# CLIMATE CHANGE AND AGRICULTURE: THE IMPACT OF CLIMATE CHANGE ON CROP PRODUCTION IN TÜRKİYE

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# CLIMATE CHANGE AND AGRICULTURE: THE IMPACT OF CLIMATE CHANGE ON CROP PRODUCTION IN TÜRKİYE

submitted by **SAİDE SİMİN BAYRAKTAR** in partial fulfillment of the requirements for the degree of **Doctor of Philosophy in Earth System Science, Middle East Technical University** by,

Prof. Dr. Halil Kalıpçılar
Dean, Graduate School of **Natural and Applied Sciences**

Prof. Dr. İsmail Ömer Yılmaz
Head of the Department, **Earth System Science**

Prof. Dr. Bülent G. Akınoğlu
Supervisor, **Department of Earth System Science, METU**

Dr. Mehmet Ufuk Atay
Co-Supervisor, **TÜBİTAK**

**Examining Committee Members:**

Prof. Dr. Oktay Fırat Tanrısever
Department of International Relations, METU

Prof. Dr. Bülent G. Akınoğlu
Department of Physics, METU

Assoc. Prof. Dr. İzzet Arı
Department of Energy Economics and Management, Social Sciences University of Ankara

Prof. Dr. Hakan Berument
Department of Economics, Bilkent University

Prof. Dr. Matthias Finger
Department of Economics, İTÜ

Date: 28.04.2023

**I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.**

Name, Last name : Saide Simin, Bayraktar

Signature :

# ABSTRACT

## CLIMATE CHANGE AND AGRICULTURE: THE IMPACT OF CLIMATE CHANGE ON CROP PRODUCTION IN TÜRKİYE

Bayraktar, Saide Simin
Doctor of Philosophy, Earth System Science
Supervisor: Prof. Dr. Bülent G. Akınoğlu
Co-Supervisor: Dr. Mehmet Ufuk Atay

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There are two critical issues that achieved global consensus. First, global climate change is happening at an increasing rate accompanied by increasing number of climate-related extreme weather conditions. Second, agriculture is the most vulnerable sector to climate change. Food production heavily relies on weather conditions as well as climate. Therefore, climate change is expected to have severe consequences on food production, food prices and inevitably on food security. Türkiye, in line with the predicted impacts of climate change, has witnessed severe weather events in the last decades. It is expected that these impacts will intensify as climate change continues. Türkiye is particularly vulnerable in agricultural sector. Thus, it is critical to analyze how climate change will affect agriculture in Türkiye.

Türkiye still requires considerable efforts to meet the challenge of climate change related damages. This thesis analyzes the impacts of climate change on major crop production in Türkiye relying at the center of Turkish agriculture. Using an econometric model, the thesis estimates a significant reduction in wheat, barley, corn rice and sunflower production in the short, medium and long-term. The impact is found to be increasing over time depending on various climate scenarios.

Keywords: Climate Change, Agricultural Production, Crop Production in Türkiye, Temperature, Precipitation

# ÖZ

## İKLİM DEĞİŞİKLİĞİ VE TARIM: İKLİM DEĞİŞİKLİĞİNİN TÜRKİYE’NİN TAHIL ÜRETİMİNE ETKİSİ

Bayraktar, Saide Simin
Doktora, Yer Sistem Bilimleri
Tez Yöneticisi: Prof. Dr. Bülent G. Akınoğlu
Ortak Tez Yöneticisi: Dr. Mehmet Ufuk Atay

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Küresel olarak kabul gören iki temel konu bulunmaktadır. İlk olarak, küresel iklim değişikliği giderek artan bir hızda devam etmekte, beraberinde aşırı hava koşullarını getirmektedir. İkinci olarak, iklim değişikliğine en hassas sektörlerin başında tarım gelmektedir. Gıda üretiminin iklime ve hava koşullarına karşı çok hassas olduğu bilinmektedir. Bu nedenle, iklim değişikliğinin gıda üretimine, gıda fiyatlarına ve kaçınılmaz olarak gıda güvenliğine ciddi etkileri bulunmaktadır. Türkiye de iklim değişikliğinin beklenen etkilerini yaşamakta ve son dönemlerde aşırı hava olaylarına maruz kalmaktadır. İklim değişikliği devam ettiği müddetçe bu etkilerin yoğunlaşması beklenmektedir. Türkiye özellikle tarım sektöründe çok kırılgandır. Bu nedenle, iklim değişikliğinin Türkiye’de tarıma olası etkilerini analiz etmek önem taşımaktadır.

Türkiye, iklim değişikliği kaynaklı hasarları ve artan gıda fiyatlarını yönetmek için ciddi önlemler almalıdır. Bu tez, iklim değişikliğinin Türkiye’nin tarım sektöründe önemli rol oynayan belirli tahıl ürünleri üretimine etkisini analiz etmektedir. Ekonometrik modellerden yararlanılarak farklı senaryolar için iklim değişikliğinin etkisi incelenmiştir. Model sonuçlarına göre kısa, orta ve uzun vadede buğday, arpa, mısır, pirinç ve ayçiçeği üretiminde ciddi düşüşler öngörülmektedir. İklim değişikliğinin tahıl üretimine negatif etkisinin zaman içerisinde artacağı hesaplanmaktadır.

Anahtar Kelimeler: İklim Değişikliği, Tarımsal Üretim, Türkiye'nin Tahıl Üretimi, Yağış, Sıcaklık

To my daughters, Zeynep and Sena

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ABBREVIATIONS

AEZ: Agro-ecological Zones

Agri-PV: Agrivoltaics

ARDL: Autoregressive-Distributed Lag

CAP: Common Agricultural Policy

CO2: Carbon dioxide

COP: Conference of Parties

CSA: Climate Smart Agriculture

DROPS: Drought Tolerant Yielding Plants

EU: European Union

FAO: The United Nations Food and Agricultural Organization

FE: Fixed Effect

GCM: Global Circulation Models

GDP: Gross Domestic Product

GHG: Greenhouse Gas

GOI: Grains and Oilseeds Index

GPS: Global Positioning System

HES: High Emissions Scenario

IFAD: International Fund for Agriculture

IGC: International Grains Council

INDC: Intended Nationally Determined Contribution

IPCC: International Panel on Climate change

KJWA: Koronovia Joint Work on Agriculture

LES: Low Emissions Scenario

MoAF: Ministry of Agriculture and Forestry

PI: Panicle Initiation

PPI: Producer Prices Index

R&D: Research and Development

SDG: Sustainable Development Goal

TURKSTAT: Turkish Statistical Institute

UNFCCC: The United Nations Framework Convention on Climate Change

WBG: World Bank Group

WHO: World Health Organization

%: Percent

°C: Degree Celsius

Mm: Millimeter

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Global climate change is happening at an unprecedented rate. While climate change is accelerating, the major cause is known to be increasing greenhouse gas (GHG) emissions caused by human activities. There is scientific consensus that human-caused emissions are mainly responsible for climate change. According to a new survey of around 90,000 of peer reviewed scientific work published since 2012, more than 99.9% agree that climate change is caused by human activities (Lynas et al., 2021). According to the landmark report by IPCC (2021) “human influence has warmed the atmosphere, ocean and land”.

It is evident that GHG have already begun to warm the Earth surface (IPCC, 2007). Global surface temperature has reached 1.1°C above pre-industrial level over the last decade (IPCC, 2021). According to data published by NASA, long-term trend of global temperature is rising at an increasing rate, while 2016 and 2020 marks the warmest two years since 1880 (see Figure 1.1).

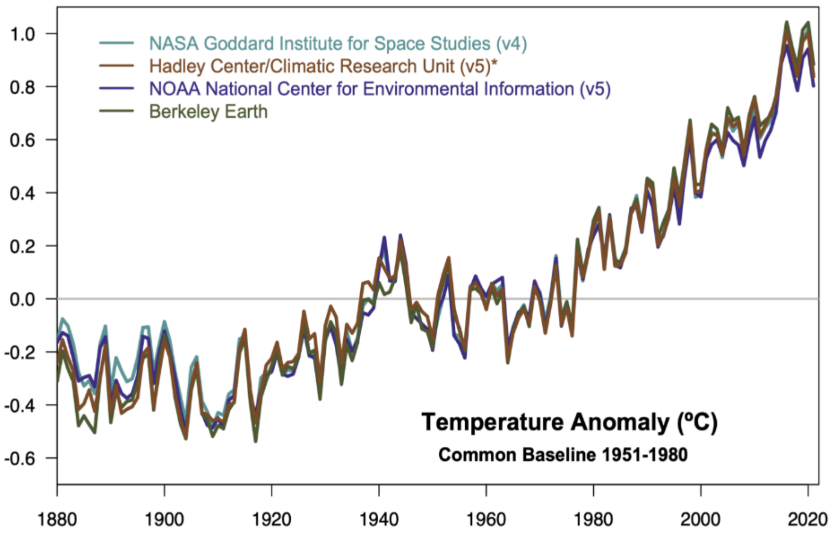


Figure 1.1. Global Temperature Anomaly (relative to 1951-1980, °C)
Source: (NASA Goddard Institute for Space Studies, 2023)

If nothing is done to fight with climate change, existing GHG in the atmosphere would grow significantly over the century mainly due to fossil fuels and land use change. These are causing substantial increases in temperatures and changes in precipitation patterns (IPCC, 2007). To avoid the worst consequences of climate change, scientists say global warming should be limited to 1.5°C by 2100, yet, without additional measurements, the Earth could warm by more than 2°C. According to a report by Climate Action Tracker published in 2021, the warming is projected to be 2.7°C by 2100 under current policies scenario (see Figure 1.2).

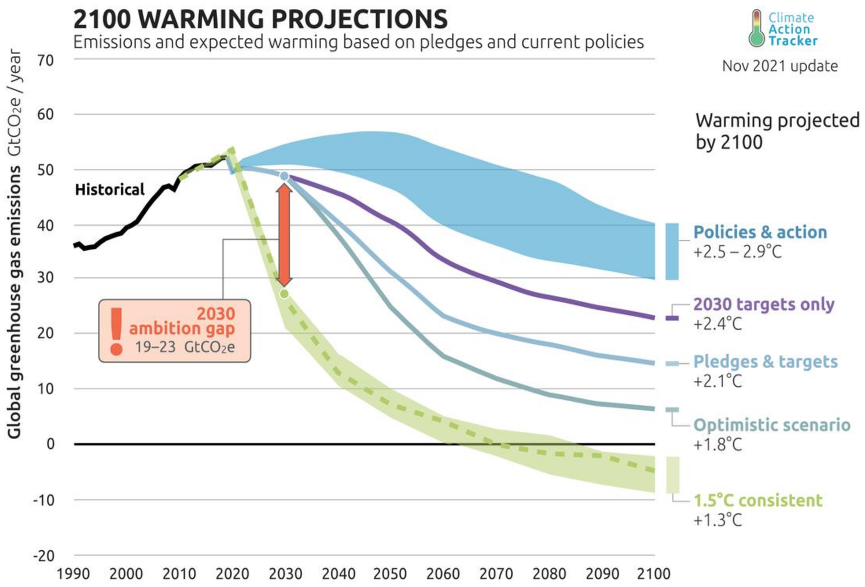


Figure 1.2. Global Warming Projections for 2100
Source: (Climate Action Tracker, 2022)

According to the report, “Limiting warming to 1.5°C above pre-industrial levels means that the emissions of greenhouse gases need to be reduced rapidly in the coming years and decades, and brought to zero around mid-century”.

Global climate change is already having vivid impacts across the world.  Climate change has severe effects across many sectors ranging from the economy, health as well as the environment. Among other sectors, agriculture is extremely vulnerable to global warming caused by climate change. The information on the sensitivity of agriculture on climate change is based on four major sources (IPCC, 2007; Mendelsohn, 2014):

- Experimental studies were conducted by agronomists under different greenhouse levels.
- Crop simulation model approach was used as a tool to measure the impact on staple crops.
- Cross sectional analyses were used for measuring crop yields across different regions.

- Cross sectional Ricardian approach was used to estimate the net revenues using land values in different regions.

These studies all come together under one finding that crops are critically vulnerable to climate change. Depending on the crop's unique properties, increased temperature may benefit or reduce the yields. Occurrence of extreme weather events such as floods and droughts may harm crop yields. Increased temperature also increases the need for more irrigation while decreasing the amount of water available.

It is also important to discuss the indirect effects of climate change on agricultural production. Most of the weeds and pests increase in population under warmer and wetter weather conditions as well as higher CO2 levels. Moreover, while in some cases higher CO2 levels increase crop growth, it decreases the quality in most of the crops. It is found that increasing level of CO2 reduces the protein and minerals in wheat, soybeans and rice (Ziska et al., 2016).

While the Earth's temperature is increasing, this change has different impacts across different regions of the world. While temperature will increase more in certain regions, precipitation would increase more in other regions and extreme events occur more frequently in others. The ocean is expected to warm slower compared to the land. Moreover, the center of the continents is expected to warm more compared to the rest of the continent. Higher latitudes are also become warmer faster (see Figure 1.3). Regional topography plays an important role as well. Improvements in data and modelling has revealed that adverse impacts of climate change are more substantial in some regions like semi-arid tropics, while impacts are positive in some other highland tropics and in temperate regions (Parry et al., 2004). In that sense, it is critical to make regional analysis when looking at the impacts of climate change.

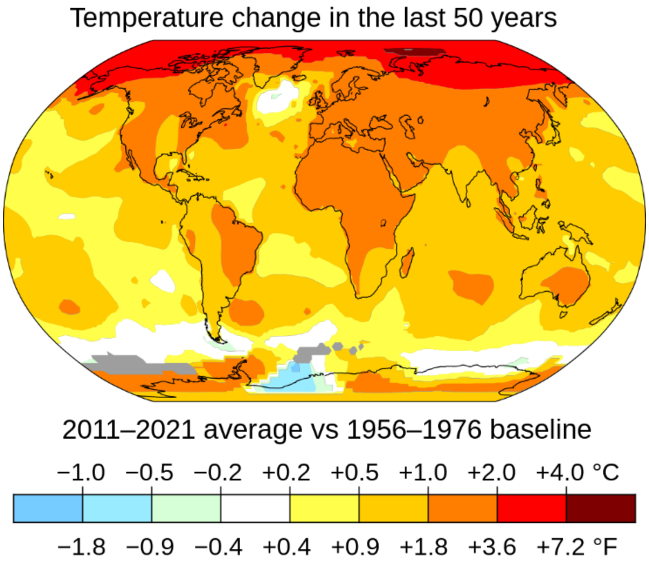


Figure 1.3. Temperature Change in the Last 50 Years
Source: (NOAA National Centers for Environmental Information, 2022)

The effects of climate change are becoming extremely noticeable. Increases in temperature, changes in precipitation, increase in the occurrence of extreme weather events are already causing reductions in agricultural production. In particular, crop production is being affected from these changes. The impacts of climate change on crop production vary across crop type and region. Therefore, it is critical to conduct analysis based on crop as well as where it is grown.

This thesis focuses on staple crop production, namely wheat, barley, corn, rice and sunflower in Türkiye. The thesis elaborates on how climate-related variables, mainly precipitation and temperature change, effect the production levels of each crop type depending on their unique circumstances. More specifically, detailed regional analysis is conducted based on climate requirement during the development stages of the crop and where the crop is commonly grown. The next subchapter discusses the objective and the research question of this thesis.

## 1.2 Objectives and Research Question

Agriculture is one of the most critical and climate-sensitive sectors of the economy. The literature confirms that climate change has direct, through changes in temperature and precipitation, as well as indirect impacts. Moreover, due to climate change arable land becomes less and less fertile.

Wheat is the most produced, harvested and consumed crop across the globe. In particular, wheat production is very sensitive to precipitation and temperature changes. Since it is one of the most critical food, the literature pays significant attention to the impact of climate change on wheat production. However, the literature finds inconclusive results. While some studies find that wheat yield increases due to climate change, others conclude the opposite. According to Kersebaum and Nendel (2014) he findings differ due to regional differences. Empirical evidence also supports this argument (Kersebaum & Nendel, 2014). Sultana et al (2009) how that in arid and semi-arid regions like the Mediterranean, an increase in temperature causes reduction in wheat yield, yet, the result is opposite for the wet zone of Pakistan. Similar patterns are found for changes in precipitation as well (Sultana et al., 2009)

Vulnerability of each region or country depends on their own adaptive capacity and unique circumstances (Guiteras, 2009). Therefore, regional analysis is critical in understanding the impacts of climate change on agricultural production. In that sense, developing countries with lower adaptive capacities are more critical to analyze, yet, the literature mostly focuses on developed countries. In addition, developing countries being located in the regions already close to the tolerance level of the crops are more important to focus. In that sense, Türkiye located in the Mediterranean climate zone requires significant attention in understanding the negative impacts of climate related events on agricultural production.

The literature has several critical papers on the impact of climate related variables on crop production. So far, the existing studies lack some important points which are listed below:

- Most of the studies focus on wheat production. There are a few studies including rice in their analysis. However, other major staple crops constituting a significant amount of crop production in Türkiye are missing.
- Existing literature mostly uses crop models based on climate simulation models. Economic analysis is not commonly conducted.
- Although economic studies are rising in the literature, the literature falls behind in Türkiye. There are a couple of studies adopting Ricardian approach to perform an economic analysis but the number of studies using panel data is very limited.
- Major studies in the literature on Turkish agricultural production focuses Türkiye as a whole, yet, even across the country regional analysis is found to be critical to focus.

In recent studies, panel data approach is commonly performed to estimate the impact of climate-related variables on agricultural production. This thesis also adopts panel data approach to estimate the impact of climate-related variables on crop production in Türkiye.

This thesis aims to fill an important gap in the literature. Firstly, it takes a comprehensive approach and includes five major staple crops produced in the country, namely, wheat, barley, corn, rice and sunflower. In total, these crops constitute almost 90% of total crop production of the country. Secondly, the thesis elaborates on the regional differences across different parts of Türkiye. Depending on where the crop is majorly grown, the data used in the study is narrowed to that region. For instance, the wheat production is concentrated in the Central Anatolia and Southeastern part of the country. The analysis is conducted for these regions considering the weather patterns in those regions.

Combining the results of climate models with economic models is lacking in the literature. This study adds on its econometric model by integrating existing work on climate predictions. The study firstly estimates the impact of changes in temperature and precipitation on crop production. As a second step, the results are further extended conducting a static analysis. The predictions of climate models in the existing literature for Türkiye are used to make a static analysis on how crop production will be impacted in the future based on different climate scenarios over the short, medium and long-term.

Another novel part of this thesis is the data and the model used in the analysis. As far as to our knowledge, the data of this thesis is the most comprehensive so far in the existing literature. This data is critical since it enables to use panel data approach with many control variables. The data, model and methodology are discussed thoroughly in the next subchapter.

## 1.3 Data and Methodology

The impacts of climate change on agriculture has attracted a lot of attention in the literature. The attention increased internationally since the first International Panel on Climate Change (IPCC) was published in 1990. The literature confirms that climate change has direct, through changes in temperature and precipitation, as well as indirect impacts.

Early studies involved limited data and simpler methods, generally leading to negative impact of temperature increase in selected crops in selected regions. The methodologies involved large extrapolation results. With the advancements in data, methodologies and models our understanding of the impacts of climate change on agriculture has changed. In this regard, observation of the real meteorological data has become increasingly important for the analyses.

The data used in this thesis is the most comprehensive data used in similar studies, as far as to our knowledge. The study uses a wide range of dataset from different sources. The main dataset is agricultural production and meteorological data. Agricultural production data is a province-level yearly data, while meteorological data is province-level daily data. The analysis dates back to 1991 covering a 21 years of time span.

The wide-ranging dataset adopted in this thesis enables the analysis to perform a panel data model. Panel data models are used to estimate the impact of meteorological variables on agricultural production. In the quantitative analysis of this thesis, panel data fixed effects model is used. Separate regressions are conducted for each crop, where crop production is treated as the dependent variable. The main independent variable is meteorological variables, namely temperature and precipitation, are the point of interest of the analysis. Moreover, different price variables are controlled.

Understanding the impacts of climate change using real data and better models has become crucial for designing new polices to mitigate the negative impacts of climate change as well as to build better adaptation policies. Therefore, the approach of this thesis fills an important gap in the literature.

## 1.4 Findings

The thesis fills an important gap in the literature by quantifying the impact of climate change on crop production in Türkiye. The thesis analyzes the impact of meterological variables, precipitation and temperature on staple crops like wheat, barley, corn, rice and sunflower through an econometric model. Moreover, the analysis is further extended for different climate scenarios. The findings are significantly important as it sheds light to how selected crop production will develop depending on various climate scenarios over different time periods.

According to the findings, under both high and low emissions scenario, temperature increase especially during spring and summer months, would decrease wheat and barley production significantly over the couse of short, medium and long term.

Moreover, while wheat and barley are impacted in the same direction due to the nature of these crops, some differences are estimated for corn, rice and sunflower. While increase in spring temperature neagtively impacts wheat and barley production, the opposite is expected for the heat resistant crops like corn, rice and sunflower (see Table 1.1).

Table 1.1. Estimated Impact of Temperature Change under HES and LES

| | | **Estimated Impact on Wheat** | **Estimated Impact on Barley** | **Estimated Impact on Corn** | **Estimated Impact on Rice** | **Estimated Impact on Sunflower** |
|---|---|---|---|---|---|---|
| **2030-2050** | **Spring** | - | - | + | + | + |
| | **Summer** | - | - | - | - | - |
| **2050-2070** | **Spring** | - | - | + | + | + |
| | **Summer** | - | - | - | - | - |
| **2070-2100** | **Spring** | - | - | + | + | + |
| | **Summer** | - | - | - | - | - |

Source: Based on Author’s Calculations

It is important to mention that the impact increases over time. For example, under HES expected temperature increase during summer months is estimated to decrease wheat production by 14.6% in the short term. This number increases to 42.1% over the long term. Under the LES, while the estimated reduction is less, it still increases over the long-run.

The thesis concludes that the impact of climate change (increasing temperatures) would be very significant on all of the staple crops of Türkiye. Under the HES the reduction can reach uo to 50% depending on the crop type. Therefore, immediate actions need to be taken to prevent or at least lessen the expected negative impacts.

## 1.5 Chapters of the Thesis

The thesis is structured in 8 chapters. **Chapter 1** starts with introductory remarks. To give a gist of information on the entire thesis, the chapter starts by a brief background information followed by the objectives and the research problem of the thesis. This section also provides how this thesis fits into the literature and how it contributes to the field. A short discussion on data and methodology of the thesis is also included in this chapter.

**Chapter 2** discusses the relationship between climate change and agriculture. This chapter is important to understand how climate change and agriculture is interrelated and why this topic is vital globally. In order to form a baseline for the overall analysis, this chapter firstly discusses what climate change is and the consequences of climate change. Adding to that discussion, the chapter elaborates on climate change in Türkiye. This subsection puts forth why it is critical to focus on Türkiye being located in an arid to semi-arid region. The chapter discusses the impacts of climate change on agricultural production with a specific focus on crop production. Moreover, the specific impacts on developing countries and Türkiye is further included in detail.

Adding on Chapter 2, **Chapter 3** thoroughly lists existing literature on climate change and agriculture. The literature review is structured based on the methodological approaches and divides the literature into 3 categories: crop modelling, Ricardian approach and econometric approach. The last part of this chapter further discusses the studies on Türkiye.

**Chapter 4** presents the data and methodology used in the thesis. Firstly, descriptive statistics is given for each dataset. Secondly, econometric model and how the dataset is incorporated into the model is discussed. This chapter also include the climate scenarios of other studies which are used for future predictions in the static analysis of the next chapter.

**Chapter 5** is the most critical chapter of the thesis. This chapter presents the regression results of various models conducted for different crops. This chapter provides the analysis of how climate-related variables (discussed in Chapter 4) impact crop production in Türkiye. The Chapter discusses each crop, namely wheat, barley, corn, rice and sunflower separately. Each subsection elaborates on one of these crops and specifies different results for robustness.

**Chapter 6** further extends the results of Chapter 5 by adding climate scenarios to predict future crop production. The chapter provides information on how crop production will be affected depending on different climate scenarios. While several scenarios are discussed, the extended results are presented for high emissions and low emissions scenario for each of the crop.

Chapter 5 and 6 are the most critical chapters of this thesis. They discuss the results as well as the possible future scenarios. In line with the literature, these chapters put forth the severe impact of climate change on crop production in Türkiye.

**Chapter 7** is an additional chapter for discussion purposes. The chapter elaborates on numerous widespread adaptation and mitigation strategies in the literature. Additionally, it discusses the legal framework for adaptation and mitigation for Türkiye. This chapter highlights the lessons that Türkiye can learn and perform with a set of policy recommendations for future developments in agricultural sector.

**Chapter 8** concludes the thesis. Firstly, the chapter lays out the importance of this thesis and how it fits the literature. Secondly, it provides a fruitful summary of all the findings of Chapter 5 and 6. Additionally, a brief discussion on what can be done to overcome the negative consequences of climate change on crop production in Türkiye is included. The chapter ends by discussing what can be done for further extend this study.

# CHAPTER 2

# CLIMATE CHANGE AND AGRICULTURE

Agriculture is one of the most vulnerable sectors to climate change expecting to face a significant amount of yield reduction in the near future. The negative impacts of climate change are already being observed in agriculture. Increasing temperatures, variable weather, invasive pests and crops as well as well as frequent extreme weather events is being felt across the globe. Moreover, due to climate change arable land becomes less and less fertile causing production losses. It is evident that climate change has major negative impacts on agricultural production. The literature confirms that climate change has direct, through changes in temperature and precipitation, as well as indirect impacts on agriculture.

The demand for food is expected to increase substantially by 2050 (Valin et al., 2014). This increase is primarily due to growing population. This growth, accompanied by rising incomes in the developing countries leading to changes in food requirements and increasing consumption of certain goods like meat. All these are increasing the global food demand which is projected to increase by 59% up to 98% by 2050 (Valin et al., 2014). The United Nations Food and Agricultural Organization (FAO) estimates that food production must be increased by 70% by 2050 to meet the world’s rising food demand. This challenge of increasing food demand is aggravated by negative impacts of climate change. While we need to increase production and yields to meet the demand, climate change is already decreasing the production and yields.

The aim of this thesis is to understand how climate change impacts agricultural production. As the primary research question is crop production in Türkiye, this Chapter elaborates on the developing countries. In this regard, to form a background information the relationship between climate change and agriculture is analyzed. The

Chapter initially discusses what climate change is and how it effects Türkiye. This discussion is followed by how climate change impacts agricultural production with an emphasis on crop production in Türkiye.

## 2.1 Climate Change

There is a global concensus on climate change and this change being caused by human sources (see Figure 2.1). This concensus is also supported by the academic and scientific community. There are studies in the literature surveying the existing studies on climate change to measure the scientific community's approach towards climate change. According to a comprehensive review by Powell (2017), the consensus on the existance of climate change reaches 100% in the literature (Powell, 2017). A more recent study confirms that 99% agrees on human activities are the main cause of climate change (Lynas et al., 2021).

Climate change refers to long term shifts in climate patterns over a decade, century or even longer periods. It is primarily caused by increasing GHG gases, mainly CO2 and methane, in the atmosphere. While the shifts may have natural causes like variations in the solar cycle, the primary cause is known to be human activities like burning fossil fuels. Additionally, losses of greenlands, some agricultural and industrial activities, land use, buildings and transport are among major GHG emitters.

GHG emissions continue to rise with an increasing pace. Earth's surface temperature is 1.1°C higher compared to pre-industrial levels (IPCC, 2021). The last decade (2011-2020) was the warmest decade in history. The IPCC report projects that, in 20 years time global temperature would reach 1.5°C of warming (IPCC, 2021).

Climate change has severe consequences and these affect major aspects of all our lives. It is estimated that over the last 35 years, major climatic events caused approximately 3 trillion US dollars of global damage with expectations to grow faster due to climate change (World Bank, 2013). There are natural, social and economic consequences. Some of them can be listed as below:

- Increasing temperatures,
- Increasing droughts and wildfires,
- Increasing sea surface levels,
- Decreasing available freshwater,
- Increasing floods,
- Decreasing biodiversity,
- Decreasing available food,
- Increasing health risks,
- Increasing soil erosion (European Comission, 2022).

The International Panel on Climate Change's (IPCC) Sixth Assesment Report (2022) puts out a very starking picture about the impacts of climate change. There are critical points in the report that needs to be mentioned to better understand where the World stands in terms of climate change. Some of the key major takeaways are as such:

- The impacts of climate change are already more common and widespread than it is expected to be.
- Even with significant measures taken, in the short term we are bound to face the negative impacts with the existing emissions. The Report estimates that 32 to 132 million people will ve forced into poverty due to climate change in the next 10 years.
- According to the report, every tenth of a degree of warming of the Earth's atmosphere will cause significant threat to people. Even under the scenario in which Paris Agreement targets are reached, the problems do not disappear. Under the scenario of a global warming exceeding 1.5°C more severe and irreversible impacts of climate change is expected.

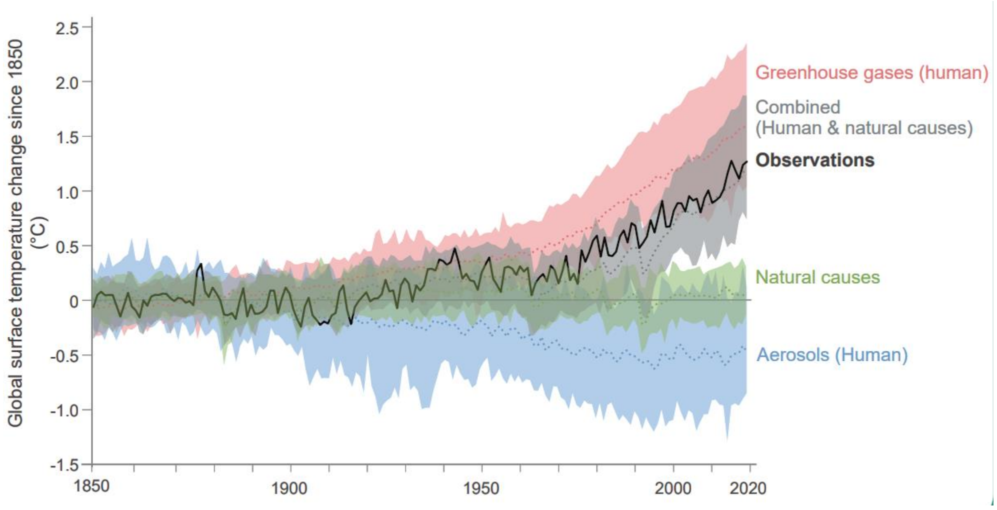
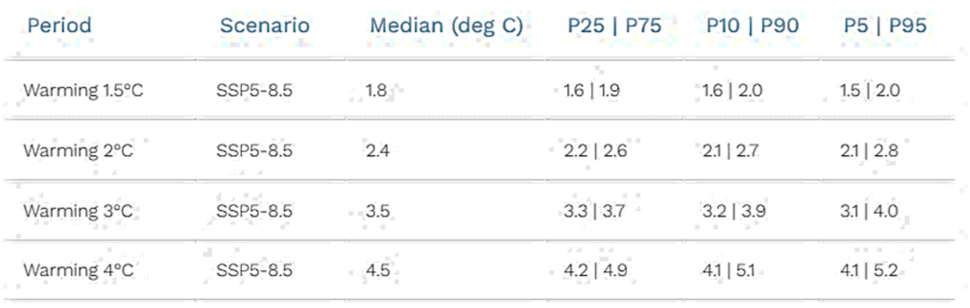


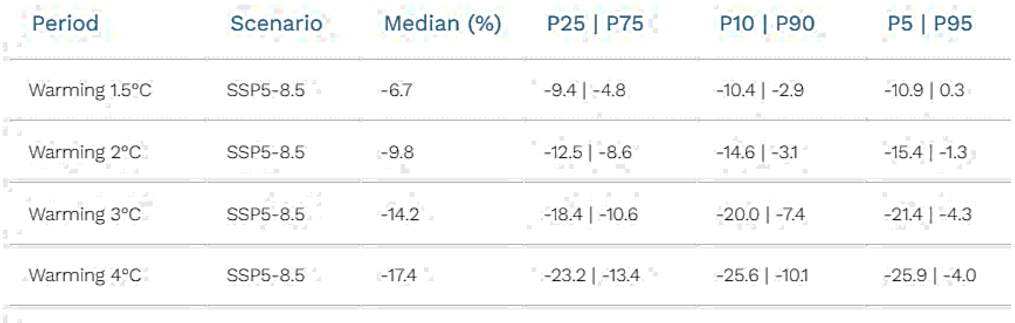
Figure 2.1. Change in Average Surface Temperature
Source: (IPCC, 2022)

Another importance of the Sixth IPCC Report is that it provides a comprehensive regional analysis of climate change for the first time in the literature. The Report provides important information on risk assessment, adaptation and other aspects of decision makers. The regional information is useful in translating climate related variables into what they actually mean for the society. The report presents regional information on multiple variables. For example, Figure 2.2 and Figure 2.3 present estimations for mean temperature and total precipitation changes for the Mediterannean based on different scenarios. More variables, models and scenarios are included in the online Interactive Atlas provided by the IPCC (2021).



| Period | Scenario | Median (deg C) | P25 \| P75 | P10 \| P90 | P5 \| P95 |
|---|---|---|---|---|---|
| Warming 1.5°C | SSP5-8.5 | 1.8 | 1.6 \| 1.9 | 1.6 \| 2.0 | 1.5 \| 2.0 |
| Warming 2°C | SSP5-8.5 | 2.4 | 2.2 \| 2.6 | 2.1 \| 2.7 | 2.1 \| 2.8 |
| Warming 3°C | SSP5-8.5 | 3.5 | 3.3 \| 3.7 | 3.2 \| 3.9 | 3.1 \| 4.0 |
| Warming 4°C | SSP5-8.5 | 4.5 | 4.2 \| 4.9 | 4.1 \| 5.1 | 4.1 \| 5.2 |

Figure 2.2. Mean Temperature Change Relative to 1850-1900 Average (Region: Mediterranean)
Source: IPCC Interactive Atlas (2021)



| Period | Scenario | Median (%) | P25 \| P75 | P10 \| P90 | P5 \| P95 |
|---|---|---|---|---|---|
| Warming 1.5°C | SSP5-8.5 | -6.7 | -9.4 \| -4.8 | -10.4 \| -2.9 | -10.9 \| 0.3 |
| Warming 2°C | SSP5-8.5 | -9.8 | -12.5 \| -8.6 | -14.6 \| -3.1 | -15.4 \| -1.3 |
| Warming 3°C | SSP5-8.5 | -14.2 | -18.4 \| -10.6 | -20.0 \| -7.4 | -21.4 \| -4.3 |
| Warming 4°C | SSP5-8.5 | -17.4 | -23.2 \| -13.4 | -25.6 \| -10.1 | -25.9 \| -4.0 |

Figure 2.3. Total Precipitation Change Relative to 1850-1900 Average (Region: Mediterranean)
Source: IPCC Interactive Atlas (2021)

The regional analysis is very critical since the impacts of climate change is not evenly distributed across the globe. The negative impacts are more likely to be observed in lower latitude countries. Türkiye, being located in the Mediterranean basin, is expected to be affected by the negative consequences of climate change (IPCC, 2007). To form a baseline for later discussions, the next subchapter elaborates on how climate change would impact Türkiye.

### 2.1.1 Climate Change in Türkiye

There are 5 major determinants of climate in Türkiye which are as follows:

- General circulation of the atmosphere,
- The latitudinal location,
- Topography,
- Distance to moisture sources (mainly to the North Atlantic),
- The seas around the country (Şen, 2021)

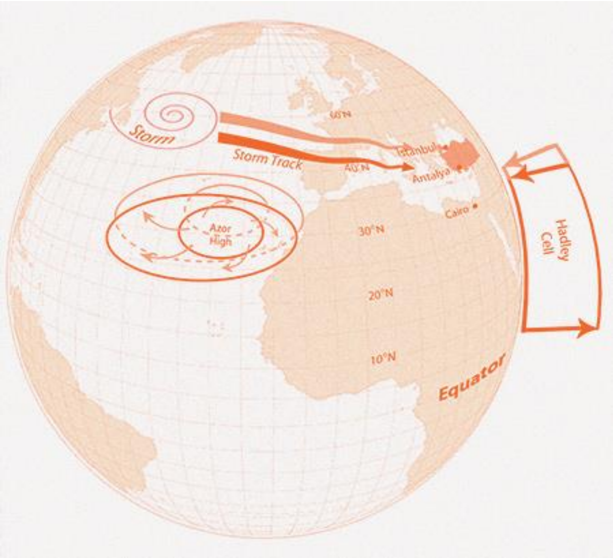


Figure 2.4. Illustration of Climate Change in Türkiye
Source: (Şen, 2021)

All these determinants do not change except the general circulation of the atmosphere. Therefore, understanding the changes in the general circulation of the atmosphere plays a critical role in understanding the climate change in Türkiye. Hadley Cells are critical for the formation of trade winds in the Tropics as well as determining the low latitude weather patterns. Hadley cells lie between the Equator and 30° latitude. According to climate models, Hadley Cell in both hemispheres are expected to expand towards the Poles (see Figure 2.4). The expansion towards the North will translate into less precipitation especially in the southern parts of Türkiye. Moreover, the shift of Hadley Cell will shift the Azor High as well. This shift will cause storm trends to shift upward causing Türkiye to receive less precipitation in southern parts of Türkiye but higher precipitation in the northern parts.

Türkiye is extremely vulnerable to the impact of climate change. During the last few decades, minimum temperatures in the winter and minimum and maximum temperatures in the summer has been increasing (Türkeş & Sümer, 2004). Semi humid regions have shifted towards semi dry regions while the semi dry regions shifted towards dry regions across the country (Türkeş, 2003). Being located in the southern belt of the Mediterranean the country has been experiencing increasing temperatures and decreasing precipitation. According to Köppen Climate Classification, the northern part of the country is located in the cold, no dry season and hot-warm summer climatic zone, while the southern part is located in more temperate climate zone (see Figure 2.5). However, the same classification projects that due to climate change, Türkiye will shift towards a more temperate climatic condition rather than a colder climate as of 2070 (see Figure 2.6).

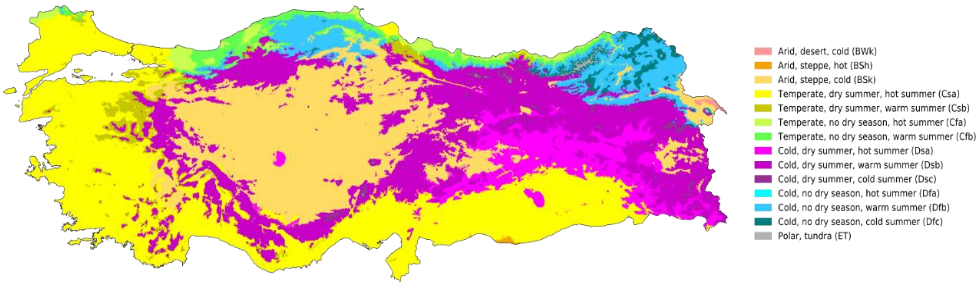


Figure 2.5. Köppen Climate Classification Map for Türkiye (1980–2016)
Source: (Beck et al., 2018)

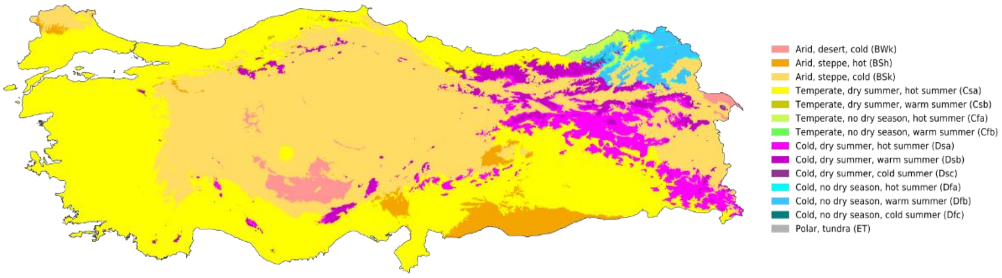


Figure 2.6. Predicted Köppen Climate Classification Map for Türkiye in the Future (2071–2100)
Source: (Beck et al., 2018)

The IPCC Report mentions that three increasing trends will rise in Türkiye; increasing temperature, decreasing precipitation and rising sea levels. Therefore, more extreme and frequent weather events are more likely to occur in Türkiye over the next years (IPCC, 2007). The report projects that by 2050 the eastern and central parts of the country will experience 2.5°C temperature increase. This increase will be 1.5°C in the coastal regions. Extreme temperatures are expected to occur more frequently during summer for longer periods. In addition to increase in temperature, precipitation is expected to decline by 10% by 2050. The decrease is mainly expected in the west and the Mediterranean. In this regard, Türkiye has developed some stratgies to combat the negative impacts of climate change.

Türkiye became a party to the Kyoto Protocol in 2009. The country ratified the Paris Agreement in October 2021. Following the ratification, Türkiye has published its “Revolution of Green Development” based on the global commitments. Moreover, the 11th Development Plan (2019-2023) acknowledged the country’s commitment to reduce greenhouse gas emissions. According to this Plan: “It is seen that climate change accelerating due to high greenhouse gas emissions causes natural disasters and poses a serious threat to humanity." and "International climate change negotiations will be conducted within the framework of the Intended National Contribution with the principles of common but differentiated responsibilities and respective capabilities, and within the scope of national conditions, climate change will be tackled in sectors causing greenhouse gas emissions and the resilience of the economy and society to climate risks will be increased by capacity building for adaptation to climate change" (Presidency of Strategy and Budget, 2019). All of these documents highlight the importance of the efforts to combat climate change. If Türkiye does not give enough attention to climate change the country would face severe consequences.

One of the most vulnerable sectors to climate change is agriculture. Climate change is closely intertwined with agriculture. Agriculture depends on specific climatic conditions. Climate change is expected to affect agriculture in multiple ways with primary impact being on agricultural production. The next subchapter elaborates on the impacts of climate change on agricultural production.

## 2.2 Climate Change and Agricultural Production

Global climate change is expected to impact many sectors and areas, yet, one of the largest impacts is expected to be on agriculture (Cline, 2007; Nordhaus, 1991). Climate change and agriculture are inextricably linked, yet, fast transitions in climatic conditions cause risks for food security. According to an important joint report of FAO, International Fund for Agriculture (IFAD), UNICEF, World Food Programme (WFP) and World Health Organization (WHO) the rate of increase in crop production is not enough to meet the rising demand (FAO et al., 2018). According to Food and Agriculture Organization (FAO), if the emissions continue to rise the World will face a major reduction in staple crops by 2100 (FAO & Gitz, 2015). It is expected that if necessary measures are not taken, losses in crops will lead to a significant decline in total production, which will cause substantial pressure on food prices. According to the IPCC projections, since production of major crops are mainly located in a few numbers of producing countries, crop production is extremely vulnerable to climate change resulting in higher global food prices (IPCC, 2019).

World population is increasing and estimated to reach 9.7 billion until 2050. While the global population is increasing, developing countries are beginning to switch their food preferences to more resource demanding foods like meat. This increase puts additional pressure on agricultural production demand which is already facing pressure from climate change. Moreover, a significant amount of crop production is diverted towards biofuel production causing a decrease in the available crop for food consumption. It is also a fact that productivity growth of crops is decreasing. If demand continues to outgrow productivity growth especially in crops, food prices will surge with severe consequences. According to FAO, climate change is expected to increase crop prices by 29% by 2050 (OECD-FAO, 2022)While the major impacts will be on poorer countries, developed countries will feel indirect consequences as well.

The International Panel on Climate Change’s (IPCC) Sixth Assessment Report puts out a striking picture about the impacts of climate change on agriculture. It is evident from the report that climate change will risk food security. The report mentions "climate-related extremes have affected the productivity of all agricultural and fishery sectors, with negative consequences for food security and livelihoods" (IPCC, 2021). Additionally, the IPCC report analyzes the links between climate change, food security and agriculture. The report clearly states how climate change already effects agricultural systems negatively. Due to increase in the occurrence of the climate related extreme weather events, food and crop supply is already being disrupted. According to the report, "Climate-related extremes have affected the productivity of all agricultural and fishery sectors, with negative consequences for food security and livelihoods".

The impact of global climate change is comprehensive and becoming visible in the agricultural sector. Climate change particularly impacts agricultural production. The affects happen through different mechanisms mainly driven by higher mean temperature, extreme weather events, changing precipitation patterns as well as increasing CO2 levels. Studies show that extreme weather events causing negative agricultural production shocks occurring in every 100 years is expected to occur in every 30 years before the middle of 2000s (Bailey et al., 2015). There are direct and indirect effects of climate change on agriculture. Firstly, agricultural productivity is projected to be affected both in terms of quality and quantity. Secondly, agricultural practices are likely to change. Due to changes in climatic conditions, water use and agricultural input use (Pesticides, fertilizers etc.) would shift. There will be additional environmental effects mostly related to soil drainage and erosion. Climate change would also cause reductions in crop diversity. In addition, adaptation issues would rise. Some types of organisms might get more or less competitive. For example, depending on the needs, humans might like to develop more or less competitive organisms such as flood or salt resistant varieties of rice.

Climate change impacts every aspect of crop production. It has significant impacts on the area, intensity as well as the yield of major crops. While most studies focus on estimating the impacts of climate on yields a small part of literature also looks at the impacts on cropping area and intensity as well.

Extreme weather events are critical for agricultural productivity. The occurrence of extreme weather events such as droughts and floods are likely to increase with climate change. Both droughts and floods are becoming more common and causing crops to be destroyed. A detailed study on the analysis of drought index and crop yield data reveals that three quarters of total harvested area of crops have been affected severely by droughts globally (W. Kim et al., 2019). As the temperature increase and extreme weather events occur more frequently, agricultural areas would get less arable. Moreover, studies show that a decrease in available water for irrigation (Bhardwaj et al., 2018) and a change in rainfall pattern (Aryal et al., 2020) decrease agricultural production. According to the estimations of the IPCC Report (2021) three fourths of total global harvested area of crops have experienced some kind of production loss due to increasing droughts. Droughts have caused a significant decline in the yields of maize and wheat. Combined with the effect of increased temperature average maize and wheat yield is expected to decrease by 11.6% and 9.2%, respectively.

Changes in climate variables such as temperature and precipitation are significant determinants of crop yields (Anderson & Hazell, 1989; Hazell, 1984). Wheat is the most produced, harvested and consumed crop across the globe. In particular, wheat production is very sensitive to precipitation and temperature changes. Since it is one of the most critical food, the literature pays significant attention to the impact of climate change on wheat production. However, the literature finds inconclusive results. While some studies find that wheat yield increases due to climate change, others conclude the opposite. According to Kersebaum and Nendel the findings differ due to regional differences (Kersebaum & Nendel, 2014). Empirical evidence also supports this argument. Sultana et al (2009) show that in arid and semi-arid regions like the Mediterranean, an increase in temperature causes reduction in wheat yield, yet, the result is opposite for the wet zone of Pakistan (Sultana et al., 2009). Similar patterns are found for changes in precipitation as well.

The uncertainty regarding the impact of climate change on agricultural production is mainly caused by scenario limitations. First, GHG emission scenarios vary. Moreover, climate models used for estimation varies and adapts over time. While the models used until the 21st century told us more optimistic scenarios, the models using 21st century projections tell the problem is approaching sooner than anticipated. An influential NASA study draws more pessimistic outcomes. According to this study, under a high GHG emissions scenario, climate change would affect maize and wheat production in 2030 (Jägermeyr et al., 2021a). While the production of maize is expected to decrease 24%, wheat production is expected to increase by 17%. The significance of this Project is that, the estimations are much starker compared to their previous study in 2014. Moreover, the study also finds out that, even under a very ambitious optimistic climate change scenario, global agriculture would face a climate challenge which is inevitable.

Climate change effects agricultural production globally, yet, the impacts of climate change on agriculture is unevenly distributed across the globe. The negative impacts are most likely to be observed more in low latitude countries. The effects on higher latitudes may be positive or negative. That is why it is crucial to make regional analysis to better understand the impacts. The impact of climate on agricultural production is related to local climate fluctuations rather than global variabilities. Therefore, making concrete assessments require local analysis. The next subsection discusses how differently developing countries are affected by climate change compared to the developed world.

### 2.3 Climate Change and Agriculture in Developing Countries

The potential negative impacts of global climate change on agriculture has critical implications primarily for developing countries as agriculture is an important contributor of poverty reduction in those countries (Cervantes-Godoy & Dewbre, 2010). It is widely accepted by agronomists that the developing countries are more sensitive to climate change compared to developed countries (Mendelsohn, 2014; Rosenzweig & Parry, 2022; Tol, 2002). The economies of the developing countries rely more on agriculture and usually are located in regions which are already too hot or dry by nature.

An important book by Cline (2007) analyzes how climate change affects agricultural production across different countries and regions (Cline, 2007). He finds that, without any efforts for mitigation, agricultural productivity will be negatively affected with most severe impacts to be observed in developing countries (see Figure 2.7).

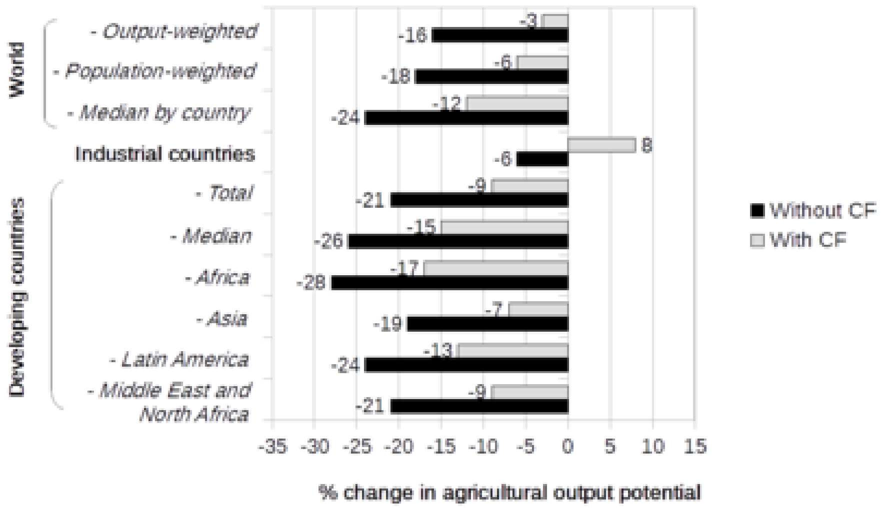


Figure 2.7. Global Agricultural Productivity Effects in Developing Countries
Source: (Cline, 2007)

Another study by Lobell et al. (2008) shows that South Asia and South Africa are likely to experience severe negative impacts on crucial crops hence taking sufficient measures is required (Lobell et al., 2008). Battisti and Naylor (2009) finds that increase in seasonal temperatures would negatively impact agricultural production mainly in the tropics (Battisti & Naylor, 2009). IPCC in its 2007 report projects that climate change would decrease crop productivity in Southern Europe, while for

Northern Europe crop productivity is expected to increase (IPCC, 2007). According to report by European Environment Agency, wheat, sugar beet and corn yields are expected to decrease by 50% by 2050 in Southern Europe (European Environment Agency, 2019)

The negative impacts are most likely to be observed more in low latitude countries. The effects on higher latitudes may be positive or negative. That is why it is crucial to make regional analysis to better understand the impacts of climate change on agriculture. Climate change is reducing yields of certain staple crops as well as their nutritional quality. Climate change also may cause an increase in pest insects causing decrease in yields of major crops like wheat, soybean and corn. While increased temperature causes longer growth rates form any plants, it also increases the breeding cycles of insects (Leonard, 2006). It is more likely for higher latitude areas to experience this problem (Stange & Ayres, 2010). For example, one study on soybean plan growth and Japanese beetle populations showed that as temperature and CO2 level rise, soybeans grew faster with higher yields. However, the beetle population also increased causing lower yields in the long run (Union of Concerned Scientists, 2017). Similarly, diseases and weeds would increase due to climate change. Climate change could cause an increase in precipitation in some areas causing an increase in the humidity and duration of the wet seasons. As the temperature and humidity increases, the likelihood of fungal diseases also increases (Johns Hopkins Medicine, 2020).

It is expected that for arid and semi-arid regions temperature would increase while precipitation would decrease (El-Beltagy & Madkour, 2012; World Water Council & Arab Water Council, 2009). Moreover, for tropical regions crop yields are expected to be negatively affected (Tubiello et al., 2007). It is crucial that many major crops which are staple goods are vulnerable to increasing temperature. For example, when temperature reaches over 36°C, soybeans and corn get negatively affected (Epstein & Ferber, 2011; Thomson et al., 2010). It is projected that, a yearly increase of 1 °C will cause a 10% decrease in wheat, corn and rice yields (Daloz et al., 2021). Another study by You et al. (2009) finds out that a 1°C increase in mean temperature potentially reduces yields up to 10%. According to a more recent study by NASA corn yields are estimated to decrease by 24% while wheat yields are projected to rise by 17% due to climate change (Jägermeyr et al., 2021b). On the other hand, for temperature climate regions closer to Equator, temperature increase may positively affect the crop yields. As the duration of growing season increases due to increased temperature, some areas would benefit from increased crop growth.

Vulnerability of each region or country depends on their own adaptive capacity and unique circumstances (Guiteras, 2009). Therefore, regional analysis is critical in understanding the impacts of climate change on agricultural production. In that sense, developing countries with lower adaptive capacities are more critical to analyze, yet, the literature mostly focuses on developed countries. In addition, developing countries being located in the regions already close to the tolerance level of the crops are more important to focus. There are still many uncertainties in this field simply because of the lack of information. The lack of information is mainly due to missing studies on specific local regions. In that sense, Türkiye being located in an arid to semi-arid area requires significant attention in understanding the negative impacts of climate related events on agricultural production.

## 2.4 Climate Change and Agriculture in Türkiye

Türkiye, being located in the Mediterranean basin, is expected to be significantly affected by the negative consequences of climate change (IPCC, 2007). Agricultural production in the country is very vulnerable to temperature change. Sudden temperature increases during spring and summer in this region cause critical risks for agricultural production in Türkiye. According to Demircan et al. (2017) a 2-3°C increase in mean temperature is expected (Demircan et al., 2017). Similar result is found by Duygu et. al (2017). They also predict that precipitation would decrease 25 to 50% in the Konya Basin (Duygu et al., 2017).

In addition to temperature changes, crop production is vulnerable to changes in precipitation. 20% of the agricultural land is irrigated in Türkiye and 70% of the water resources is used for this purpose (I. Dellal & Unuvar, 2019). Rain and irrigation are extremely critical in growing staple crops, namely, wheat, barley and corn. Therefore, water shortages due to climate change will diminish crop production across the country. According to Fujihara et al. (2008) 160 mm annual reduction in precipitation is expected in the Seyhan River Basin of Türkiye (Fujihara et al., 2008).

Türkiye produces a variety of crops which are critical both for domestic consumption and exports. Wheat is a staple crop grown across numerous regions of the country. Wheat is mostly grown in arid and semiarid regions of Türkiye. The growth process requires irrigation. Therefore, water scarcity due to decrease in precipitation would rise as a limiting factor in wheat production. Tonkaz et al. (2007) reported that 6°C increase in minimum and maximum temperatures leads to a 30% decline in wheat production of Türkiye (Tonkaz et al., 2007).

Türkiye is also an important barley producer. Barley is grown in the areas similar to wheat, yet, barley is more tolerant to lack of irrigation compared to wheat. According to the observations of Soylu and Sade (2012) barley production reduced less compared to wheat during the dry years in the Central Anatolian part of the country (Soylu & Sade, 2012).

Maize is an important crop for animal feed of Türkiye. Most of the maize producers are located around regions with Mediterranean type of climatic conditions. According to climate change predictions significant temperature increases and precipitation decreases are expected in these regions. Moreover, maize growth is restricted when the maximum temperature exceeds 41°C (Challinor et al., 2014) Şanlıurfa Basin has already experienced degrees above this threshold. In this regard, maize is very sensitive to additional increases in temperature.

Sunflower production is critical for oil production of Türkiye. Sunflower was grown mostly in the Northwest part of Anatolia until last decade. The production has rapidly spread towards Central Anatolia in the last decades. In the Central Anatolia sunflower is grown in irrigated areas requiring adequate precipitation for optimal growth.

Climate change effects agricultural production globally. However, Türkiye is more exposed to the risks as being located in the Mediterranean Basin. Overall, the agricultural sector is exposed to 3 major challenges:

- It must produce more food to meet the increasing demand due to population growth.
- In order to meet growing demand, it must overcome the negative impacts of climate change on agricultural goods, primarily crops.
- Being a significant emitter, it must contribute to global goal of emission reduction targets set by the Paris Agreement.

Combatting the above-mentioned challenges requires global action, yet, due to different impacts of climate change on the agriculture of developed and developing countries there have been a longstanding disagreement among those countries. Despite the ongoing disagreement, a decision was taken at 23rd COP under the name of the Koronovia Joint Work on Agriculture (KJWA).

KJWA is a platform under UNFCCC where issues related to agriculture is discussed. While KJWA focuses on the potential of agriculture on fighting climate change, it also focuses on the socioeconomic and food security dimensions. The KJWA was adopted in 2017 at COP23 and has been ongoing since then. According to COP26 held in 2021, considering the resilience of agriculture on climate change, the parties agreed on “the need for a transition towards sustainable and climate resilient food systems” (Directorate-General for Agriculture and Rural Development, 2021).

The awareness of the impact of climate change on agricultural productivity as well as crop production and on food security is raising globally. It is crucial to quantify the impact of climate change on agriculture in order to build mitigation and adaptation policies. There are many studies in the literature that quantify the climate impacts on agriculture. In addition, the economic analysis of agricultural production has been increasing in the literature over the past decade. The next Chapter covers extensively the literature on how climate change impacts agricultural production with a primary focus on crop production in Türkiye.

# CHAPTER 3

# LITERATURE REVIEW

The detrimental effects of climate change on agriculture is undeniable. The previous Chapter elaborated on these effects from various approaches that was discussed in the literature. In particular, there is a consensus on the negative impacts of climate change on agricultural production as well as crop production (Challinor et al., 2014). Global climate change and its detrimental impacts have been a major research topic in the literature. Over the last decade, the economic analysis of agricultural production has been increasing in the literature as well.

The literature on the impacts of climate change on agriculture is very comprehensive. In this Chapter, in line with the research question of the thesis, the literature is limited to studies analyzing the impacts on agricultural production. In particular, the impacts on crop production is thoroughly discussed. More detailed review will be provided for econometric studies using time series and panel data approaches. Studies on how crop production in Türkiye is affected from climate change is the field of interest of this thesis. Hence, each econometric study, as far as to my knowledge, published on Türkiye's crop production is discussed in detail. This detailed discussion enables to present where this thesis fits in the literature and how it fills gaps in the literature.

The literature can be classified into three broad categories according to their methodological approaches: crop modelling/production function approach, Ricardian approach and econometric approach. The next subchapters will present the major literature on each of these three approaches. Among these approaches econometric approach is the most recent, yet most developing one. The upcoming subchapters pay special attention to econometric studies since this thesis uses panel data approach for the analysis on crop production in Türkiye. In this regard, after discussing other approaches, the last part of this Chapter focuses on econometric studies done for Türkiye.

## 3.1 The Crop Modelling (Production Function Approach)

The literature has two broad categories to analyze the impacts of climate change on agriculture: crop modelling and statistical modelling (ricardian and econometric approaches). Both of these approaches have their advantages and disadvantages. Crop modelling combines science of phsiology, agriculture and soil as well as agricultural meteorology. Analyses using crop modelling predict how a product can be grown in a certain area under specific environmental conditions (Shi et al., 2013). Crop modelling is a common tool in the analysis of climate change on agriculture, yet, it requires very detailed information related to the meteorological data, soil structure, growing conditions and etc. Therefore, application of crop modelling to larger scale regions is difficult (Schlenker & Roberts, 2009).

This approach estimates the impacts of climate change through a production function by changing input variables one by one (Mendelsohn, Nordhaus, review, et al., 1994). This method is based on simulations in a labaratory-type environment. The method is critisized for overestimating the results by disregarding many components (Mendelsohn & Dinar, 2003; Sarker et al., 2014).

Table 3.1 presents a summary of major studies incorporating production functions to estimate the impact of climate change on agricultural production.

Table 3.1. Selected Literature on Crop Modelling

| **Author** | **Country / Period** | **Dependent & Independent Variables** | **Findings** |
|---|---|---|---|

Table 3.1. Selected Literature on Crop Modelling (cont’d)

| | | | |
|---|---|---|---|
| (Lal et al., 1999) | India<br>(1970s-1997) | D: Soybean yields<br>I: CO2 level | Doubling CO2 levels would increase soybean yields. |
| (Alexandrov & Hoogenboom, 2000) | Bulgaria (1961-1990) | D: Maize yield, winter wheat grain yield<br>I: Rainfall, temperature and solar radiation | At current CO2 levels, a decrease in maize and winter wheat yields are expected in 2020s, 50s and 80s. |
| (Olesen et al., 2000) | Denmark (1971-1997) | D: Winter wheat<br>I: CO2 emissions, rainfall, temperature, evapotranspiration | Using CLIMCROP crop simulation model, the study suggests that a 1°C increase in mean temperature during grain filling increases the duration of grain filling by 5% |
| (Mathauda et al., 2000) | India<br>(1970-1990) | D: Rice yield<br>I: Temperature changes | Depending on 5 different weather scenarios, CERES RICE simulation model was used showing that increase in temperature reduces rice yields. |

Table 3.1. Selected Literature on Crop Modelling (cont’d)

| | | | |
|---|---|---|---|
| (Krishnan et al., 2007) | Eastern India | D: Rice yields<br>I: Radiation, temperature, precipitation | This study uses RYZA1 and the INFOCROP rice models. For every 1C increase in temperature average yield decreased around 7% keeping CO2 levels constant. Increase in CO2 concentration causes an increase in the average yield up to 30%. |
| (Aggarwal et al., 2010) | India<br>(1969-1990) | D: Rice and wheat yields<br>I: Radiation, temperature, precipitation, wind speed and vapor pressure | This study uses infoCropWheat and InfoCropRice models. Results suggest that changes in climate variables will impact wheat and rice yields. |
| (Dias et al., 2016) | Sri Lanka<br>(2013-2014) | D: Rice yields<br>I: Radiation, temperature, precipitation | This study uses DSSET model. Results suggest that increasing temperature and radiation and decreasing precipitation has impact on both yield and growth in the midterm. |

Table 3.1. Selected Literature on Crop Modelling (cont'd)

| | | | |
|---|---|---|---|
| (Araya et al., 2022) | Ethiopia<br>(1980-2009) | D: Wheat yields<br>I: Temperature, precipitation and CO2 levels. | This study uses DSSAT-CSM Model to analyze the impact of climate change on wheat yields. The results suggested that negative effect of increased temperature was compensated by the positive effect of increased CO2 levels. The change in rainfall was not significant. |

Crop simulation-based models are commonly used to forecast the impacts of climate change on future agricultural production and serve as an important tool for policymakers to build adaptation strategies. However, crop simulation modelling has its own limitations. Deciding on the appropriate model complexity depending on the question being asked is critical. In some cases, simple models are not enough for prediction. In other cases, complex models are not practical for data availability purposes. In that sense, modelers need to be very precise in what they are looking for.

## 3.2 The Ricardian Approach

Earlier studies involved limited data and simpler methods. The methodologies used in these studies generally relied on large extrapolation results. With the advancement in data, technology and models, the understanding of the impact of climate change has changed substantially.

The Ricaridan approach is an empirical apporach using cross-sectional data for analysis purposes. The name of the approach is based on Ricardo (1817) and described in detail by Mendelsohn et al. (1994) (Mendelsohn, Nordhaus, & Shaw, 1994; Ricardo, 2014). Ricardian apporach analyzes the performance of farm lands in climate regions assuming perfect competitive markets. The approach aims to fix the bias of the production function approach by incorporating economic data on the value of land. It is important to mention that; Ricardian approach considers farmers adaptation to different climates (efficient adaptation) unlike crop modelling approach. This is consistent with the field data which shows that in reality farmers make adaptation decisions on what to grow, whether to irrigate, which crop mix to choose.

This method assesses the overall impact on a specific region rahter than focusing on certain crops. This approach analyzes how climatic conditions in different regions impact the rentor value of the farm land. Table 3.2 presents relevant literature using Ricardian approach for their analysis.

Table 3.2. Selected Literature on Ricardian Approach

| **Author** | **Country / Period** | **Dependent & Independent Variables** | **Findings** |
|---|---|---|---|

Table 3.2. Selected Literature on Ricardian Approach (cont'd)

| | | | |
|---|---|---|---|
| (Mendelsohn & Dinar, 1999) | India and Brazil (1998) | D: Grain yields<br>I: Temperature and Precipitation | Results show that even though the agriculture is sensitive to climate, adaptation ability of farmers mitigate the impact of climate change on production. |
| (Chang, 2002) | Taiwan<br>(1977-1996) | D: 60 crops<br>I: Temperature and Precipitation | Climate change significantly impacts crop yields. |
| (Kumar & Parikh, 2001) | 271 districts of India (1970-1980) | D: Farm level net revenue<br>I: Temperature and Precipitation, soil characteristics, number of cultivators, bullocks, population density, literacy rate | The results of the study find strong relationship between agricultural performance and climate. Over the entire country 8.4% of net revenue loss is expected (based on a scenario). |

Table 3.2. Selected Literature on Ricardian Approach (cont'd)

| | | | |
|---|---|---|---|
| (Mendelsohn & Dinar, 2003) | USA<br>(1997) | D: Farmland value<br>I: Temperature and Precipitation | Increase in temperature increases net income. Precipitation has a negative impact. The impact of temperature is found to be larger. |
| (Deressa et al., 2005) | South Africa (1977-1998) | D: Sugar cane production<br>I: Temperature and Precipitation | Sugar cane production is sensitive to climate change. |
| (Kurukulasuriya et al., 2006) | 11 African countries | D: Net revenue<br>I: Temperature and Precipitation, soil characteristics, economic variables, water flow | Net revenues fall in drier regions, yet, increase for irrigated crops located in cooler areas of the region. First estimations show that these effects offset each other. However, more immediate response is expected in the drier regions. Moreover, precipitation is an important determinant as well. |

Table 3.2. Selected Literature on Ricardian Approach (cont’d)

| | | | |
|---|---|---|---|
| (Seo & Mendelsohn, 2008) | 7 Countries in South America | D: Farm land value/revenue<br>I: Temperature, precipitation, soil characteristics, electricity dummy | Agriculture in South American countries is vulnerable to climate change. The impact is expected to be smaller if climate change is milder. However, in case of stronger climate change farmers can lose 50% of their net revenue. |
| (De Salvo et al., 2013) | Italy<br>(2003-2007) | D: Average net revenue<br>I: Average temperature | Climate change decreases average net revenue in Alpines region of Italy. |

The common feature of the studies mentioned above are, using Ricardian approach, each study regresses land values or net revenue on climate, economic variables and geographic variables which are independent of farmer’s own decision. The approach is a comparative static analysis capturing the adjustments of the farmers in response to climate related changes. However, the model is not dynamic and does not measure the transition costs.

There are advantages of using a Ricardian model, yet, this approach does not consider time independent and region-specific factors. It does not consider the effects of variables that are unchanging over the region such as CO2 concentration, extreme weather events and annual weather fluctuations (De Salvo et al., 2013). Another drawback of Ricardian approach is that it assumes prices to be fixed causing an overestimation of the welfare changes.

Similar to all other empirical studies, there is a room for improvement in the functional form and selection of missing variables in the regressions.

## 3.3 Econometric Approach

Besides Crop modelling and Ricardian approaches, econometric approach is becoming a widespread method in recent studies estimating the impact of climate related variables on agricultural production. Econometric modelling is mainly based on historical data. In the areas where adequate information on soil structure required for production function (crop modelling) approach is not available econometric models are more useful for analysis purposes (Schlenker & Lobell, 2010). Econometric approach can be categorized under panel data and time series approaches.

Time series approach has been widely used in the literature to analyze the impact of climate-related variables on the crop yields at global, regional and country level (Maharjan & Joshi, 2013). This method uses previous year data to make projections on the future. Table 3.3 presents related literature using time series approach.

Table 3.3. Selected Literature on Time Series Approach

| **Author** | **Country / Period** | **Dependent & Independent Variables** | **Findings** |
|---|---|---|---|

Table 3.3. Selected Literature on Time Series Approach (cont'd)

| | | | |
|---|---|---|---|
| (Sarker et al., 2012) | Bangladesh (1972-2009) | D: Rice yields<br>I: Temperature and precipitation | Change in climate related variables impact each type of rice differently. Average maximum temperature generates more risks to Aus and Aman rice. Minimum temperature creates risks for Boro rice. |
| (Maharjan & Joshi, 2013) | Nepal (1978-2008) | D: Wheat, rice, barley, millet and potato yields<br>I: Temperature and precipitation | Increase in summer precipitation & max temperature increases rice yields. Increase in summer precipitation & max temperature decrease maize yields. |

Table 3.3. Selected Literature on Time Series Approach (cont'd)

| | | | |
|---|---|---|---|
| (Zaied & Zouabi, 2015) | Tunisia<br>(1980-2012) | D: Olive production<br>I: Temperature, precipitation, labor and capital stock | Olive production decreases as temperature increases. |
| (Amponsah et al., 2015) | Ghana<br>(1961-2010) | D: Crop yield<br>I: CO2 emissions and real GDP | CO2 and crop yields are negatively related. Income and crop yield is positively related. |
| (Rahim et al., 2016) | Malaysia<br>(1983-2013) | D: GDP<br>I: Temperature, precipitation and farm area | Cointegration exist between the variables in this study. There is a unidirectional causal impact of temperature, precipitation and farm area on GDP. |
| (Guntukula, 2020) | India (1961-2017) | D: Rice, wheat, cotton, sugarcane, and groundnut yields I: Temperature and precipitation | Increase in precipitation negatively effects al crops except for pulses. |

According to Lobell and Burke (2010), the best model capturing temperature and precipitation fluctuations is panel data models (Lobell & Burke, 2010). Panel data approach is critical in analyzing the impacts of year-on-year climate variable changes (Deschênes & Greenstone, 2007). The panel data approach, primarily random effects model, has the advantage of considering time invariant and unobservable variables. Table 3.4 summarizes major studies using panel data approach for analysis.

Table 3.4. Selected Literature on Panel Data Approach

| **Author** | **Country / Period** | **Dependent & Independent Variables** | **Findings** |
|---|---|---|---|
| (Deschênes & Greenstone, 2007) | US<br>(1978, 1982, 1987, 1992, 1997, and 2002 Census of Agriculture) | D: Agricultural profits<br>I: Temperature and precipitation | Climate change is expected to increase agricultural profits by 4% annually. |
| (Guiteras, 2009) | India<br>(1961-1999) | D: Crop yield<br>I: Temperature, Precipitation, urbanization, soil characteristics | Crop yields are expected to decrease by 4.5 to 9% during 2010-2039. |
| (M. Kim & Pang, 2009) | Korea (1977-2008) | D: Rice yields and variability<br>I: Temperature and precipitation | Rice yield increases with temperature, decreases with precipitation. |

Table 3.4. Selected Literature on Panel Data Approach (cont'd)

| | | | |
|---|---|---|---|
| (Brown et al., 2010) | 133 Countries<br>(1961-2003) | D: GDP growth, Value-added agricultural and industrial GDP<br>I: Temperature and precipitation | Increase in precipitation increases the share of agriculture in GDP. Temperature has the opposite impact. |
| (Lobell et al., 2011) | USA<br>(1980-2008) | D: maize, wheat, rice, soybean yields<br>I: Temperature and Precipitation | Maize and wheat production are expected to decrease by 3.8% and 5.5%, respectively. |
| (Akram, 2013) | 8 Asian Countries<br>(1972-2009) | D: GDP, value-added agricultural GDP, growth rate<br>I: Temperature and precipitation, population | Temperature and precipitation impact GDP negatively. The impact on agricultural GDP is higher than manufacturing and services sectors. |

Table 3.4. Selected Literature on Panel Data Approach (cont'd)

| | | | |
|---|---|---|---|
| (Dell et al., 2012) | 125 Countries<br>(1950-2003) | D: GDP<br>I: Temperature and precipitation | Increase in temperature causes reduction in GDP growth in less developed countries. |
| (Barnwal & Kotani, 2013) | India<br>(1971-2004) | D: Rice yields<br>I: Temperature and Precipitation | Kharif rice is affected more compared to Rabi (winter) rice. |
| (Loum & Fogarassy, 2015) | Gambia<br>(1960-2013) | D: Maize and millet production<br>I: Temperature and Precipitation, CO2 emissions, fertilized and planted area | CO2 emissions have positive, temperature and precipitation have negative impact on maize and millet production. |
| (Atay, 2015) | Mediterranean countries | Panel ARDL method for pooled mean group (PMG), mean group (MG) and dynamic fixed effect (DFE) estimators. | North African countries are more vulnerable to climate change than South European. Impact of temperature change is higher compared to precipitation. |

The previous subchapters summarized the results of the important literature categorized under different methodological approaches. As the interest of this thesis is on Türkiye, next subchapter elaborates on the existing literature on Türkiye.

## 3.4 Studies on Türkiye

There are numerous studies on Türkiye using different methodologies. An early study was carried out by Cline (2007). Cline (2007) in his comprehensive book finds a significant negative impact of an increase in mean temperature and decrease in precipitation on agricultural productivity in Türkiye (Cline, 2007). Özdoğan (2011) in his study based on simulation models, finds out that higher emissions and temperature and lower precipitation would reduce wheat yields between 5 to 35% in the Northwestern part of the country (Özdoğan, 2011). Dudu and Çakmak (2018) combines an economy wide model with a crop water requirement model and conclude that negative impacts of climate change would be more significant after 2030s (Dudu & Çakmak, 2018). Results of a farm field level data analysis by Vanli et al. (2019) also find the negative impact of climate related events on agriculture (Vanli et al., 2019). Dellal et al. (2011) and Dellal and Unuvar (2019) use both economic analysis and biophysical models. In the 2011 study, the results indicate that climate change is expected to decrease yields in major crops up to 10.1% (Đ. Dellal et al., 2011). The 2019 study extends the results and finds out that yield reductions will be 2 to 7% in 2020, 4 to 12% in 20150 and 5 to 20% in 2080 (Olgun & Erdogan, 2009).

The literature using econometric analysis is developing in the recent years, yet, there are still a lot of remaining parts in this field. Table 3.5 summarizes existing literature that uses econometric methods.

Table 3.5. Selected Literature Using Econometric Approach for Türkiye

| **Author** | **Approach** | **Period** | **Dependent & Independent Variables** | **Findings** |
|---|---|---|---|---|
| (Olgun & Erdogan, 2009) | Panel Data | 1995-2007 | D: Wheat yield<br>I: Temperature, precipitation and humidity | Wheat yield in Eastern Anatolia significantly depends on |
| (Başoğlu & Teletar, 2013) | Time Series | 1973-2011 | D: Agricultural GDP<br>I: Temperature and Precipitation, population, diploma from secondary school | Positive impact: Precipitation<br>Negative impact: Temperature |
| (Eruygur & Özokcu, 2022) | Panel Data | 1995-2014 | D: Wheat yield<br>I: Temperature, maximum temperature, precipitation, solar radiation | According to the average scenario (worst scenario), wheat yield is expected to decline 8% (23%) by 2100. |

Table 3.5. Selected Literature Using Econometric Approach for Türkiye (cont’d)

| | | | | |
|---|---|---|---|---|
| (Bayraç & Doğan, 2016) | Time Series | 1980-2013 | D: Agricultural GDP<br>I: Temperature and Precipitation, CO2 emissions, agricultural yield, GDP | Positive impact: Changes in agricultural yield and precipitation<br>Negative impacts: CO2 emissions and temperature |
| (Kilicarslan & Dumrul, 2017) | Time Series<br>(ARDL) | 1961-2013 | D: Agricultural GDP<br>I: Temperature and rainfall | Positive impact: increase in precipitation<br>Negative impact: increase in temperature |
| (Dogan & Karakas, 2018) | Panel Data<br>(Panel DOLS) | 1997-2016 | D: Wheat yield<br>I: Temperature and precipitation | Climate related factors have long-term impacts on yield. |

Table 3.5. Selected Literature Using Econometric Approach for Türkiye (cont'd)

| | | | | |
|---|---|---|---|---|
| (Chandio et al., 2020) | Time Series (ARDL) | 1968-2004 | D: Cereal yield<br>I: Temperature and rainfall, CO2 emissions, energy consumption, labor force, land area | Positive impact: Precipitation<br>Negative impact: CO2 emissions and temperature |
| (Chandio et al., 2021) | Time Series (ARDL & JJC) | 1980-2016 | D: Wheat and rice production<br>I: CO2 emissions, temperature, precipitation, domestic credit, agricultural labor | Positive impact: Precipitation for wheat; Precipitation and temperature for rice<br>Negative impact: CO2 emissions and temperature for wheat; CO2 for rice |

Among very limited number of studies, using an ARDL method, Dumrul and Kilicarslan (2017) analyze the impacts of climate related variables on agricultural GDP(Kilicarslan & Dumrul, 2017)Their results indicate that an increase in precipitation increases agricultural GDP but an increase in temperature causes a decrease in agricultural GDP. Başoğlu and Teletar (2013) confirms the result of Dumrul and Kilicarslan by also adding population and number of diplomas from secondary education as control variables (Başoğlu & Teletar, 2013). Bayrac and Dogan (2016) also uses agricultural GDP as dependent variable and finds similar results. In this study the impact of a change in temperature is found to be larger than the change in precipitation. (Bayraç & Doğan, 2016) For this reason, the overall impact tends to be negative.

Chandio et al (2020) examine the dynamic relationship between climate variables and cereal yield in Türkiye between 1968-2014 using an ARDL model. The empirical results of the study confirm the long-run equilibrium relation between climate variables and cereal yield. The results show that while CO2 emissions and temperature have diverse impacts, increase in mean precipitation increases cereal yield both in the short and long run (Chandio et al., 2020). The extended results also indicate that temperature and precipitation effect cereal yield more compared to other factors like land and labor use. A more recent study by Chandio et al. (2021) analyzes the short- and long-term impacts of climate and non-climate related factors on wheat and rice production in Türkiye (Chandio et al., 2021). The study uses annual time series data from 1980 to 2016 and employs different econometric techniques. According to ARDL Model and Johansen and Juselius (JJC) cointegration test they show that there is a long-term cointegrating relationship between the variables used in the analysis. According to the estimation results, while increases in CO2 emissions and temperature negatively effects wheat production both in the short run and long run, increase in precipitation increases wheat production. For rice, the results indicate that CO2 emissions decreases production whereas precipitation and temperature decrease production. The Granger Causality results show that climatic and nonclimatic variables have significant impacts on wheat and rice production (Chandio et al., 2021).

Similar results are found using panel data analysis. Eruygur and Özokcu (2022) use panel data approach to analyze the impact of climate related variables on wheat yields in Türkiye. Their results suggest that 8% reduction in wheat yields is expected based on the “average” scenario until 2100 (Eruygur & Özokcu, 2022). Similarly, using panel data approach Dogan and Karakas (2018) finds that the impact of temperature and precipitation has significant impacts on agricultural production in the long-term (Dogan & Karakas, 2018).

Over the last decades, extensive implication of econometric methods in environmental and agricultural economics have significantly contributed to the analysis of the relationship between climate change and agricultural production. However, as discussed in the Tables above, most of the studies in this field are done in developed countries. Although the contribution of the above-mentioned studies in the literature is undeniable for Türkiye, the amount of econometric studies conducted on Türkiye remains to be very limited. It is important to mention that most of the literature in Türkiye use time series analysis rather than panel data approach mainly due to data unavailability.

This thesis aims to fill an important gap in the literature by analyzing the impact of climate change on crop production in Türkiye using a panel data approach. The study adds to the literature by including crop types other than wheat and rice (studies on rice is very limited). In addition, this study extends to regional and provincial analysis unique to each crop type. As far as to my knowledge, the dataset of the thesis is the most comprehensive so far. The next Chapter discusses the datasets and the methodology used throughout the thesis.

# CHAPTER 4

# DATA AND METHODOLOGY

The literature review presented major studies analyzing the impact of climate related variables on crop production. Each of these studies use different variables and datasets depending on their research quesition and selected methodology. Chapter 3 discussed those methodologies used in the prominent studies of the field. Building on that discussion, this chapter presents the data and methodological approach of this thesis and how it differ from previous works in terms of data structure and methodology.

This thesis is based on quantitative analyses. In this Chapter, all datasets that is used throughout the thesis is presented. Major properties and descriptive statistics of the data is put forth to provide a better understanding of the data structure. There are multiple data sources used in the statistical analysis which can be categorized under four main topics: Agricultural production data, meteorological data, data related to other control variables and climate scenarios. Each of these datasets is critical in the analysis, therefore, elaborated thoroughly in this Chapter. The data sources are summarized in Table 4.1 which is discussed one by one throughout the following subchapters.

Table 4.1. Data Sources used in the Thesis

| Data | Years | Frequency | Source |
|---|---|---|---|
| **Production** | 1991-2021 | Annual | Ministry of Agriculture and Forestry |
| **Meteorological Data** | 1990-2022 | Daily | Turkish State Meteorological Service |
| **Agricultural PPI** | 1991-2022 | Monthly | TURKSTAT (Index) |
| **Fertilizer Prices** | 2000-2022 | Monthly | Ministry of Agriculture and Forestry (Index) |
| **Commodity Prices** | 2000-2022 | Daily | International Grains Council Index |
| **Climate Scenarios** | 2030-2050 / 2050-2070 / 2070-2100 | Seasonal | IPCC Interactive Atlas (IPCC, Gutiérrez, et al., 2021) / (Bağçaci et al., 2021) |

The thesis uses an econometric model to capture the impact of climate change on agricultural production. The second part of this Chapter elaborates on the methodology used in the analysis. The econometric model selected for this analysis is discussed in detail. Moreover, how the data is incorporated in the model is further presented.

## 4.1 Descriptive Statistics

This thesis focuses on the impacts of climate-related variables, mainly temperature and precipitation, on agricultural production. Therefore, it is important to understand the characteristics of both production and climate variables. It is important to discuss these variables since they are not generic across regions, countries and even provinces. The properties of these variables differ within a country and over time. Thus, the following subchapters provides descriptive analysis of major variables used in the econometric model to provide a background information on the analysis of the upcoming chapters.

### 4.1.1 Agricultural Production

The focal point of this thesis is how crop production in Türkiye is affected from climate change. Therefore, the data that forms the baseline of the analysis is amount of agricultural production data which is published by Turkish Statistical Institute (TURKSTAT). This data is published annually and provided for each agricultural good including crops, fruits, vegetables, nuts and milk. The data is published in the second month of each year and available from 1991 until 2021 (the most recent data available).

This thesis focuses on how crop production is affected from changes in climate related variables. The specific crops analyzed in the thesis are major crops that Türkiye produces. The selected crops for the analyses are wheat, barley, corn, rice and sunflower. Wheat, barley and corn production constituted 43%, 14% and 16% of of total crop production of Türkiye in 2021 (see Table 4.2). In total, the selected produces amount to almost 90% of crop production of Türkiye (see Table 4.3). Therefore, the analysis is very representative of total crop production of the country.

Table 4.2. Share in Crop Production (%)

| | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|
| **Wheat** | 52.22 | 48.58 | 46.15 | 49.79 | 42.87 |
| **Barley** | 17.24 | 17 | 18.46 | 20.16 | 13.97 |
| **Corn** | 14.33 | 13.84 | 14.57 | 15.79 | 16.39 |
| **Rice** | 2.19 | 2.28 | 2.43 | 2.38 | 2.43 |
| **Sunflower** | 4.77 | 4.73 | 5.1 | 5.02 | 5.87 |
| **TOTAL** | 90.75 | 86.43 | 86.71 | 93.14 | 81.53 |

Source: (TurkStat, 2021b)

Wheat is a staple food for Türkiye and strategically important for the overall economy. In that sense, wheat production is very critical for the country. While the importance of wheat production remains the same, the amount of production has not been increasing as it was projected. Wheat production decreased 16% from 2004 to 2021 (see Table 4.3). Similar to wheat, barley is a critical crop especially in the animal feed. Türkiye's barley production is also in decline. Barley production reduced 36.1% from 9 million tonnes in 2004 to 5.8 million tonnes in 2021 (see Table 4.3).

Table 4.3. Amount of Production (million tonnes)

| | 2004 | 2010 | 2015 | 2020 | 2021 | *2004 - 2021 (% Change)* |
|---|---|---|---|---|---|---|
| **Wheat** | 21.0 | 19.7 | 22.6 | 20.5 | 17.7 | *-16.0* |
| **Barley** | 9.0 | 7.3 | 8.0 | 8.3 | 5.8 | *-36.1* |
| **Corn** | 3.0 | 4.3 | 6.4 | 6.5 | 6.8 | *125.0* |
| **Sunflower** | 0.9 | 1.3 | 1.7 | 2.1 | 2.4 | *168.3* |
| **Rice** | 0.5 | 0.9 | 0.9 | 1.0 | 1.0 | *104.1* |

Source: (TurkStat, 2021b)

Importance of crop production is highly linked with self sufficiency ratios. In the last couple of decades, with rising supply chain issues, many countries found self sufficiency ratio to be one of their key priorities in agircultural policies. Self sufficiency, extent to which a country can satisfy its agricultural requirements from its domestic production, is becoming more and more critical as food security concerns are rising globally.

Self suffiency in key staple crops is essential for Türkiye. While Türkiye is a major crop producer, self sufficency ratio in wheat (except drum wheat), corn, barley, sunflower and rice is below 100% (see Figure 4.1. Self-Sufficiency Ratio (%)). Thus, increasing the amount of crop production is critical, yet, the projected climate change is expected to make it even worse.

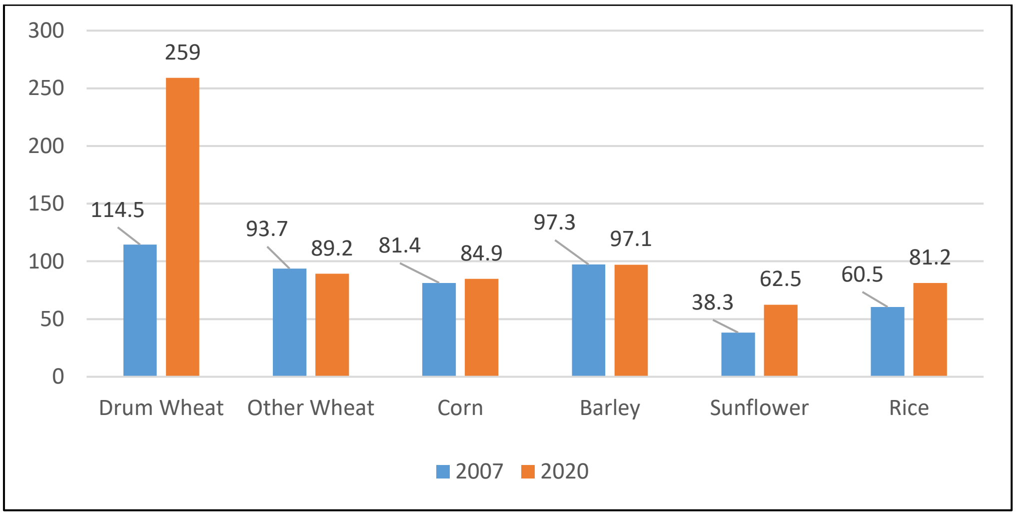


Figure 4.1. Self-Sufficiency Ratio (%)
Source: Based on data from (TurkStat, 2021a)

In the analysis of the thesis each of the crop is treated seperately due to their unique properties. Therefore, it is important to understand the charachteristics of the selected crops one by one. Each crop selected for the analysis have their unique properties and production requirements. They are grown in different regions with different climatic conditions. Thus, to estimate the impact of climate related variables on production more accurately meteorological properties of each region should be analyzed separately. While climatic conditions differ across regions and crops, they also differ across time. In this regard, the next section also presents the related timeline of each crop's sowing and harvesting periods.

#### 4.1.1.1 Wheat

Türkiye produced 17.7 million tonnes of wheat in 2021 (see Table 4.3). Wheat production is mostly grown in Central Anatolia region of the country with over 17% of total production (see Figure 4.2). Moreover, wheat production is widespread in Southeastern Anatolia with 15% and the Mediterranean with 11%. Trace region is also an important wheat producer especially for winter wheat (see Figure 4.3).

Figure 4.2. Wheat Production Map of Türkiye (2021, %)
Source: Ministry of Agriculture and Forestry (Agricultural Economics and Policy Development Institute, 2022)

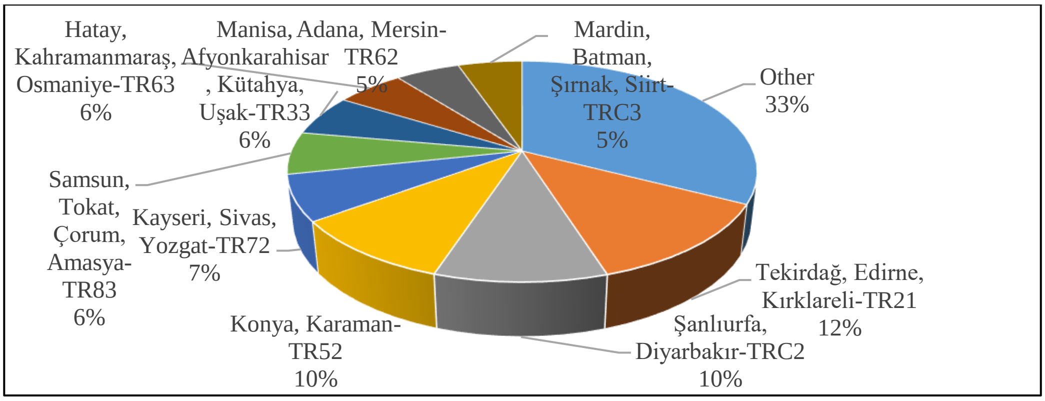


Figure 4.3. Wheat Production by Region (2021, %)
Source: Based on (TurkStat, 2021a)

Analyzing the impact of climate-related variables on wheat production it is important to examine the climatic conditions in the Central Anatolia, Southeast Anatolia, the Mediterranean as well as the Trace. Additionally, it is critical to consider the harvesting and sowing timeline for wheat in different regions. Table 4.4 presents the timeline for wheat grown in different regions. Accordingly, for sowing September to December and for harvesting June and July are critical for wheat depending on the region. Thus, for wheat meteorological developments in those months should be analyzed in particular.

#### 4.1.1.2 Barley

Barley is an important crop for Türkiye used primarily in the animal feed. Türkiye produced 5.8 million tonnes of barley in 2021 (see Table 4.3). Barley can be grown in each region across the country. The production is centered in Central Anatolia region of the country constituting almost half of the total production (see Figure 4.4). Rest of the production is spread across the Aegean and the Southeast Anatolia regions (see Figure 4.5). The sowing and harvesting timelines are similar to wheat which is presented in Table 4.4.

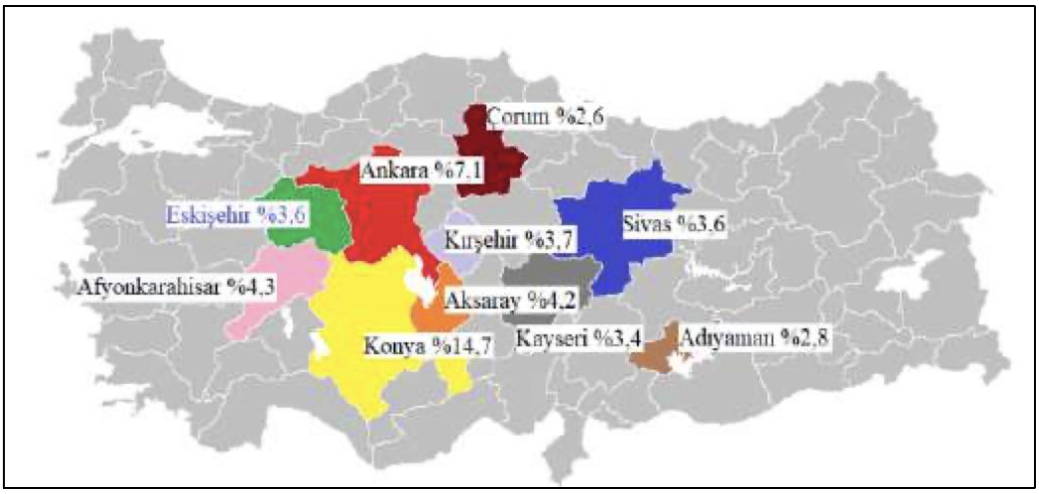


Figure 4.4. Barley Production Map (2021, %)
Source: Ministry of Agriculture and Forestry (Agricultural Economics and Policy Development Institute, 2022)

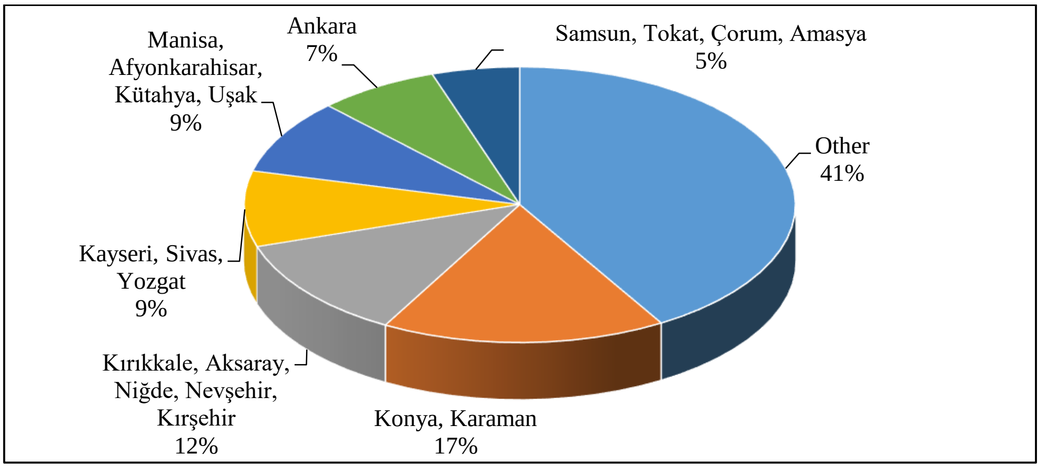


Figure 4.5: Barley Production by Region (2021, %)
Source: Based on (TurkStat, 2021a)

Table 4.4. Sowing and Harvesting Timeline for Wheat and Barley

| | Sowing Period | Harvest – Start | Harvest - Finish |
|---|---|---|---|
| Central Anatolia | Oct-Nov | June | July |
| Southeast Anatolia | Nov-Dec | June | July |
| Marmara | Nov-Dec | June | July |
| Mediterranean | Nov-Dec | May-June | July |
| Black Sea | Oct-Nov | June | July |
| Eastern Anatolia | Sep-Oct | June | July |
| Aegean | Nov-Dec | May-June | July |

Source: Ministry of Agriculture and Forestry

#### 4.1.1.3 Corn

Corn production in Türkiye has been increasing since 2004 reaching 6.8 million tonnes in 2021 (see Table 4.3). Similar to barley, corn is commonly used in animal feed. Historically, corn was grown in the Southeast Anatolia and Mediterranean regions of the country (see Figure 4.6). Recently, production has been spreading towards Aegean and Central Anatolian regions as well.

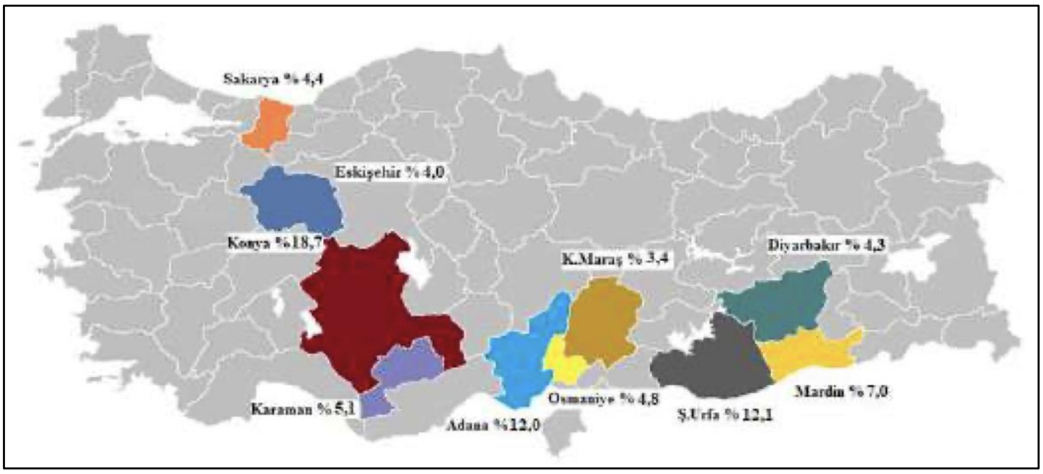


Figure 4.6. Corn Production Map (2021, %)
Source: Ministry of Agriculture and Forestry (Agricultural Economics and Policy Development Institute, 2022)

In 2021, 25% of corn was grown in Southeast Anatolia and the Mediterranean constituting half of the total corn production (see Figure 4.7). Corn is mostly grown in hotter regions of the country and not very sensitive to temperature compared to precipitation. Precipitation in the sowing period is highly critical which is between April and July for both produces (see Table 4.5). While corn is not very sensitive to temperature, the crop doesn't like extreme temperatures during harvesting season. Therefore, temperature during spring and summer is important.

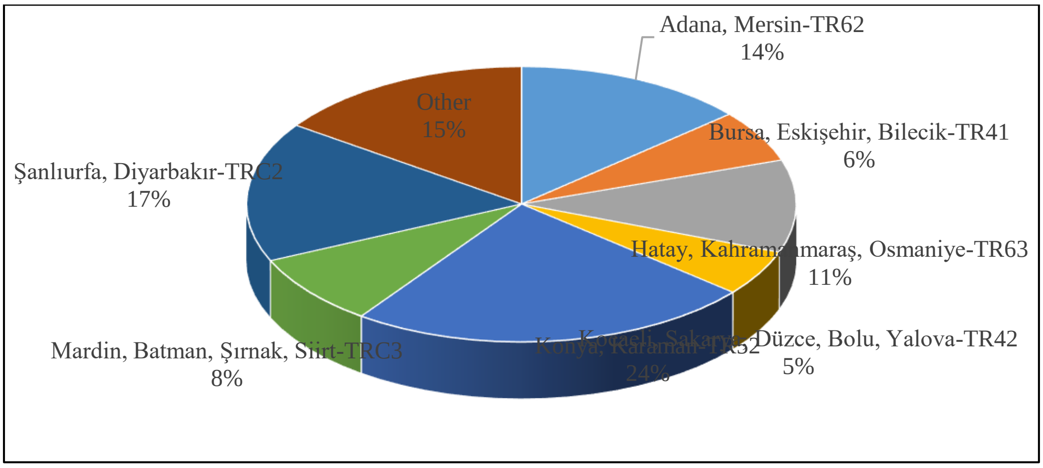


Figure 4.7. Corn Production by Region (2021, %)
Source: Based on (TurkStat, 2021a)

Table 4.5. Sowing and Harvesting Timeline for Corn

| | Sowing Period | Harvest – Start | Harvest - Finish |
|---|---|---|---|
| Central Anatolia | May | October-November | December |
| Southeast Anatolia | 1st produce: April-May<br>2nd produce: June-July | October-November | December |
| Marmara | 1st produce: April-May<br>2nd produce: June-July | September-October | November |
| Mediterranean | 1st produce: April-May<br>2nd produce: June-July | September | October |
| Black Sea | 1st produce: April-May<br>2nd produce: June-July | September-October | November |
| Eastern Anatolia | May-June | September-October | November |
| Aegean | 1st produce: April-May<br>2nd produce: June-July | September | October |

Source: Ministry of Agriculture and Forestry

#### 4.1.1.4 Rice

Rice production in Türkiye increased over 100% since 2004 (see Table 4.3). With the increase in production, self-sufficiency ratio reached to 81.2% in 2020 (see Figure 4.8). Rice production in the country is highly dense with Marmara region and the Black Sea region constituting 95% of total production (see Figure 4.9).

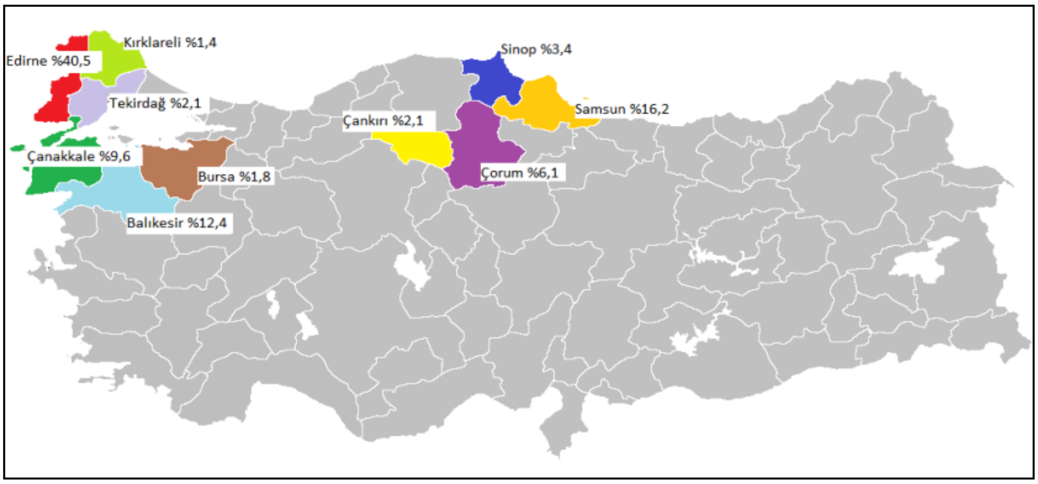


Figure 4.8. Rice Production Map (2021, %)

Source: Ministry of Agriculture and Forestry (Agricultural Economics and Policy Development Institute, 2022)

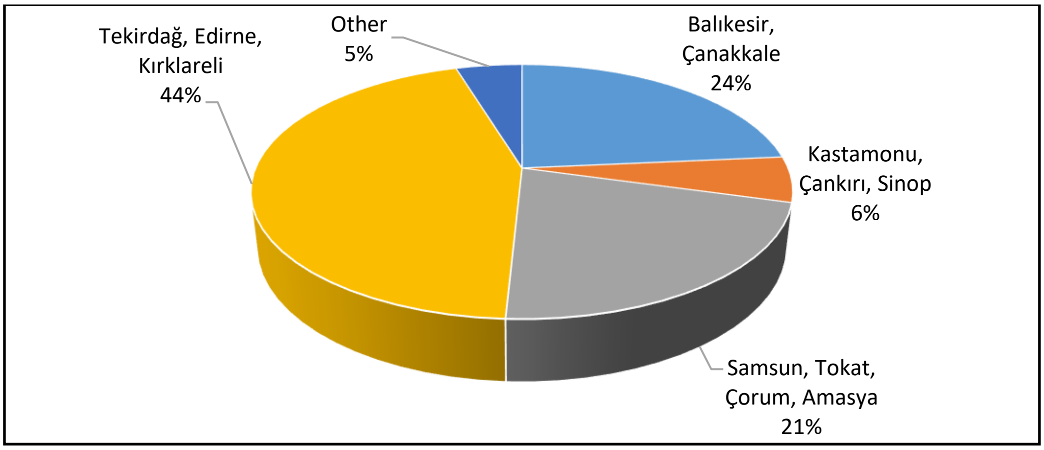


Figure 4.9. Rice Production by Region (2021, %)
Source: Based on (TurkStat, 2021a)

Corn production is very sensitive to both temperature and irrigation. Since rice production is mostly done in irrigated areas, it is more important to consider the temperature changes in sowing and harvesting periods which are May-April and September-October (see Table 4.6).

Table 4.6. Sowing and Harvesting Timeline for Rice

| | Sowing Period | Harvest – Start | Harvest - Finish |
|---|---|---|---|
| Central Anatolia | May | September-October | October |
| Southeast Anatolia | April-May | September-October | October |
| Marmara | May | October | October |
| Thrace Region | May | October | October |

Source: Ministry of Agriculture and Forestry

#### 4.1.1.5 Sunflower

Sunflower is an important produce used as an input for sunflower oil production. Self-sufficiency ratio of sunflower is the lowest among other selected crops in this study reaching only 62.5% in 2020 (Figure 4.1).

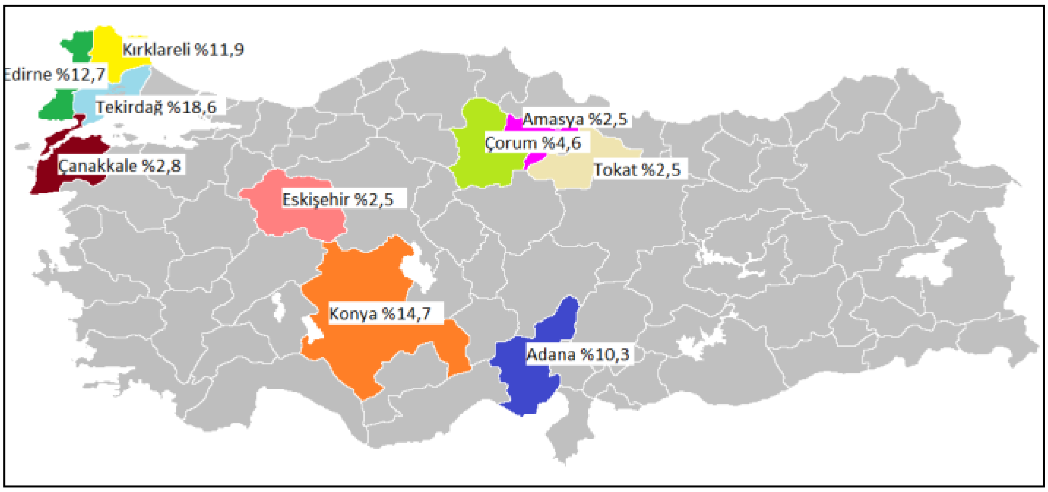


Figure 4.10. Sunflower Production Map (2021, %)
Source: Ministry of Agriculture and Forestry (Agricultural Economics and Policy Development Institute, 2022)

Sunflower production is mainly centered around the Marmara region with 38% of the total production followed by Central Anatolia with 21% and the Black Sea region with 10% (see Figure 4.11). Sowing and harvesting timeline of sunflower is the same across the country. Sowing of sunflower is during March, April and May and the harvesting period is during July to October (see Source: Based on (TurkStat, 2021a)

Table 4.7). Sunflower is very susceptible to hot and dry weather conditions. However, with the required precipitation, yields increase significantly. Therefore, changes in precipitation during harvesting period remains to be critical.

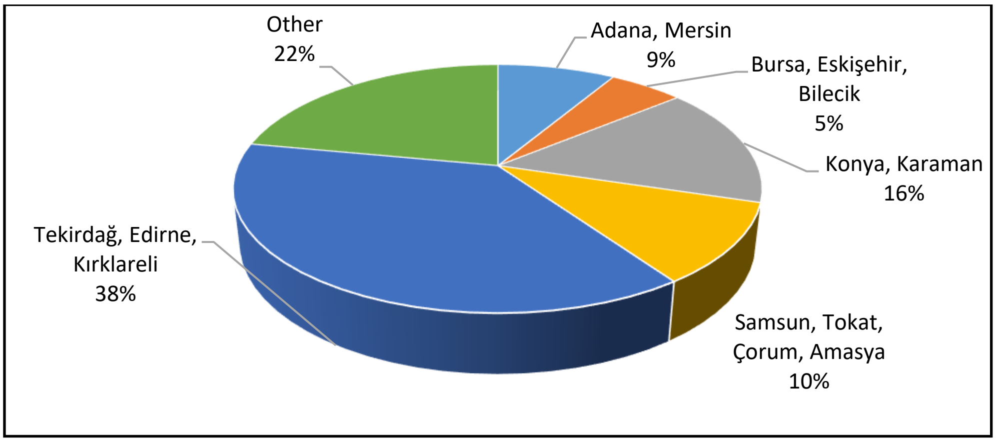


Figure 4.11. Sunflower Production by Region (2021, %)
Source: Based on (TurkStat, 2021a)

Table 4.7. Sowing and Harvesting Timeline for Sunflower

| | Sowing Period | Harvest – Start | Harvest - Finish |
|---|---|---|---|
| Central Anatolia | March-April-May | July | October |
| Southeast Anatolia | March-April-May | July | October |
| Marmara | March-April-May | July | October |
| Mediterranean | March-April-May | July | October |
| Black Sea | March-April-May | July | October |
| Eastern Anatolia | March-April-May | July | October |
| Aegean | March-April-May | July | October |

Source: Ministry of Agriculture and Forestry

So far, amount of production in selected crops, their geographical distribution and sowing and harvesting timelines are presented in detail. Moving forward, the next subsection provides information on the climate-related variables which lies at the very center of this thesis.

### 4.1.2 Meteorological Data

Impact of climate related variables on crop production has attracted a lot of attention in the literature as outlined in the previous Chapter. Our understanding of the impacts of climate change on agriculture has changed with the advancement in the data. In this regard, observation of the real meteorological data has become increasingly important for statistical analysis in this field of study. Understanding the impacts of climate change using real data and better models has become crucial for designing new polices to mitigate the negative impacts of climate change.

Analyzing the negative impacts of climate change, it is important to differentiate between local climates. The impacts are not evenly distributed across the globe and the impacts are expected to be significantly felt in the arid and semi-arid regions like Türkiye. In that sense, understanding the climatic conditions of the country and the region is key to the analysis.

Along with the agricultural production data, meteorological data is the focal point of the analysis of the thesis. For analysis purposes this study focuses on changes in temperature and precipitation. Meteorological data is obtained from Turkish State Meteorological Service and available from 1990 to 2022. The frequency of the data is daily and obtained for each province separately. To use in the econometric analysis, temperature and precipitation variable for each month over time is calculated.

Figure 4.12 suggests that winters get milder in Türkiye. Moreover, mean temperature especially in summer months are higher compared to their historical average. Analyzing temperature changes monthly is critical because growing timeline of each crop is different. The analysis is conducted on each crop based on their unique growing conditions, regions and timeline.

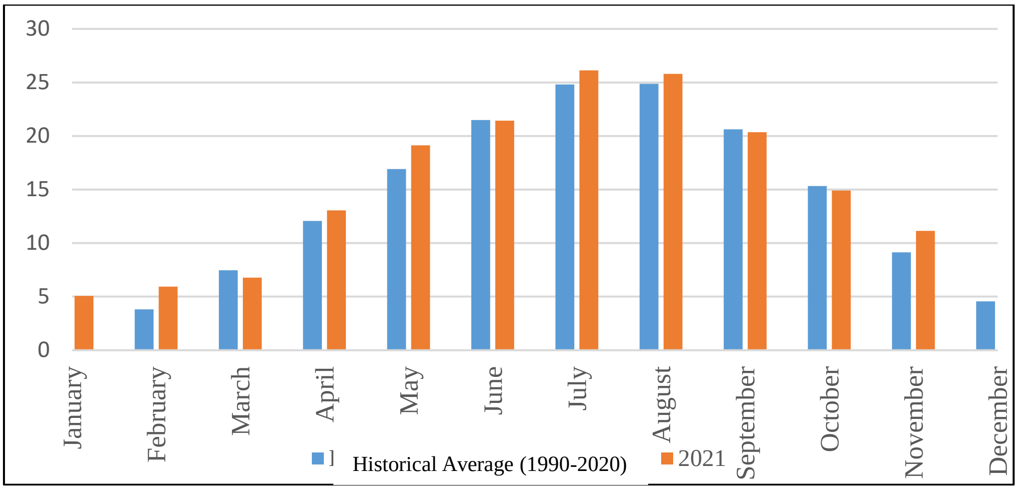


Figure 4.12. Mean Temperature
Source: Based on data from Turkish State Meteorological Service

Structural change in precipitation is drastically more significant compared to temperature. Precipitation in each month is lower than the historical average (see Figure 4.13). This finding is very crucial especially for the crops that rely heavily on rainfall patterns.

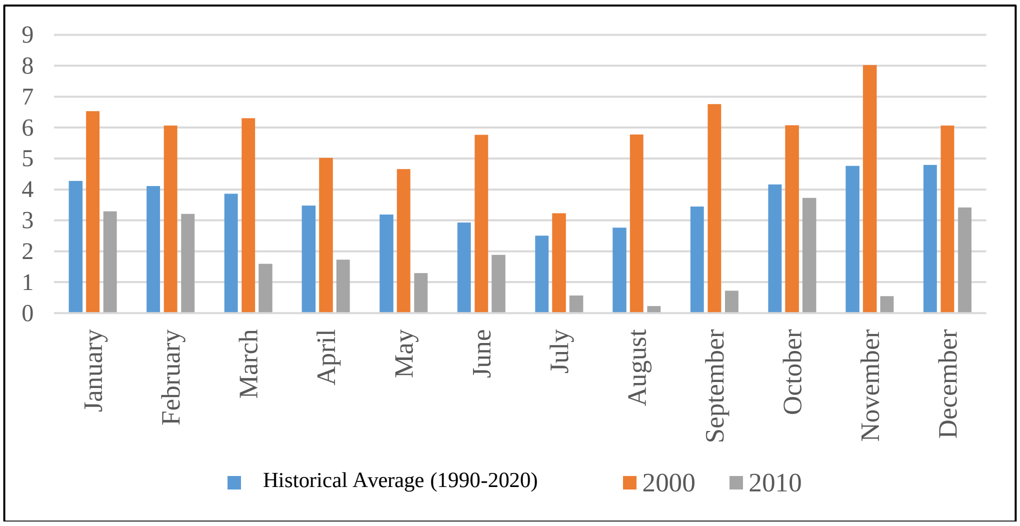


Figure 4.13. Mean Precipitation
Source: Based on data from Turkish State Meteorological Service

This subsection provided information on the climate variables which will be used as an input for the econometric analysis. The coefficients of these variables will provide fruitful estimations for the impacts of temperature and precipitation on crop production. However, climate related variables are not the only variables that affect agricultural production. To get more accurate results, it is crucial to take out the impacts of other variables correlated with crop production.

### 4.1.3 Price Variables

The literature suggests that in addition to climate change, changes in input, commodity as well as producer prices have significant impacts on agricultural production. In this regard, to reach the direct impact of climate related variables on agricultural production it is important to take out the effect of the variables related to price. Therefore, this study controls for fertilizer prices, prices of other goods, commodity prices and producer prices for agricultural products.

#### 4.1.3.1 Fertilizer Prices

Fertilizer use is an important determinant of crop production. Fertilizers enable crops to reach required nutrients allowing them to grow better and faster. Total fertilizer consumption has been increasing globally. Out of the total consumption, almost 50% is estimated to be consumed by cereals. Maize, wheat and rice are the top three contributors to fertilizer use in the world.

Potassium, phosphorus, and nitrogen are primary nutrients for major cereals and used as fertilizers. Depending on the nutrient requirement of different crops, contribution of these fertilizers differ significantly. Especially for cereal and oilseed growth, nitrogen-based fertilizers are found to be critical.

At country level, use of fertilizer vary depending on the cereal categories grown in that specific region as well as climatic conditions. In Türkiye, the major fertilizer types used during crop plantation and growth are: ammonium sulphate, calcium ammonium sulphate, DAP, urea and 20.20 named depending on their level of potassium, phosphorus and nitrogen.

Fertilizer use in wheat, barley, corn, sunflower and rice growth is very critical in Türkiye. In this regard, fertilizer prices maintain to play a significant role in the amount of production of these cereals. In addition to climate related variables, cereal production decreases due to surges in fertilizer prices. Therefore, the analysis controls for fertilizer prices to remove the impact of fertilizer prices on cereal production.

In the analysis, five different fertilizers which are commonly used in Turkish agriculture are included. In order to generate an index for fertilizer prices, different ratios for different fertilizer types were calculated. In the final model, a simple average of fertilizer prices was incorporated. As Table 4.8 presents, fertilizer prices increased 132.6% from 2020 to 2021 and continue to increase in 2022. Therefore, it is highly important to consider the effect of increasing fertilizer prices on cereal production.

Table 4.8. Annual Mean Fertilizer Prices in Türkiye (Tl/tonnes)

| | **Ammonium Sulphate** | **Calcium Ammonium Nitrate** | **Urea** | **DAP** | **20.20** |
|---|---|---|---|---|---|
| **2000** | 77 | 86 | 113 | 165 | 121 |
| **2001** | 160 | 173 | 213 | 290 | 221 |
| **2002** | 179 | 190 | 260 | 367 | 269 |
| **2003** | 219 | 248 | 337 | 446 | 316 |
| **2004** | 298 | 295 | 421 | 533 | 371 |
| **2005** | 273 | 314 | 474 | 553 | 398 |
| **2006** | 288 | 327 | 526 | 593 | 434 |
| **2007** | 376 | 372 | 661 | 767 | 528 |
| **2008** | 638 | 597 | 981 | 1,719 | 1,128 |
| **2009** | 343 | 453 | 679 | 865 | 632 |
| **2010** | 387 | 470 | 692 | 982 | 660 |
| **2011** | 619 | 675 | 1,071 | 1,428 | 1,014 |
| **2012** | 652 | 742 | 1,195 | 1,477 | 1,064 |
| **2013** | 605 | 770 | 1,086 | 1,344 | 971 |

Table 4.8. Annual Mean Fertilizer Prices in Türkiye (Tl/tonnes) (cont’d)

| | | | | | |
|---|---|---|---|---|---|
| **2014** | 622 | 832 | 1,145 | 1,536 | 1,038 |
| **2015** | 700 | 842 | 1,191 | 1,783 | 1,222 |
| **2016** | 574 | 676 | 913 | 1,36 | 984 |
| **2017** | 709 | 865 | 1,156 | 1,538 | 1,096 |
| **2018** | 1,011 | 977 | 1,664 | 2,383 | 1,587 |
| **2019** | 1,219 | 1,222 | 2,018 | 2,654 | 1,892 |
| **2020** | 1,282 | 1,435 | 2,195 | 2,647 | 1,974 |
| **2021** | 3,188 | 3,267 | 5,412 | 6,201 | 4,059 |

Source: Ministry of Agriculture and Forestry

#### 4.1.3.2 Commodity Prices

Fluctuations in agricultural commodity prices are important indicators of changes in supply and demand balances. Thus, level of commodity prices can cause agricultural production to worsen.

Turkish agricultural production is also affected from global commodity prices. In that sense, the analysis incorporates a grain and oilseed index to capture the impacts of global prices. The analysis uses International Grains Council’s (IGC) Grains and Oilseeds Index (GOI) which provides daily index for wheat, maize, rice and barley prices (IGC, 2021).

#### 4.1.3.3 Crop Prices

In addition to global prices, it is important to consider prices of cereals and other crop products in the local economy. In that sense, this study utilizes yearly price data at product and province level. This data is obtained from TURKSTAT and available yearly for wheat, barley, sunflower, corn and rice for each province since 1980.

In the analysis, prices for substitute goods are also controlled. From field information obtained from the Ministry of Agriculture and Forestry, it is common that wheat farmers substitute for barley depending on the seasonal circumstances. Therefore, when analyzing wheat production, prices of barley is also considered as a control variable.

#### 4.1.3.4 Producer Prices

Producer prices are also considered to be an important factor affecting agricultural production. Therefore, this study uses agricultural producer prices for Türkiye as a control variable. The PPI data is published by TURKSTAT monthly.

### 4.1.4 Climate Scenarios

This thesis aims to estimate the impacts of meteorological variables (temperature and precipitation) on crop production (wheat, barley, corn, rice and sunflower). Building upon the results of the econometric analysis, another question that the thesis seeks answer to is “what will happen to crop production in the future?”. Finding an answer to this question, the thesis utilizes most common climate scenarios available in the literature and extends its estimation results based on these scenarios.

It is widely accepted that climate change profoundly effects agricultural production. In that sense, it is critical for policymakers to obtain necessary information regarding future changes in climate-related variables to better anticipate potential risks and build required policy tools. However, predicting future climate patterns is not an easy task. Particularly, it is difficult to quantify the future greenhouse gas emissions due to uncertain factors. Depending on global economic and geopolitical developments, technological enhancements and the strictness of the application of emission reduction policies, future climate patterns will be determined. For this reason, various climate scenarios with different assumptions were developed by the climate scientists.

According to IPCC climate scenarios are classified under 3 major types based on their construction methodology. These 3 scenarios are: synthetic scenarios, analogue scenarios and climate model-based scenarios. In this thesis the third type climate model-based scenarios are used. These scenarios utilize Global Circulation Models (GCMs) outputs and are commonly constructed according to a baseline climate, mainly a reference period.

IPCC presents a wide range of climate scenarios. Although some are more likely to happen based on current climate policies and economic trends, it is important to put forth potential outcomes and future storylines. In its last report IPCC presented 5 scenarios: optimistic (SSP2-.5), middle (SSP2-4.5), worse (SSP3-7.0), and pessimistic (SSP5-8.5).

In the thesis, a comprehensive study conducted for Türkiye by Bağçaci et al. (2021) is used for climate scenario analysis. In their study, Bağcaci et al. (2021) consider the IPCC Assessment Report (AR6) with baseline 1995–2014. According to IPCC projections, temperature and precipitation for the short (2030–2050), medium (2050–2070) and long-term (2070–2100) were estimated (Bağçaci et al., 2021).

The thesis focuses on the results of this study because it provides scenarios for both seasons and regions which is critical for crop production. In the analysis, only two scenarios were focused: optimistic (SSP2-.5) and pessimistic scenarios (SSP5-8.5). The results for temperature and precipitation for different regions, seasons and scenarios are presented in the next subchapters.

#### 4.1.4.1 Precipitation

According to Bağçaci et al. (2021), the most significant precipitation reduction is expected in summer (autumn) with SSP2–4.5 (SSP5–8.5) in the long term. For precipitation in winter and spring similar patterns can be observed with changes in the pessimistic scenario (SSP5–8.5) to become more significant (see Table 4.9).

Anomalies in spring precipitation is significant across all regions of Türkiye except northeastern and eastern parts of the country. While to anomalies in the spring precipitation is not expected in the long term, in the near and medium term a significant reduction in precipitation is expected across Central Anatolia and Mediterranean regions under optimistic scenario (see Table 4.9).

Table 4.9. Estimated Precipitation Changes for High Emissions Scenario (SSP5-8.5)

| | | Marmara | Black Sea | Eastern Anatolia | Aegean | Central Anatolia | Mediterranean | Southeastern Anatolia |
|---|---|---|---|---|---|---|---|---|
| **2030 - 2050** | **Spring** | 0.4 | 2.8 | 0.5 | -1.7 | -3.5 | -6.2 | -3.8 |
| | **Summer** | -14.2 | -10 | -4.9 | -14.3 | -5.4 | -3.9 | 5 |
| | **Autumn** | -7.6 | -7.5 | -7.3 | -9.4 | -8.6 | -11.6 | -0.9 |
| | **Winter** | 9.5 | 4.3 | 2.2 | 4.8 | 5.2 | 1.6 | -3.6 |
| **2050 - 2070** | **Spring** | 2.5 | 4.2 | 4.6 | -0.5 | -2.3 | -5.8 | 4 |
| | **Summer** | -30.7 | -20 | -5.6 | -27.2 | -9.2 | -10.5 | 11.3 |
| | **Autumn** | -11.5 | -9.1 | -10.8 | -16.8 | -10.7 | -10.6 | -1.1 |
| | **Winter** | 1.4 | 2.8 | 0.3 | -6.8 | -2.7 | -8.2 | -8.8 |
| **2070 - 2100** | **Spring** | -13.3 | 0.6 | -6 | -18 | -11.7 | -17.5 | -13.9 |
| | **Summer** | -37.3 | -30.9 | -13.7 | -30.6 | -9.4 | -9.3 | 21.1 |
| | **Autumn** | -27.2 | -17.6 | -18.3 | -29.6 | -25.4 | -25.5 | -18.3 |
| | **Winter** | 5.8 | 9.3 | 4.9 | -9 | 0.4 | -12.5 | -5.6 |

Source: Bağçaci et. al. (2021)

Table 4.10. Estimated Precipitation Changes for Lower Emissions Scenario (SSP2-.5)

| | | **Marmara** | **Black Sea** | **Eastern Anatolia** | **Aegean** | **Central Anatolia** | **Mediterranean** | **Southeastern Anatolia** |
|---|---|---|---|---|---|---|---|---|
| **2030-2050** | **Spring** | -3 | 2.1 | -0.9 | -6.1 | -6.2 | -10.6 | -0.4 |
| | **Summer** | -11.4 | -12.4 | -10.5 | -11.9 | -8.8 | -8.8 | 1 |
| | **Autumn** | -4.6 | -9.5 | -5.5 | -5.1 | -6.3 | -2.5 | -2.4 |
| | **Winter** | 1.3 | 1 | -1 | -0.5 | -1 | -3.6 | -3.3 |
| **2050-2070** | **Spring** | -7.6 | 2.5 | -1 | -10.9 | -6.4 | -12.8 | -5.6 |
| | **Summer** | -22.3 | -10.6 | -15.8 | -22.3 | -8.7 | -11.6 | -8.1 |
| | **Autumn** | -7 | -4 | 1.9 | -6.4 | -6.6 | -6.2 | 8.4 |
| | **Winter** | 5.7 | 7.4 | 3.8 | -1.2 | 2.5 | -4.2 | -3 |
| **2070-2100** | **Spring** | -0.5 | 8.3 | 2.4 | -1.5 | 1.1 | -4.7 | -5 |
| | **Summer** | -31.2 | -20.4 | -20.3 | -33.7 | -22 | -29.1 | -9 |
| | **Autumn** | -7.1 | -8.3 | -7.4 | -12.3 | -16.4 | -17.3 | -3.8 |
| | **Winter** | 6.4 | 8.5 | 5.6 | -0.7 | 2.3 | -5.2 | 0.6 |

Source: Bağçaci et. al. (2021)

#### 4.1.4.2 Temperature

Results in precipitation vary depending on the scenario and the season. However, unlike precipitation, temperature projections are all positive regardless of the scenario (see Table 4.11 and Table 4.12). According to the results, Southeast Anatolia is the most vulnerable region to autumn temperature increase based on the optimistic scenario. This may indicate that drying in the region might occur even without changes in the precipitation pattern.

Under the pessimistic scenario, most of the regions will be affected from negative impacts of climate change. Temperature is expected to increase in winter reaching 2.5–4.5°C increase in Eastern parts of the country according to both of the scenarios in the long-term (see Table 4.11 and Table 4.12). Temperature increase in spring impact mostly southern and eastern parts of the country (see Table 4.11 and Table

4.12). It is important to mention that long term spring temperature changes will be mostly prominent in the Mediterranean and Aegean regions. Moreover, summer temperature increases will be felt in these regions. Temperature increases across seasons and regions indicate that hot extremes will be more frequently observed in the country.

Table 4.11. Estimated Temperature Change for High Emissions Scenario (SSP5-8.5)

| | | Marmara | Black Sea | Eastern Anatolia | Aegean | Central Anatolia | Mediterranean | Southeastern Anatolia |
|---|---|---|---|---|---|---|---|---|
| **2030-2050** | **Spring** | 1.1 | 1.1 | 1.2 | 1.1 | 1.1 | 1.2 | 1.2 |
| | **Summer** | 1.9 | 1.7 | 1.9 | 2 | 2 | 2 | 2 |
| | **Autumn** | 1.4 | 1.5 | 2 | 1.5 | 1.8 | 1.7 | 2 |
| | **Winter** | 0.8 | 0.8 | 1.3 | 0.8 | 0.9 | 0.9 | 1.2 |
| **2050-2070** | **Spring** | 2.1 | 2 | 2.6 | 2.2 | 2.3 | 2.5 | 2.7 |
| | **Summer** | 3 | 2.8 | 3.5 | 3.4 | 3.6 | 3.6 | 3.5 |
| | **Autumn** | 2.5 | 2.6 | 3.5 | 2.7 | 3.2 | 3.1 | 3.6 |
| | **Winter** | 1.7 | 1.9 | 2.9 | 1.7 | 2.1 | 1.9 | 2.5 |
| **2070-2100** | **Spring** | 3.4 | 3.1 | 3.9 | 3.6 | 3.6 | 4 | 4.2 |
| | **Summer** | 4.9 | 4.7 | 5.9 | 5.5 | 6 | 5.8 | 6 |
| | **Autumn** | 3.7 | 3.9 | 5.1 | 4.1 | 4.7 | 4.8 | 5.2 |
| | **Winter** | 2.8 | 2.9 | 4.2 | 2.8 | 3.1 | 3 | 3.7 |

Source: Bağçaci et. al. (2021)

Table 4.12. Estimated Temperature Change for Low Emissions Scenario (SSP2-.5)

| | | **Marmara** | **Black Sea** | **Eastern Anatolia** | **Aegean** | **Central Anatolia** | **Mediterranean** | **Southeastern Anatolia** |
|---|---|---|---|---|---|---|---|---|
| **2030-2050** | **Spring** | 0.9 | 0.8 | 1 | 0.9 | 0.9 | 1 | 1 |
| | **Summer** | 1.6 | 1.5 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 |
| | **Autumn** | 1.1 | 1.2 | 1.6 | 1.2 | 1.4 | 1.4 | 1.6 |
| | **Winter** | 0.7 | 0.8 | 1.3 | 0.7 | 0.9 | 0.8 | 1.1 |
| **2050-2070** | **Spring** | 1.2 | 1.1 | 1.5 | 1.3 | 1.3 | 1.5 | 1.6 |
| | **Summer** | 2 | 1.9 | 2.2 | 2.1 | 2.2 | 2.3 | 2.3 |
| | **Autumn** | 1.5 | 1.5 | 2.1 | 1.6 | 1.8 | 1.9 | 2.2 |
| | **Winter** | 1 | 1 | 1.6 | 1 | 1 | 1.1 | 1.4 |
| **2070-2100** | **Spring** | 1.7 | 1.7 | 2.1 | 1.8 | 1.8 | 2 | 2.1 |
| | **Summer** | 2.7 | 2.5 | 3 | 2.9 | 3.1 | 3.1 | 3.1 |
| | **Autumn** | 1.9 | 1.9 | 2.7 | 2.1 | 2.4 | 2.5 | 2.8 |
| | **Winter** | 1.2 | 1.3 | 2.1 | 1.2 | 1.4 | 1.4 | 1.8 |

Source: Bağçaci et. al. (2021)

## 4.2 Methodology

Previous chapter discussed different approaches used in the literature to analyze the impact of climate change on agricultural production. Among other techniques, econometric approach has been rising in the literature in the last decade. This study uses the panel data approach to evaluate the impact of climate-related variables (temperature and precipitation) on major food crop production (i.e., wheat, barley, rice, corn and sunflower) in Türkiye.

In econometric modelling a strand of literature focuses on the impact on agricultural GDP and other strand takes agricultural production as dependent variable. Following the recent literature on economic impacts of climate change on agriculture, this study takes cereal production as dependent variable and temperature and precipitation as the main independent variables. The empirical model can be expressed as follows:

$$Agricultural\ Production = f\,(Temperature, Precipitation, Price\ Variables) \quad \textit{(Equation 1 )}$$

The thesis uses micro-level data which is transformed into logarithmic scale as it provides more consistent results which is simpler to interpret. Moreover, it is assumed that the model is linear. Monthly and provincial production data is used for the period 1990 to 2022. Major time series data are taken from TURKSTAT and Turkish State Meteorological Service. The functional form of the model is given in the equation below:

$$\begin{gathered} log(Agricultural\ Production_{i,t}) = \beta_0 + \\ \beta_1\, log\big(Agricultural\ Production_{i,t-1}\big) + \\ \beta_2\, log\big(Mean\ Precipitation_{i,t}\big) + \beta_3\, log\big(Mean\ Temperature_{i,t}\big) + \\ \big(\beta_4\, log\big(Mean\ Precipitation_{i,t-1}\big) + \beta_5\, log\big(Mean\ Temperature_{i,t-1}\big)\big) + \\ \alpha_1 Price\ Deviation_{i,t-1} + \alpha_2 Fertilizer\ Prices_{i,t-1} + \\ \alpha_3 Commodity\ Prices_{i,t-1} + \alpha_4 Producer\ Prices_{i,t-1} + \gamma_1 City\ Level\ FE_i + \\ e_{i,t} \quad \textit{(Equation 2 )} \end{gathered}$$

where Agricultural Production is the amount of production of each crop measured in million tonnes. Mean Precipitation is measured in mm and Mean Temperature is measured in Celcius degrees. Fertilizer prices are an average of different types of fertilizer used in the crop production. Price variables are all in Turkish Liras. In the Equation 2, “t” is for yearly time variable and “i” is for each province. The “β” coefficients represent meteorological variables “α” coefficients represent price variables. The motivation of this thesis is to find the best estimation for “β” coefficients.

Equation (2) is a generic equation with dependent variable being the amount of production. The equation is estimated for each selected crop separately. Depending on the characteristics of the selected crop independent variables vary based on the relevancy.

Moreover, Equation (2) can also be restricted for specific areas by selecting a set of provinces (“i”). Selecting the regions where the crops are majorly grown and considering the climate in that region, the analysis is more scrutinized.

In the next chapter, the analysis will be discussed in detail. Selected models and results for each crop is thoroughly presented.

# CHAPTER 5

# ANALYSIS

## 5.1 Introduction

In agricultural economics, especially requiring regional field data, it is highly critical to combine qualitative knowledge with quantitative analysis. Using a combination of both methodologies improves the limitations of the total analysis. The combined analysis ensures that overall understanding of the research problem is enhanced by integrating different types of knowledge supporting and complementing each other. The first four chapters of the thesis thoroughly elaborated on the background information required for the econometric analysis of this thesis.

Chapter 1 introduces the thesis by providing information on how climate change impacts agricultural production. Chapter 2 elaborates more on the relationship between climate change and agriculture and discusses why this issue is extremely important especially for vulnerable regions like Türkiye. As this thesis aims to understand the impact of climate change related variables on crop production, Chapter 3 covers a wide range of literature on the impacts of meteorological variables on agricultural production. The extensive literature is categorized based on their methodology: crop modelling and statistical approach. The categorization based on methodology provides a clear guideline for the analysis of this thesis. This thesis uses econometric modelling approach which is further discussed in Chapter 3. In addition to methodological categorization, the studies conducted on Türkiye is also separately discussed. All the existing literature using econometric model, both time series and panel data, for Türkiye is included in this literature review chapter.

The literature has significant amount of studies on the impacts of climate change on agricultural production primarily focusing on developed countries. However, it is widely accepted that regional analysis is very crucial to get more accurate results due to the differences in regional climate patterns and growing conditions of specific crop types. To form a baseline for the econometric analysis, Chapter 4 lays out related quantitative data which will be used in the analysis chapter. Since the analysis utilizes panel data approach, the data must be in panel form. In this regard, a wide set of data is provided with both time and province components. The data ranges from production data to meteorological and price data.

Chapter 5 is the analysis chapter which brings together all the information from the previous chapters. This chapter provides econometric analyses based on the quantitative data from Chapter 4. Understanding the inextricable link between climate change and agriculture this Chapter elaborates on the impacts of climate change on agricultural production in Türkiye. The analysis further focuses on how crop production, namely wheat, barley, corn, rice and sunflower production, is affected from the changing weather patterns in different regions of the country.

In addition to the field and literature information asserting that climate change negatively impacts crop production in Türkiye, this study confirms these findings by an econometric approach. The quantitative analysis conducted in this chapter is built on the data and methodology discussed in Chapter 4. Using the production, weather and price datasets for Türkiye, this chapter conducts analysis for major crop production in Türkiye. The crops analyzed in this chapter are wheat, barley, corn, rice and sunflower. Each analysis is conducted separately depending on the unique circumstances of the specific crop.

This chapter is structured as follows. There are subchapters for each crop providing results separately. For each crop, first, brief information is provided followed by the model selection based on the characteristics of that crop. Later, model results are discussed for different scenarios.

## 5.2 Wheat

### 5.2.1 Background

There are numerous varieties of wheat grown in different regions globally. Depending on the genetic potential of the variety grown in that region, the quality and the yield of the product is determined. Breeders try to improve the variety of wheat to better suit the needs of the specific growing region. In this regard, this method is commonly used as an adaptation tool for the changes happening in the soil, temperature and irrigation structure.

Wheat is the most important agricultural commodity for Türkiye, a strategic and staple good serving as an essential food for majority of the households. In Türkiye, wheat breeding was first started in 1925 and since then 617 different types of wheat were released (Keser, 2022). However, unexpected weather patterns linked with increasing temperatures and decreasing precipitation pose challenges for the wheat breeders to adapt the needs of the region. Türkiye is ranked the 11th largest wheat producer in the World according to 2021 production levels (FAOSTAT, 2021). Türkiye produced 17.7 million tonnes of wheat in 2021 constituting 42.9% of total crop production (see Table 4.2 and Table 4.3).

Wheat's growth cycle has the following broad categories: emergence (germination), tillering, stem extension, head emergence, flowering and ripening (grain filling and maturity) (see Figure 5.1). It usually takes 120 days for wheat to grow and mature. Thus, it is possible to plant wheat two times a year, generally referred as spring and winter wheat. In Türkiye, wheat is sown twice a year. The winter wheat is grown between October to June. In some cases, late harvesting occurs in August. Crop growth usually reaches its maximum during March and April, the flowering stages of the crop. The development stages of wheat are summarized in the Figure below.

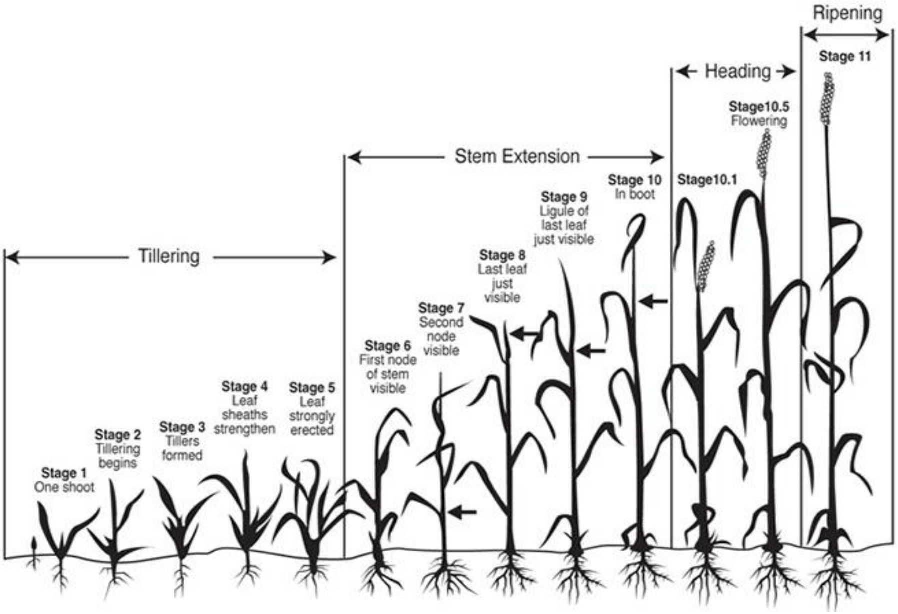


Figure 5.1. Development Stages of Wheat
Source: (Prairie Californian, 2015)

Wheat is commonly a cool season crop grows best in temperatures between 21°C to 24°C. The crop does not like extreme hot or cold temperatures. If the weather falls below 4°C during germination, seeds will be harmed. If the weather exceeds 35°C during the maturation period, yields will be lower. Moreover, when the grains start to fill out wheat requires additional sunlight.

The crop also does not require a lot of water. For example, in 2011, main wheat producing regions, Central Anatolia and Southeast Anatolia, of Türkiye received a heavy rainfall during spring from April to June, the important growing season of wheat. However, Southeast Anatolia received late season rainfall unlike Central Anatolia which slowed down the growth of the crop as well as the grain formation period in this region.

In summary, winter wheat is sown between October to December and harvested between late May to the end of July in Türkiye (see Table 4.4). For wheat development, during the cultivation period cold temperatures and moist weather is needed while during harvesting higher temperature and sunlight is required. The important months in this timeline which is effective for determining the yield of the season is March through June. In general, weather in spring is very critical for wheat growth.

### 5.2.2 Model Selection

The methodology used in this thesis is discussed in Chapter 4. Although the methodology is same for all crop types the model differentiates depending on the crop specific features. In that sense, for example, the model for wheat is very different from corn. Therefore, for each crop different model is adopted which will be discussed in each subchapter allocated for each crop.

The previous subchapter discussed the meteorological requirements for the optimal wheat growth in Türkiye. The model is formulated based on the local information about wheat production in Türkiye. Therefore, it combines regional information with information discussed in the literature. The model formulated for how changes in meteorological variables impact wheat production in Türkiye is given in the equation below.

$$
\begin{aligned}
log(Wheat\ Production_{i,t})& \\
&= \beta_0 + \beta_1\, log\left(Wheat\ Production_{i,t-1}\right) \\
&+ \beta_2\, log\left(Mean\ Precipitation\ March_{i,t}\right) \\
&+ \beta_3\, log\left(Mean\ Precipitation\ April_{i,t}\right) \\
&+ \beta_4\, log\left(Mean\ Precipitation\ May_{i,t}\right) \\
&+ \beta_5\, log\left(Mean\ Precipitation\ June_{i,t}\right) \\
&+ \beta_6\, log\left(Mean\ Precipitation\ October_{i,t}\right) \\
&+ \beta_7\, log\left(Mean\ Precipitation\ November_{i,t}\right) \\
&+ \beta_8\, log\left(Mean\ Temperature\ February_{i,t}\right) \\
&+ \beta_9\, log\left(Mean\ Temperature\ March_{i,t}\right) \\
&+ \beta_{10}\, log\left(Mean\ Temperature\ April_{i,t}\right) \\
&+ \beta_{11}\, log\left(Mean\ Temperature\ May_{i,t}\right) \\
&+ \beta_{12}\, log\left(Mean\ Temperature\ June_{i,t}\right) \\
&+ \beta_{13}\, log\left(Mean\ Temperature\ July_{i,t}\right) \\
&+ \ \alpha_1 Price\ Deviation_{i,t-1} + \ \alpha_2 Fertilizer\ Prices_{i,t-1} \\
&+ \ \alpha_3 Commodity\ Prices_{i,t-1} + \ \gamma_1 City\ Level\ FE_i + e_{i,t}
\end{aligned}
$$

$$i = province\ , t = year$$

*(Equation 3)*

The model includes variables for spring precipitation as well as precipitation during October and November which are critical periods in the development phase of wheat. Moreover, temperature variables starting from winter months to July are highly critical for wheat production, thus, added as an additional variable. Other variables are controlled for robustness check. However, they are found to be insignificant.

The model estimates how a percentage change in major meteorological variables, precipitation and temperature, impacts the change in wheat production. For example, keeping everything else constant, a 1% change in mean temperature in April across different provinces from 1990 to 2022, changes mean wheat production by $\beta_{10}$ %. In this regard, we are interested in all the $\beta$ coefficients from $\beta_2$ to $\beta_{13}$.

### 5.2.3 Estimation Results

Selected model for wheat production is run for different control variables for robustness analysis. This subchapter provides results for the model discussed in the previous subchapter. Moreover, regional results are provided to be able to differentiate between different climate conditions across the country.

Weather conditions, both precipitation and temperature, in spring plays a crucial role in determining the level of wheat production. Higher temperatures in spring and summer is expected to decrease wheat production. While precipitation in spring is highly crucial, continuous rainfall might slow crop development, delaying the maturity of wheat. Given the information from the field and the literature, Table 5.1 presents the results of the model selected for wheat.

Table 5.1. Estimates for Wheat Production

| VARIABLES | (1) Model 1 | (2) Model 2 | (3) Model 3 | (4) Model 4 |
|---|---|---|---|---|
| ln_amount | 0.604*** | 0.590*** | 0.596*** | 0.577*** |
| | (0.0232) | (0.0236) | (0.0236) | (0.0242) |
| ln_mean_precip_3 | 0.0424*** | 0.0504*** | 0.178* | 0.0802 |
| | (0.0151) | (0.0160) | (0.0929) | (0.0971) |
| ln_mean_precip_4 | 0.0250** | 0.0232 | -0.317** | -0.228* |
| | (0.0124) | (0.0142) | (0.127) | (0.134) |
| ln_mean_precip_5 | 0.0197* | 0.00334 | -0.134 | -0.0772 |
| | (0.0108) | (0.0119) | (0.199) | (0.206) |
| ln_mean_precip_6 | -0.0372*** | -0.0296*** | 0.468** | 0.630*** |
| | (0.00921) | (0.00969) | (0.208) | (0.224) |
| ln_mean_precip_10 | -0.000996 | -0.0157* | 0.156* | 0.0853 |
| | (0.00782) | (0.00936) | (0.0893) | (0.0948) |
| ln_mean_precip_11 | -0.0156* | -0.0243** | -0.00735 | -0.0168 |
| | (0.00806) | (0.00985) | (0.0306) | (0.0323) |
| ln_mean_temp_2 | 0.0199 | 0.0568*** | 0.0199 | 0.0555*** |
| | (0.0169) | (0.0189) | (0.0173) | (0.0194) |
| ln_mean_temp_3 | 0.0577 | 0.0662 | 0.0821 | 0.0509 |
| | (0.0445) | (0.0768) | (0.0580) | (0.0847) |
| ln_mean_temp_4 | -0.143** | -0.171 | -0.182** | -0.170 |
| | (0.0721) | (0.135) | (0.0769) | (0.142) |

Table 5.1. Estimates for Wheat Production (cont'd)

| | | | | |
|---|---|---|---|---|
| ln_mean_temp_5 | -0.578*** | -0.985*** | -0.658*** | -1.025*** |
| | (0.138) | (0.232) | (0.150) | (0.245) |
| ln_mean_temp_6 | -0.692*** | -0.855*** | -0.479** | -0.557* |
| | (0.199) | (0.305) | (0.208) | (0.319) |
| ln_mean_temp_7 | -1.087*** | -0.445 | -1.147*** | -0.590* |
| | (0.232) | (0.350) | (0.233) | (0.355) |
| c.ln_ mean_precip2# c.ln_ mean_temp2 | | | 0.00438 | 0.00158 |
| | | | (0.00622) | (0.00719) |
| c.ln_ mean_precip3# c.ln_ mean_temp3 | | | -0.0611 | -0.0148 |
| | | | (0.0416) | (0.0433) |
| c.ln_ mean_precip# c.ln_ mean_temp4 | | | 0.130*** | 0.0963* |
| | | | (0.0487) | (0.0516) |
| c.ln_ mean_precip5# c.ln_ mean_temp5 | | | 0.0522 | 0.0263 |
| | | | (0.0671) | (0.0697) |
| c.ln_ mean_precip6# c.ln_ mean_temp6 | | | -0.158** | -0.206*** |
| | | | (0.0654) | (0.0701) |
| c.ln_ mean_precip10# c.ln_ mean_temp10 | | | -0.0570* | -0.0370 |
| | | | (0.0321) | (0.0339) |
| c.ln_ mean_precip11# c.ln_ mean_temp11 | | | -0.00246 | -0.00365 |
| | | | (0.0140) | (0.0146) |
| price_deviation | 0.000537 | 0.00742 | 0.000843 | 0.00798 |
| | (0.000774) | (0.00498) | (0.000781) | (0.00499) |
| d_commodity_index | 0.0741 | -0.805 | 0.0780 | -0.702 |
| | (0.0649) | (0.590) | (0.0678) | (0.601) |
| d_fertilizer_index | -0.0110 | 0.0868 | -0.00891 | 0.117 |
| | (0.0378) | (0.0887) | (0.0411) | (0.0906) |
| Constant | 12.15*** | 11.84*** | 12.04*** | 11.67*** |
| | (0.918) | (1.210) | (0.945) | (1.264) |
| | | | | |
| Observations | 1,202 | 1,202 | 1,201 | 1,201 |
| R-squared | 0.445 | 0.472 | 0.454 | 0.479 |
| Number of provinces | 76 | 76 | 76 | 76 |
| Year FE | | YES | | YES |

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The results are in line with the field information as well as the literature. According to Table 5.1, precipitation during the stem extension period, commonly March to April, positively impacts wheat production. However, precipitation during the harvesting period, June, negatively impacts production.

The impact of temperature can be observed more significantly. The table suggests that, higher mean temperature from April to July is expected to decrease wheat production. Especially, temperature increase during the harvest time has a negative impact on production. According to the estimated "*β*" coefficients (sum of ln_mean_temp_4 to ln_mean_temp_7), a 1% increase in mean temperature during May to July decreases wheat production by 2.5%.

The results show how important temperature change is for wheat production. Additionally, it is critical to keep in mind that Türkiye has different climate regions. Therefore, regional analysis is also important as a further analysis. Wheat is grown across all regions of the country. The main production areas are Central Anatolia and Southeastern part of Türkiye (see Figure 4.3). Moreover, there is also significant production in the Mediterranean and the Trace region. Table 5.1, provides separate regression outputs of "Model 1" constrained to wheat producing regions.

The results provided in Table 5.1 suggest that the impact of a change in mean precipitation is felt more in the main producing regions: Central Anatolia, Mediterranean and Southeast Anatolia. It is estimated that, a 1% change in mean precipitation during March and April increase wheat production in Central Anatolia two times more than all regions in total. Aegean side of the country is also estimated to be positively affected from a precipitation increase during April.

Central Anatolia, accounting almost a quarter of total production, is found to be more sensitive to temperature increase. While 1% temperature increase is found to decrease wheat production by 2.5% in total, this number reaches to 3.8% in Central Anatolia. In addition to Central Anatolia, increasing temperature also negatively impacts production in the West Black Sea, Mediterranean and Southeast Anatolia. It is important to note that the impact of temperature increase is expected to be felt earlier in the Mediterranean and the Southeast Anatolia.

The results of the econometric model find impacts in line with the existing literature. While precipitation in the development phase positively impacts production, the temperature increase negatively impacts during harvesting. Moreover, the results are more significant in the Central Anatolia, Mediterranean and Southeast Anatolia. The results are felt earlier in the southern parts of the country compared to the West and North (see Table 5.2).

Table 5.2. Regional Estimates for Wheat Production

| | (1)<br>Model 1 | (2)<br>Model 5<br>*West Marmara* | (3)<br>Model 6<br>*West Black Sea* | (4)<br>Model 7<br>*Aeagean* | (5)<br>Model 8<br>*Central Anatolia* | (6)<br>Model 9<br>*Mediterranean and Southeaast Anatolia* | (7)<br>Model 10<br>*Wheat growing regions* |
|---|---|---|---|---|---|---|---|
| ln_amount | 0.604*** | 0.490*** | 0.737*** | 0.412*** | 0.414*** | 0.210*** | 0.371*** |
| | (0.0232) | (0.101) | (0.0532) | (0.0828) | (0.0816) | (0.0562) | (0.0317) |
| ln_mean_precip_3 | 0.0424*** | -0.0157 | 0.00427 | 0.0396 | 0.0898*** | -0.0469* | 0.0298** |
| | (0.0151) | (0.0319) | (0.0281) | (0.0294) | (0.0335) | (0.0279) | (0.0141) |
| ln_mean_precip_4 | 0.0250** | 0.0115 | 0.0130 | 0.100*** | 0.0438* | 0.0492* | 0.0253** |
| | (0.0124) | (0.0214) | (0.0196) | (0.0249) | (0.0233) | (0.0286) | (0.0114) |
| ln_mean_precip_5 | 0.0197* | 0.0372* | -0.00539 | 0.0218 | -0.0477 | 0.0328 | 0.0158 |
| | (0.0108) | (0.0188) | (0.0195) | (0.0162) | (0.0290) | (0.0208) | (0.00992) |
| ln_mean_precip_6 | -0.0372*** | 0.00835 | -0.00804 | -0.0453** | -0.0394* | -0.0510*** | -0.0538*** |
| | (0.00921) | (0.0240) | (0.0252) | (0.0183) | (0.0222) | (0.0144) | (0.00841) |
| ln_mean_precip_10 | -0.000996 | -0.0316 | 0.0184 | -0.0163 | 0.0345*** | -0.0159 | 0.000316 |
| | (0.00782) | (0.0266) | (0.0151) | (0.0199) | (0.0126) | (0.0143) | (0.00729) |
| ln_mean_precip_11 | -0.0156* | 0.0373** | -0.0106 | -0.0150 | -0.0745*** | 0.00906 | -0.00957 |
| | (0.00806) | (0.0145) | (0.0152) | (0.0145) | (0.0166) | (0.0174) | (0.00767) |
| ln_mean_temp_2 | 0.0199 | 0.0319 | -0.0422 | -0.00681 | -0.00635 | 0.240*** | 0.0395** |
| | (0.0169) | (0.0341) | (0.0397) | (0.0445) | (0.0250) | (0.0665) | (0.0176) |
| ln_mean_temp_3 | 0.0577 | -0.0462 | 0.127* | 0.241** | 0.280** | -0.613*** | 0.00345 |
| | (0.0445) | (0.167) | (0.0668) | (0.122) | (0.111) | (0.122) | (0.0468) |
| ln_mean_temp_4 | -0.143** | -0.0110 | 0.0950 | 0.395** | 0.0886 | -0.495** | -0.153** |
| | (0.0721) | (0.189) | (0.107) | (0.178) | (0.155) | (0.201) | (0.0739) |
| ln_mean_temp_5 | -0.578*** | -0.810** | -0.755*** | -0.269 | -1.130*** | -0.613* | -0.657*** |
| | (0.138) | (0.322) | (0.221) | (0.282) | (0.257) | (0.326) | (0.133) |
| ln_mean_temp_6 | -0.692*** | 0.0824 | -0.180 | -0.958** | -0.203 | -1.104** | -0.482** |
| | (0.199) | (0.436) | (0.322) | (0.400) | (0.356) | (0.549) | (0.196) |
| ln_mean_temp_7 | -1.087*** | 0.313 | -1.007*** | -0.797 | -2.657*** | 0.995 | -0.937*** |

Table 5.2. Regional Estimates for Wheat Production (cont’d)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | (0.232) | (0.607) | (0.313) | (0.531) | (0.387) | (0.746) | (0.230) |
| price_deviation | 0.000537 | 0.000313 | 0.00240* | 0.000179 | 0.00626*** | -0.00236 | 0.000556 |
| | (0.000774) | (0.00152) | (0.00137) | (0.00138) | (0.00184) | (0.00169) | (0.000750) |
| d_commodity_index | 0.0741 | 0.244** | 0.0455 | 0.190 | 0.104 | -0.0166 | -0.0138 |
| | (0.0649) | (0.121) | (0.115) | (0.141) | (0.189) | (0.138) | (0.0624) |
| d_fertilizer_index | -0.0110 | -0.245*** | 0.0456 | -0.142* | -0.0622 | 0.0311 | -0.000782 |
| | (0.0378) | (0.0670) | (0.0596) | (0.0788) | (0.0888) | (0.0838) | (0.0364) |
| Constant | 12.15*** | 7.832*** | 8.409*** | 11.88*** | 18.89*** | 14.19*** | 14.49*** |
| | (0.918) | (2.542) | (1.372) | (2.084) | (1.757) | (2.690) | (0.928) |
| Observations | 1,202 | 97 | 181 | 155 | 160 | 291 | 884 |
| R-squared | 0.445 | 0.442 | 0.660 | 0.403 | 0.530 | 0.293 | 0.264 |
| Number of provinces | 76 | 5 | 10 | 8 | 11 | 17 | 51 |

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

## 5.3 Barley

### 5.3.1 Background

Barley is one of the most important crop types across the world, with its wide usage of animal feed and malting. Barley is of utmost importance for livestock feeding, which accounts for about 85% of barley production globally. Türkiye is among the top 10 barley producers in the world, ranking the 9th after the United Kingdom and Canada (see Figure 5.2).

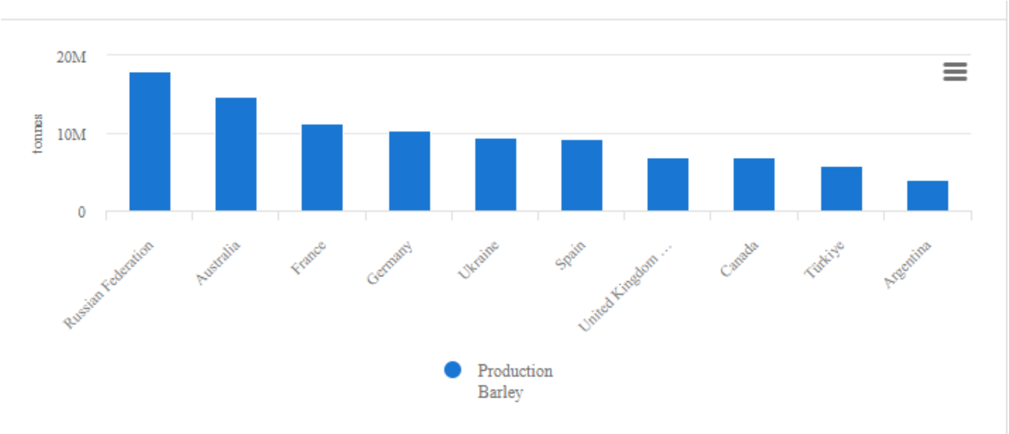


Figure 5.2. Top 10 Country Production of Barley, 2021
Source: (FAOSTAT, 2021)

In Türkiye, being the most produced grain product after wheat and corn, 65% of barley is used as animal feed, 33% of it as malt for alcoholic beverages and biodiesel production and 2% of it as human food in food industry. The share of barley in total crop production of Türkiye has dropped from 20% to 14% since 2017 (see Table 4.2. Share in Crop Production (%)). In 2021, barley production for Türkiye was 5.8 million tonnes decreasing 36.1% since 2004 (see Table 4.3). The barley yield of Türkiye has been decreasing in the last decade which might pause threat to animal feed supply in the near future (see Figure 5.3).

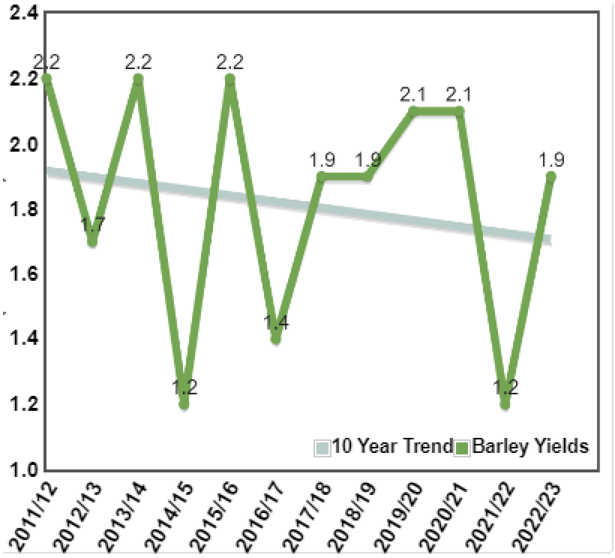


Figure 5.3. Türkiye's Barley Yields
Source: (USDA Foreign Agricultural Service, 2021)

Similar to wheat, barley’s development and growth cycle has the following categories: Germination, leaf production, tillering, head emergence, kernel development and maturity (see Figure 5.4).

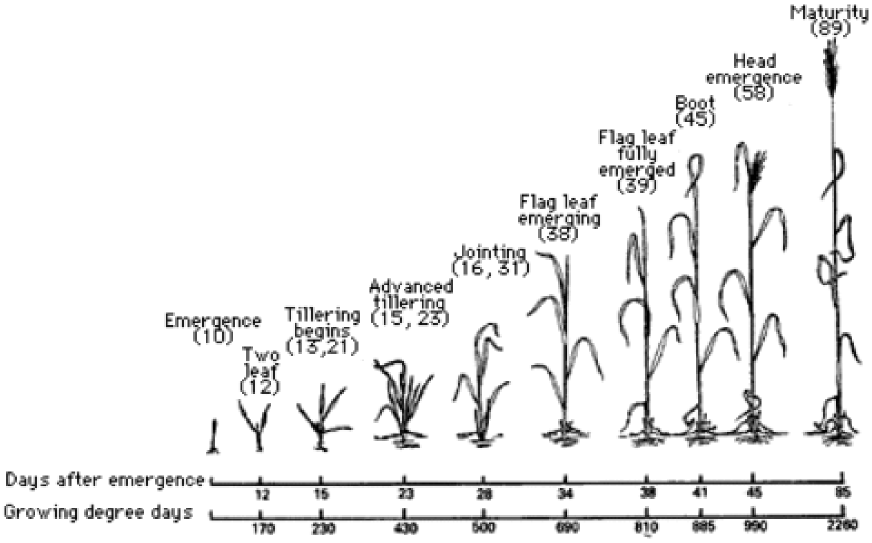


Figure 5.4. Development Stages of Barley

Source: (University of Minnesota Extension, 2021)

Barley is a crop type that can be grown in temperate climates. Barley requires a milder winter weather conditions and its growth prefers dry and cooler regions rather than moist and hot regions (Poehlman, 1985). The climate requirements are very similar to wheat. They are tolerant to cold which enables them to be planted both in the spring and winter. For both wheat and barley, 100 mm to 125 mm of water is required for the development phase to move from germination to grain production.

Barley is known to be tolerant to drought which enables the crop to be grown in low precipitation and only rain-fed regions. Similar to wheat, barley, being a temperate region crop, is adversely affected from excessive temperatures. Although barley is tolerant to heat, temperature rising above 25°C during summer is found to decrease crop growth (Chapter 3). Therefore, formulating the model, specific requirements of barley growth has taken into consideration.

### 5.3.2 Model Selection

Model selected for barley is very similar to wheat as their climate requirements during their growth stages are alike. While it is important to estimate the impact of spring and early summer precipitation on barley production, it is also crucial to analyze the impact of temperature. The model estimates the impact of temperature during the planting season as well as the harvesting season which are known to impact the production of the crop in the literature.

$$
\begin{aligned}
&log(\,Barley\ Production_{i,t}) \\
&\qquad = \beta_0 + \beta_1\, log\big(Barley\ Production_{i,t-1}\big) \\
&\qquad + \beta_2\, log\big(Mean\ Precipitation\ March_{i,t}\big) \\
&\qquad + \beta_3\, log\big(Mean\ Precipitation\ April_{i,t}\big) \\
&\qquad + \beta_4\, log\big(Mean\ Precipitation\ May_{i,t}\big) \\
&\qquad + \beta_5\, log\big(Mean\ Precipitation\ June_{i,t}\big) \\
&\qquad + \beta_6\, log\big(Mean\ Temperature\ February_{i,t}\big) \\
&\qquad + \beta_7\, log\big(Mean\ Temperature\ March_{i,t}\big) \\
&\qquad + \beta_8\, log\big(Mean\ Temperature\ April_{i,t}\big) \\
&\qquad + \beta_9\, log\big(Mean\ Temperature\ May_{i,t}\big) \\
&\qquad + \beta_{10}\, log\big(Mean\ Temperature\ June_{i,t}\big) \\
&\qquad + \beta_{11}\, log\big(Mean\ Temperature\ July_{i,t}\big) \\
&\qquad + \beta_{12}\, log\big(Mean\ Temperature\ August_{i,t}\big) \\
&\qquad + \ \alpha_1 Price\ Deviation_{i,t-1} + \ \alpha_2 Fertilizer\ Prices_{i,t-1} \\
&\qquad + \ \alpha_3 Commodity\ Prices_{i,t-1} + \ \gamma_1 City\ Level\ FE_i + e_{i,t}
\end{aligned}
$$

$$i = province\ ,t = year$$

*(Equation 4)*

### 5.3.3 Estimation Results

Barley and wheat are similar crop types with similar growing regions and climate requirements. Therefore, the results for barley are in line with the results discussed for wheat. Table 5.3 presents the results estimated for barley production.

Table 5.3. Estimates for Barley Production

| VARIABLES | (1)<br>Model 1 | (2)<br>Model 2 | (3)<br>Model 3 | (4)<br>Model 4 |
|---|---|---|---|---|
| ln_amount | 0.516*** | 0.514*** | 0.516*** | 0.514*** |
| | (0.0245) | (0.0250) | (0.0245) | (0.0250) |
| ln_mean_precip_3 | 0.0176 | 0.0425** | 0.253** | 0.178 |
| | (0.0176) | (0.0188) | (0.108) | (0.112) |
| ln_mean_precip_4 | 0.0515*** | 0.0376** | -0.425*** | -0.304** |
| | (0.0143) | (0.0166) | (0.147) | (0.154) |
| ln_mean_precip_5 | 0.0186 | -0.00391 | 0.0754 | 0.0415 |
| | (0.0129) | (0.0141) | (0.237) | (0.242) |
| ln_mean_precip_6 | -0.0194* | -0.0165 | -0.162 | -0.170 |
| | (0.0106) | (0.0110) | (0.241) | (0.249) |
| ln_mean_temp_2 | -0.0155 | 0.0274 | -0.0155 | 0.0239 |
| | (0.0204) | (0.0226) | (0.0204) | (0.0228) |
| ln_mean_temp_3 | -0.0102 | 0.133 | 0.0689 | 0.150 |
| | (0.0533) | (0.0919) | (0.0663) | (0.0989) |
| ln_mean_temp_4 | -0.149* | -0.158 | -0.257*** | -0.280* |
| | (0.0886) | (0.161) | (0.0936) | (0.169) |
| ln_mean_temp_5 | -0.0789 | -0.590** | -0.107 | -0.569* |
| | (0.167) | (0.276) | (0.178) | (0.290) |
| ln_mean_temp_6 | -0.638*** | -0.506 | -0.566** | -0.468 |
| | (0.237) | (0.357) | (0.251) | (0.374) |
| ln_mean_temp_7 | -0.922*** | -0.639 | -0.913*** | -0.665 |
| | (0.297) | (0.432) | (0.297) | (0.433) |
| ln_mean_temp_8 | 0.237 | 0.529 | 0.115 | 0.420 |
| | (0.322) | (0.384) | (0.328) | (0.390) |
| c.ln_mean_precip3# c.ln_ mean_temp3 | | | -0.104** | -0.0599 |
| | | | (0.0479) | (0.0495) |
| c.ln_mean_precip4# c.ln_mean_temp4 | | | 0.184*** | 0.132** |
| | | | (0.0562) | (0.0592) |
| c.ln_mean_precip5# c.ln_ mean_temp5 | | | -0.0196 | -0.0155 |
| | | | (0.0800) | (0.0819) |
| c.ln_mean_precip6# c.ln_ mean_temp6 | | | 0.0449 | 0.0479 |
| | | | (0.0755) | (0.0777) |
| price_deviation | -0.000695 | 0.00855* | -0.000575 | 0.00914* |
| | (0.000955) | (0.00501) | (0.000957) | (0.00503) |
| d_commodity_index | -0.0784 | -1.066* | -0.0776 | -0.993* |
| | (0.0526) | (0.580) | (0.0535) | (0.584) |
| d_fertilizer_index | 0.0949** | 0.113 | 0.0955** | 0.129 |
| | (0.0437) | (0.110) | (0.0437) | (0.110) |
| Constant | 9.836*** | 8.624*** | 10.17*** | 9.163*** |
| | (1.139) | (1.551) | (1.172) | (1.614) |
| | | | | |
| Observations | 1,236 | 1,236 | 1,236 | 1,236 |
| R-squared | 0.347 | 0.389 | 0.355 | 0.393 |
| Number of provinces | 78 | 78 | 78 | 78 |
| Year FE | | YES | | YES |

Similar to wheat, barley production is positively affected from precipitation increase during spring. Moreover, barley production is expected to be negatively impacted from temperature increase in spring and summer. It is estimated that a 1% increase in mean temperature during April to July decreases barley production by 1.7%.

Regional results for barley are also provided in Table 5.4. Almost half of the barley production in Türkiye is centered around Central Anatolia, with the rest spreading across Aegean and West Black Sea regions (see Figure 4.4). Therefore, the results in the table below provides separate results for these three regions. The regional results suggest that the impact of spring precipitation is felt in the Aegean and the Black Sea, yet, there is no significant impact on the barley production in Central Anatolia. Moreover, the negative impact of a percentage change in spring and summer temperature is only visible in the Central Anatolia. Compared to the total impact of a temperature change, the impact on Central Anatolia is more than two times which is an important point to draw.

So far, we presented the results for wheat and barley which were similar crops grown in similar regions. Now we turn our focus to different type of crops, more heat resistant types; corn, rice and sunflower.

Table 5.4. Regional Estimates for Barley Production

| | (1) Model 1 | (2) Model 5 *Aegean* | (3) Model 6 *Central Anatolia* | (4) Model 7 *West Black Sea* | (5) Model 8 *Barley growing regions* |
|---|---|---|---|---|---|
| ln_amount | 0.516*** | 0.615*** | 0.513*** | 0.777*** | 0.588*** |
| | (0.0245) | (0.0746) | (0.0788) | (0.0506) | (0.0366) |
| ln_mean_ precip_3 | 0.0176 | 0.0313 | 0.0133 | -0.0200 | 0.00240 |
| | (0.0176) | (0.0292) | (0.0435) | (0.0285) | (0.0189) |
| ln_mean_ precip_4 | 0.0515*** | 0.0805*** | 0.0360 | 0.0581*** | 0.0575*** |
| | (0.0143) | (0.0236) | (0.0265) | (0.0198) | (0.0131) |
| ln_mean_ precip_5 | 0.0186 | 0.0479*** | -0.0332 | -0.0229 | 0.0162 |
| | (0.0129) | (0.0178) | (0.0356) | (0.0202) | (0.0127) |

Table 5.4. Regional Estimates for Barley Production (cont'd)

| | | | | | |
|---|---|---|---|---|---|
| ln_mean_precip_6 | -0.0194* | -0.00451 | -0.0376 | -0.0169 | -0.0322** |
| | (0.0106) | (0.0178) | (0.0290) | (0.0268) | (0.0133) |
| ln_mean_temp_2 | -0.0155 | -0.0139 | -0.0130 | 0.000473 | -0.00892 |
| | (0.0204) | (0.0466) | (0.0316) | (0.0432) | (0.0208) |
| ln_mean_temp_3 | -0.0102 | 0.0833 | 0.450*** | -0.00459 | 0.146*** |
| | (0.0533) | (0.125) | (0.104) | (0.0743) | (0.0514) |
| ln_mean_temp_4 | -0.149* | 0.280 | -0.257 | 0.247** | 0.0110 |
| | (0.0886) | (0.187) | (0.178) | (0.121) | (0.0873) |
| ln_mean_temp_5 | -0.0789 | -0.535* | -0.884*** | -0.288 | -0.520*** |
| | (0.167) | (0.286) | (0.326) | (0.239) | (0.153) |
| ln_mean_temp_6 | -0.638*** | -0.140 | -0.750 | -0.338 | -0.428* |
| | (0.237) | (0.392) | (0.459) | (0.341) | (0.226) |
| ln_mean_temp_7 | -0.922*** | -1.240** | -2.404*** | -0.488 | -1.267*** |
| | (0.297) | (0.553) | (0.538) | (0.373) | (0.270) |
| ln_mean_temp_8 | 0.237 | 0.828 | -0.683 | -0.118 | -0.0368 |
| | (0.322) | (0.572) | (0.666) | (0.479) | (0.309) |
| price_deviation | -0.000695 | -0.000333 | 0.00104 | -0.00100 | 0.000118 |
| | (0.000955) | (0.00136) | (0.00247) | (0.00159) | (0.000983) |
| d_commodity_index | -0.0784 | 0.173* | -0.155 | -0.0106 | 0.00698 |
| | (0.0526) | (0.0968) | (0.145) | (0.0838) | (0.0559) |
| d_fertilizer_index | 0.0949** | -0.0927 | 0.0199 | 0.0121 | 0.0231 |
| | (0.0437) | (0.0721) | (0.0956) | (0.0669) | (0.0454) |
| Constant | 9.836*** | 6.704*** | 20.18*** | 5.317*** | 11.13*** |
| | (1.139) | (2.306) | (2.267) | (1.528) | (1.089) |
| Observations | 1,236 | 155 | 163 | 181 | 499 |
| R-squared | 0.347 | 0.534 | 0.397 | 0.686 | 0.465 |
| Number of provinces | 78 | 8 | 11 | 10 | 29 |

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

## 5.4 Rice

### 5.4.1 Background

Wheat and barley are similar crop types that can be grown in a wide range of regions especially in arid and semi-arid regions. Different from these two types of crops, rice and corn are similar in their development stages as well as climate requirements.

Rice is the most cultivated crop and widely consumed in the majority of the world population, in particular, Asia and Africa. Following maize and sugarcane it is the most produced agricultural commodity across the world (FAOSTAT, 2020)

Rice constitutes an important element of Turkish diet as the urbanization rate of the population increases. Rice consumption per capita reached 15.8 kg in 2017, 3.8% more than 2016 reaching the historical high since 1964 (FAOSTAT, 2020). Although Türkiye continues to import rice, rice production in Türkiye has been increasing over the last decades. Rice production in Türkiye increased 100% since 2004 increasing from 0.5 million tonnes in 2004 to 1 million tonnes in 2021 (TurkStat, 2021b).

The growth of the rice plant can be broadly categorized under three stages: vegetation (seed germination to PI), reproduction (PI to flowering) and ripening (flowering to maturity) (see Figure 5.5).

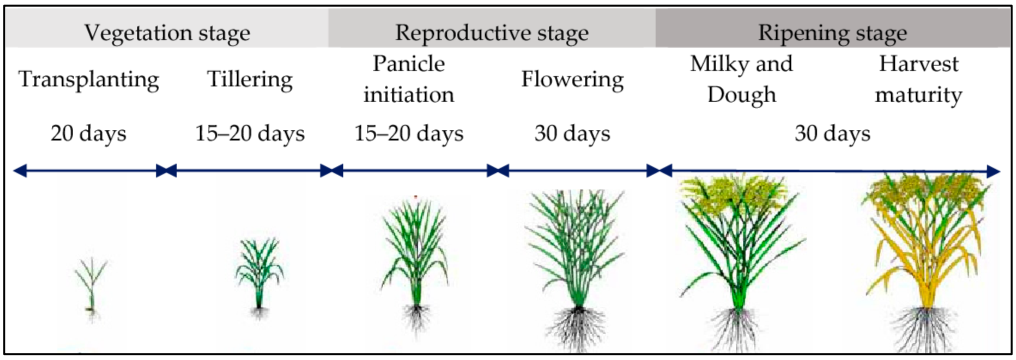


Figure 5.5. Growth Stages of Rice
Source: (Prathumchai et al., 2018)

Rice is a heat resistant crop which requires hot and humid climate conditions. It is best suited to be grown in the regions with high humidity levels and long sunshine days as well as adequate supply of water. It requires an average temperature of 20°C to 27°C during growing season. Sunlight is critical during the growth of rice. The minimum temperature should be above 15°C during that period. In addition to temperature requirements, water is most critical for rice than any other crop. Rice can only be grown in irrigated areas and requires consistent irrigation all season to grow. The Figure below presents the timeline for rice growth to understand the climatic requirements of each season (see Figure 5.6).

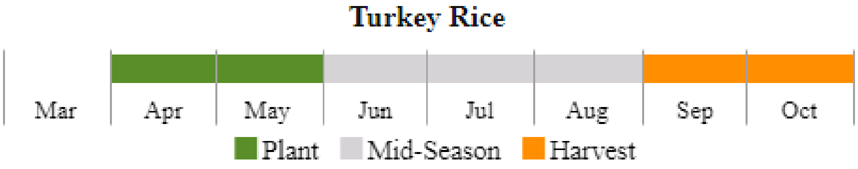


Figure 5.6. Timeline for Rice Production
Source: (USDA Foreign Agricultural Service, 2021)

### 5.4.2 Model Selection

Wheat and barley are cold resistant crops. From now on the crop types that will be analyzed are heat resistant. Among one of the heat resistant crops is rice. Rice requires consistent irrigation all times to grow. Therefore, the model includes the precipitation of the driest months which are summer months in Türkiye. However, it is important to keep in mind that since the crop is grown in the water, precipitation level remains to be insignificant in the model due to high irrigation levels.

For rice growth, the analysis mainly focuses on the impact of temperature on production level. The most important temperatures are the spring and summer temperatures as discussed in the previous subchapter. In the analysis, we are interested in the $\beta$ coefficients. For instance, estimated $\beta_5$ means a 1% increase in mean temperature in April translates into a $\beta_5$% change in total rice production.

$$\begin{aligned}
&log(\,Rice\ Production_{i,t}) \\
&\qquad = \beta_0 + \beta_1\, log\big(Rice\ Production_{i,t-1}\big) \\
&\qquad + \beta_2\, log\big(Mean\ Precipitation\ July_{i,t}\big) \\
&\qquad + \beta_3\, log\big(Mean\ Precipitation\ August_{i,t}\big) \\
&\qquad + \beta_4\, log\big(Mean\ Precipitation\ September_{i,t}\big) \\
&\qquad + \beta_5\, log\big(Mean\ Temperature\ April_{i,t}\big) \\
&\qquad + \beta_6\, log\big(Mean\ Temperature\ May_{i,t}\big) \\
&\qquad + \beta_7\, log\big(Mean\ Temperature\ June_{i,t}\big) + \\
&\qquad + \ \alpha_1 Price\ Deviation_{i,t-1} + \ \alpha_2 Fertilizer\ Prices_{i,t-1} \\
&\qquad + \ \gamma_1 City\ Level\ FE_i + e_{i,t}
\end{aligned}$$

$$i = province\ , t = year$$

*(Equation 5)*

### 5.4.3 Estimation Results

Rice is a heat resistant crop only grown in irrigated areas. Therefore, while water is extremely critical it is not possible to analyze the impact of precipitation given the fact that the crop is grown in irrigated areas. Table 5.5 provides the regression output for rice production.

In line with the literature, the table suggests that a temperature increase in spring positively impacts rice production. However, rice production is negatively affected from temperature increase during summer. It is expected that 1% temperature increase during summer decreases rice production by 1.23%.

Table 5.5. Estimates for Rice Production

|  | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| VARIABLES | Model 1 | Model 2 | Model 3 | Model 4 |
| ln_amount | 0.599*** | 0.591*** | 0.593*** | 0.593*** |
|  | (0.0350) | (0.0361) | (0.0352) | (0.0352) |
| ln_mean_temp_4 | 0.301** | 0.324 | 0.284** | 0.284** |
|  | (0.142) | (0.290) | (0.142) | (0.142) |
| ln_mean_temp_5 | 0.385 | 0.358 | 0.413 | 0.413 |
|  | (0.312) | (0.555) | (0.313) | (0.313) |
| ln_mean_temp_6 | -1.233** | -0.944 | -1.247*** | -1.247*** |
|  | (0.477) | (0.730) | (0.480) | (0.480) |
| ln_mean_precip_7 | 0.000246 | -0.00207 | 0.546 | 0.546 |
|  | (0.0141) | (0.0153) | (0.354) | (0.354) |
| ln_mean_precip_8 | 0.0198 | 0.0290* | -0.274 | -0.274 |
|  | (0.0137) | (0.0148) | (0.340) | (0.340) |
| ln_mean_precip_9 | 0.00652 | 0.00779 | -0.202 | -0.202 |
|  | (0.0163) | (0.0197) | (0.286) | (0.286) |
| c.ln_mean_precip7# c.ln_mean_temp7 |  |  | -0.168 | -0.168 |
|  |  |  | (0.109) | (0.109) |
| c.ln_mean_precip8# c.ln_ mean_temp8 |  |  | 0.0896 | 0.0896 |
|  |  |  | (0.104) | (0.104) |
| c.ln_mean_precip9# c.ln_ mean_temp9 |  |  | 0.0676 | 0.0676 |
|  |  |  | (0.0925) | (0.0925) |
| price_deviation | -0.000266 | 0.00338 | -0.000537 | -0.000537 |
|  | (0.00147) | (0.00523) | (0.00148) | (0.00148) |
| d_fertilizer_index | -0.00885 | -0.179 | -0.0158 | -0.0158 |
|  | (0.0742) | (0.189) | (0.0746) | (0.0746) |
| Constant | 5.087*** | 4.360** | 5.142*** | 5.142*** |
|  | (1.341) | (2.097) | (1.355) | (1.355) |

Table 5.5. Estimates for Rice Production

| | | | | |
|---|---|---|---|---|
| Observations | 589 | 589 | 589 | 589 |
| R-squared | 0.366 | 0.387 | 0.370 | 0.370 |
| Number of provinces | 39 | 39 | 39 | 39 |
| Year FE | | YES | | YES |

Standard errors in parentheses

The analysis is also extended for rice growing regions. Unlike wheat and barley, due to its climatic requirements, rice is grown in a limited area of the country. These regions are the most humid regions which are West Marmara and West Black Sea. Table 5.6 provides the outputs of the regional estimations. The results suggest that the impact of temperature both in spring and summer is felt more in the West Marmara compared to West Black Sea. West Marmara constitutes almost 70% of total production laying out the importance of how increasing temperatures would negatively impact the total production. While the impact of an increase in spring temperature is 0.3% for the general model, this number reaches to 2.2% for West Marmara.

Table 5.6. Regional Estimates for Rice

|  | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| VARIABLES | Model 1 | Model 5 | Model 6 | Model 7 |
|  |  | *West Marmara* | *West Black Sea* | *Rice growing regions* |
| ln_amount | 0.605*** | 0.624*** | 0.760*** | 0.723*** |
|  | (0.0352) | (0.0612) | (0.0406) | (0.0342) |
| ln_mean_temp_4 | 0.307** | 0.806*** | 0.283** | 0.424*** |
|  | (0.151) | (0.272) | (0.122) | (0.121) |
| ln_mean_temp_5 | 0.352 | 1.394** | -0.0404 | 0.303 |
|  | (0.334) | (0.602) | (0.248) | (0.256) |
| ln_mean_temp_6 | -1.193** | -1.891** | -0.216 | -0.890** |
|  | (0.497) | (0.757) | (0.398) | (0.379) |
| ln_mean_precip_3 | 0.0646 | -0.0519 | -0.0265 | -0.0367 |
|  | (0.0399) | (0.0588) | (0.0348) | (0.0310) |
| ln_mean_precip_4 | 0.0250 | 0.00956 | 0.0264 | 0.0109 |
|  | (0.0319) | (0.0411) | (0.0234) | (0.0213) |
| ln_mean_precip_5 | -0.0164 | -0.0409 | -0.0244 | -0.0420* |
|  | (0.0317) | (0.0360) | (0.0317) | (0.0232) |
| ln_mean_precip_6 | -0.0147 | -0.0746 | 0.00142 | -0.0281 |
|  | (0.0244) | (0.0452) | (0.0326) | (0.0259) |
| ln_mean_precip_7 | 0.000601 | -0.0135 | 0.00877 | -0.00256 |
|  | (0.0147) | (0.0181) | (0.0178) | (0.0120) |
| price_deviation | -0.000344 | -0.000885 | -0.00160 | -0.00154 |
|  | (0.00146) | (0.00257) | (0.00123) | (0.00123) |
| d_fertilizer_index | -0.0109 | -0.0510 | 0.0218 | 0.0217 |
|  | (0.0746) | (0.111) | (0.0655) | (0.0574) |
| Constant | 4.927*** | 3.978* | 2.249** | 3.562*** |
|  | (1.399) | (2.365) | (1.122) | (1.090) |
| Observations | 589 | 100 | 158 | 258 |
| R-squared | 0.367 | 0.771 | 0.730 | 0.729 |
| Number of provinces | 39 | 5 | 8 | 13 |

Standard errors in parentheses

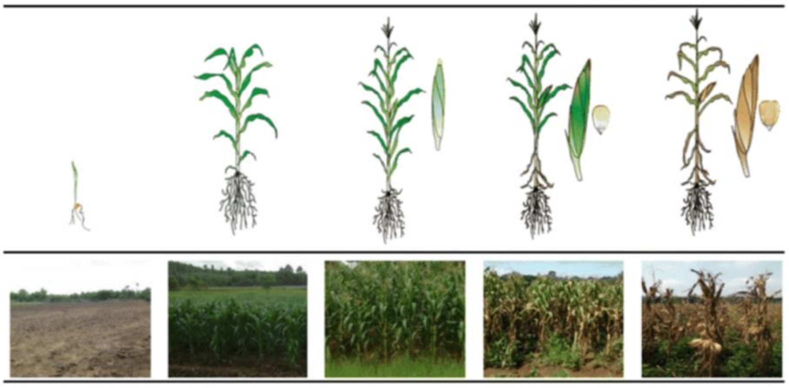
## 5.5 Corn

### 5.5.1 Background

After wheat and rice, corn is the most important crop globally playing a variety of roles in the agricultural system (NSW Department of Primary Industries & O’Keeffe, 2009). Corn (Maize), with its multipurpose use, has increasingly becoming a staple food across the world. Its total production has already surpassed wheat and rice, with its total production reaching 1.2 billion tonnes across the world (World Agricultural Production.com, 2022).

Corn is primarily used as animal feed, yet, it is critical for human consumption as well. It is estimated that while 60% of production is directed to livestock feed, 20% is used for human consumption (Miller Magazine, 2014). Moreover 10% of corn production is used for processed food such as corn syrup and corn starch. Besides its usage as human food and animal feed; used as the raw material of many products in the industry, corn becomes a more strategic plant both in the world and in Türkiye gradually.

Corn (maize) growth stages can be divided into two broad categories: vegetative growth and reproductive development (see Figure 5.7).



| Stage | VE | V10 | R1 | R4 | R6 |
|---|---|---|---|---|---|
| Days | 3 | 30 | 60 | 90 | 120 |
| Months | June | July | August | September | October |
| Monthly rainfall (mm) | 290.9 | 640.5 | 420 | 220 | 31.8 |
| Average temperature (°C) | 33.2 | 30.9 | 30.9 | 31.7 | 32.7 |

Figure 5.7. Development Stages of Maize
Source: (Panitlertumpai et al., 2018)

Corn can be grown across different types of climates. The optimal climate requirement of the crop type is similar to rice, which is temperate and humid regions. Since it is a hot season crop, it requires high night and day temperature as well as sufficient soil moisture. During its vegetative stage, optimum required temperature is around 34°C (4 to 6°C higher than wheat). When average temperature falls below 20°C crop duration extends significantly reaching to 200 days to mature when the temperature is below 15°C. Corn is drought and heat resistant especially during the early development phases. However, during reproductive development temperature rising above 32°C can decrease the corn yields. Similar to rice, it is risky to grow corn in exclusively rain-fed regions, thus, irrigation is highly crucial. The below figure presents the timeline of corn growth in Türkiye.

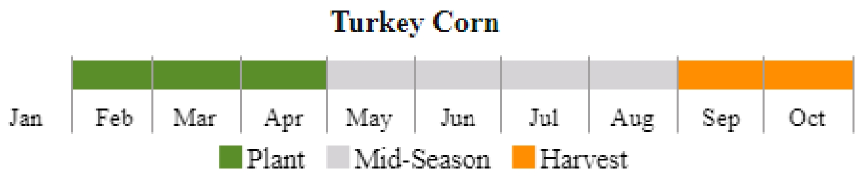


Figure 5.8. Timeline for Maize Production
Source: (USDA Foreign Agricultural Service, 2021)

In Türkiye, corn is planted during winter to spring and harvested in fall (see Figure 5.8). The growth requires heat during the planting season, yet extreme heat harms he growth after planting. Therefore, the model is selected accordingly in the next subsection.

### 5.5.2 Model Selection

Development of corn is similar to rice with precipitation being extremely important, yet, being insignificant due to high irrigation levels. Temperature during spring is also critical and remains to be important to analyze by the model.

$$
\begin{aligned}
&log(\,Corn\ Production_{i,t}) \\
&\quad = \beta_0 + \beta_1\, log\big(Corn\ Production_{i,t-1}\big) \\
&\quad + \beta_2\, log\big(Mean\ Precipitation\ March_{i,t}\big) \\
&\quad + \beta_3\, log\big(Mean\ Precipitation\ April_{i,t}\big) \\
&\quad + \beta_4\, log\big(Mean\ Precipitation\ May_{i,t}\big) \\
&\quad + \beta_5\, log\big(Mean\ Precipitation\ June_{i,t}\big) \\
&\quad + \beta_6\, log\big(Mean\ Precipitation\ July_{i,t}\big) \\
&\quad + \beta_7\, log\big(Mean\ Precipitation\ August_{i,t}\big) \\
&\quad + \beta_8\, log\big(Mean\ Precipitation\ September_{i,t}\big) \\
&\quad + \beta_9\, log\big(Mean\ Temperature\ April_{i,t}\big) \\
&\quad + \beta_{10}\, log\big(Mean\ Temperature\ May_{i,t}\big) \\
&\quad + \beta_{11}\, log\big(Mean\ Temperature\ June_{i,t}\big) + \ \alpha_1 Price\ Deviation_{i,t-1} \\
&\quad + \ \alpha_2 Fertilizer\ Prices_{i,t-1} + \ \gamma_1 City\ Level\ FE_i + e_{i,t}
\end{aligned}
$$

$$i = province\ , t = year$$

*(Equation 6)*

### 5.5.3 Estimation Results

Similar to rice, it is not possible to comment on the impact of a change in precipitation on production due to high irrigation levels. The results of the model are provided in the Table 5.7 below.

The results suggest that, a temperature increase in spring positively effects corn production. However, a temperature increase during summer months cause a decline in production. A 1% increase in temperature during summer is estimated to decrease corn production by 1.8%.

Table 5.7. Estimates for Corn Production

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| VARIABLES | Model 1 | Model 2 | Model 3 | Model 4 |
| ln_amount | 0.805*** | 0.805*** | 0.800*** | 0.800*** |
| | (0.0158) | (0.0156) | (0.0160) | (0.0158) |
| ln_mean_temp_4 | 0.204* | -0.00599 | 0.290** | 0.108 |
| | (0.107) | (0.177) | (0.125) | (0.204) |
| ln_mean_temp_5 | 0.743*** | 0.780* | 0.535** | 0.549 |
| | (0.243) | (0.405) | (0.266) | (0.434) |
| ln_mean_temp_6 | -1.786*** | -1.788*** | -1.493*** | -1.372*** |
| | (0.348) | (0.468) | (0.368) | (0.496) |
| ln_mean_precip_3 | -0.0463 | -0.0550* | -0.0462 | -0.0546* |
| | (0.0282) | (0.0300) | (0.0284) | (0.0303) |
| ln_mean_precip_4 | 0.0124 | -0.0339 | 0.213 | 0.113 |
| | (0.0235) | (0.0277) | (0.193) | (0.202) |
| ln_mean_precip_5 | 0.0413** | 0.0419* | -0.732** | -0.566 |
| | (0.0208) | (0.0237) | (0.340) | (0.344) |
| ln_mean_precip_6 | -0.0140 | -0.00688 | 0.891** | 0.918** |
| | (0.0190) | (0.0198) | (0.371) | (0.372) |
| ln_mean_precip_7 | 0.00129 | -0.000160 | 0.00255 | 0.00122 |
| | (0.0114) | (0.0117) | (0.0114) | (0.0118) |
| c.ln_mean_precip4 #c.ln_mean_temp4 | | | -0.0785 | -0.0591 |
| | | | (0.0744) | (0.0782) |
| c.ln_mean_precip5 #c.ln_mean_temp5 | | | 0.263** | 0.207* |
| | | | (0.115) | (0.117) |
| c.ln_mean_precip6 #c.ln_mean_temp6 | | | -0.288** | -0.294** |
| | | | (0.118) | (0.118) |
| price_deviation | 0.00114 | 0.00217 | 0.00115 | 0.00226 |
| | (0.00117) | (0.00269) | (0.00116) | (0.00269) |
| d_fertilizer_index | 0.114** | 0.0873 | 0.112** | 0.0681 |
| | (0.0559) | (0.136) | (0.0558) | (0.136) |
| Constant | 4.566*** | 4.966*** | 4.081*** | 4.120*** |
| | (1.006) | (1.446) | (1.098) | (1.586) |
| Observations | 1,262 | 1,262 | 1,262 | 1,262 |
| R-squared | 0.698 | 0.719 | 0.701 | 0.721 |
| Number of provinces | 77 | 77 | 77 | 77 |
| Year FE | | YES | | YES |

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Corn is mostly grown in warmer regions of the country. Most of the production is done in Central Anatolia, Mediterranean and Southeast Anatolia. There is a limited amount of production in East Marmara as well (see Figure 4.6). Therefore, the next table shows the estimation results for each of the growing regions.

According to table 5.8, the impact of the change in spring temperature disappears in East Marmara, Southeast Anatolia and Mediterranean. However, the impact of a temperature increase during summer is much more visible in each region. For example, a 1% increase in mean summer temperature is estimated to translate into a 1.8% decline in corn production. This number reaches to 2.6% when the sample is restricted to East Marmara region only (see Table 5.8).

Table 5.8. Regional Estimates for Corn Production

| | (1)<br>Model 1 | (2)<br>Model 5<br>*East Marmara* | (3)<br>Model 6<br>*West Anatolia* | (4)<br>Model 7<br>*Southeast Anatolia and Mediterranean* | (5)<br>Model 8<br>Corn growing regions |
|---|---|---|---|---|---|
| ln_amount | 0.805*** | 0.875*** | 0.815*** | 0.858*** | 0.865*** |
| | (0.0158) | (0.0631) | (0.0665) | (0.0356) | (0.0276) |
| ln_mean_temp_4 | 0.204* | 0.265 | 1.355** | 0.367 | 0.306 |
| | (0.107) | (0.419) | (0.537) | (0.328) | (0.214) |
| ln_mean_temp_5 | 0.743*** | 0.0497 | 1.579 | 0.749 | 0.611 |
| | (0.243) | (0.839) | (1.031) | (0.521) | (0.417) |
| ln_mean_temp_6 | -1.786*** | -2.581* | -2.208 | -1.457* | -2.098*** |
| | (0.348) | (1.414) | (1.403) | (0.795) | (0.632) |
| ln_mean_precip_3 | -0.0463 | -0.0872 | -0.322* | 0.0481 | -0.0201 |
| | (0.0282) | (0.140) | (0.165) | (0.0440) | (0.0462) |
| ln_mean_precip_4 | 0.0124 | -0.0953 | 0.153 | 0.0546 | 0.0224 |
| | (0.0235) | (0.111) | (0.120) | (0.0455) | (0.0415) |
| ln_mean_precip_5 | 0.0413** | 0.0448 | -0.00734 | 0.0517* | 0.0400 |
| | (0.0208) | (0.114) | (0.120) | (0.0309) | (0.0342) |
| ln_mean_precip_6 | -0.0140 | 0.0802 | 0.112 | -0.0435* | -0.0202 |
| | (0.0190) | (0.102) | (0.126) | (0.0245) | (0.0282) |

Table 5.8. Regional Estimates for Corn Production (cont’d)

| | | | | | |
|---|---|---|---|---|---|
| ln_mean_precip_7 | 0.00129 | -0.0113 | -0.0332 | -0.0138 | -0.00864 |
| | (0.0114) | (0.0472) | (0.0518) | (0.0171) | (0.0175) |
| price_deviation | 0.00114 | 0.00457 | 0.00393 | 0.00335 | 0.00194 |
| | (0.00117) | (0.00583) | (0.00527) | (0.00211) | (0.00201) |
| d_fertilizer_index | 0.114** | 0.343 | 0.286 | 0.0340 | 0.166* |
| | (0.0559) | (0.221) | (0.260) | (0.102) | (0.0958) |
| Constant | 4.566*** | 8.063** | 1.147 | 2.867 | 5.346*** |
| | (1.006) | (3.939) | (4.562) | (2.590) | (1.892) |
| Observations | 1,262 | 146 | 53 | 230 | 429 |
| R-squared | 0.698 | 0.629 | 0.929 | 0.778 | 0.746 |
| Number of provinces | 77 | 8 | 3 | 17 | 28 |

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

## 5.6 Sunflower

### 5.6.1 Background

Sunflower is a crop that is mainly grown for its edible seeds. While mainly used as an input for cooking oil, it is also used for animal feed. Sunflower production is led by Ukraine and the Russian Federation constituting more than 50% of total world production (FAOSTAT, 2021). Türkiye is among top ten producers with its total production reaching 2.4 million tonnes in 2021, rising 168.3% since 2014 (see Figure 5.9 and Table 4.3).

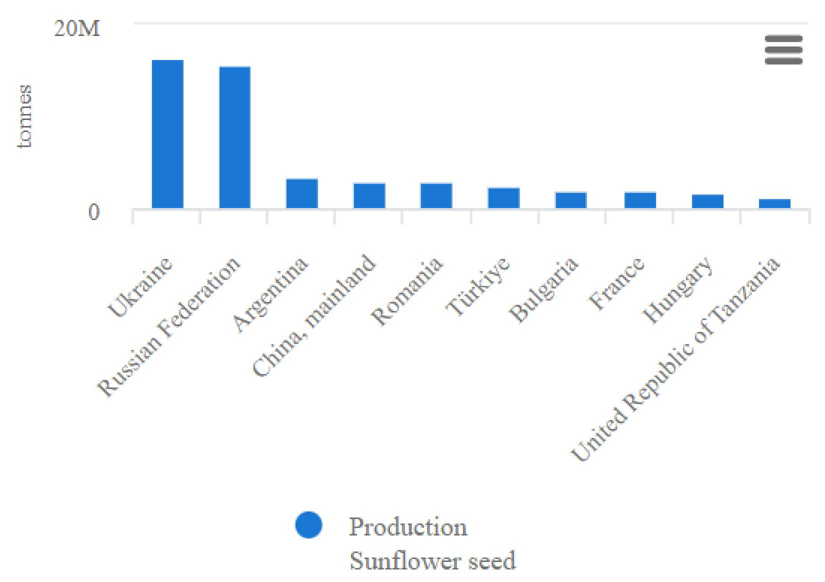


Figure 5.9. Top 10 country Production of Sunflower Seed, 2021
Source: (FAOSTAT, 2021)

Sunflower is an important crop especially for the European diet with its use as an input for sunflower oil production. Similar to corn and rice, sunflower is a temperate zone crop. It is a heat resistant crop grown in irrigated areas. The optimal temperature for sunflower growth is between 20°C to 28°C. However, the crop is tolerant to heat between 8°C to 34°C. High temperature during the growing season is projected to reduce maturity time. While sunflower is more resistant to cold compared to maize, frost is expected to harm the crop in all stages of the development.

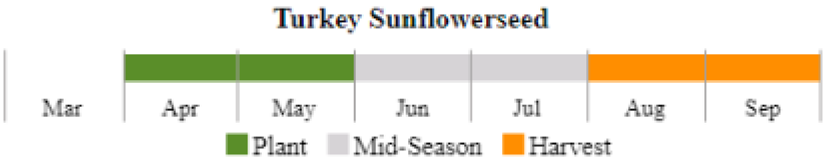


Figure 5.10. Timeline of Sunflower Seed Growth in Türkiye
Source: (USDA Foreign Agricultural Service, 2021)

Sunflower is critical for Turkish diet as it constitutes more than 50% of vegetable oil production. It is planted during spring and harvested in the end of summer and fall (see Figure 5.10Figure 5.10). The temperature during the planting season remains to be very important for sunflower growth which is considered in the model selection.

### 5.6.2 Model Selection

Sunflower is also grown in irrigated areas. While it is not possible to analyze the impact of precipitation due to consistent irrigation, temperature during spring and summer is critically important.

$$
\begin{aligned}
& log(\,Sunflower\ Production_{i,t}) \\
& = \beta_0 + \beta_1\, log\big(Sunflower\ Production_{i,t-1}\big) \\
& + \beta_2\, log\big(Mean\ Precipitation\ March_{i,t}\big) + \beta_3\, log\big(Mean\ Precipitation\ April_{i,t}\big) \\
& + \beta_4\, log\big(Mean\ Precipitation\ May_{i,t}\big) + \quad \beta_5\, log\big(Mean\ Precipitation\ August_{i,t}\big) \\
& + \beta_6\, log\big(Mean\ Precipitation\ September_{i,t}\big) \\
& + \beta_7\, log\big(Mean\ Temperature\ March_{i,t}\big) \\
& + \beta_8\, log\big(Mean\ Temperature\ April_{i,t}\big) + \beta_9\, log\big(Mean\ Temperature\ May_{i,t}\big) \\
& + \beta_{10}\, log\big(Mean\ Temperature\ June_{i,t}\big) \\
& + \beta_{1''}\, log\big(Mean\ Temperature\ July_{i,t}\big) + \beta_{12}\, log\big(Mean\ Temperature\ August_{i,t}\big) \\
& + \beta_{13}\, log\big(Mean\ Temperature\ September_{i,t}\big) + \alpha_1 Price\ Deviation_{i,t-1} \\
& + \alpha_2 Fertilizer\ Prices_{i,t-1} + \gamma_1 City\ Level\ FE_i + e_{i,t}
\end{aligned}
$$

$$i = province\ , t = year$$

*(Equation 7)*

### 5.6.3 Estimation Results

Followed by corn and rice, sunflower is also a heat resistant crop grown in irrigated areas. The model estimation results are provided in the table below Table 5.9 suggests that, increase in spring temperatures positively impacts sunflower production, yet the opposite is expected during summer.

The impact of summer temperatures is striking. It is estimated that a 1% change in mean temperature during summer months is expected to decrease sunflower production by 2.6%.

Table 5.9. Estimates for Sunflower Production

| VARIABLES | (1) Model 1 | (2) Model 2 | (3) Model 3 |
|---|---|---|---|
| ln_amount | 0.705***<br>(0.0211) | 0.693***<br>(0.0213) | 0.706***<br>(0.0213) |

Table 5.9. Estimates for Sunflower Production (cont'd)

| | | | |
|---|---|---|---|
| ln_mean_temp_3 | 0.123** | 0.0177 | 0.0649 |
| | (0.0564) | (0.0721) | (0.0675) |
| ln_mean_temp_4 | 0.539*** | 0.297 | 0.486*** |
| | (0.169) | (0.284) | (0.185) |
| ln_mean_temp_5 | 0.483 | -0.640 | 0.639* |
| | (0.322) | (0.555) | (0.352) |
| ln_mean_temp_6 | -1.110** | -0.925 | -1.160** |
| | (0.477) | (0.653) | (0.484) |
| ln_mean_temp_7 | 0.991* | 0.0369 | 0.860 |
| | (0.576) | (0.928) | (0.581) |
| ln_mean_temp_8 | -2.455*** | -2.095*** | -2.299*** |
| | (0.614) | (0.766) | (0.644) |
| ln_mean_temp_9 | 0.489 | 0.361 | 0.482 |
| | (0.389) | (0.641) | (0.390) |
| ln_mean_precip_3 | 0.0134 | 0.0446 | -0.155 |
| | (0.0392) | (0.0411) | (0.122) |
| ln_mean_precip_4 | 0.0556* | 0.0258 | 0.00996 |
| | (0.0316) | (0.0348) | (0.296) |
| ln_mean_precip_5 | -0.0967*** | -0.0442 | 0.514 |
| | (0.0271) | (0.0304) | (0.489) |
| ln_mean_precip_8 | -0.0193 | -0.0206 | -0.00309 |
| | (0.0139) | (0.0143) | (0.358) |
| ln_mean_precip_9 | -0.0142 | -0.00123 | -0.189 |
| | (0.0164) | (0.0177) | (0.294) |
| c.ln_mean_precip3 #c.ln_ mean_temp3 | | | 0.0791 |
| | | | (0.0553) |
| c.ln_mean_precip4 #c.ln_ mean_temp4 | | | 0.0174 |
| | | | (0.113) |
| c.ln_mean_precip5 #c.ln_ mean_temp5 | | | -0.206 |
| | | | (0.165) |
| c.ln_mean_precip8 #c.ln_ mean_temp8 | | | -0.00569 |
| | | | (0.110) |
| c.ln_mean_precip9 #c.ln_ mean_temp9 | | | 0.0575 |
| | | | (0.0946) |
| l_price | -0.00308 | | -0.00263 |
| | (0.00683) | | (0.00711) |
| d_fertilizer_index | 0.140 | -0.276 | 0.140 |
| | (0.0930) | (0.480) | (0.0940) |
| Constant | 5.987** | 12.12*** | 5.860** |
| | (2.344) | (3.017) | (2.447) |
| | | | |
| Observations | 1,030 | 1,030 | 1,030 |
| R-squared | 0.590 | 0.623 | 0.592 |
| Number of provinces | 63 | 63 | 63 |
| Year FE | | YES | |

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Similar to the other analysis conducted for other crops, regional results for sunflower is also presented in Table 5.10. Sunflower production is centered around Marmara followed by Central Anatolia and Black Sea regions. The estimation results for different regions are presented below.

Table 5.10. Regional Estimates for Sunflower Production

| | (1)<br>Model 1 | (2)<br>Model 4<br>*Marmara* | (3)<br>Model 5<br>*West Anatolia and Black Sea* | (4)<br>Model 6<br>*Mediterranean* | (5)<br>Model 7<br>*Sunflower growing regions* |
|---|---|---|---|---|---|
| ln_amount | 0.705*** | 0.674*** | 0.830*** | 0.615*** | 0.719*** |
| | (0.0211) | (0.0543) | (0.0457) | (0.0524) | (0.0264) |
| ln_mean_temp_3 | 0.123** | 0.238** | -0.0198 | 0.0995 | 0.160* |
| | (0.0564) | (0.106) | (0.158) | (0.362) | (0.0913) |
| ln_mean_temp_4 | 0.539*** | 0.249 | 0.514 | 0.148 | 0.435** |
| | (0.169) | (0.244) | (0.336) | (0.963) | (0.202) |
| ln_mean_temp_5 | 0.483 | 0.492 | -0.697 | 0.794 | 0.294 |
| | (0.322) | (0.506) | (0.699) | (1.102) | (0.386) |
| ln_mean_temp_6 | -1.110** | -1.593** | -0.666 | -1.601 | -0.820 |
| | (0.477) | (0.710) | (1.100) | (2.020) | (0.594) |
| ln_mean_temp_7 | 0.991* | 1.005 | 2.421** | 3.056 | 1.326** |
| | (0.576) | (0.881) | (1.069) | (2.563) | (0.673) |
| ln_mean_temp_8 | -2.455*** | -2.031* | -0.755 | -4.222 | -2.310*** |
| | (0.614) | (1.045) | (1.345) | (2.788) | (0.780) |
| ln_mean_temp_9 | 0.489 | -0.00710 | 0.651 | -0.941 | 0.393 |
| | (0.389) | (0.623) | (0.817) | (1.562) | (0.494) |
| ln_mean_precip_3 | 0.0134 | 0.0487 | -0.130 | -0.116 | -0.0214 |
| | (0.0392) | (0.0604) | (0.106) | (0.115) | (0.0485) |
| ln_mean_precip_4 | 0.0556* | 0.00533 | 0.0805 | 0.0611 | 0.0308 |
| | (0.0316) | (0.0440) | (0.0686) | (0.102) | (0.0355) |
| ln_mean_precip_5 | -0.0967*** | 0.0112 | -0.0537 | -0.0845 | -0.0344 |
| | (0.0271) | (0.0446) | (0.0664) | (0.0692) | (0.0319) |
| ln_mean_precip_8 | -0.0193 | -0.000630 | 0.00427 | -0.0191 | -0.0155 |
| | (0.0139) | (0.0216) | (0.0329) | (0.0415) | (0.0171) |

Table 5.10. Regional Estimates for Sunflower Production (cont'd)

| | | | | | |
|---|---|---|---|---|---|
| ln_mean_ precip_9 | -0.0142 | -0.0475 | -0.0310 | 0.0190 | -0.0168 |
| | (0.0164) | (0.0322) | (0.0448) | (0.0454) | (0.0219) |
| l_price | -0.00308 | -0.00797 | -0.0261* | -0.00805 | -0.00870 |
| | (0.00683) | (0.0117) | (0.0148) | (0.0187) | (0.00801) |
| d_fertilizer_ index | 0.140 | -0.0808 | 0.405* | 0.272 | 0.116 |
| | (0.0930) | (0.137) | (0.231) | (0.267) | (0.111) |
| Constant | 5.987** | 8.817*** | -2.688 | 11.81 | 4.708 |
| | (2.344) | (3.356) | (5.144) | (10.83) | (2.865) |
| | | | | | |
| Observations | 1,030 | 240 | 195 | 149 | 584 |
| R-squared | 0.590 | 0.509 | 0.771 | 0.597 | 0.649 |
| Number of provinces | 63 | 12 | 10 | 8 | 30 |

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

# CHAPTER 6

# CLIMATE SCENARIOS

## 6.1 Introduction

The impact of climate change on agricultural production is highly critical especially for a country like Türkiye with an economy relying on agriculture. Among many agricultural products, Türkiye is a major crop producer and consumer. Therefore, analyzing the impacts of climate change on major crop production remains to be an important issue. Chapter 5, the baseline of this chapter, analyzed the impacts of meteorological variables, precipitation and temperature, on crop production. The chapter concluded that each of the analyzed crop is highly susceptible to changes in temperature as well as precipitation.

The details of the impacts of meteorological changes on wheat, barley, corn, rice and sunflower production is laid out in the previous chapter. The analysis of Chapter 5 estimated the impact of a 1% increase in temperature and precipitation on crop production. The important question remains is how much the actual temperature and precipitation change will be over time. By using a forecast for potential climate change scenarios, this chapter estimates the impact on future crop production.

Complementing the econometric analysis of Chapter 5, this chapter discusses different climate scenarios that are higly reputable in the literature. The Chapter focuses on two different scenarios, high emissions and low emissions scenarios forecasted by IPCC. The IPCC scenarios are focused on the Mediterannean region. This study adds the calculated projections for Türkiye so that it matches the estimations of the previous chapter more precisely.

## 6.2 Climate Scenarios

“A climate scenario is a plausible representation of future climate that has been constructed for explicit use in investigating the potential impacts of anthropogenic climate change. Climate scenarios often make use of climate projections (descriptions of the modelled response of the climate system to scenarios of greenhouse gas and aerosol concentrations), by manipulating model outputs and combining them with observed climate data.” (IPCC, 2001)

The scenarios released by IPCC are widely accepted and commonly cited by anyone who is interested in climate analysis. According to IPCC, climate scenarios are classified under 3 major types based on their construction methodology. These 3 scenarios are: synthetic scenarios, analogue scenarios and climate model-based scenarios. In this thesis “climate model-based scenarios” are used. These scenarios utilize Global Circulation Models (GCMs) outputs and are commonly constructed according to a baseline climate, mainly a reference period.

IPCC presents a wide range of climate scenarios. Although some are more likely to happen based on current climate policies and economic trends, it is important to put forth potential outcomes and future storylines. The IPCC scenarios not only uses past and the current climatic conditions but more importantly it considers possible future climates.

In its highly influential 2021 report, IPCC presented 5 scenarios: most optimistic (SSP1-1.9), next best (SSP1-2.6), middle of the road (SSP2-4.5), dangerous (SSP3-7.0) and avoid at all costs (SSP5-8.5) (see Figure 6.1).

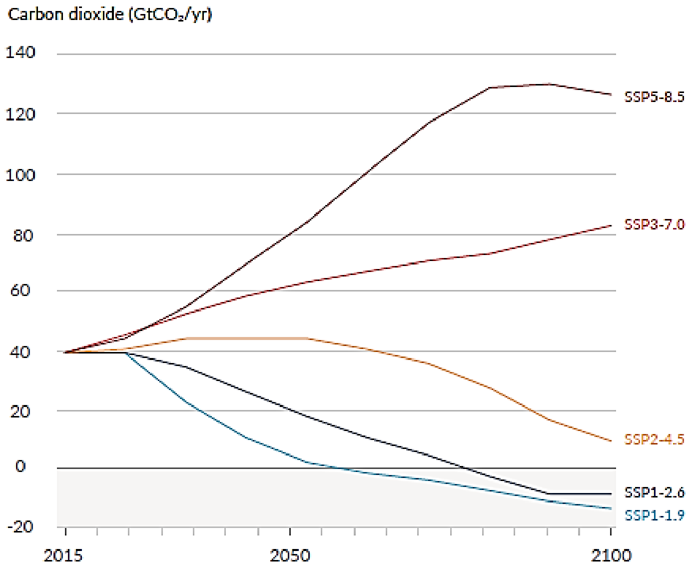


Figure 6.1. Future $CO_2$ emissions in the 5 Scenarios of IPCC
Source: (IPCC, 2022)

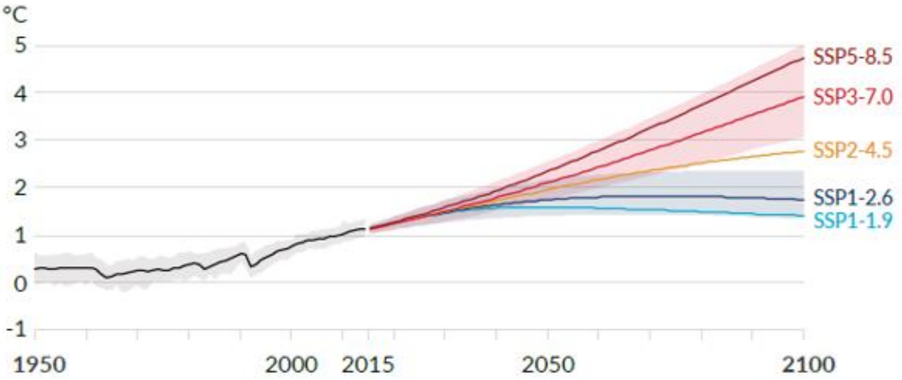


Figure 6.2. Global Surface Temperature Changes Relative to 1850-1900
Source: (IPCC, 2022)

These five scenarios cover a wide range of potential GHG emissions in the future. While in the most optimistic scenario CO2 emissions drop significantly, in the worst-case scenario CO2 emissions increase drastically reaching three time of the current level by 2100 (see Figure 6.1). In the report, mean changes in several climate related variables are also described. For example, depending on the scenario, surface temperature increase is assumed to be ranging from 1.4 °C to 4.5 °C by 2100 (see Figure 6.2).

Scenario 1 is the most optimistic scenario which presumes a world with global emissions that are cut to net zero in 2050. Under this scenario, people tend to switch sustainable lifestyles, health and education investments increase and people take measures to deal with the impacts of climate change. The only scenario that meets the Paris Agreement goal of keeping global warming at 1.5 °C above preindustrial levels is the Scenario 1. The second scenario is the next best scenario where the global warming is projected to be 1.8 °C higher compared to preindustrial levels. In this scenario, there is an intense reduction in global CO2 emissions but not fast enough to reach net zero in 2050.

Scenario 3 is the middle of the road scenario. Under this scenario, shift towards a sustainable lifestyle is slow. This scenario projects a temperature increase of 2.7 °C by the end of the century. Scenario 4 is the dangerous scenario under which 3.6 °C of a temperature increase by 2100 is projected. In the scenario a steady increase of temperature and emissions is expected. CO2 emissions are expected to double from current levels by 2100. The last scenario is the 5th scenario in which a worst-case scenario. Under this scenario, doubling of current CO2 levels is projected until 2050. The global temperature increase is estimated to be around 4.4°C higher.

All these scenarios are possibilities that can happen depending on many factors. Among these factors are government policies, global policies as well as the individual practices. These scenarios provide a potential representation of an unknown future. The use of different scenarios enables analysts to understand the evolution of societies and their potential implications on the climate. It is important to understand that the choices we make today will shape our future.

The scenarios and their impacts discussed above are all described at a global level. Another import feature of the Sixth IPCC Report is that it provides a comprehensive regional analysis of climate change for the first time in the literature. The Report provides important information on risk assessment, adaptation and other aspects of decision makers. The regional information is useful in translating climate related variables into what they actually mean for the society (IPCC, Gutiérrez, et al., 2021). The interactive online atlas provided in the report enables users to explore the differences of climate related variables over time and across regions.

The IPCC Interactive Atlas is a useful mapping tool allowing end users to select among a wide range of datasets for their temporal and spatial analysis. The functional tool incorporates key atmospheric and oceanic variables, extreme events as well as climatic impact drivers. The Atlas consists of two major components: regional information and regional synthesis.

> “Regional information allows users to generate global maps, time series, scatter plots, tables, climate stripes, and more, for observed and projected climate change for time periods, emissions scenarios or global warming levels of interest. Regional synthesis provides qualitative information about changes in climatic impact-drivers. Users can select one or more impact-drivers and visualize the regional historical trends and projected changes across regions” (IPCC, Gutiérrez, et al., 2021).

The IPCC Atlas enables researchers to analyze the dataset they want to focus across more than 25 different climate variables under numerous different climate scenarios and time scales. This thesis utilizes two major variables in this Atlas: mean temperature and total precipitation. As the primary focus of this thesis is Türkiye the selected region is the Mediterannean. More variables, models and scenarios are available in the online Interactive Atlas provided by the IPCC.

Figure 6.3 presents an overview of projected regional changes in precipitation an temperature across different regions of the world. The orange and green color show the prospect for mean precipitation and mean temperature, respectively. For our region of interest, precipitation is expected to increase with low confidence.

Moreover, temperature is expected to increase with high confidence and an upward trend (see Figure 6.3).

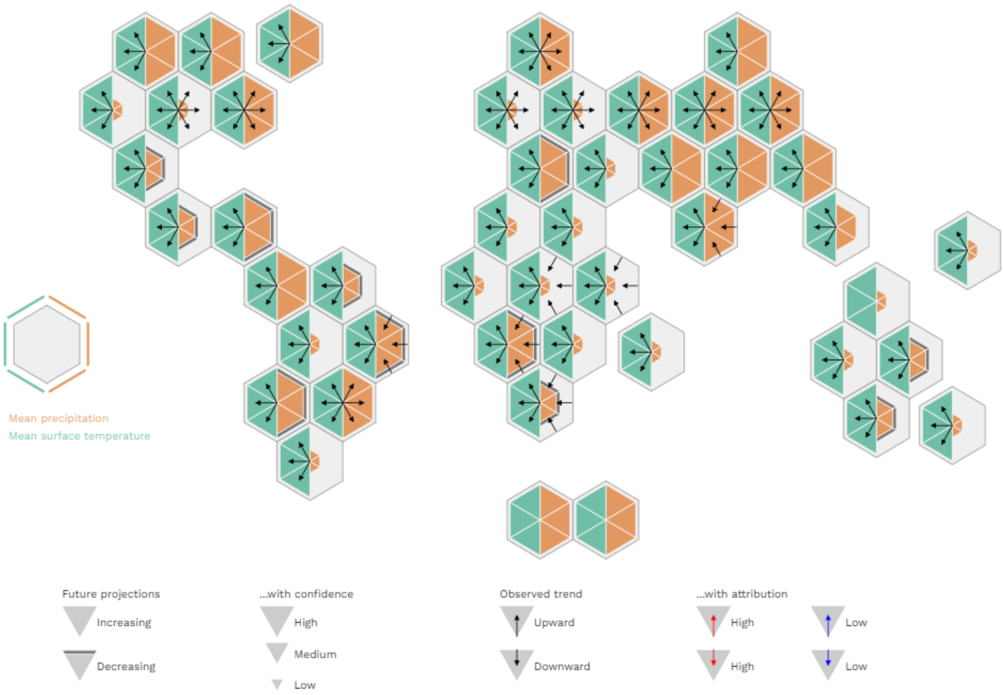


Figure 6.3. Regional Synthesis of Precipitation and Temperature Change
Source: IPCC Interactive Atlas (2021)

The analysis of the thesis is focused on the precipitation and temperature change in Türkiye. Therefore, we elaborate on the temperature and precipitation change in the Mediterranean. To make the analysis more to the point, we selected two different scenarios: High Emissions Scenario (SSP5-8.5) and Low Emissions Scenario (SSP2-4.5). The figures below present the projected precipitation and temperature changes under these two scenarios (see Figure 6.4 and Figure 6.5). Accordingly, a temperature increase is expected in both scenarios with a higher increase in the high emissions scenario. Moreover, the precipitation change is expected to be more significant in the high emissions scenario (see Figure 6.6).

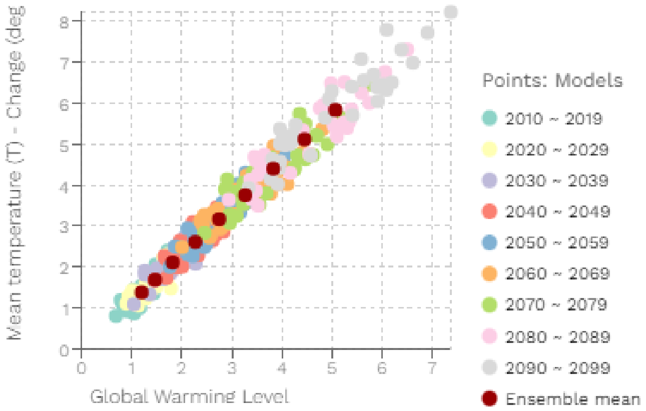


Figure 6.4. Mean Temperature Change (Rel. to 1850-1900, SSP5-8.5)
Source: IPCC Interactive Atlas (2021)

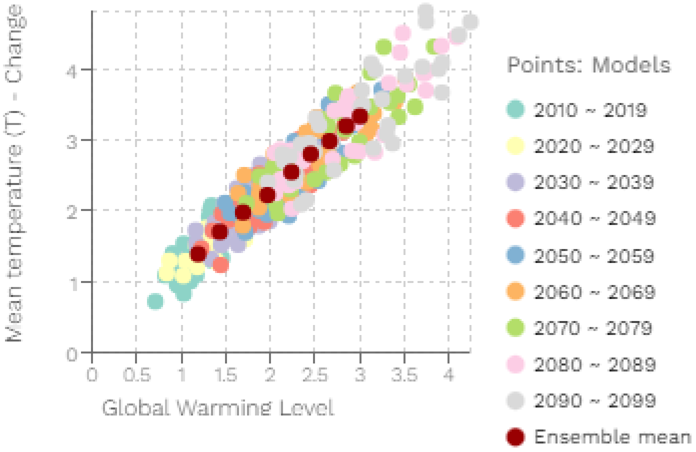


Figure 6.5. Mean Temperature Change (Rel. to 1850-1900, SSP2-4.5)
Source: IPCC Interactive Atlas (2021)

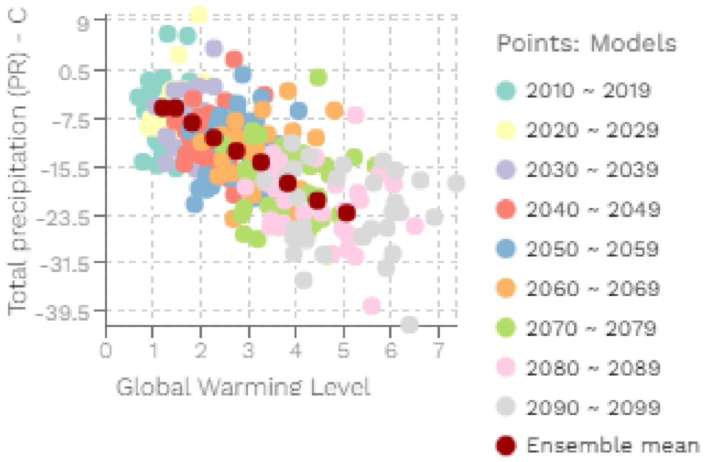


Figure 6.6. Total Precipitation Change (Rel. to 1850-1900, SSP5-8.5)
Source: IPCC Interactive Atlas (2021)

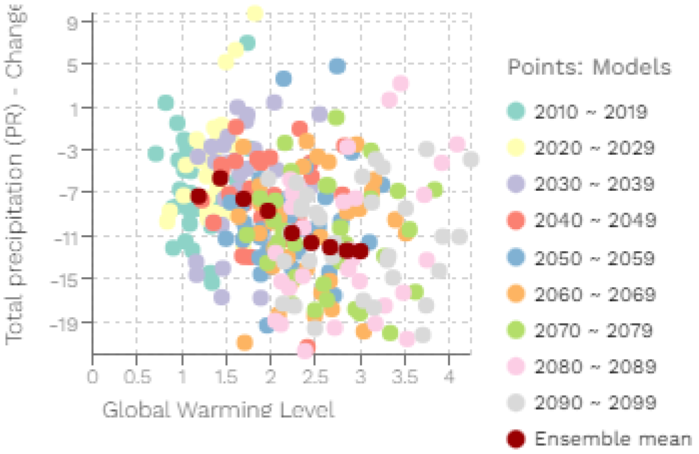


Figure 6.7. Total Precipitation Change (Rel. to 1850-1900, SSP2-4.5)
Source: IPCC Interactive Atlas (2021)

The Interactive Atlas provides information on the Mediterranean, yet, the predicted temperature and precipitation change for Türkiye is not available based on the publicly accessible data. Adding upon the information provided by the IPCC, a novel study by Bağçaci et al. (2021) provides further information on the expected impacts of climate change on Türkiye (Bağçaci et al., 2021).

## 6.3 The Selected Scenarios for Türkiye

In the thesis, a comprehensive study conducted for Türkiye by Bağçaci et al. (2021) is used for climate scenario analysis. In their study, Bağcaci et al (2021) consider the IPCC Assessment Report (AR6) with baseline 1995–2014. According to IPCC projections, temperature and precipitation for the short (2030–2050), medium (2050–2070) and long-term (2070–2100) for Türkiye were estimated. This study is crucial for the thesis as it provides regional projections for each season over different time scales. Moreover, it differentiates between two climate scenarios: low emissions scenario (SSP2-.5) and high emissions scenario (SSP5-8.5).

The selected scenarios and projected precipitation and temperature changes are discussed under Chapter 4.1.4. While Table 4.9 presents projected precipitation changes under HES, Table 4.10 presents the results for LES. Similarly, Table 4.11 and Table 4.12 provide the projected estimation results for temperature change for different regions, seasons as well as climate scenarios.

According to Bağçaci et al (2021), the most significant precipitation reduction is expected in summer and autumn under both SSP2–4.5 and SSP5–8.5 scenarios. Under HES, in the short and medium-term an increase in precipitation is expected in the Marmara, Black Sea and Eastern Anatolia regions. The impact decreases over the long-term. Moreover, the impacts are more significant over the long term. Precipitation in winter is expected to increase under both scenarios. Winter and spring precipitation follow a similar pattern with changes in the high emissions scenario (SSP5–8.5) expected to become more significant (see Table 4.9).

Anomalies in spring precipitation is significant across all regions of Turkey except northeastern and eastern parts of the country. While the anomalies in the spring precipitation is not expected in the long term, in the near and medium term a significant reduction in precipitation is expected across Central Anatolia and Mediterranean regions under optimistic scenario (see Table 4.10).

Results in precipitation vary depending on the scenario and the season. However, unlike precipitation, temperature projections are all positive regardless of the scenario (see Table 4.11 and Table 4.12). According to the results, Southeast Anatolia is the most vulnerable region to autumn temperature increase based on the low emissions scenario. This may indicate that drying in the region might occur even without changes in the precipitation pattern.

Under the high emissions scenario, most of the regions will be affected from negative impacts of climate change. Temperature is expected to increase in winter reaching 2.5–4.5◦C increase in Eastern parts of the country according to both of the scenarios in the long-term (see Table 4.11 and Table 4.12). Temperature increase in spring impact mostly southern and eastern parts of the country (see Table 4.11 and Table 4.12). It is important to mention that long term spring temperature changes will be mostly prominent in the Mediterranean and Aegean regions. Moreover, summer temperature increases will be felt in these regions. Temperature increases across seasons and regions indicate that hot extremes will be more frequently observed in the country.

## 6.4 Interpretation

In Chapter 5, we estimated econometric models to analyze the impacts of a change in temperature and precipitation on crop production. The chapter answered the question “how a 1% percentage change in temperature and precipitation across different seasons impact production of wheat, barley, corn, rice and sunflower”. In this Chapter, we provided estimations on how much that “1%” actually be depending on different seasons, regions, scenarios and time.

It is now time to bring together the results of the model estimations calculated in Chapter 5 with the projected temperature and precipitation changes for Türkiye under high and low emissions scenario presented by Bağçaci et al. (2021) based on IPCC calculations. The combined results will be discussed for two different scenarios across different seasons and time periods. Moreover, the results will be provided for each of the crop separately.

These chapters are the most critical parts of the thesis as it sets forth a concrete estimation results for the expected changes in the crop production depending on pessimistic and optimistic scenario. In he next chapters, results for HES and LES would be discussed separately for clarity purposes.

### 6.4.1 High Emissions Scenario (HES)

The high emissions scenario is the pessimistic scenario which estimates doubling of current emission levels by 2050. The next two subchapter combines the analysis of Chapter 5 with the projected temperature and precipitation changes presented in Table 4.9 and Table 4.11 for HES.

#### 6.4.1.1 Impact of Projected Temperature Change under HES

Table 6.1 and Table 6.2 present the impact of forecasted changes in temperature on production of wheat, barley, rice, corn and sunflower. The two tables below combine the estimated coefficients of Table 5.1 for wheat, Table 5.3 for barley, Table 5.5 for rice, Table 5.7 for corn and Table 5.9 for sunflower.

According to Table 6.1, projected temperate increase in spring under high emissions scenario translates into a 6.5%, 13.6% and 21.9% reduction in wheat production in the short, medium and long term, respectively. The temperature increase in summer is expected to decrease wheat and barley production more significantly across different periods of time.

Table 6.1. Estimated Impact of Temperature Change on Wheat and Barley Production under the High Emissions Scenario (%) (SSP5-8.5)

| | | **Projected Temperature Increase (°C)*** | **Historical Average Temperature (1995-2014) (°C)**** | **Projected Change (%)** | **Wheat***** | **Estimated Impact (%)** | **Barley***** | **Estimated Impact (%)** |
|---|---|---|---|---|---|---|---|---|
| **2030-2050** | **Spring** | 1.1 | 11.8 | 9.3 | -0.7 | -6.5 | -0.1 | -0.9 |
| | **Summer** | 1.9 | 23.5 | 8.1 | -1.8 | -14.6 | -1.6 | -12.9 |
| **2050-2070** | **Spring** | 2.3 | 11.8 | 19.5 | -0.7 | -13.6 | -0.1 | -1.9 |
| | **Summer** | 3.3 | 23.5 | 14.0 | -1.8 | -25.3 | -1.6 | -22.5 |
| **2070-2100** | **Spring** | 3.7 | 11.8 | 31.4 | -0.7 | -21.9 | -0.1 | -3.1 |
| | **Summer** | 5.5 | 23.5 | 23.4 | -1.8 | -42.1 | -1.6 | -37.4 |

* (Bağçaci et al., 2021)
**Turkish State Meteorological Service
***Based on writer’s calculations

For corn, rice and sunflower, the calculated impact of a temperature increase during spring months is positive, while in summer it is negative. In the short-term under high emissions scenario, corn production is expected to decrease by 14.6% with temperature increase during summer. This number is higher for rice production.

Table 6.2. Estimated Impact of Temperature Change on Corn, Rice and Sunflower Production under the High Emissions Scenario (%) (SSP5-8.5)

| | | Temp Increase (°C)* | Historical Avg Temp (°C)** | Projected Change (%) | Corn *** | Impact (%) | Rice*** | Impact | Sunflower *** | Impact (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| **2030-2050** | **Spring** | 1.1 | 11.8 | 9.3 | 0.9 | 8.4 | 0.3 | 2.8 | 0.7 | 6.5 |
| | **Summer** | 1.9 | 23.5 | 8.1 | -1.8 | -14.6 | -1.2 | -9.7 | -3.6 | -29.1 |
| **2050-2070** | **Spring** | 2.3 | 11.8 | 19.5 | 0.9 | 17.5 | 0.3 | 5.8 | 0.7 | 13.6 |
| | **Summer** | 3.3 | 23.5 | 14.0 | -1.8 | -25.3 | -1.2 | -16.9 | -3.6 | -50.6 |
| **2070-2100** | **Spring** | 3.7 | 11.8 | 31.4 | 0.9 | 28.2 | 0.3 | 9.4 | 0.7 | 21.9 |
| | **Summer** | 5.5 | 23.5 | 23.4 | -1.8 | -42.1 | -1.2 | -28.1 | -3.6 | -84.3 |

* (Bağçaci et al., 2021)
** Turkish State Meteorological Service
***Based on writer's calculations

### 6.4.1.2 Impact of Projected Precipitation Change under HES

The impact of precipitation change is expected to be lower for both wheat and barley compared to the impact of a temperature change. While change in spring precipitation is expected to increase production, increase in summer precipitation causes a decline (see Table 6.3).

Table 6.3. Estimated Impact of Precipitation Change on Wheat and Barley Production under the High Emissions Scenario (%) (SSP5-8.5)

| | | **Projected Precipitation Change (°C)*** | **Historical Average Precipitation (1995-2014) (°C)**** | **Projected Change (%)** | **Wheat***** | **Estimated Impact (%)** | **Barley***** | **Estimated Impact (%)** |
|---|---|---|---|---|---|---|---|---|
| **2030-2050** | **Spring** | -1.6 | 3.8 | -42.1 | 0.09 | -3.7 | 0.05 | -2.2 |
| | **Summer** | -6.8 | 2.9 | -234.5 | -0.04 | 8.7 | -0.02 | 4.5 |
| **2050-2070** | **Spring** | 1.0 | 3.8 | 26.3 | 0.09 | 2.3 | 0.05 | 1.4 |
| | **Summer** | -13.1 | 2.9 | -451.7 | -0.04 | 16.8 | -0.02 | 8.8 |
| **2070-2100** | **Spring** | -11.4 | 3.8 | -300.0 | 0.09 | -26.1 | 0.05 | -15.5 |
| | **Summer** | -15.7 | 2.9 | -541.4 | -0.04 | 20.1 | -0.02 | 10.5 |

* (Bağçaci et al., 2021)
** Turkish State Meteorological Service
***Based on writer's calculations

### 6.4.2 Low Emissions Scenario (LES)

Under the low emissions scenario, shift towards a sustainable lifestyle is still slow. A temperature increase of 2.7°C is expected which was 4.4°C under the high emissions scenario. The results for this more optimistic scenario are presented in the next subchapters.

#### 6.4.2.1 Impact of Projected Temperature Change under LES

Similar to tables presented for high emissions scenario, Table 6.4, Table 6.5 and Table 6.6 present the estimated results for low emission scenario. While the estimated impacts are smaller in magnitude compared to the pessimistic scenario, the signs are the same.

According to Table 6.4, a reduction of 5.3%, 8.9% and 11.9% in wheat production is estimated for a temperature change in spring in the short, medium and long term.

These numbers are smaller for barley production. The impact of temperature change in summer is estimated to be larger. 21.4% reduction in wheat production is expected in the long run for a projected temperature change under the low emissions scenario.

Table 6.4. Estimated Impact of Temperature Change on Wheat and Barley Production under the Low Emissions Scenario (%) (SSP2-.5)

| | | **Projected Temperature Increase (°C)*** | **Historical Average Temperature (1995-2014) (°C)**** | **Projected Change (%)** | **Wheat***** | **Estimated Impact (%)** | **Barley***** | **Estimated Impact (%)** |
|---|---|---|---|---|---|---|---|---|
| **2030-2050** | **Spring** | 0.9 | 11.8 | 7.6 | -0.7 | -5.3 | -0.1 | -0.8 |
| | **Summer** | 1.7 | 23.5 | 7.2 | -1.8 | -13.0 | -1.6 | -11.6 |
| **2050-2070** | **Spring** | 1.5 | 11.8 | 12.7 | -0.7 | -8.9 | -0.1 | -1.3 |
| | **Summer** | 2.1 | 23.5 | 8.9 | -1.8 | -16.1 | -1.6 | -14.3 |
| **2070-2100** | **Spring** | 2.0 | 11.8 | 16.9 | -0.7 | -11.9 | -0.1 | -1.7 |
| | **Summer** | 2.8 | 23.5 | 11.9 | -1.8 | -21.4 | -1.6 | -19.1 |

* (Bağçaci et al., 2021)
** Turkish State Meteorological Service
***Based on writer’s calculations

Corn, rice and sunflower production is expected to increase with the forecasted change in spring months. However, the impact is expected to be negative for summer months. Moreover, the impact on sunflower is the largest compared to corn and rice (see Table 6.5).

Table 6.5. Estimated Impact of Temperature Change on Corn, Rice and Sunflower Production under the Low Emissions Scenario (%) (SSP2-.5)

| | | **Temp Increase (°C)*** | **Historical Average Temp (1995-2014) (°C)**** | **Projected Change (%)** | **Corn***** | **Impact (%)** | **Rice***** | **Impact** | **Sunflower***** | **Impact (%)** |
|---|---|---|---|---|---|---|---|---|---|---|
| **2030-2050** | **Spring** | 0.9 | 11.8 | 7.6 | 0.9 | 6.9 | 0.3 | 2.3 | 0.7 | 5.3 |
| | **Summer** | 1.7 | 23.5 | 7.2 | -1.8 | -13.0 | -1.2 | -8.7 | -3.6 | -26.0 |
| **2050-2070** | **Spring** | 1.5 | 11.8 | 12.7 | 0.9 | 11.4 | 0.3 | 3.8 | 0.7 | 8.9 |
| | **Summer** | 2.1 | 23.5 | 8.9 | -1.8 | -16.1 | -1.2 | -10.7 | -3.6 | -32.2 |
| **2070-2100** | **Spring** | 2.0 | 11.8 | 16.9 | 0.9 | 15.3 | 0.3 | 5.1 | 0.7 | 11.9 |
| | **Summer** | 2.8 | 23.5 | 11.9 | -1.8 | -21.4 | -1.2 | -14.3 | -3.6 | -42.9 |

* (Bağçaci et al., 2021)
** Turkish State Meteorological Service
***Based on writer's calculations

### 6.4.2.2 Impact of Projected Precipitation Change under LES

Precipitation changes in spring impacts wheat and barley production negatively. Unlike spring, the impact of expected precipitation change in summer months is estimated to be positive. For example, a decline in projected precipitation change during spring months is expected to decrease wheat production by 8.3% in the midterm, while the change increases wheat production in summer months (see Table 6.6).

Table 6.6. Estimated Impact of Precipitation Change on Wheat and Barley Production under the Low Emissions Scenario (%) (SSP2-.5)

| | | Projected Precipitation Change (°C)* | Historical Average Precipitation (1995-2014) (°C)** | Projected Change (%) | Wheat*** | Estimated Impact (%) | Barley*** | Estimated Impact (%) |
|---|---|---|---|---|---|---|---|---|
| **2030-2050** | **Spring** | -3.6 | 3.8 | -42.1 | 0.1 | -8.3 | 0.1 | -4.9 |
| | **Summer** | -9.0 | 2.9 | -234.5 | 0.0 | 11.5 | 0.0 | 6.0 |
| **2050-2070** | **Spring** | -6.0 | 3.8 | 26.3 | 0.1 | -13.8 | 0.1 | -8.1 |
| | **Summer** | -14.2 | 2.9 | -451.7 | 0.0 | 18.2 | 0.0 | 9.5 |
| **2070-2100** | **Spring** | 0.0 | 3.8 | -300.0 | 0.1 | 0.2 | 0.1 | 0.1 |
| | **Summer** | -23.7 | 2.9 | -541.4 | 0.0 | 30.4 | 0.0 | 15.9 |

* (Bağçaci et al., 2021)
** Turkish State Meteorological Service
***Based on writer's calculations

The combined results of the analysis presented in Chapter 5 and the climate scenarios discussed in this chapter clearly lays out the significant changes in crop production due to changes in climate related variables. The next chapter provides a summary of the results and concludes the thesis.

# CHAPTER 7

# MITIGATION AND ADAPTATION

## 7.1 Introduction

Developing adaptation strategies and finding potential solutions are critical to decrease the adverse effects of climate change on agricultural production. To mitigate and adapt the potential impacts of climate change, it is important to forecast the global and regional changes in climate related variables as well as estimating the impact on agricultural production.

In Chapter 5 we estimated econometric models to calculate the impact of temperature and precipitation change on crop production. In Chapter 6, we combined the results with several climate change scenarios to provide possible outcomes for the future. These two chapters confirm and support the literature by putting forth the negative impact of climate change on crop production in Türkiye. Laying out the impact, it is also important to discuss the adaptation strategies. Although the focal point of this thesis is not generating adaptation policies, this chapter mentions several potential policies for discussion purposes.

Developing adequate and appropriate policies is not an easy task for policymakers. It has been long debated that agriculture should play a significant role in the international climate change negotiations. In this regard, The Koronivia Joint Work on Agriculture (KJWA) is critical in terms of the role of agriculture in climate change debate. KJWA, adopted in COP23 in 2017, recognized and increased the significance of the interrelation between climate change and agriculture. Following the adoption of this decision, agriculture was included in Nationally Determined Contributions of 90% of the signatory countries of the Paris Agreement. Moreover, the European Union published the European Green Deal in 2019 and approved the Deal in 2020.

The Deal aims the EU to become the first “climate-neutral” bloc in the world by 2050 (European Comission, 2020). Common Agricultural Policy (CAP) which was initiated in 1962 is also important in setting the standards for European agricultural system (European Commission, 2021). Although the roots of CAP dates back 60 years ago, the agreement on the reform of the CAP was adopted in December 2021. The new version of the CAP for 2023-27 will be essential in achieving the objectives of the European Green Deal (European Commission, 2021).

Moreover, Food security is critical in meeting the Sustainable Development Goals (SDGs). The second goal (SDG2) to “End hunger, achieve food security and improved nutrition and promote sustainable agriculture” clearly states that transforming the food and agriculture is required to achieve the SDGs (United Nations Department of Economic and Social Affairs, 2020). “Without action, the changing climate will affect food availability and hinder access to food by disrupting the livelihoods of millions of rural people. It will expose urban and rural poor to higher and more volatile food prices. It will cause forced migration and jeopardize the SDGs. Delivering on country commitments to transform food systems and promote sustainable agriculture can still create a world without hunger and malnutrition by 2030. But we must work urgently to transform agriculture through inclusive, multisectoral approaches that reduce greenhouse gas emissions and build resilience and adaptive capability” (FAO et al., 2016). To meet SDGs, agricultural systems need to be reformed to increase efficiency and productivity.

In line with the targets set by the international agreements and reaching SDGs, there are several approaches discussed in the literature to address the problems linking climate change and agriculture (see Figure 7.1). Possible adaptation and mitigation strategies for achieving improved crop yields to combat the impacts of climate change are further discussed in the next subchapters.

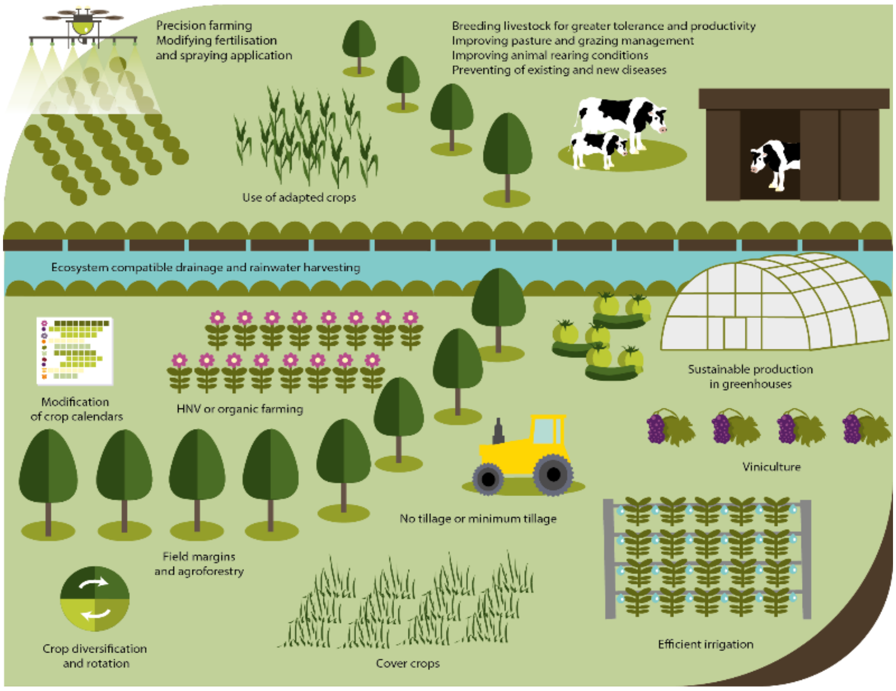


Figure 7.1. Climate Change and Adaptation in Agriculture
Source: (EEA, 2019)

## 7.2 Adaptation Strategies

### 7.2.1 Climate Smart Agriculture

One of the major approaches to deal with the negative impacts of climate change on agriculture is climate-smart agriculture (CSA). CSA is an integrated approach that addresses the challenges associated with climate change and food security. CSA has 3 main goals to achieve; increasing productivity, enhancing resilience and reducing emissions. CSA practice is context based. Depending on the socioeconomic, climatic and economic factors of a region or a country CSA implements different systems. In this regard, it follows the Paris Agreement and Sustainable Development Goals (SDGs). CSA also supports the Food and Agriculture Organization's (FAO) Strategic Framework of 2022-2031. The World Bank Group (WBG) supports CSA in several ways. In their Climate Action Plan 2021-2025WB clearly mentions that they will support through policy and technological interventions working with public and private sector partners (World Bank Group, 2021a). Among many others, some of the examples are as follows:

- In China through new technological investment on 44,000 hectares of area to increase water use efficiency, production of rice and maize increased by 12% and 9%, respectively.
- An Agricultural Information and Decision Support System was established in Uruguay to prepare plans for better soil management (World Bank Group, 2021b).

CSA practices vary depending on the unique case. The solutions may focus on reducing emissions related to livestock production, keeping carbon stored in the soil, diversifying farming systems through agroforestry or mixed farming and exchanging knowledge of better practice applications (see Figure 7.2). The highlighted solutions using CSA practices would address local challenges and help to build more resilient farming.

Figure 7.2. Solutions for Resilient Farming and Forestry
Source: (EIP-AGRI, 2021)

### 7.2.2 Irrigation Efficiency and Rainwater Harvesting

One of the major consequences of climate change is decrease or shift in precipitation patterns. “The world’s crops require 2.7 trillion cubic meters of water a year, but countries around the world are struggling to find enough. As climate change makes extreme weather more common, an urgent search has begun to find ways to meet the growing water challenge." (Ro, 2021). Irrigation is very critical especially for vegetation of major crops. Therefore, providing stable irrigation during the growth of a plant is critical for agricultural production. In this regard, improved irrigation systems like drip or tape irrigation enables farmers to access required water when there is water scarcity.

Another mechanism to increase available water is to collect rainfalls especially in drought prone areas. Storing the irrigation when precipitation is available and using it when there is no precipitation is also offered as a solution. However, this method is subject to criticism mainly due to its potential effects on groundwater system.

### 7.2.3 Cover Crops and No-Tillage Farming

Climate change is expected to cause increased number of soil erosion across different parts of the globe. Planting cover crops when there is no harvesting is found to be a potential solution to deal with soil erosion and loss of water due to climate change. Cover crops can also serve as a type of fertilizer to the soil and help for the better growth of the plant.

Another method to decrease soil erosion is no-tillage farming. It is a farm management practice where the soil is partially disturbed or not disturbed at all. Tillage is a commonly used method in today's farming, yet, for some specific cases using no-tillage farming can provide benefits in the yield of crops. Especially in dry soils and farms with a slope, no-till farming decreases the amount of erosion. Moreover, it increases the amount of water going under the soil and increase the nutrition cycle required for crop growth. South America has the most adoption of no-till farming. In Argentina, no-till faming constitutes 80% of total farming and estimated to reduce 80% of total soil erosion (Gianessi, 2014). In Brazil, soil erosion was decreased 97% by the use of no-till farming (Bolliger et al., 2006).

### 7.2.4 Breeding

Climate change causes rising temperatures which negatively impact yield of major crops that form the basis of our food system. Maintaining a certain temperature during the growth of crop production is critical for most of the crop types. High heat during the heading and flowering of the crop can reduce pollen viability and in turn decrease the yields. As both the world population and temperature are increasing, more staple crops mainly wheat, barley and rice that are better able to cope with more heat and less precipitation is required. Traditionally, breeding is used to increase crop yields rather than increasing their tolerance levels to increased temperature and droughts. However, due to climate change, there is a growing need to breed new crop types which are more tolerant to extreme heat and droughts.

There have been many studies on exploiting existing genetic variability to develop new type of more tolerant varieties of crops. For example, an EU project called DROPS (Drought-tolerant yielding plants) has investigated new approaches to improve yield for crops which are being exposed to extreme weather events. They modelled crop performance for wheat and maize across different environment scenarios based on different climatic conditions. Their study enabled to differentiate between genes based on their climate sensitivity. The Project enabled identification and providing a set of combination of genes which provide better yields under more heat and less precipitation across different regions of Europe (Cordis, 2016). Similar applications can be found for different countries. Developing and planting more resistant crops can play a critical role in combatting the negative impacts of climate change on agriculture.

### 7.2.5 Precision Farming

Another method that is commonly used to combat the impacts of climate change on crop production is precision farming. Precision agriculture is a method in which through drone observations, satellite data and online solutions, ideal farming areas for the exact product is determined. More optimal production can be planned which decreases the losses associated with climate change.

The practice has started by the development of GPS and with the enhancement in the drone technology it has been widely used (see Figure 7.3). As its name suggests, this method enables the use of exact amount of inputs such as water, fertilizer etc. required for the growth of the crop at the required time. Precision farming reduces the amount of crop inputs while increasing the yields (Pepitone, 2016). While the method itself requires an investment, farmers can benefit through saving on input costs. Use of less input also brings environmental benefits since using the right amount of chemical for crop growth, benefits the entire crop cycle. Therefore, precision farming is critical for sustainable agriculture.

Use of smartphone applications are also important in the use of precision farming. Smartphones are already equipped with camera, microphone and GPS. There are certain applications created to measure weather and crop information and more. Through the use of these applications, precision farming can be more commonly and easily implemented in the future (see Figure 7.3).

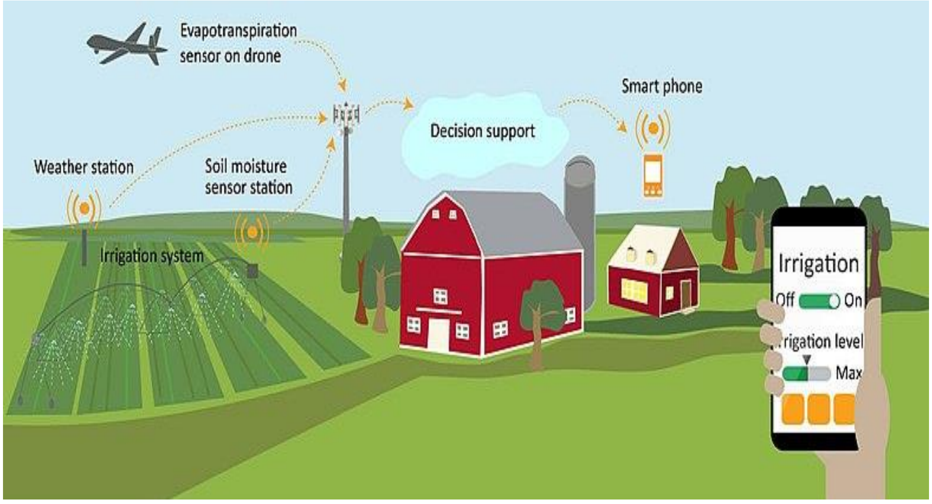


Figure 7.3. A Possible Configuration of a Smartphone-Integrated Precision Agriculture System
Source: (US GAO, 2019)

### 7.2.6 Agri-PV Systems

One of the major consequences of climate change on agriculture is decrease in arable land. In this regard, agricultural land is getting more valuable. Agrivoltaics comes as a solution to use land more efficiently. This system integrates the use of land for agriculture and energy simultaneously (see Figure 7.4).

This method provides efficient use of soil and provides benefits for crop growth as well. While the panels cause additional shading, it also increases the humidity which turns out to be a positive factor for major crop growth. “This dual approach of harvesting energy and food together in a given land area can maximize the land productivity with additional synergistic benefits including reduced water budget, improved crop yield, agricultural land preservation, and, socio-economic welfare of farmer” (Riaz et al., 2021). Moreover, “Agrivoltaics can be leveraged to enable crop resilience against the increasing climate change vulnerabilities, such as the excessive heat stress and drought, in particular for hot and arid climates” (Elamri et al., 2018)

Figure 7.4. A Demonstration of an Agri-PV System
Source: (Engie, 2022)

### 7.2.7 Using Agroforestry Systems

Agroforestry rises as a method to combat the negative impacts of climate change on agricultural production. It is a comprehensive land management system which requires planned mixing of forests, shrubs as well as crops. While trees around the crops produce a range of useful goods, they also contribute to the growth of the nearby crops and increase overall yields.

Using agroforestry systems provide social, environmental and economical interactions between different components. In particular, agroforestry is important to rural areas and in particular smaller farmers. Agroforestry systems increases their food supply, income as well as health (see Figure 7.5).

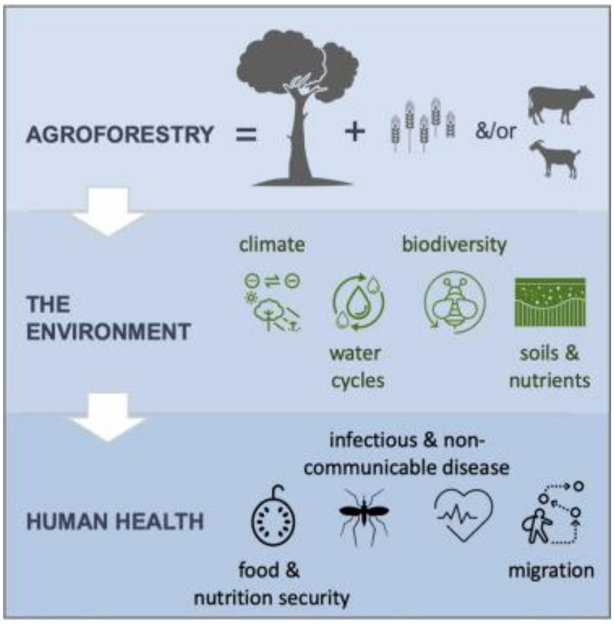


Figure 7.5. Representation of Agroforestry Systems
Source: (Rosenstock et al., 2019)

There are numerous methods used as agricultural adaptation strategies throughout the history. The adaptation strategies vary depending on the plant type, the region as well as the culture. More recently, technological developments have played significant role in combatting the negative impacts of climate change on agriculture. It is critical to consider the policy suggestions discussed above due to several reasons:

- For the past decades, GHG emissions have already surpassed 0.1°C per decade. Therefore, it is already inevitable to take some adaptation measures.
- GHG emissions continue to increase at a rate higher than the IPCC scenarios. If this pace continues to increase then faster and more proactive measures will be required.
- Although emission reduction targets are set at the Paris Agreement, the realizations fall behind the commitments. This causes uncertainty about the future of emissions and requires early adaptation measures.
- Increasing temperature might have unexpected nonlinear and exponentially increasing negative impacts on agricultural practices. It is important to avoid this possibility by taking early measures.

The agricultural practices vary across different countries due to different climatic conditions, cultural, economic as well as institutional factors. That is why it is not possible to propose a one solution fits all model, yet, each country should consider its unique circumstances and take necessary adaptation and mitigation measures accordingly.

## 7.3 Adaptation Strategies for Türkiye

### 7.3.1 Legal Framework

In Türkiye, international agreements, national legislative framework, strategic plan documents and action plans form the baseline of the adaptation and mitigation strategies of the government. Turkey has been a part of the UNFCCC since 2004. Since then, there have been numerous documents related to combatting the negative impacts of climate change climate change strategies. The main documents are listed below:

- 11th Development Plan 2019-2023,
- The Medium-Term Program 2022-2024,
- Turkey's National Climate Change Adaptation Strategy and Action Plan 2011-2023,
- Republic of Turkey Climate Change Strategy 2010-2023,
- Strategic Plan of Ministry of Food Agriculture and Livestock 2018-2022,
- National Rural Development Strategy 2021-2023

All of the strategy papers mentioned above has one thing in common which is the urgency of tackling with negative impacts of climate change. The National Vision in Climate Change Action Plan is defined as follows:

> "Turkey's national vision within the scope of "climate change" is to become a country fully integrating climate change-related objectives into its development policies, disseminating energy efficiency, increasing the use of clean and renewable energy resources, actively participating in the efforts for tackling climate change within its "special circumstances", and providing its citizens with a high quality of life and welfare with low-carbon intensity." (Ministry of Environment and Urbanization, 2012a)

In addition to dealing with the negative impacts of climate change, the strategy papers also prioritize sustainable agricultural production.

In line with these targets Turkey has been a signatory to the Paris Climate Accords since 2016. In 2021, Türkiye ratified the agreement and committed to net zero emissions by 2053. The country has submitted its Intended Nationally Determined Contribution (INDC) in 2015. The long-term strategies and action plans to increase adaptation and mitigation of emissions is yet to be prepared.

### 7.3.2 Agricultural Strategies towards Adaptation

Agricultural policies mentioned under the strategy and action papers listed in the previous subsection concentrate mainly on capacity building and conservation of resources. In addition, the development and efficient use of advanced technologies to preserve water, land, seeds, fertilizers and pesticides is mentioned. In line with these policies, developing required programs and institutional arrangements remains to be critical.

Being located in the Mediterranean basin, Türkiye is prone to droughts. In this regard, “Agricultural Drought Management Board” has been established. According to the decisions of this Board an early warning, monitoring and forecasting system is to be established. Moreover, as a long-term project, increasing capacity of the agricultural system to adapt to drier conditions is at the center of this Board.

R&D investments are critical to establish long term policies. The government needs to prioritize R&D projects on adapting to climate change is important. Breeding and agronomy projects need to be integrated into Integrated Crop Management Programmes. Moreover, drought management tools supported by fertilizer and disease management are required to be set.

Farmer integration is among the most critical elements of the adaptation strategies. There are numerous programmes developed to promote agricultural practices which would enable agricultural production to adapt the negative impacts of climate change. Main areas that these programmes would support mentioned below:

- “use of certified quality seeds,
- unexpected severe droughts and other disasters,
- protection of land and water resources,
- use of alternative energy sources,
- organic agriculture,
- conservation and rehabilitation of pastures,
- utilization of soil and water analysis services

- investments for o advanced irrigation tools,
- reduced tillage practices,
- agricultural insurance schemes." (Dusunceli et al., 2010)

"Agro-Ecological Zones and Land Use Planning" is also important for adaptation policies.

> "The agro-ecological zoning approach aims at answering questions about land and climate related zonation of an area. Depending on the available data and resolution the area size can be on the scale of a single mountain side or the whole globe. The aim is to identify the potential use the zones in this area can be put to. Focusing on agriculture and natural resources, questions center around crop suitability or other natural resource-based land uses, best management practices, and potential yields." (FAO, 2021)

This methodology was developed in 1970. With the technological developments, computer modelling and availability of data, the methodology has become a widespread use. There are several studies focusing on the agro ecological zones of Türkiye, yet, this area needs to be strengthened for better planning of crop production and adaptation.

> "Climate change will lead to shifts in water cycle and temperatures; and to seasonal alterations. These changes will inevitably have direct impacts on the agriculture sector that is directly linked to and controlled by these systems. As a result of changes in temperature and precipitation patterns, impacted area from agricultural pests will expand and number of species concerned will increase. Climate change will affect production, production sites and stockbreeding activities. The volume and frequency of these changes as well as the possibility of increased occurrence will lead to a higher risk of reduction in agricultural yield. All these are directly related to food safety. Impact of climate change on agriculture sector is pivotal for food safety because in Turkey agriculture is the priority sector for socio-economic reasons and it is where the population's food supply mostly comes from. As

> a result of impacts of climate change, amount of water for agriculture will diminish, quality of water will decrease, biodiversity and ecosystem services will be lost, sustainable agricultural production patterns will change, pastures will degrade, stockbreeding activities will be affected and farmers will find themselves incapacitated in terms of adaptation to climate change; and all these will eventually risk food security. Climate change in Turkey is expected to lead to increasingly negative impacts on water and soil resources and rural development that are vital for food production and food safety" (Ministry of Environment and Urbanization, 2012b)

Therefore, developing mitigation and adaptation strategies to combat the negative impacts of climate change is highly critical especially for developing countries like Türkiye. So far, important action plans and strategy papers were prepared; critical investment projects were completed. However, there is still major work to be done to create better mitigation adaptation strategies and implement them with the changing needs.

# CHAPTER 8

# CONCLUSION

## 8.1 Background

It is a fact that climate change has severe negative impacts on agricultural production. Higher temperatures and less precipitation eventually lead to reduction in production. Agricultural production is facing a challenge to keep up the demand as the impact of climate change gets more severe. According to a report by FAO published in 2020, 8.9% of the world population are hungry, higher than 60 million people from 5 years ago (FAO, 2020). This numbers would get more dramatic as we need to produce 70% more food by 2050 globally. Among other reasons, climate change worsens this debate.

The negative impacts of climate change are already being felt with an increasing pace. Temperatures increase, the occurrence of extreme weather events increase, weather variability increase, precipitation changes and so on. From a production point of view, crop yields as well as their nutritional quality are decreasing due to climate change. This reduction requires a significant amount of investment in order to sustain the current yields and meet the increasing demand.

The negative impact of climate change on agricultural production has reached a global consensus in the literature. It is shown that the impacts are being felt more in the more vulnerable regions like Türkiye. Türkiye is located in an arid and semi-arid region where the effects of changes in temperature and precipitation is forecasted to be high. Moreover, the economy of the country is heavily reliant on agricultural production. Therefore, it is important to analyze the impacts of climate related variables on agricultural production, mainly crop production, in Türkiye.

## 8.2 Research Question

This thesis aims to fill an important gap in the literature by focusing on the effects of climate change on selected major crop production in Türkiye. The existing literature is mainly on developed countries. Developing countries have attracted less attention in the literature. This thesis extends the literature by adding a comprehensive study on a developing country with high reliance on agriculture.

Most of the studies in the literature focus on the impacts of climate change on wheat production. There are only a few studies including rice in their analysis. However, other major staple crops constituting a significant amount of crop production in Türkiye are missing. Firstly, this thesis takes a comprehensive approach and includes five major staple crops produced in the country, namely, wheat, barley, corn, rice and sunflower. In total, these crops constitute almost 90% of total crop production of the country.

Secondly, the thesis incorporates the regional differences across different parts of Türkiye. Depending on where the crop is majorly grown, the data used in the study is narrowed to that region.  For instance, the wheat production is concentrated in the Central Anatolia and Southeastern part of the country. The analysis is conducted for these regions considering the weather patterns in those regions.

Existing literature mostly uses crop models based on climate simulation models. Economic analysis is not commonly conducted, yet, becoming increasingly popular. In recent studies, econometric models are commonly performed to estimate the impact of climate-related variables on agricultural production. Although economic studies are rising in the literature, the literature falls behind in Türkiye. There are only a couple of studies adopting Ricardian approach to perform an economic analysis but the number of studies using panel data is very limited. This thesis adopts panel data approach to estimate the impact of climate-related variables on crop production in Türkiye.

Combining the results of climate models with econometric models is lacking in the literature. This study adds on its econometric model by integrating existing work on climate predictions. The study firstly estimates the impact of changes in temperature and precipitation on crop production. As a second step, the results are further extended conducting a static analysis. The predictions of climate models in the existing literature for Türkiye are used to make a static analysis on how crop production will be impacted in the future based on different climate scenarios.

Another novel part of this thesis is the data and the model used in the analysis. As far as to our knowledge, the data of this thesis is the most comprehensive so far in the existing literature. This data is critical since it enables to use panel data approach with many control variables.

## 8.3 Findings

The thesis has important findings regarding the impacts of climate change on crop production in Türkiye. The thesis analyzed the impact of meterological variables, precipitation and temperature on staple crops like wheat, barley, corn, rice and sunflower through an econometric model. The analysis are further extended for different climate scenarios. The findings are significantly important as it sheds light to how selected crop production will develop depending on various climate scenarios over different time periods.

The data and methodology of this thesis is novel as it fills an important gap by analyzing the impact of temperature and precipitation change on crop production using a comprehensive dataset. This data set enables to perform a panel data regression. Based on the regression outputs of the econometric model, the results for each selected crop for different emissions scenarios across time is presented in the tables below. The tables summarize the findings of Chapter 5 combined with the climate scenarios discussed in Chapter 6.

The results are presented separately for two selected climate scenarios of the IPCC: high emissions and low emissions scenarios. Moreover, impacts of temperature change and precipitation change are selected as the climate related variables of interest in this thesis. The impacts of these two meteorological changes are separately discussed under two climate scenarios for each crop.

### 8.3.1 High Emissions Scenario

The high emissions scenario (HES) is the most pessimistic scenario of the IPCC which estimates doubling of current emission levels by 2050. This scenario is often referred to as “business as usual” because it is the potential outcome if the societies do not take any additional measures to decrease GHG emissions. Under this scenario, critical consequences are expected.

The thesis quantifies that alarming consequences are expected on crop production under this scenario. According to the estimation results, if the temperature increases as projected by HES, wheat and barley production would decrease significantly. The reduction increases as we move from short term to long term. For example, under HES, the projected increase in spring (summer) temperature would translate into a 6.5% (14.6%) reduction in wheat production in the short term (see Table 8.1). This number reaches to 13.6% (25.3%) in the mid-term and 21.9% (42.1%) in the long-term (see Table 8.1). The impact is estimated to be in the same direction but with slightly less impact on barley production.

Corn, rice and sunflower which are heat-resistant crops are expected to be positively affected from a temperature increase in spring months. The increase in temperature during summer months is expected to negatively impact the production of corn, rice and sunflower. Among these similar types of crops, the most affected crop is estimated to be sunflower. An increase in temperature during summer months is estimated to decrease sunflower production by 84.3% in the long-run (see Table 8.1).

Table 8.1. Estimated Impact of Temperature Change on Crop Production under the High Emissions Scenario (%)

| | | Estimated Impact on Wheat | Estimated Impact on Barley | Estimated Impact on Corn | Estimated Impact on Rice | Estimated Impact on Sunflower |
|---|---|---|---|---|---|---|
| **2030-2050** | **Spring** | -6.5 | -0.9 | 8.4 | 2.8 | 6.5 |
| | **Summer** | -14.6 | -12.9 | -14.6 | -9.7 | -29.1 |
| **2050-2070** | **Spring** | -13.6 | -1.9 | 17.5 | 5.8 | 13.6 |
| | **Summer** | -25.3 | -22.5 | -25.3 | -16.9 | -50.6 |
| **2070-2100** | **Spring** | -21.9 | -3.1 | 28.2 | 9.4 | 21.9 |
| | **Summer** | -42.1 | -37.4 | -42.1 | -28.1 | -84.3 |

Source: Based on Author's calculations

The impact of precipitation change is only analyzed for wheat and barley since the other crops are grown only in irrigated areas. The estimated impact of precipitation is less compared to temperature. Both wheat and barley are positively affected from increased summer precipitation. However, they are negatively affected from increased spring precipitation (see Table 8.2).

Table 8.2. Estimated Impact of Precipitation Change on Crop Production under the High Emissions Scenario (%)

| | | Estimated Impact on Wheat | Estimated Impact on Barley |
|---|---|---|---|
| **2030-2050** | **Spring** | -3.7 | -2.2 |
| | **Summer** | 8.7 | 4.5 |
| **2050-2070** | **Spring** | 2.3 | 1.4 |
| | **Summer** | 16.8 | 8.8 |
| **2070-2100** | **Spring** | -26.1 | -15.5 |
| | **Summer** | 20.1 | 10.5 |

Source: Based on Author's calculations

### 8.3.2 Low Emissions Scenario

Low emissions scenario (LES) is more optimistic compared to HES. However, under the LES, shift towards a sustainable lifestyle is still slow. A temperature increase of 2.7°C is expected which was 4.4°C under the HES.

The signs of the estimated impact of temperature change is the same under the LES. While the impact is still very high, it is less than the estimated numbers of HES. In the short term, an increase in spring (summer) temperature is estimated to decrease wheat production by 5.3% (13%). Moreover, in the long term, this number reaches to 11.9% (21.4%) (see Table 8.3).

Similar to HES, under the LES, corn, rice and sunflower are positively affected from an increase in spring temperature. While the opposite is expected for summer temperatures (see Table 8.3).

Table 8.3. Estimated Impact of Temperature Change on Crop Production under the Low Emissions Scenario (%)

| | | **Estimated Impact on Wheat** | **Estimated Impact on Barley** | **Estimated Impact on Corn** | **Estimated Impact on Rice** | **Estimated Impact on Sunflower** |
|---|---|---|---|---|---|---|
| **2030-2050** | **Spring** | -5.3 | -0.8 | 6.9 | 2.3 | 5.3 |
| | **Summer** | -13 | -11.6 | -13 | -8.7 | -26 |
| **2050-2070** | **Spring** | -8.9 | -1.3 | 11.4 | 3.8 | 8.9 |
| | **Summer** | -16.1 | -14.3 | -16.1 | -10.7 | -32.2 |
| **2070-2100** | **Spring** | -11.9 | -1.7 | 15.3 | 5.1 | 11.9 |
| | **Summer** | -21.4 | -19.1 | -21.4 | -14.3 | -42.9 |

Source: Based on Author's calculations

Precipitation changes in spring decreases wheat and barley production. However, it increases production in summer months (see Table 8.4).

Table 8.4. Estimated Impact of Precipitation Change on Crop Production under the Low Emissions Scenario (%)

| | | **Estimated Impact on Wheat** | **Estimated Impact on Barley** |
|---|---|---|---|
| **2030-2050** | **Spring** | -8.3 | -4.9 |
| | **Summer** | 11.5 | 6 |
| **2050-2070** | **Spring** | -13.8 | -8.1 |
| | **Summer** | 18.2 | 9.5 |
| **2070-2100** | **Spring** | 0.2 | 0.1 |
| | **Summer** | 30.4 | 15.9 |

Source: Based on Author's calculations

All in all, temperature increase (especially during summer months) reduces crop production significantly under both scenarios. It is estimated that the impact increases over time. The impacts are estimated to be lower for corn and rice since these crops are more susceptible to heat. While the impact of temperature increase is very significant, the impact of precipitation change is not as large as temperature.

## 8.4 Concluding Remarks

The thesis quantifies the alarming impact of climate change on crop production in Türkiye. The findings of this study could potentially play an important role in the policymaking process.

Climate change is posing a great threat to the future of the World, but there is still a lot we can do to adapt to it and mitigate its negative impacts. Climate change is a global issue, yet, it is felt differently at different regional levels. In this regard, local authorities are at the forefront in the adaptation process. For the governments and local municipalities solving their own climate related issues through adaptation measures remain to be highly important. Adaptation has many forms ranging from direct government financing of infrastructure to social protection, as well as involving private sector in the process.

According to the 2014 report on Climate Change Impacts, Adaptation and Vulnerability of the UNFCCC: “Adaptation experience is accumulating across regions in the public and private sector and within communities. Governments at various levels are starting to develop adaptation plans and policies and to integrate climate-change considerations into broader development plans. In Europe, adaptation policy has been developed across all levels of government, with some adaptation planning integrated into coastal and water management, into environmental protection and land planning, and into disaster risk management” (IPCC, 2014).

COP-27 was very important for the agricultural sector because it put the climate related issues in food and agricultural sector at the forefront of the agendas. It highlighted the growing and leading role of agriculture and food security. So far, the KJWA addressed six issues related to the role of agricultural sector in dealing with climate change. COP27 held in Sharm El Sheikh in 2022, adopted an important decision addressing this problem. “Sharm el-Sheikh joint work on implementation of climate action on agriculture and food security” includes a roadmap on how to implement the important outcomes set by the KJWA. Although KJWA has addressed many issues in this sector through sharing technical knowledge and expertise, it fell behind in setting concrete actions regarding how to combat the negative impacts of climate change on agriculture.

This joint work is critical in setting forth the related policies and implementation methods and it also prioritizes national circumstances (IPCC, 2022). The Sharm el-Sheikh Implementation Plan includes a “loss and damage” fund for the first time. This new global agreement, although not biding yet, includes a commitment by developed countries to allocate money for developing countries to tackle with the natural and economic damage caused by climate change.

Türkiye being an important country for agriculture has set its necessary legal framework and action plans. It is also important to discuss the possible implementations as well.  Dealing with the negative impacts of climate change in the agricultural sector, investment in irrigation can potentially play an important role. Irrigation investment contributes to solve several problem and challenges in the agricultural sector. It would increase farmer incomes, available job opportunities and food security. It also enables farmers to mitigate the risks associated with climate shocks. In Türkiye, huge infrastructure investment on irrigation is necessary for the adaptation efforts. While there are ongoing projects with the World Bank and GEF, these projects need to be enhanced.

The water management system needs to be enhanced to prepare for the expected droughts caused by climate change. For example, sugar beets, corn and rice are grown in climates which requires much more precipitation than Türkiye receives. Thereofore, for food security huge investments in irrigation system are necessary.

Switching to less irrigation intensive crops could potentially decrease the damages. Another important aspect of adaptation policy is increasing the public awareness. The potential impacts of climate change on the rural farmers need to be clearly stated. The farmers need to be convinced that the impact is expected to be very high and measures should be taken as soon as possible. This important task needs to be achieved through the local branches of related ministries. These local authorities need to guide them what individual and institutional farmers can do for adaptation.

This thesis is an important contribution to the literature. It sheds light to many lacking aspects of the literature by analyzing a developing country which is vulnerable to climate change and heavily relies on crop production. Based on the findings of this thesis it is evident that crop production would significantly decrease regardless of the scenario. Policymakers need to consider the alarming picture presented in thesis and take immidate actions and adaptation measures to prevent a crisis in the upcoming years.

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# APPENDICES

## A. Regions of Türkiye

| Region | Regional Code | Province |
|---|---|---|
| Istanbul | 1 | İstanbul |
| West Marmara | 2 | Tekirdağ |
|  | 2 | Edirne |
|  | 2 | Kırklareli |
|  | 2 | Balıkesir |
|  | 2 | Çanakkale |
| Aegean | 3 | İzmir |
|  | 3 | Aydın |
|  | 3 | Denizli |
|  | 3 | Muğla |
|  | 3 | Manisa |
|  | 3 | Afyonkarahisar |
|  | 3 | Kütahya |
|  | 3 | Uşak |
| East Marmara | 4 | Bursa |
|  | 4 | Eskişehir |
|  | 4 | Bilecik |
|  | 4 | Kocaeli |
|  | 4 | Sakarya |
|  | 4 | Düzce |
|  | 4 | Bolu |
|  | 4 | Yalova |
| West Anatolia | 5 | Ankara |
|  | 5 | Konya |
|  | 5 | Karaman |
| Mediterranean | 6 | Antalya |
|  | 6 | Isparta |
|  | 6 | Burdur |
|  | 6 | Adana |
|  | 6 | Mersin |
|  | 6 | Hatay |
|  | 6 | Kahramanmaraş |
|  | 6 | Osmaniye |
| Central Anatolia | 7 | Kırıkkale |
|  | 7 | Aksaray |
|  | 7 | Niğde |
|  | 7 | Nevşehir |
|  | 7 | Kırşehir |
|  | 7 | Kayseri |

| | | |
|---|---|---|
| | 7 | Sivas |
| | 7 | Yozgat |
| West Black Sea | 8 | Zonguldak |
| | 8 | Karabük |
| | 8 | Bartın |
| | 8 | Kastamonu |
| | 8 | Çankırı |
| | 8 | Sinop |
| | 8 | Samsun |
| | 8 | Tokat |
| | 8 | Çorum |
| | 8 | Amasya |
| East Black Sea | 9 | Trabzon |
| | 9 | Ordu |
| | 9 | Giresun |
| | 9 | Rize |
| | 9 | Artvin |
| | 9 | Gümüşhane |
| Northeast Anatolia | 10 | Erzurum |
| | 10 | Erzincan |
| | 10 | Bayburt |
| | 10 | Ağrı |
| | 10 | Kars |
| | 10 | Iğdır |
| | 10 | Ardahan |
| Middleeast Anatolia | 11 | Malatya |
| | 11 | Elazığ |
| | 11 | Bingöl |
| | 11 | Tunceli |
| | 11 | Van |
| | 11 | Muş |
| | 11 | Bitlis |
| | 11 | Hakkari |
| Southeast Anatolia | 12 | Gaziantep |
| | 12 | Adıyaman |
| | 12 | Kilis |
| | 12 | Şanlıurfa |
| | 12 | Diyarbakır |
| | 12 | Mardin |
| | 12 | Batman |
| | 12 | Şırnak |
| | 12 | Siirt |

# CURRICULUM VITAE

## PERSONAL INFORMATION

Surname, Name: Bayraktar, Saide Simin

## EDUCATION

| Degree | Institution | Year of Graduation |
|---|---|---|
| MRes | University College London, Economics | 2015 |
| MA | Sabancı University, Economics | 2014 |
| BA | Bilkent University, Economics | 2012 |
| High School | Atatürk Anadolu High School, Ankara | 2007 |

## WORK EXPERIENCE

| Year | Institution | Position |
|---|---|---|
| 2018- to date | Central Bank of Türkiye | Researcher |
| 2016 | Ministry of Energy and Natural Resources of Türkiye | Expert |
| 2012 | Sabancı University | Research Assistant |

## FOREIGN LANGUAGES

Advanced English