiring products while managing the import of more water-intensive goods.

Keywords: Water Scarcity, Climate Change, Water Use Efficiency, Agricultural Productivity, Food Security, Virtual Water Trade, CGE Modelling

1 Introduction

The unrestrained growth of greenhouse gas emissions is raising global temperatures, leading to irregular rainfall patterns and more extreme weather events. These climatic changes significantly impact water resource availability, particularly within the agricultural sector, which is highly vulnerable to climate variability. Rising temperatures increase evaporation, thus reducing water supply while simultaneously boosting demand, especially from agriculture. As a result, crop yields are projected to decline, posing risks to food security and agricultural markets [IPCC, 2023].

According to the Intergovernmental Panel on Climate Change's Sixth Assessment Report [IPCC, 2023], the Mediterranean region is expected to experience a temperature increase 20% higher than the global average by the 21^{st} century. This rise, combined with anticipated declines in annual rainfall, poses serious risks to crop production, especially in Maghreb countries where agricultural output could decrease by approximately 64%. In Tunisia, projections from the National Institute of Meteorology [INM, 2015] indicate that the country will face both rising temperatures and decreasing rainfall, resulting in an imbalance between water supply and demand.

Tunisia's agricultural sector is the largest consumer of water, accounting for 75% to 80% of total water withdrawals [MAGRHP, 2023b]. Despite this, many farmers continue to use inefficient irrigation practices, leading to considerable water losses. Inefficiencies in water use are further exacerbated by waste within outdated and poorly maintained infrastructure, with water losses estimated at around 40% in irrigation networks [MAGRHP, 2020]. These inefficiencies lead to water wastage through evaporation, soil degradation, and over-irrigation. Studies, such as [Yilmaz et al., 2023], suggest that changing climate conditions will further compromise both the quality and quantity of Tunisia's water resources, with projected annual average yield declines from 2021 to 2050 of 2% for tomatoes and dates, 0.5% for olives, and 0.2% for wheat. These reductions in agricultural output not only threaten long-term food security but are also likely to disrupt Tunisia's trade balance, increasing reliance on imports while reducing exports.

The primary objective of this research is to investigate how freshwater resource shortages, worsened by climate change impacts on annual rainfall, could affect Tunisia's economy. Specifically, this study addresses the following questions: How do shortages in water resource availability impact Tunisia's economic growth? To what extent could efficient water use mitigate the adverse effects of projected water scarcity on the Tunisian economy?

To address these questions, we will use AGWA-TUN, a recursive dynamic Computable General Equilibrium (CGE) model tailored to Tunisia. This model enables a variety of simulations of the Tunisian economy under different water shortage scenarios, allowing for an evaluation of the economic implications of limited water availability. We will also explore how improving water use efficiency (WUE) in the agricultural sector could alleviate the negative impacts of water constraints in Tunisia.

This paper is structured as follows: Section 2 describes water issues in Tunisia; Section 3 reviews empirical literature on the Agriculture-Water-Food nexus using CGE models; Section 4 outlines the structure and calibration of the AGWA-TUN model; Section 5 presents the main scenarios considered in this research; Section 6 discusses the simulation results; and Section 7 summarizes the findings and provides recommendations.

2 Water Issues in Tunisia

Tunisia is characterized by limited and unequally distributed water resources, which vary annually and regionally. The over-exploitation of these resources has become a structural problem, placing considerable pressure on water mobilization [CCNUCC, 2023]. Water scarcity is further exacerbated by the country's growing population and the impacts of climate change, which are projected to significantly reduce both rainfall and water availability. Recent studies indicate that pressure on water resources will intensify by 2050, positioning Tunisia as one of the most water-stressed countries in the Mediterranean region [MAGRHP, 2023a].

Despite investments in water mobilization and transfer infrastructure, water availability has declined significantly over recent decades due to dam siltation, over-exploitation of aquifers, and inefficient water management. Progressive siltation of dams and over-exploitation of aquifers have decreased mobilization capacity, thus reducing Tunisia's overall water supply. In 2021, large dams experienced an average siltation[1] rate of 23%, resulting in an annual loss of 675 Mm^3 from an initial capacity of 2988 Mm^3 [MAGRHP, 2021]. Current trends show groundwater levels depleting faster than they are replenished, further compounding the issue.

Water demand in Tunisia is primarily driven by irrigation and potable water needs. Within sectoral water demand, the agricultural sector remains the largest consumer, accounting for 75% to 80% of total water withdrawals annually [MAGRHP, 2023b]. However, outdated irrigation systems and infrastructure inefficiencies lead to substantial water losses, particularly in agricultural areas.

The water sector in Tunisia faces several critical challenges, especially due to climate change. In recent years, significant warming trends have made Tunisia one of the Mediterranean countries most vulnerable to climate change [CCDR, 2023]. Projections from the National Institute of Meteorology [INM, 2015] estimate a 5% to 10% reduction in total annual rainfall by 2050 under the RCP 4.5 scenario. In the worst-case RCP 8.5 scenario, rainfall could decrease by up to 14%, further disrupting water availability. Rising temperatures, coupled with declining rainfall, are expected to intensify land erosion, soil degradation, and desertification. Additionally, rising sea levels due to climate variability pose serious risks to Tunisia's coastal regions, leading to further erosion and loss of fertile agricultural land. These climate impacts are likely to disrupt Tunisia's water supply-demand balance, creating a cycle of declining agricultural productivity and increased water stress.

Agricultural productivity in Tunisia is already under threat, especially for staple crops. According to projections under the RCP 8.5 scenario by [Yilmaz et al., 2023], Tunisia's main crops are expected to suffer significant losses, with barley and wheat production anticipated to decline annually by 0.9% and 0.2%, respectively, by 2050. Such decreases will exacerbate food security concerns, as Tunisia will need to import more food to meet domestic demand, increasing dependency on international markets and driving up food prices.

In terms of Tunisia's major agricultural exports, [Yilmaz et al., 2023] projects similar declines for key export crops like tomatoes, dates, and olives, which are vital to Tunisia's agricultural sector and export revenues. Tomatoes and dates are expected to experience

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[1] Siltation: the process by which soil particles are eroded, transported by flowing water or other means, and deposited as layers of solid particles in water infrastructure, particularly dams. Siltation presents a significant challenge in mobilizing water resources in Tunisia [ONAGRI, 2021].

an annual decline of 2%, while olive production may fall by 0.5% by 2050. These declines could severely impact Tunisia's trade balance and exacerbate existing economic challenges.

A related issue is the concept of virtual water exports. Tunisia exports many water-intensive agricultural products, such as olives and tomatoes, which deplete the country's already limited water resources. As noted by [Benalaya et al., 2017], exporting such water-intensive products increases Tunisia's virtual water footprint, placing additional strain on water resources. Given the rising demand from both domestic and export markets, urgent action is needed to improve water management efficiencies and prevent further depletion of Tunisia's water supplies.

3 Assessing the Economic Impacts of Water Scarcity Using CGE Models

This section reviews previous studies on the economic impacts of climate change and water scarcity, particularly in agricultural and trade contexts, showing the role of policy instruments aimed at improving water use efficiency for sustainable development. The economic effects of climate change have garnered significant attention, highlighting the need for effective policymaking to mitigate socioeconomic impacts [Ahmadi et al., 2022]. Agriculture, due to its heavy reliance on water resources and vulnerability to fluctuations in temperature and rainfall, is especially susceptible to these impacts [Ingram et al., 2012, Cui and Xie, 2022, Malhi et al., 2021]. Research increasingly documents the detrimental effects of climate change on GDP, growth, and employment [Salami et al., 2009, Roson and Van der Mensbrugghe, 2012, Al-Riffai et al., 2012, Khalili et al., 2021], revealing that climate-induced disruptions disproportionately affect developing economies.

For instance, [Salami et al., 2009] reported that severe droughts could reduce agricultural value-added by approximately 30%, leading to GDP declines of nearly 4%. These impacts are particularly pronounced in developing nations; [Roson and Van der Mensbrugghe, 2012] found that climate variations significantly affect GDP in such regions, exacerbating poverty and food insecurity. In India, [Udmale et al., 2015] observed that climate-induced droughts reduced crop yields and livestock production, leading to decreased income and limited unskilled employment opportunities. Similarly, [Siddig et al., 2020] demonstrated that extreme climate impacts on Sudan's GDP intensified vulnerabilities among low-income households. Expanding this context, [Shahpari et al., 2023] examined climate impacts on Iran's agricultural sector using a CGE model, simulating production reductions of 6%, 12%, and 18%, which resulted in potential GDP declines of 3.7% to 6.3%. They highlighted significant labor migration from agriculture as rural incomes shrank, projecting worsened food insecurity and a trend of converting farmland to non-agricultural uses. The authors suggested that Iran could mitigate these impacts through investments in water-efficient irrigation, climate-adapted crops, and improved water resource management.

To address climate change-induced water scarcity, CGE models are often employed to evaluate the effectiveness of various water-use policies. Strategies such as water pricing, taxes, subsidies, public investment in water infrastructure, and direct improvements in water efficiency have been assessed for their potential to conserve water and reduce economic disruptions. Studies by [Rivers and Groves, 2013] and [Zhao et al., 2016] indicate that water pricing reforms can effectively reduce water use and enhance efficiency. For example, [Rivers and Groves, 2013] assessed water pricing in Canada, showing that higher prices led to reduced consumption. Similarly, [Zhao et al., 2016] found that increased water prices in China resulted in significant water savings and improved usage efficiency. Furthermore, [Berrittella et al., 2008b] and [Qin et al., 2012] examined water taxes in China, revealing that such policies influenced the economic structure by shifting production patterns to conserve water.

Investments in desalination and wastewater treatment have also been explored as solutions to water scarcity. [Luckmann et al., 2014] and [Briand et al., 2023] reported positive economic outcomes from such investments. [Luckmann et al., 2014]'s study in Israel showed that desalination increased water availability, although high costs limited its economic benefits, underscoring efficient water use as a more cost-effective solution. [Briand et al., 2023] demonstrated that combining desalination with wastewater reuse in South Africa enhanced GDP and reduced unemployment.

Given that agriculture is a major water consumer, enhancing irrigation efficiency is essential. [Calzadilla et al., 2011], [Taheripour et al., 2020a], and [Taheripour et al., 2020b] highlight that advances in irrigation efficiency can lead to substantial water savings. For instance, [Calzadilla et al., 2011] utilized the GTAP-W model to show that improvements in irrigation efficiency in water-stressed regions not only conserved water but also boosted agricultural productivity and welfare. [Calzadilla et al., 2010] applied the IMPACT model to analyse economy-wide impacts of climate change on agricultural sectors, demonstrating that without adaptation strategies, climate change would significantly affect production and trade patterns. Similarly, [Osman et al., 2016] found that efficient irrigation practices in Egypt could offset potential water losses from the Nile, positioning water efficiency as a crucial strategy for food security. In Iran, [Javadi et al., 2023] examined the implications of climate change for food security, with a CGE model projecting reduced productivity of key staples like wheat and rice. These findings raise significant concerns regarding food availability and price stability, especially given the reliance on domestically produced crops for food security.

In Tunisia, research on water-related issues using Computable General Equilibrium (CGE) models is limited. Notably, the study by [Chemingui and Thabet, 2016] stands out, as it explores the economy-wide impacts of various water management policies in both Tunisia and Morocco. The research employs a dynamic water-CGE model for each country, integrating water as a production factor alongside land and two types of capital. The authors investigate three alternative scenarios: cutting subsidies on water prices, doubling public spending on water mobilization, and analyzing the combined effects of both policies. The results show that low water costs encourage farmers to engage in more water-intensive agricultural activities. While reducing subsidies led to improved water management by directly affecting irrigation water use and reallocating resources between agricultural and non-agricultural sectors, it also resulted in short- to medium-term income losses for farmers. However, these losses were expected to decrease over time as farmers adopted more water-efficient technologies.

Despite the valuable insights provided by this study, a significant gap remains in the literature regarding the broader economic implications of water scarcity in Tunisia. The challenge of integrating climate change impacts into standard CGE models adds complexity, as the uncertainty surrounding water availability in future climate scenarios cannot be easily addressed by traditional approaches. As a result, many studies have employed hybrid models, linking CGE with partial equilibrium models to simulate water supply under various climate scenarios.

Furthermore, while there has been some research on water management in Tunisia through taxation and subsidy schemes, there has been no comprehensive analysis of the wider economic consequences of water scarcity. This research aims to fill this gap by using CGE modelling to assess the economic repercussions of water constraints on Tunisia's economy. In addition, it will propose mitigation policies, building on previous findings to provide a thorough understanding of the challenges and potential solutions to water scarcity in Tunisia.

In summary, while water pricing and public investment in water infrastructure are valuable strategies, improving water use efficiency—particularly in agriculture—emerges as a crucial approach to addressing water scarcity and maintaining economic stability. These studies indicate that direct improvements in irrigation efficiency offer the most significant benefits for water conservation and economic resilience.

4 AGWA-TUN: An Agriculture-Water CGE Model for Tunisia

4.1 Specification

To achieve our research objectives, we explored various modelling approaches, including partial equilibrium modelling, input-output analysis, and computable general equilibrium (CGE) modelling. Among these, CGE modelling emerges as the most suitable approach for a comprehensive analysis of the economic impacts of water scarcity, allowing for detailed sectoral analysis and capturing inter-sectoral interactions across the entire economy, as suggested by [Taheripour et al., 2020b].

The Agriculture-Water focused CGE model for Tunisia, AGWA-TUN, is adapted from a CGE model developed by [Dissou, 2002] but incorporates several unique features. Tunisia is modelled as a small open economy, with world prices of imports and exports treated as exogenous. The economy is represented by five production sectors, producing the following commodities: agriculture (AGR), food processing (AFI), water (WATER), other industries (OTH_IND), and services (SERVICES). The model utilizes three primary production factors: labour (LAB), capital (CAP), and land (La). Land is treated as an implicit production factor, utilized exclusively by the agricultural sector in combination with capital. Given that water rights are often linked to land titles, the land value indirectly encompasses the water value, following the rationale of [Calzadilla et al., 2017].

AGWA-TUN operates as a sequential dynamic CGE model, enabling long-term simulations and providing a comprehensive view of the economy. The model consists of multiple equation blocks, with mathematical specifications detailed in the appendix.

4.2 Calibration

The calibration of AGWA-TUN is based on a Social Accounting Matrix (SAM) developed by [ITCEQ, 2021] for Tunisia for the year 2016. This SAM was adjusted to align with the study's objectives, incorporating modifications that involved aggregating and disaggregating economic sectors. Since the SAM does not explicitly represent the water sector, we supplemented it using Tunisia's 2016 supply-use table provided by the National Statistics Institute of Tunisia [INS, 2022]. Following the adjustments, the matrix encompasses 15 accounts, covering five activities and commodities, two production factors, three tax categories, an accumulation account, and four types of agents: households, firms, government, and the rest of the world.

5 Scenario Design

5.1 Water-Related Hypotheses

Recent studies indicate a trend toward drier, warmer climates in Tunisia, with expected increases in temperature and reductions in precipitation [INM, 2015]. Projections based on the Intergovernmental Panel on Climate Change (IPCC)'s RCP scenarios suggest a decline in precipitation by 5% to 10% under RCP 4.5 and by 1% to 14% under RCP 8.5. For a more optimistic outlook, [Roson and Sartori, 2015] suggests a 10% decline in precipitation by 2050, referencing the Special Report on Emissions Scenarios (SRES) A1B, which envisions a world characterized by rapid economic growth and sustainable energy development.

To assess the potential economic effects of these changes, we establish four water-related hypotheses:

- H0 (No water scarcity): A hypothetical benchmark scenario with no water constraints.
- H1: 5% reduction in water availability by 2050.
- H2: 10% reduction in water availability by 2050.
- H3: 14% reduction in water availability by 2050.

5.2 Water Use Efficiency Scenarios

Given that one of the primary purposes of CGE models is to evaluate the impact of policies, we compare three scenarios aimed at mitigating water shortages in Tunisia through improvements in WUE. Following [Taheripour et al., 2020a], WUE policies are particularly promising in addressing water scarcity, as they facilitate increased output with the same water volume or maintain output with reduced water use.

In Tunisia, a significant constraint on the agricultural sector is the outdated infrastructure, particularly dams, which have not received adequate maintenance. This neglect threatens water quality and results in substantial water losses during distribution. Therefore, rehabilitating water reservoirs and distribution networks could effectively conserve water resources in agriculture and enhance their efficient use. Additionally, many farmers in Tunisia continue to employ inefficient irrigation techniques, leading to increased water losses due to evaporation, soil degradation, and over-irrigation. Consequently, modernizing irrigation infrastructure could serve as a viable alternative to combat water scarcity issues, as demonstrated by [Ahmed et al., 2024] in Egypt. Furthermore, promoting the cultivation of non-water-intensive and temperature-resistant crop varieties could enhance crop productivity while reducing overall water requirements.

To evaluate the economic implications of WUE policies in the agricultural sector, we impose three levels of productivity improvements: 5%, 10%, and 15% increases in the agricultural sector's productivity factor relative to the baseline scenario (H2). These cases are examined in conjunction with the water scarcity hypothesis (H2). We treat scenario (H2) as our reference scenario, meaning that results for each WUE scenario will be compared against it, denoting these scenarios as (WUE_5%), (WUE_10%), and (WUE_15%) to differentiate between the three levels of improvements, as summarized in Table 1. To simulate these scenarios, we incorporate external shocks to enhance factor-specific

Table 1: Summary of Water Use Efficiency Scenarios

Scenario	Description	Interpretation
WUE_5%	5% improvement by 2050	Rehabilitation of water networks
WUE_10%	10% improvement by 2050	WUE_5% + Modernization of the irrigation infrastructure
WUE_15%	15% improvement by 2050	WUE_10% + Use of less water-intensive crops

Source: By author

productivity in the agricultural production function, adopting the same methodology as [Osman et al., 2016].

The varying levels of improvements allow us to assess how the combination of multiple strategies could influence the impacts of water shortages on the Tunisian economy. Importantly, we will conduct a cost-benefit analysis for each scenario to evaluate the economic costs and benefits associated with the efficient use of water in Tunisia, which is essential for justifying the proposed policy interventions.

Additionally, it is crucial to consider alternative adaptation methods, such as consumption control, virtual water-based business models, and waste management, to provide a more comprehensive approach to mitigating water scarcity. We will explore these strategies further to ensure that our recommendations encompass a range of viable options.

Our model was solved and scenarios simulated using the General Algebraic modelling System (GAMS).

6 Simulation Results

Following the sequential approach illustrated in Figure B1 in the appendix, we begin by analyzing the impacts of water shortages in Section 6.1. This section primarily focuses on the sectoral impacts of water scarcity and how these impacts influence trade patterns in Tunisia, along with their repercussions on the country's economic growth. Subsequently, in Section 6.2, we will explore how improvements in Water Use Efficiency (WUE) can mitigate the effects of limited water availability in Tunisia.

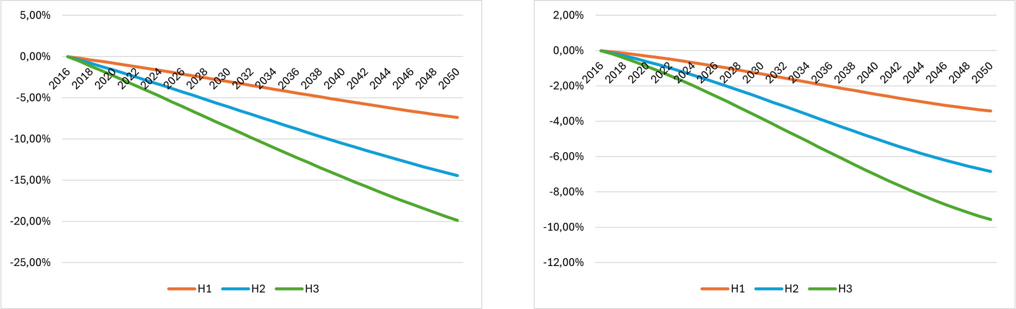
6.1 Impacts of the Decrease in Water Availability

6.1.1 Impacts on Sectoral Outputs

At this stage, we will compare the impacts of varying levels of water resource reduction against a scenario with no water constraints (H0). Our analysis will focus on the interplay between the agricultural and food processing sectors, aligning with the objectives of our research. As illustrated in Figure 1, simulation results indicate that the projected decrease in annual rainfall will adversely affect sectoral outputs. The impacts differ across sectors and are contingent on the degree of water availability reduction, revealing that both economic activities will suffer due to water resource shortages, either directly or indirectly.

The agricultural sector, as the largest consumer of water in Tunisia, experiences the most significant impact, with a projected 19.87% decrease in production levels by 2050 under the water scarcity hypothesis (H3), compared to the hypothetical situation (H0) without

Figure 1: Percent Changes in Sectoral Outputs under the Water-Related Hypotheses compared to (H0)

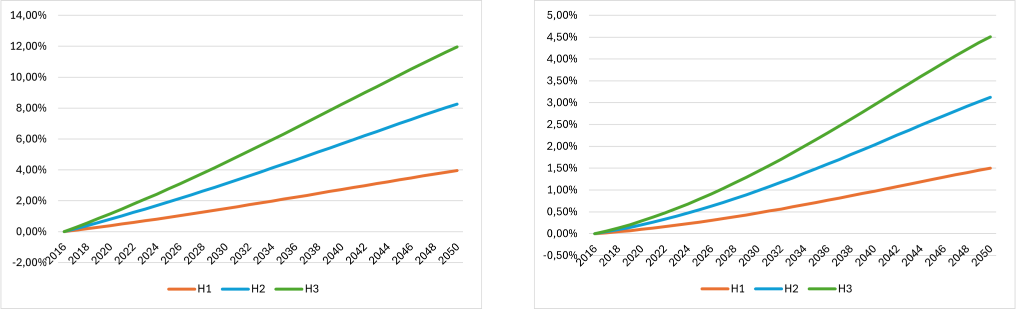


(a) Case of the Agricultural Sector (b) Case of the Food Processing Sector

Source: Authors' simulation results

water constraints. Reduced annual rainfall will constrain rainfed agricultural yields and limit irrigation capacity, adversely affecting irrigated crop yields. The long-term impacts are substantial, with decreases ranging from 7.39% (H1) to 19.87% (H3) depending on the level of water availability reduction.

Figure 2: Percent Changes in Commodities Prices under the Water-Related Hypotheses compared to (H0)



(a) Case of the Agricultural Sector (b) Case of the Food Processing Sector

Source: Authors' simulation results

Food security may also become a concern in the long term, as simulations show a significant decrease in the production of food commodities, albeit at a lower rate than that of agricultural production. The food processing sector relies heavily on crops and water as intermediate inputs, directly tying its production levels to agricultural yields and, consequently, to water availability. Thus, climate variability, which impacts both water resources and agricultural productivity, subsequently affects the production levels in the food processing sector, as illustrated in Figure 1b.

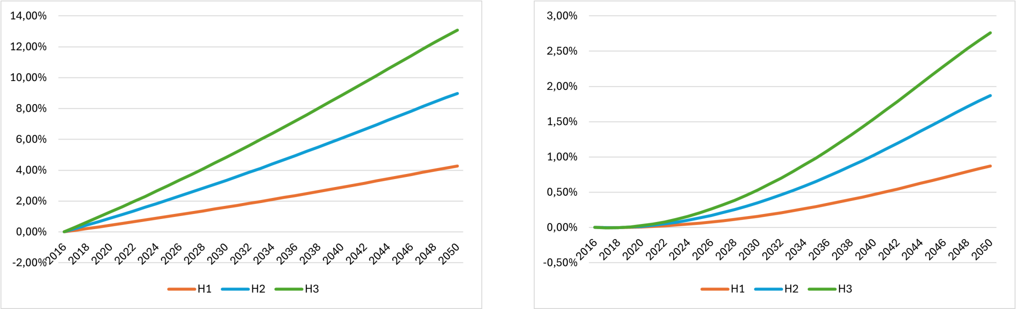
Regarding product prices, reductions in water resource availability in Tunisia are expected to increase agricultural product prices by approximately 3.97%, 8.26%, and 11.96% by 2050 under the three water-related hypotheses (H1, H2, H3), respectively. It is evident that greater reductions in water availability lead to more substantial impacts on agricultural commodity prices.

Price impacts also vary across sectors, as shown in Figure 2. An increase in food prices is anticipated due to the rising agricultural commodity prices. The food processing industries rely on agricultural produce as inputs for transformation into food commodities. Therefore, price increases in agricultural products translate into higher costs for the food processing sector, ultimately resulting in a price rise of 4.51% under (H3) by 2050 compared to the baseline situation (H0).

6.1.2 Impacts on International Trade Indicators

Water shortages, by affecting domestic production, are projected to have significant repercussions on trade patterns. Simulation results indicate that changes in climatic conditions and decreased annual rainfall will adversely impact agricultural production levels, thereby affecting trade patterns in Tunisia, as illustrated in Figures 3a and 4a.

Figure 3: Percent Changes in Sectoral Imports under the Water-Related Hypotheses compared to (H0)



(a) Case of the Agricultural Sector (b) Case of the Food Processing Sector

Source: Authors' simulation results

Under water constraints, Tunisia will increasingly rely on imports of agricultural and food commodities to ensure food security in the long term. This increase in agricultural product imports can be viewed as an increase in virtual water imports[2]. By importing agricultural or food commodities, Tunisia essentially imports water resources, which helps preserve not only food security but also its water resources. As indicated by [Hoekstra and Hung, 2003], countries facing water challenges may opt to import ”water-intensive products” rather than producing them domestically, representing a “market response strategy” to address water scarcity in Tunisia, a water-scarce country, according to [Roson and Sartori, 2015] and [Souissi et al., 2019].

With regard to sectoral exports, simulation outcomes indicate that water constraints negatively affect agricultural exports by 2050. This decline is primarily attributed to decreased agricultural production in Tunisia, which adversely impacts the production levels of food processing industries, leading to reduced exports of food commodities, as shown in Figure 4b. For both the agricultural and food processing sectors, a larger reduction in water resource availability corresponds to a greater decrease in export rates.

According to the Tunisian Ministry of Agriculture, [MAGRHP, 2023a], Tunisia's primary exports in terms of agricultural and food products include olive oil, dates, tomatoes,

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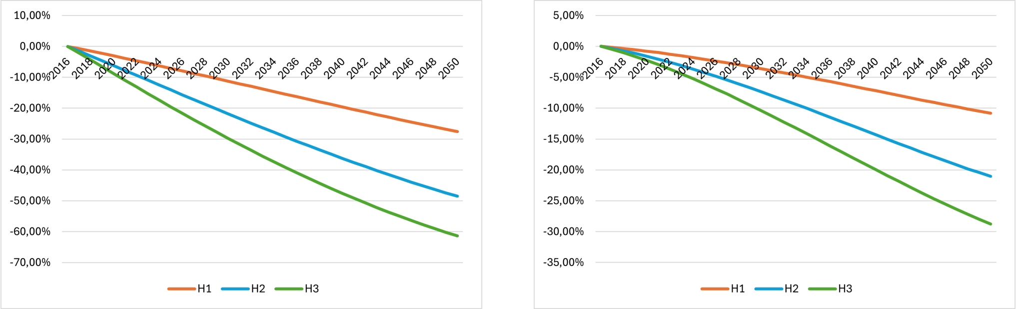
[2] Virtual water refers to the volume of water utilized in the production processes of agricultural or industrial commodities, as defined by [Hoekstra and Hung, 2003].

Figure 4: Percent Changes in Sectoral Exports under the Water-Related Hypotheses compared to (H0)

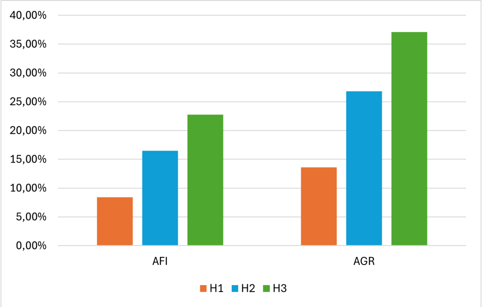


(a) Case of the Agricultural Sector (b) Case of the Food Processing Sector

Source: Authors' simulation results

tomato-based products, and citrus. As noted by [Benalaya et al., 2017], these products are considered water-intensive. Consequently, a decline in water availability leads to reduced agricultural and food exports. Furthermore, agricultural production and food processing activities, such as those for olive oil and processed tomatoes, require substantial water volumes. Thus, diminished water resource availability in Tunisia affects both agricultural commodities' production and food processing industries, resulting in decreased domestic production and, consequently, reduced exports from Tunisia.

Figure 5: Percent Changes in Agricultural and Food Trade Balances by 2050 Compared to (H0)



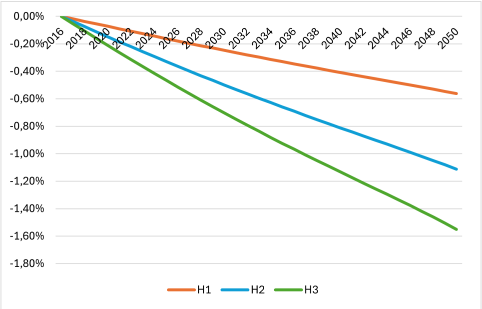
Source: Authors' simulation results

The impacts of water scarcity on trade balances are illustrated in Figure 5. The agricultural trade balance is projected to decline due to increased imports and reduced exports. Although the food processing trade balance remains stable under scenarios of slight water availability reductions, significant water shortages will also adversely affect food processing trade balances due to reduced exports in the food processing sector. Consequently, there is a projected decline in agricultural and food trade balances under all water availability reduction hypotheses (H1, H2, H3) compared to (H0).

6.1.3 Macroeconomic Impacts

The impacts of reduced water availability on Tunisian GDP are significant and negative. As illustrated in Figure 6, simulation results indicate a downward trend, projecting a decrease of 1.55% under scenario (H3) compared to (H0). Notably, GDP declines correspond with the severity of water shortages; the more severe the reduction in water availability, the greater the GDP contraction observed. This trend highlights the critical relationship between water resources and economic performance.

Figure 6: Percent Changes in the Tunisian GDP under the Water-Related Hypotheses compared to (H0)



Source: Authors' simulation results

Furthermore, the agricultural share of GDP is projected to decline between 13.68% and 37.50% by 2050, depending on the severity of water resource reductions 7a. TA similar trend is observed in the food processing sector, although the decrease is less pronounced than in agriculture 7b.

Figure 7: Percent Changes in Sectoral Share of GDP under the Water-Related Hypotheses compared to (H0)

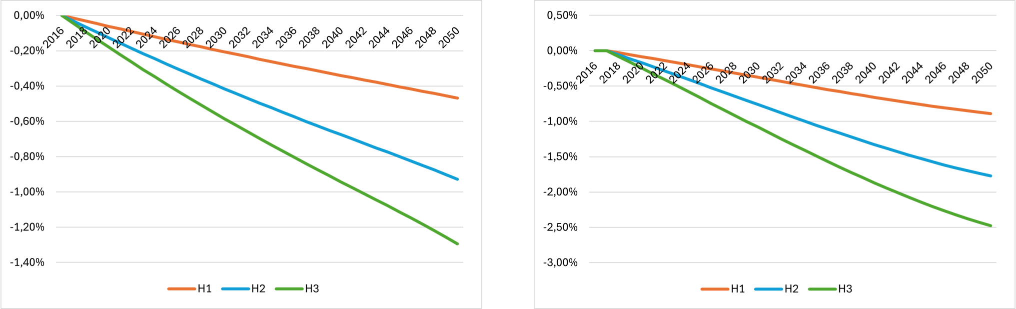
(a) Case of the Agricultural Sector (b) Case of the Food Processing Sector

Source: Authors' simulation results

As noted by [Taheripour et al., 2020b], reductions in water availability negatively affect the economic share of various sectors in national GDP. Our simulation results confirm that both agricultural and non-agricultural activities are adversely impacted by water shortages. The direct effect of diminished water resources on agricultural production also detrimentally influences other sectors that either supply agricultural inputs or process agricultural outputs.

Moreover, simulation results indicate that the wage rate is expected to decline under all water shortage scenarios 8a. This decline leads to decreased consumer revenues, which in turn diminishes consumption and savings capacities. Consequently, government revenues are expected to decrease, further exacerbating reductions in savings and total investments

Figure 8: Percent Changes in Wage Rate and Welfare under the Water-Related Hypotheses compared to (H0)



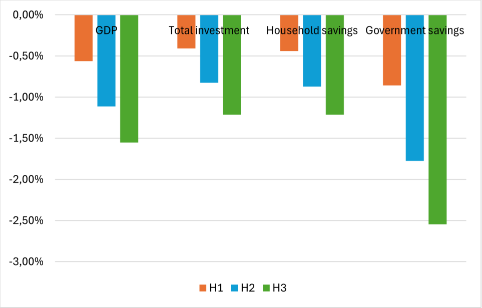
(a) Wage Rate (b) Welfare

Source: Authors' simulation results

within the economy, as depicted in Figure 9.

Social welfare is also adversely affected by water constraints, as illustrated in Figure 8b. The decline in welfare varies based on the severity of water availability reductions. Contributing factors include decreased sectoral outputs, limited domestic goods supply, rising prices of goods, and declining wage rates. Together, these factors diminish households' disposable incomes and consumption levels, ultimately resulting in deteriorating social welfare over the long term.

Figure 9: Percent Changes in Macroeconomic Indicators under the Water-Related Hypotheses compared to (H0)



Source: Authors' simulation results

Based on our simulations, we find that the impacts of water scarcity remain consistent across scenarios (H1), (H2), and (H3); however, the severity of impacts escalates with decreasing water resources. The hypotheses—5%, 10%, and 14% reductions—were analyzed under RCP scenarios 4.5 and 8.5. Scenarios (H1) and (H3) represent extreme cases, while (H2) (10%) serves as a moderate reference. This aligns with the findings of [Roson and Sartori, 2015], which identified a 10% reduction in precipitation by 2050 under the SRES Scenario A1B as significant. Thus, (H2) will be utilized as a reference scenario for subsequent analyses of water use efficiency (WUE) improvements.

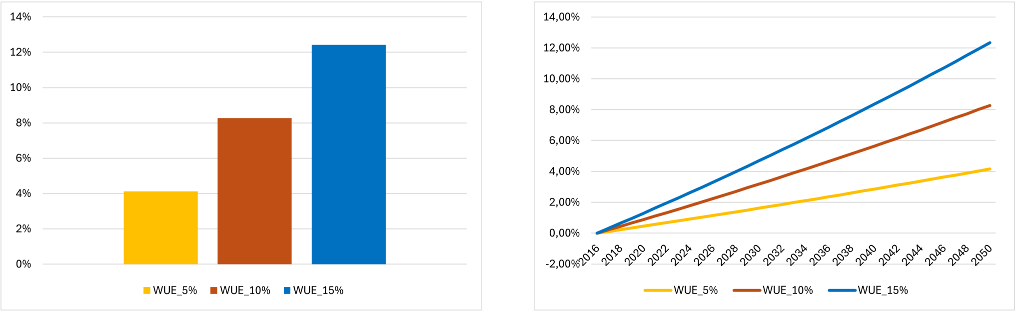
6.2 Impacts of the WUE Policies

6.2.1 Impacts on Sectoral Outputs

Enhancing Water Use Efficiency (WUE) in the agricultural sector is crucial for preserving water resources. This study simulates WUE scenarios by introducing an exogenous shock to increase factor-specific productivity in the agricultural production function, consistent with the methodology outlined by [Osman et al., 2016]. Such reforms are pivotal as they address challenges faced by the agricultural sector, enabling water conservation and equitable distribution among users. Consequently, these improvements bolster crop yields and contribute to sustainable production by allowing for increased outputs with the same water volume or maintaining output levels while reducing water consumption. This incentivizes firms to elevate production levels, thus maximizing profits and spurring further investment.

As depicted in Figure 10a, agricultural investment demand rises proportionately with the rate of WUE improvement.

Figure 10: Percent Changes in Investment Demand and Productivity of the Agricultural Sector, by 2050, under WUE Policies Compared to (H2)



(a) Investment Demand (b) Productivity

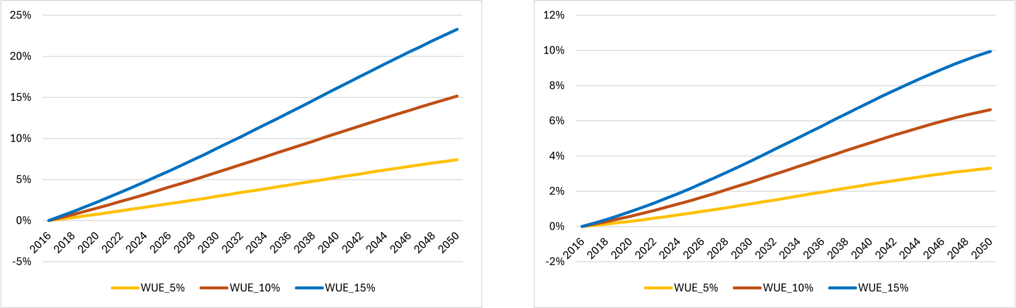
Source: Authors' simulation results

Figure 11illustrates that while the intensity of impact varies between sectors, both benefit from the agricultural sector's expansion driven by WUE improvements. Long-term projections indicate significant increases in sectoral outputs, ranging from 7.42% (WUE_5%) to 23.29% (WUE_15%) by 2050, dependent on the improvement levels. Implementing WUE strategies facilitates not only optimal water usage but also the conservation of hydraulic resources, thereby boosting productivity, as shown in Figure 10b.

The food processing sector also experiences positive outcomes from these agricultural advancements, with food production projected to rise by approximately 9.94% by 2050 under the WUE_15% scenario compared to (H2). The literature supports the notion that WUE policies in agriculture can mitigate some adverse effects of water scarcity on food security, as highlighted in previous studies [Osman et al., 2016, Taheripour et al., 2020b, Ahmed et al., 2024].

Both sectors derive benefits from WUE policies in agriculture, with simulations indicating that higher rates of WUE improvement correlate with greater economic benefits. The observed increases in agricultural outputs stem from enhanced water use efficiency strategies, including the rehabilitation of water reservoir infrastructure and distribution networks, which reduce water losses and improve water quality. Implementing more

Figure 11: Impacts on Sectoral Output under WUE Policies Compared to (H2)

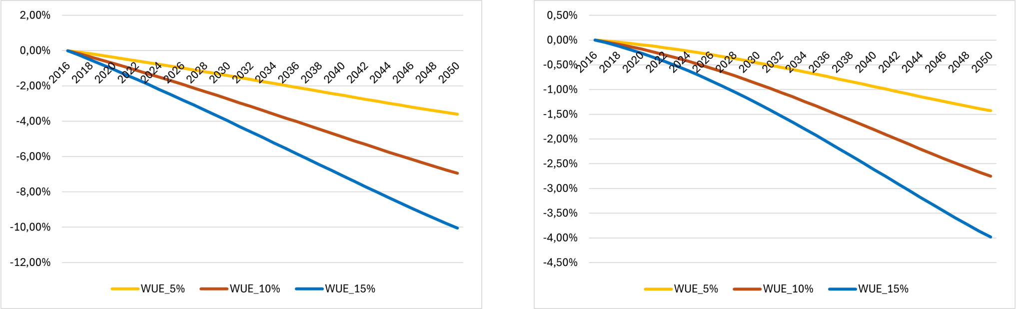


(a) Case of the Agricultural Sector (b) Case of the Food Processing Sector

Source: Authors' simulation results

efficient irrigation techniques further minimizes water usage during irrigation, thus increasing productivity per unit of water used. Additionally, cultivating crop varieties with lower water requirements supports water resource preservation and enhances crop yields. Regarding consumer prices, Figure 12 demonstrates that enhancing water efficiency mitigates some price increases induced by water shortages under (H2).

Figure 12: Impacts on Sectoral Prices under WUE Policies Compared to (H2)



(a) Case of the Agricultural Sector (b) Case of the Food Processing Sector

Source: Authors' simulation results

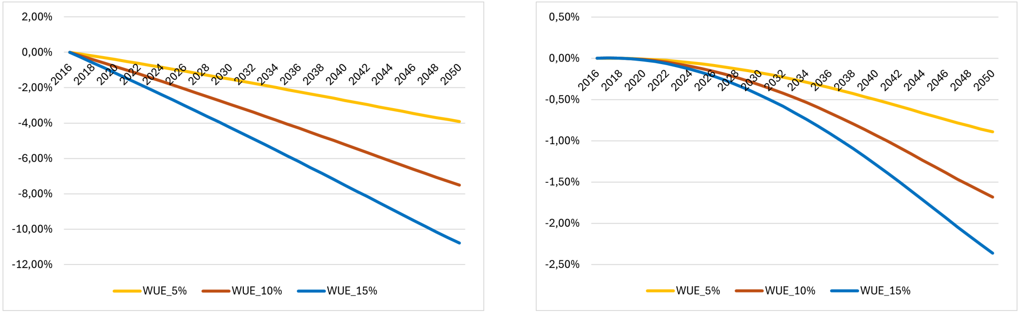
This reduction in crop prices will be transmitted to the food processing sector through production linkages, influencing their costs and, consequently, their pricing, as supported by [Liu et al., 2017]. A comparison of results from the (WUE_5%), (WUE_10%), and (WUE_15%) scenarios reveals that a 15% improvement in WUE (WUE_15%) alleviates price pressures more effectively than the 5% (WUE_5%) and 10% (WUE_10%) improvements.

6.2.2 Impacts on International Trade Indicators

Figures 13 and 14 illustrate the effects of WUE improvements on trade patterns in Tunisia.

Improvements in WUE will lead to increased sectoral production, varying by the degree of WUE enhancement. Consequently, domestic production is expected to rise, reducing Tunisia's dependency on external sources. By 2050, imports of agricultural products are

Figure 13: Impacts on Sectoral Imports under WUE Policies Compared to (H2)

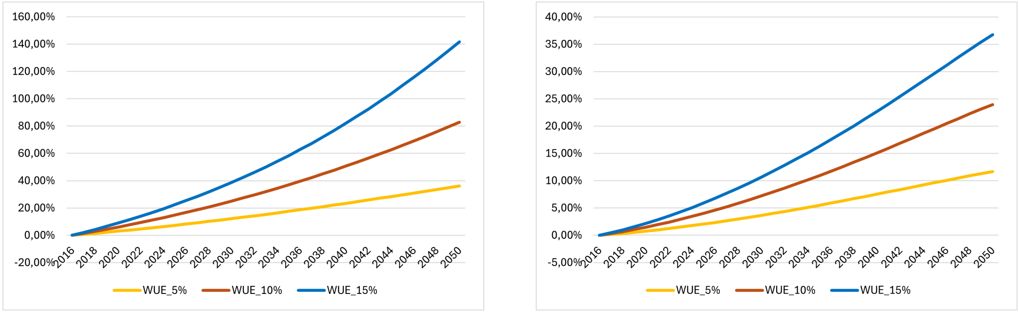


(a) Case of the Agricultural Sector (b) Case of the Food Processing Sector

Source: Authors' simulation results

projected to decrease by 3.92% to 10.79%, depending on the level of WUE improvement.

Figure 14: Impacts on Sectoral Exports under WUE Policies Compared to (H2)



(a) Case of the Agricultural Sector (b) Case of the Food Processing Sector

Source: Authors' simulation results

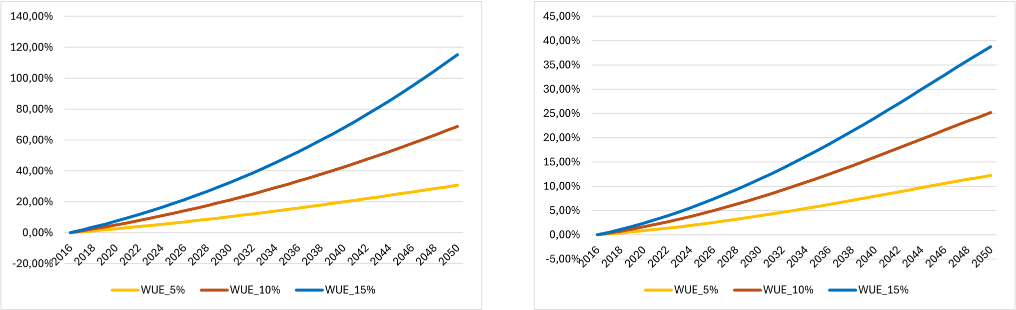
Additionally, food imports are expected to decline by 0.89% to 2.36%, contingent on WUE improvements. Thus, enhanced WUE contributes to partially alleviating the impacts of water scarcity under (H2), promoting self-reliance in agri-food imports.

On the export front, both sectors are anticipated to increase their export volumes, as indicated in Figure 14. Improvements in WUE lead to reduced production costs over time, making domestically produced crops more competitive internationally due to the substitution between local and exported goods. In the long term, exports of agricultural and food products are expected to rise by approximately 36.20% and 11.66%, respectively, under the WUE scenario (WUE_5%) compared to the water-constrained situation (H2).

Under WUE scenarios, increased agricultural and agri-food exports correspond to a rise in virtual water exports, as shown in Figure 15.

Regarding the increase in virtual water exports through agricultural and food products, Tunisia, which faces water resource constraints exacerbated by climate change, should prioritize importing water-intensive products from trade partners to address its water deficits. Simultaneously, Tunisia can enhance its export portfolio by diversifying and

Figure 15: Impacts on Virtual Water Exports under WUE Policies Compared to (H2)

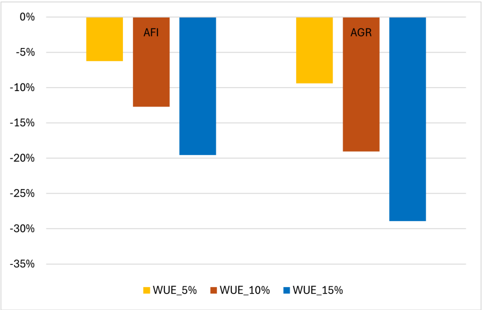


(a) Case of the Agricultural Sector (b) Case of the Food Processing Sector

Source: Authors' simulation results

increasing the share of high-value, low-virtual-water agricultural and food commodities. This strategic shift allows Tunisia to optimize its limited water resources, improving economic resilience while supporting sustainable trade practices.

Figure 16: Changes in Agricultural and Food Trade Balances under WUE Policies Compared to (H2)



Source: Authors' simulation results

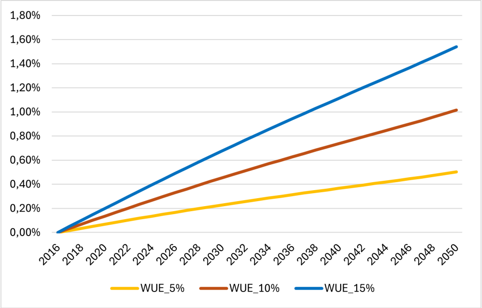
Higher exports and reduced imports, depicted in Figure 16, illustrate the trade balance improvements for agriculture and agri-food under WUE (Water Use Efficiency) scenarios relative to the baseline scenario (H2). By 2050, WUE improvements are projected to decrease agricultural trade balance deficits by over 28.90% (WUE_15%) and food processing sector deficits by over 19.57% (WUE_15%), resulting in a positive impact on Tunisia's current account balance and boosting GDP.

6.2.3 Macroeconomic Impacts

The findings demonstrate that WUE improvements mitigate some adverse effects of water scarcity on Tunisia's GDP, with greater efficiency gains yielding more substantial benefits.

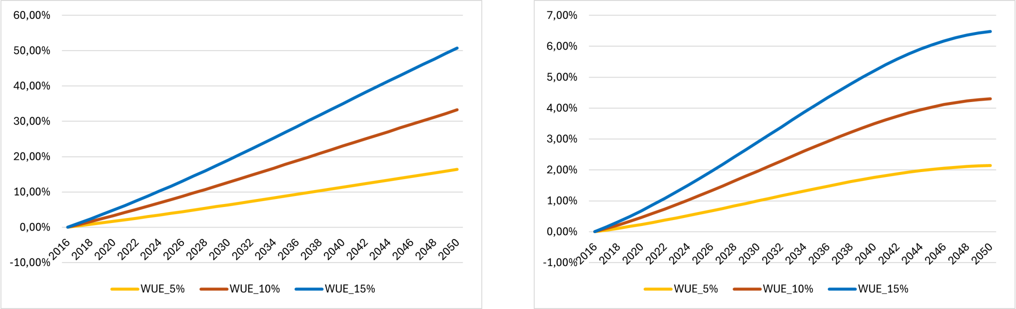
Figure 17 shows that improvements in WUE boost agricultural productivity, which in turn drives productivity gains across other sectors, notably food processing. In the long term, WUE policies result in higher GDP levels compared to the water-constrained scenario (H2), with GDP growth rates ranging from 0.5% (WUE_5%) to 1.54% (WUE_15%).

Figure 17: Percent Changes in GDP under WUE Policies Compared to (H2)



Source: Authors' simulation results

Figure 18: Percent Changes in Sectoral Share of GDP under WUE Policies Compared to (H2)



(a) Case of the Agricultural Sector (b) Case of the Food Processing Sector

Source: Authors' simulation results

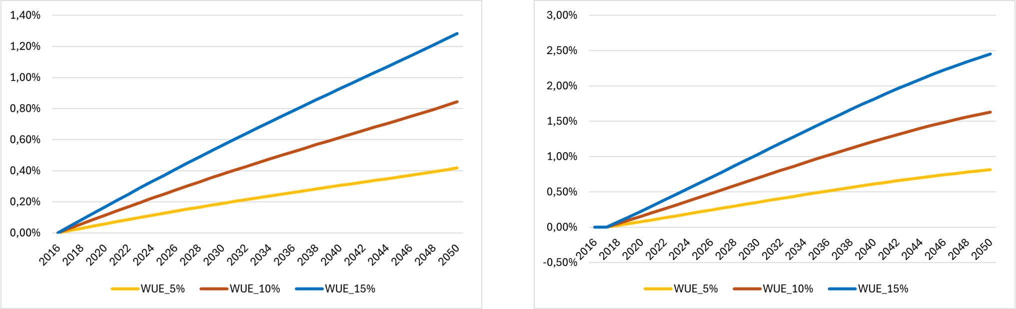
The simulation results also highlight an increase in the share of agriculture and food processing within GDP, as seen in Figure 18.Improved agricultural productivity under WUE policies positively influences wage rates, as shown in Figure 19a, creating new job opportunities and enhancing household welfare.

The increase in wage rates enhances household income, purchasing power, and savings, as shown in Figure 20. Rising disposable income boosts domestic consumption, contributing to overall social welfare.

In summary, the simulations indicate that enhancing WUE in agriculture can offset some of the negative impacts of limited water availability, thereby improving sectoral productivity, decreasing imports, and increasing exports. This strategy ultimately supports Tunisia's economic growth and long-term welfare gains.

Comparing our results with prior studies on water scarcity and water use efficiency (WUE) policies reveals consistency across findings. Under water scarcity scenarios, we observe declines in agricultural output similar to those reported by [Berrittella et al., 2007], [Calzadilla et al., 2010], [Osman et al., 2016], and [Briand et al., 2023]. These constraints adversely impact food security in the long term. Limited water availability prompts farmers to adopt alternative irrigation methods, increasing agricultural production costs, which subsequently drive up consumer prices, as noted by [Narayanan et al., 2015]. Additionally, the decline in agricultural productivity leads to wage rate reductions, im-

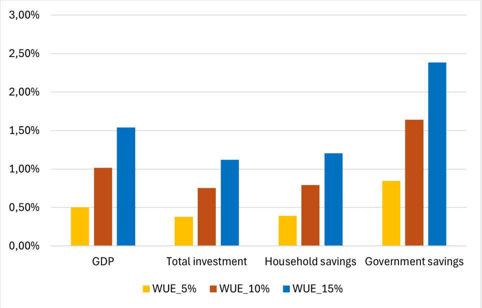
Figure 19: Percent Changes in Wage Rate and Welfare under WUE Policies Compared to (H2)



(a) Wage Rate (b) Welfare

Source: Authors' simulation results

Figure 20: Percent Changes in Macroeconomic Indicators, by 2050, under WUE Policies Compared to (H2)



Source: Authors' simulation results

pacting household income, savings, and consumption, thereby diminishing welfare levels, as demonstrated by [Briand et al., 2023] and [Narayanan et al., 2015]. The reduction in domestic agricultural output necessitates increased imports of food and agricultural products to sustain national food security, echoing the conclusions of [Roson and Sartori, 2010] and [Osman et al., 2016]. These factors cumulatively slow economic growth and reduce GDP, consistent with findings from [Narayanan et al., 2015] and [Briand et al., 2023]. Regarding WUE policies, our findings align with prior research, showing that water-saving strategies and irrigation modernization increase agricultural productivity, which, in turn, bolsters the food processing sector. This outcome is consistent with results from [Calzadilla et al., 2011], [Liu et al., 2017], [Briand et al., 2023], and [Ahmed et al., 2024]. Efficient water use reduces irrigation costs, leading to lower consumer prices, as also found by [Taheripour et al., 2020a] and [Taheripour et al., 2020b]. WUE improvements help Tunisia become more self-reliant in agricultural and food production, mitigating the impacts of water shortages and enhancing the competitiveness of domestically produced goods on the international market. This trend toward increased exports in a WUE-improved scenario aligns with outcomes from [Calzadilla et al., 2011] and [Osman et al., 2016]. Furthermore, enhanced agricultural productivity supports growth in the food processing sector, leading to higher wage rates, increased consumption, and improved social welfare, as also demonstrated by [Briand et al., 2023]. In line with findings from [Freire-González, 2019], [Taheripour et al., 2020a], [Briand et al., 2023], and [Ahmed et al., 2024], our simulations confirm that improvements in WUE help mitigate the adverse impacts of water scarcity and contribute to long-term economic growth.

7 Main Findings and Conclusions

Historically, agriculture has been crucial to the Tunisian economy. However, Tunisia faces escalating water scarcity, worsened by insufficient maintenance of water infrastructure and inefficient irrigation practices. This ongoing water loss reduces agricultural productivity, especially under climate-induced shifts in water availability, ultimately impacting Tunisia's economic growth.

Our objective was to quantify the economic effects of reduced water availability on agricultural production and its broader economic implications. To achieve this, we developed a dynamic CGE model focused on agriculture and water, simulating various water availability reduction scenarios projected to 2050. Additionally, we assessed how improvements in water use efficiency (WUE) could mitigate these impacts.

The results indicate that water scarcity significantly hampers the Tunisian economy. Simulations show that declining rainfall reduces agricultural yields, negatively affecting long-term food security and driving up imports while decreasing exports. These factors increase the trade deficit and lower GDP. Water shortages are also expected to raise commodity prices, decrease wage rates, and reduce welfare gains by 2050. Our findings reveal that the severity of economic losses from water shortages varies with the extent of water reductions from baseline levels (H0).

To explore mitigation strategies, we analysed three WUE policy scenarios. These scenarios indicate that enhanced WUE can partially alleviate water scarcity impacts by increasing productivity in the agricultural and food processing sectors. This boosts exports, reduces imports, narrows the trade deficit, and supports economic growth. We also examined impacts on virtual water trade and found that despite WUE improvements, embedded water exports still rise, suggesting a need for better management of exported goods.

Long-term simulations suggest that higher rates of WUE improvement strengthen mitigation potential, positively influencing both economic activities and overall economic performance. This implies that a combination of strategies would be more effective in countering water scarcity and fostering economic growth.

Our findings indicate the need for policies to offset the macroeconomic effects of water scarcity. Rehabilitating water infrastructure and improving distribution networks is essential to preserve water quantity and quality. Adopting high-efficiency irrigation technologies and shifting from traditional to advanced methods would minimize water loss. Additionally, cultivating non-water-intensive, temperature-resistant crops, and limiting water-demanding crops would reduce water use. Research into optimal crop varieties suited to water and temperature constraints is recommended. Improving soil quality for better water retention can also reduce irrigation needs.

For a water-scarce country like Tunisia, importing water-intensive products while exporting high-value, low-water-use goods would alleviate food and water deficits. Trade agreements should ensure a diversified export-import portfolio to enhance resilience. extensions of our study could provide further insights. Differentiating land and capital factors within agricultural production would add specificity to our analysis. We could also increase the disaggregation of agricultural and food processing accounts within the SAM. Adopting approaches similar to [Decaluwé et al., 1999], we could regionalize Tunisia by climate and water availability for more nuanced analysis. Additionally, exploring unconventional water resources, as suggested by [Kahsay et al., 2019] and [Briand et al., 2023], or implementing taxation policies as in [Berrittella et al., 2008a], [Freire-González and Ho, 2018], and [Shan et al., 2023] could yield insights into water resource preservation and economic growth enhancement.

References

[Ahmadi et al., 2022] Ahmadi, F., Nazeri Tahroudi, M., Mirabbasi, R., and Kumar, R. (2022). Spatiotemporal analysis of precipitation and temperature concentration using pci and tci: a case study of khuzestan province, iran. *Theoretical and Applied Climatology*, 149(1):743–760.

[Ahmed et al., 2024] Ahmed, Y. N., Negm, M. M., Alnafissa, M., and Hefnawy, F. (2024). An empirical analysis of irrigation modernization projects using the cge model. *Environment, Development and Sustainability*, 26(1):1177–1194.

[Al-Riffai et al., 2012] Al-Riffai, P., Breisinger, C., Verner, D., and Zhu, T. (2012). Droughts in syria: an assessment of impacts and options for improving the resilience of the poor. *Quarterly Journal of International Agriculture*, 51(1):21–49.

[Benalaya et al., 2017] Benalaya, A., Chebil, A., Souissi, A., Frija, A., Makhlouf, M., and Stambouli, T. (2017). Quantification of virtual water balance of tunisia: flows embedded in the main produced, consumed and exchanged agricultural commodities. *New Medit: Mediterranean Journal of Economics, Agriculture and Environment= Revue Mediterraneenne dEconomie Agriculture et Environment*, 16(2):11.

[Berrittella et al., 2007] Berrittella, M., Hoekstra, A. Y., Rehdanz, K., Roson, R., and Tol, R. S. (2007). The economic impact of restricted water supply: A computable general equilibrium analysis. *Water research*, 41(8):1799–1813.

[Berrittella et al., 2008a] Berrittella, M., Rehdanz, K., Roson, R., and Tol, R. S. (2008a). The economic impact of water taxes: a computable general equilibrium analysis with an international data set. *Water Policy*, 10(3):259–271.

[Berrittella et al., 2008b] Berrittella, M., Rehdanz, K., Tol, R. S., and Zhang, J. (2008b). The impact of trade liberalization on water use: A computable general equilibrium analysis. *Journal of Economic Integration*, pages 631–655.

[Briand et al., 2023] Briand, A., Reynaud, A., Viroleau, F., Markantonis, V., and Branciforti, G. (2023). Assessing the macroeconomic effects of water scarcity in south africa using a cge model. *Environmental Modeling & Assessment*, 28(2):259–272.

[Calzadilla et al., 2017] Calzadilla, A., Rehdanz, K., Roson, R., Sartori, M., and Tol, R. S. (2017). Review of cge models of water issues. *World Scientific Reference on Natural Resources and Environmental Policy in the Era of Global Change: Volume 3: Computable General Equilibrium Models*, pages 101–123.

[Calzadilla et al., 2010] Calzadilla, A., Rehdanz, K., and Tol, R. S. (2010). The economic impact of more sustainable water use in agriculture: A computable general equilibrium analysis. *Journal of Hydrology*, 384(3-4):292–305.

[Calzadilla et al., 2011] Calzadilla, A., Rehdanz, K., and Tol, R. S. (2011). Water scarcity and the impact of improved irrigation management: a computable general equilibrium analysis. *Agricultural Economics*, 42(3):305–323.

[CCDR, 2023] CCDR (2023). Tunisia country climate and development report. Technical report, World Bank.

[CCNUCC, 2023] CCNUCC (2023). Quatrième communication nationale de la tunisie au titre de la convention cadre des nations unies sur les changements climatiques. Technical report, Tunisia.

[Chemingui and Thabet, 2016] Chemingui, M. A. and Thabet, C. (2016). Economy-wide analysis of alternative water management policies: a comparative analysis for morocco and tunisia. *Water Economics and Policy*, 2(04):1650030.

[Cui and Xie, 2022] Cui, X. and Xie, W. (2022). Adapting agriculture to climate change through growing season adjustments: Evidence from corn in china. *American Journal of Agricultural Economics*, 104(1):249–272.

[Decaluwé et al., 1999] Decaluwé, B., Patry, A., Savard, L., et al. (1999). *When water is no longer heaven sent: Comparative pricing analysis in an AGE model.* Université Laval, Département d'économique.

[Dissou, 2002] Dissou, Y. (2002). Dynamic effects in senegal of the regional trade agreement among uemoa countries. *Review of international economics*, 10(1):177–199.

[Freire-González, 2019] Freire-González, J. (2019). Does water efficiency reduce water consumption? the economy-wide water rebound effect. *Water Resources Management*, 33(6):2191–2202.

[Freire-González and Ho, 2018] Freire-González, J. and Ho, M. S. (2018). Environmental fiscal reform and the double dividend: Evidence from a dynamic general equilibrium model. *Sustainability*, 10(2):501.

[Hoekstra and Hung, 2003] Hoekstra, A. Y. and Hung, P. Q. (2003). Virtual water trade. In *Proceedings of the international expert meeting on virtual water trade*, volume 12, pages 1–244.

[Ingram et al., 2012] Ingram, J., Ericksen, P., and Liverman, D. (2012). *Food security and global environmental change.* Routledge.

[INM, 2015] INM (2015). Le changement climatique en tunisie.

[INS, 2022] INS (2022). Les comptes de la nation base 2015 : Agrégats et tableaux d'ensemble 2015-2020 : Éléments de méthodologie et principaux résultats.

[IPCC, 2023] IPCC (2023). *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* H. Lee, J. Romero, Geneva, Switzerland.

[ITCEQ, 2021] ITCEQ (2021). Réforme de ciblage des subventions alimentaires: Enseignements d'une Évaluation ex-ante des effets attendus.

[Javadi et al., 2023] Javadi, A., Ghahremanzadeh, M., Sassi, M., Javanbakht, O., and Hayati, B. (2023). Economic evaluation of the climate changes on food security in iran: application of cge model. *Theoretical and applied climatology*, 151(1):567–585.

[Kahsay et al., 2019] Kahsay, T. N., Arjoon, D., Kuik, O., Brouwer, R., Tilmant, A., and van der Zaag, P. (2019). A hybrid partial and general equilibrium modeling approach to assess the hydro-economic impacts of large dams–the case of the grand ethiopian renaissance dam in the eastern nile river basin. *Environmental Modelling & Software*, 117:76–88.

[Khalili et al., 2021] Khalili, N., Arshad, M., Farajzadeh, Z., Kächele, H., and Müller, K. (2021). Does drought affect smallholder health expenditures? evidence from fars province, iran. *Environment, Development and Sustainability*, 23:765–788.

[Liu et al., 2017] Liu, Y., Hu, X., Zhang, Q., and Zheng, M. (2017). Improving agricultural water use efficiency: A quantitative study of zhangye city using the static cge model with a ces water- land resources account. *Sustainability*, 9(2):308.

[Luckmann et al., 2014] Luckmann, J., Grethe, H., McDonald, S., Orlov, A., and Siddig, K. (2014). An integrated economic model of multiple types and uses of water. *Water Resources Research*, 50(5):3875–3892.

[MAGRHP, 2020] MAGRHP (2020). Rapport national du secteur de l'eau, année 2020. Internal report.

[MAGRHP, 2021] MAGRHP (2021). Rapport national du secteur de l'eau, année 2021. Internal report.

[MAGRHP, 2023a] MAGRHP (2023a). Tableau de bord de l'agriculture, 2023. Technical report.

[MAGRHP, 2023b] MAGRHP (2023b). Élaboration de la vision et de la stratégie du secteur de l'eau à l'horizon 2050 pour la tunisie : Eau 2050. Internal report.

[Malhi et al., 2021] Malhi, G. S., Kaur, M., and Kaushik, P. (2021). Impact of climate change on agriculture and its mitigation strategies: A review. *Sustainability*, 13(3):1318.

[Narayanan et al., 2015] Narayanan, B. G., Taheripour, F., Hertel, T. W., Sahin, S., and Escurra, J. J. (2015). Water scarcity in south asia: A dynamic computable general equilibrium analysis.

[ONAGRI, 2021] ONAGRI (2021). Evolution de l'envasement des barrages en tunisie. Observatoire National de l'Agriculture.

[Osman et al., 2016] Osman, R., Ferrari, E., and McDonald, S. (2016). Water scarcity and irrigation efficiency in egypt. *Water Economics and Policy*, 2(04):1650009.

[Qin et al., 2012] Qin, C., Jia, Y., Su, Z., Bressers, H. T., and Wang, H. (2012). The economic impact of water tax charges in china: a static computable general equilibrium analysis. *Water international*, 37(3):279–292.

[Rivers and Groves, 2013] Rivers, N. and Groves, S. (2013). The welfare impact of self-supplied water pricing in canada: a computable general equilibrium assessment. *Environmental and Resource Economics*, 55(3):419–445.

[Roson and Sartori, 2010] Roson, R. and Sartori, M. (2010). Water scarcity and virtual water trade in the mediterranean. *University Ca'Foscari of Venice, Dept. of Economics Research Paper Series*, (08_10).

[Roson and Sartori, 2015] Roson, R. and Sartori, M. (2015). System-wide implications of changing water availability and agricultural productivity in the mediterranean economies. *Water Economics and Policy*, 1(01):1450001.

[Roson and Van der Mensbrugghe, 2012] Roson, R. and Van der Mensbrugghe, D. (2012). Climate change and economic growth: impacts and interactions. *International Journal of Sustainable Economy*, 4(3):270–285.

[Salami et al., 2009] Salami, H., Shahnooshi, N., and Thomson, K. J. (2009). The economic impacts of drought on the economy of iran: An integration of linear programming and macroeconometric modelling approaches. *Ecological economics*, 68(4):1032–1039.

[Shahpari et al., 2023] Shahpari, G., Ashena, M., Martinez-Cruz, A. L., and León, D. G. (2023). Implications for the iranian economy from climate change effects on agriculture—a static computable general equilibrium approach. *Theoretical and Applied Climatology*, 153(3):1221–1235.

[Shan et al., 2023] Shan, S., Ni, H., Lin, X., and Chen, G. (2023). Evaluation of water saving and economy impact for tax reform policy using cge model with integrated multiple types of water. *Water*, 15(11):2118.

[Siddig et al., 2020] Siddig, K., Stepanyan, D., Wiebelt, M., Grethe, H., and Zhu, T. (2020). Climate change and agriculture in the sudan: Impact pathways beyond changes in mean rainfall and temperature. *Ecological Economics*, 169:106566.

[Souissi et al., 2019] Souissi, A., Chebil, A., Mtimet, N., and Thabet, C. (2019). Virtual water flows and water value in tunisia: The case of wheat and olive. *Arabian Journal of Geosciences*, 12:1–10.

[Taheripour et al., 2020a] Taheripour, F., Tyner, W. E., Haqiqi, I., and Sajedinia, E. (2020a). Water scarcity in morocco: Analysis of key water challenges. *World Bank*.

[Taheripour et al., 2020b] Taheripour, F., Tyner, W. E., Sajedinia, E., Aguiar, A., Chepeliev, M., Corong, E., de Lima, C. Z., and Haqiqi, I. (2020b). Water in the balance: The economic impacts of climate change and water scarcity in the middle east—technical report. Technical report, World Bank, Washington, DC.

[Udmale et al., 2015] Udmale, P. D., Ichikawa, Y., Manandhar, S., Ishidaira, H., Kiem, A. S., Shaowei, N., and Panda, S. N. (2015). How did the 2012 drought affect rural livelihoods in vulnerable areas? empirical evidence from india. *International Journal of Disaster Risk Reduction*, 13:454–469.

[Yilmaz et al., 2023] Yilmaz, D., Ben-Nasr, S., Mantes, A., Ben-Khalifa, N., Daghari, I., and Godin, A. (2023). Climate change, loss of agricultural output and the macro-economy: The case of tunisia. *AFD Research Papers*, (286):1–106.

[Zhao et al., 2016] Zhao, J., Ni, H., Peng, X., Li, J., Chen, G., and Liu, J. (2016). Impact of water price reform on water conservation and economic growth in china. *Economic Analysis and Policy*, 51:90–103.

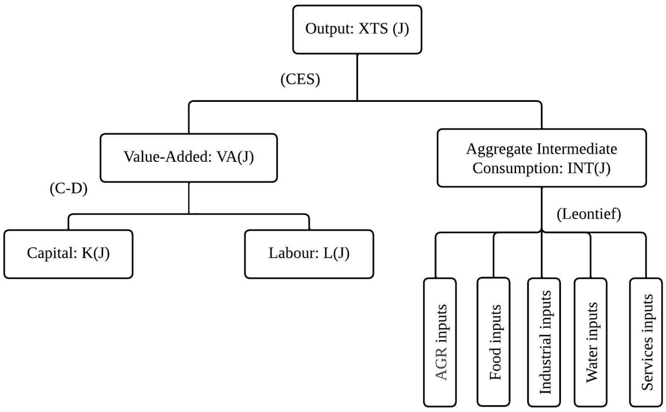
Appendix

A- AGWA-TUN: Mathematical Specification

Production Modelling

Firms are assumed to compete in perfect competition. Each sector (J) has a representative firm that maximises profits, subject to its production technology. Each firm produces an output using factors of production, labour and capital (in addition to land, in the case of the agricultural sector), and intermediate inputs, as depicted in figure A1.

Figure A1: Company Technology: Nested Production Functions



Source: Elaborated by author

At the second level, each industry's value-added consists of a combination of labour and capital through a Cobb-Douglas technology.

$$VA_j = AP_j^{\left(\sigma_j^P - 1\right)} XTS_j \left[\frac{\alpha_j^P PXTS_j}{PVA_j} \right]^{\sigma_j^P} \qquad \text{(Eq1)}$$

On the intermediate consumption side, the aggregate is made up of different inputs, combined using a Leontief function, to produce a composite of intermediate inputs.

$$INT_j = AP_j^{\left(\sigma_j^P - 1\right)} XTS_j \left[\frac{\left(1 - \alpha_j^P\right) PXTS_j}{PINT_j} \right]^{\sigma_j^P} \qquad \text{(Eq2)}$$

Income and Savings Modelling

This module allows measuring the income and expenditure of the four economic agents. Households maximise their welfare which is represented by a CES utility function given their budget constraints. Each household earns his income from different sources; from payments for production factors (labour and capital), and transfers received from the government and the rest of the world, equation (Eq3). His disposable income, equation (Eq4), is derived by subtracting direct taxes collected by the government. His savings and total consumption are considered as fixed proportions of the disposable income, equation (Eq5).

$$YTH = W\sum_j LD_j + \beta_{KH}\sum_j r.K_j + TRGH + TRROWH \tag{Eq3}$$

$$YDH = YTH(1 - TY_H) \tag{Eq4}$$

$$SAV_H = SH \times YDH \tag{Eq5}$$

Enterprise income is made of its share of capital income, equation (Eq6). The enterprise savings are the difference between its total income and its direct taxes paid to the government.

$$YE = \Big(1 - \beta_{KH}\Big)\sum_j r.K_j \tag{Eq6}$$

Government's revenues are made of a large variety of taxes. Equation (Eq7) shows that the government collects its revenues from direct taxes paid by households and enterprises, indirect taxes on products and consumption, and taxes collected on imports.

$$YG = \sum_i t_{c_i} PC_i C_i + \sum_i t_{G_i} PC_i G_i + \sum_i tinv_i PC_i Dinv_i + \sum_j t_{P_j} PXS_j XTS_j \tag{Eq7}$$

$$+ t_{y_E} YE + t_{y_H} YTH \tag{1}$$

Government savings in equation (Eq8), are the difference between its revenues and expenditures obtained by subtracting from its income the current consumption of goods and services and its transfers to households and the rest of the world.

$$SAVG = YG - \sum_i PC_i\Big(1 + t_{G_i}\Big)G_i - TRGH - TRGROW \tag{Eq8}$$

When it comes to the rest of the world, it receives payments from imports and transfers from the government, and its expenditures consist mainly of exports payments and transfers to households. Equation (Eq9) presents the difference between foreign revenues and expenditures, the rest of the world's savings that is equal to the absolute value of the current account balance, but of opposite sign.

$$SAVF = \sum_i \Big(PWM_i \times M_i\Big) - \sum_i \Big(PWEX_i \times EX_i\Big) + TRGROW - TRROWH \tag{Eq9}$$

Demand Modelling

Demand for goods and services, domestically produced or imported from the rest of the world, consists of the households' and the government's final consumption of goods and services, the investment demand and the intermediate consumption demand, equation Eq10.

$$XTD_i = C_i + G_i + DINV_i + \sum_j V_{ij} \tag{Eq10}$$

A CES utility function was used, where households' demand for each good or service is determined by utility maximisation, subject to the budget constraint. Household's demand function is given by equation (Eq11).

$$C_i = \left[\frac{\alpha_i^C}{PC_i\,(1+t_{C_i})}\right]^{\sigma^C} \frac{CH}{\sum_i \left(\alpha_i^C\right)^{\sigma^C} \left[PC_i\,(1+t_{C_i})\right]} \tag{Eq11}$$

Investment demand by each sector (I) is determined as a fixed share from total savings, as shown in equation (Eq12), where $BETAV(I)$ is the fixed industry share.

$$DINV_i = \frac{BETAV_i\,.TOTSAV}{PCINV_i} \tag{Eq12}$$

Goods and services are also used as inputs in the production process. The intermediate demand for commodity (J) is determined by the equation (Eq13).

$$INT_j = AP_j^{\left(\sigma_j^P - 1\right)} XTS_j \left[\frac{\left(1-\alpha_j^P\right) PXTS_j}{PINT_j}\right]^{\sigma_j^P} \tag{Eq13}$$

International Trade Modelling

On both sides, imports and exports, Armington's assumptions were used. A CES function was then implemented to model the relationship between both imported and locally produced goods, as shown in equation (Eq14).

$$M_i = (AM_i)^{\left(\sigma_i^m - 1\right)} XTD_i \left[\frac{\alpha_i^m PC_i}{PM_i}\right]^{\sigma_i^m} \tag{Eq14}$$

Supplier behaviour is symmetrical to that of the producer. In that, imperfect substitution is also assumed for exports. To determine the relationship between goods produced for local and foreign markets, a CET function is used, as illustrated in equation (Eq15).

$$EX_i = (AX_i)^{-\left(1+\sigma_i^X\right)} XTS_i \left[\frac{PEX_i}{\alpha_i^X / PXTS_i(1+t_{P_i})}\right]^{\sigma_i^X} \tag{Eq15}$$

Equilibrium Modelling

The equation (Eq16) checks the supply and demand equilibrium for each commodity on the goods and services markets.

$$XTS_i = C_i + DINV_i + G_i + \sum_j V_{ij} \tag{Eq16}$$

Since labour is assumed to be mobile across sectors, market wage W plays a key role in balancing supply and demand. Thus, labour market equilibrium is given by the equation (Eq17).

$$\sum_j LD_j = LS \tag{Eq17}$$

Similarly for the capital market equilibrium using the rental price R, equation (Eq18).

$$\sum_j K_j = KTOT \tag{Eq18}$$

Another equilibrium condition that should be verified is related to the total investment expenditure, which must be equal to the sum of savings relative to the economic agents in our economy, as in equation (Eq19).

$$TOTSAV = SAVE + SAVH + SAVF + SAVG \tag{Eq19}$$

Domestic demand for commodity (I), must be equal to the total supply of that type of commodity, equation (Eq20).

$$XDD = XDS \tag{Eq20}$$

Dynamic Module

In order to analyse the long term impacts of different scenarios, a dynamic approach is proposed. To transform our static version to a dynamic one, we used the static model, indexed all variables in time (T), introduced the following equation (Eq21), a capital accumulation equation, and made the necessary adjustments:

$$K_{J,T+1} = K_{J,T} \,.\, (1 - \delta_j) + IND_{J,T} \tag{Eq21}$$

In addition to the dynamic equations that we added to our static model, we also integrated population growth. Since in our static model there is no population variable, we considered a population growth rate $PG(T)$, making it variable from one period to another. We used this rate in order to update the values of exogenous variables that are assumed to grow at the population growth rate. Labour supply $LS(T)$, foreign savings $SAV\_F(T)$, public consumption $G(I,T)$, and transfers are all assumed to grow at the population growth rate $PG(T)$.

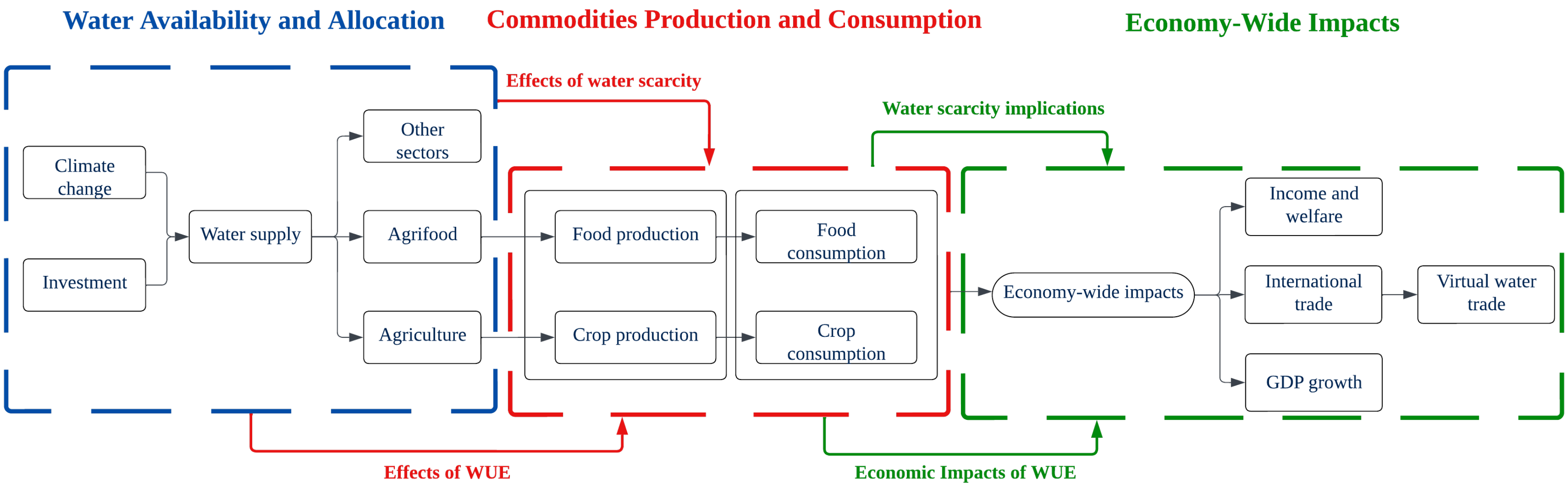
The reason behind this assumption, assuming that labour supply and the other exogenous variables grow at the same rate, is to enable the model to simulate a balanced growth path, which means that all quantities or variables grow at a constant rate, the population growth rate in our case, while relative prices remain constant.

Model Closure

Our model is a neoclassical model. The equilibrium on goods and services markets and factors markets is determined by the flexibility of prices and wages. Supply of labour and capital factors are exogenous. We also considered that the government's savings are flexible, while tax rates are fixed. Foreign savings are also exogenous and the exchange rate is assumed to be the “numeraire”.

B- Conceptualisation of the Methodological Approach

Figure B1: Conceptualisation of the Methodological Approach



Source: Author's conceptualisation