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The Impact of Climate Change on the Primary Sector in Greece: An Overview

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ABSTRACT
This article aims to review the existing literature on the impact of climate change on Greece's primary sector, focusing on sustainable management. Climate change has already caused and will persistently cause significant adverse impacts in various sectors due to environmental degradation, resource depletion, and extreme weather events. These impacts are evident in the natural environment, the economy, and society, resulting in infrastructure damage, decreased agricultural productivity, and economic downturn. The EU and Greek strategies and policies are focused on adapting to and mitigating the impacts of human activities. In Greece, the primary sector is a critical pillar of the national economy, contributing significantly to GDP and employment. Greek agriculture is known for its small farms and diverse topography, which lead to high productivity for specific crops and a significant role in the agri-food sector. The agricultural sector's importance goes beyond domestic production and has impact on exports and regional development. This highlights the critical need for sustainable agricultural practices to improve efficiency and resilience against climate change. The review underscores the ongoing need for research and policy support to maintain the viability of the primary sector, considering evolving climate conditions.

Keywords: *climate change; GHG emissions; primary sector; agriculture;*

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I. Introduction

For more than a century, climate change has been a contentious and widely debated topic. According to the Intergovernmental Panel on Climate Change (IPCC), this phenomenon refers to a significant and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years. In short, climate change appears to alter the balance of the environment from its previous state. Human activities have undeniably contributed to significantly to climate change by releasing substantial amounts of carbon dioxide (CO_2) into the atmosphere [1-4]. Deforestation also contributes to carbon emissions through changes in land use, further exacerbating the negative impact on the planet [5-8].

The concept of global warming was first introduced in 1975 to explain the rising global average temperatures [9]. Temperature has been rising for nearly 50 years [10], with the first decade of the 21st century being the warmest that has ever been recorded. In 2023 [11], the global average temperature was the highest since 1850, at 1.18°C (2.12°F) above the 20th-century average of 13.9°C (57.0°F). This temperature was 0.15°C (0.27°F) higher than the previous record set in 2016.

The IPCC predicts that by the end of the 21st century, warming could range from 1.1ºC to 6.4ºC [9]. Climate models suggest that if current trends continue, global average temperature could increase by 1.5ºC between 2030 and 2050 [12], while a doubling of atmospheric CO_2 concentration could lead to a 4ºC increase in global atmospheric temperature by 2080 [13]. Rising temperatures will have a significant impact on numerous countries and regions globally [13,14], particularly in the agricultural areas [15,16]. It is also important to consider the effect of extreme weather events on agricultural productivity [17].

Temperature variability significantly affects various aspects of life, including agriculture, forestry, water supplies, and the ecosystem's health [18]. Moreover, extreme weather events further increase the unpredictability of weather conditions [19]. Extreme weather events are rare incidents at specific locations and times of the year. When these events persist for a certain period, they are classified as extreme climate events with potentially harmful consequences [20]. The characteristics of extreme weather or climate events can vary from one place to another. Examples of such events include heat waves, heavy rainfall, floods, landslides, droughts, fires, and severe storms. When multiple events coexist, they are referred to as complex events [20]. Europe has been experiencing heat waves recently, with record-breaking temperatures in 2019 and 2022 exceeding 40 degrees Celsius in some areas [21].

According to climate projections [20], Europe is expected to experience several key climate trends:

- Extreme temperatures and heat indices are projected to rise, leading to more frequent and intense heat waves with higher maximum temperatures.
- Agricultural droughts are also expected to increase in Western and Central Europe and Southern Europe while decreasing in Northern Europe.
- In Southern Europe, hot and dry events are expected to become more prevalent. Frost and cold events, on the other hand, are anticipated to decrease across Europe.
- Heavy rainfall is predicted to increase throughout the continent.

Energy, industry, agriculture, transport, and land use change are the sectors that contribute the most to greenhouse gas emissions and global warming [22]. Agriculture, in particular, generates both direct and indirect greenhouse gas emissions [23], albeit in a different manner compared to other sectors [22].

An increase in GHGs is expected in the near future [24], resulting in a rise in global temperatures due to human activities [10]. Direct emissions originate from fertilizer-enriched agricultural soils and livestock [25,26], while indirect emissions result from fertilizer leaching, land use changes, fossil fuel use, mechanization, transportation, and fertilizer production [23].

Agriculture is vulnerable to the impacts of climate change and is a significant contributor to GHGs [27] [28]. Agriculture directly contributes to approximately 14% of the annual global GHG emissions and indirectly accounts for an additional 4-8% due to deforestation for creating arable land [13]. On a global scale, agriculture is responsible for 30-40% of anthropogenic GHG emissions. It is also influenced by changes in global environmental conditions and contributes to approximately 20% of GHG emissions, particularly methane (CH_4) and nitrous oxide (N_2O), varying based on the country, region, and geographical location [12,14,23,29-35].

Agriculture is responsible for about two-thirds of N_2O emissions [23,36]. The primary cause of N_2O emissions in crops is the lack of synchronization between crop nitrogen demand and soil nitrogen supply [36].

Moreover, agriculture is closely linked to various activities, economic sectors, social factors, regulations, and policies forming the food system [37]. Global food systems contribute approximately 25% to 35% of total GHG emissions. Without significant improvements in the efficiency of food production, agricultural emissions are expected to rise, particularly due to the projected 50% increase in global population by the mid-21st century [38].

The per capita GHG emissions are highest in the US, followed by Russia, Japan, China, and the EU. In the EU, agriculture significantly contributes to climate change, accounting for almost 10% of total GHG emissions [37]. GHG emissions from agriculture account for approximately 11% of EU-27 emissions and are fully covered by national emission targets as per legislation. Agricultural emissions in 2019 and 2020 were about the same as in 2005, with the most notable reductions in this sector occurring before 2005.

CH4 is the most important gas produced by agriculture and livestock, accounting for about 5% -10% of the total agricultural contribution [40]. The sector is responsible for 47% of global CH4 emissions [23]. The primary source of GHG emissions in the agricultural sector is livestock. Livestock is responsible for greater GHG emissions than all other means and modes of transport combined and contributes significantly to critical land use changes worldwide, including deforestation. Livestock produces more than 50% of GHG emissions, including all aspects of livestock production, such as animal transport and related industries. The FAO's 14% figure includes only limited aspects of livestock production, such as raising animals for food [41].

To stabilize global temperature increase by the end of 2100 between 1.5-2°C, according to the Paris Agreement [29,42], there will need to be a rapid, deep, and, in most cases, immediate reduction in greenhouse gas (GHG) emissions. The Paris Agreement [42] establishes a long-term temperature objective, aiming to limit the increase in global surface temperature to well below 2 °C (3.6 °F) above pre-industrial levels. The agreement also recommends that the increase should not exceed 1.5 °C (2.7 °F). To attain this temperature target, reducing greenhouse gas (GHG) emissions as swiftly and significantly as possible is essential, aiming to achieve net zero emissions by the middle of the 21st century. To achieve this goal, emissions must be reduced by approximately 50% by 2030.

The Paris Agreement identifies elements related to agriculture, food security, and LULUCF (Land Use, Land-use Change, and Forestry) [42]. However, two necessary conditions for its implementation are agreed-upon commonly accepted rules for carbon pricing and achieving convergence between each country's targets [43]. By the end of 2020, the EU-27 had fully achieved its climate and energy targets, but much more effort is needed to reduce GHG emissions, particularly in the agricultural sector, which is vulnerable to disruption through, among other things, the fertilizer market [44].

II. Climate Change and Agriculture

The study of climate change effects, initiated in the mid-1970s [45], has made significant strides. It's important to note the reciprocal relationship between agriculture and the environment [25,46-48]. Reports since 1990 have delved into the impact of agriculture on the environment. Given its reliance on natural resources, agricultural production is at risk from climate variability, including extreme weather events [49].

The future global climate is expected to be uncertain and changing, which will affect agricultural activities and water resources [50] through extreme weather events. These impacts are discussed in various reports [9,29,51,52]. The impacts can be direct or indirect over time [23]. They may be related to a specific primary sector [26,40,53,54], or even to specific products [55,56]. Furthermore, there are comparisons of impacts between developed and developing countries. The geographical approach to climate change impacts has been the subject of reports, at the local or country level [12,14-19,25,27,31,34,35,47,48,55,58-65] at EU level and its policies [20,32,37,39,42,51,57,66-76] or globally and in wider geographical areas [9,28,30,38,41,49,50,77-82].

2.1 Environmental impacts

The effects of climate change on agriculture, as well as other primary sectors like livestock [40] and fisheries [35], are marked by uncertainty [6] and ambiguity [7]. Assessing and predicting these effects is one of the most difficult aspects of climate change [40], which is bigger, more complex, and more unpredictable than any other environmental issue [10].

Developing countries that rely on the agricultural sector and its economic activities are particularly vulnerable to climate change [27,48,77]. Poverty is often linked to food production in the developing world, exacerbating agricultural systems' vulnerability. Vulnerable agricultural systems are most prevalent in the developing world's arid, semi-arid, and dry regions, where half of the world's undernourished population resides [38]. Another approach [31] captured the agricultural parameters that are affected by climate change are shown in Figure 1.

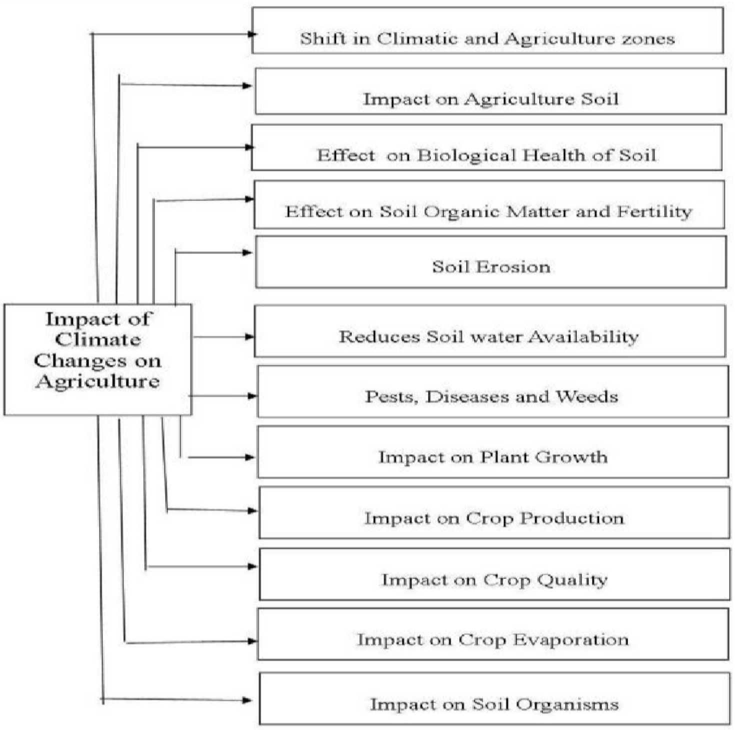

Figure 1 : Agricultural parameters affected by climate change [31]

To assess the impact of climate change on agriculture, researchers have developed different climate scenarios to depict future world conditions based on the prevailing climate. Climate change is expected to have varying impacts on agriculture globally. Crop yields will be affected differently depending on where the crops are grown [57]. With the global population projected to reach 9 billion by 2050, agricultural production will need to increase by about 70% [59] to meet the increased demand for food. The food chain must meet the growing feeding needs of the population while also working towards mitigating climate change. Climate change is already affecting food security and its sustainability [36]. Moderate temperature increases (up to 3°C) may have minor beneficial effects on main crops like cereals, while changes in precipitation may impact production [77].

Many scholarships examine climate change's biophysical and environmental effects, focusing on specific geographic areas, regions, or global markets [57].

The European continent exhibits a wide spectrum of climate, soil, land use, infrastructure, and political and economic conditions [32]. Food production in Europe is influenced by many factors, such as droughts, heat waves, biodiversity loss, and social and economic conditions [76].

The impact of climate change on agriculture in the EU varies significantly by region [36,57]. A previous EU-wide assessment [39] indicates that there are current differences in crop productivity between northern and southern Europe that are growing due to climate change. In the Mediterranean region, the rate of increase in crop yields is decreasing. In the 2010s, compared to the 1990s, there was reduced yield growth or decreased yields for 15 out of 21 Mediterranean countries with agricultural production. Therefore, yields are expected to decline unless new technologies are combined with new crop patterns. However, climate change will affect crops differently depending on whether a crop is grown under irrigation or rainfall [67].

The productivity of summer crops in Southern Europe is expected to decrease due to increased heat stress, higher rainfall intensity, and longer drought duration. This may result in a shift in production zones northwards for crops like maize, sunflower, and soybean, which are currently dominant in southern Europe [38,73]. Conversely, Northern Europe is expected to experience yield increases, while Southern Europe will face challenges from increased water scarcity and extreme weather events such as heat, drought, and storms [73].

Several studies have been carried out to evaluate the effects of extreme events on agriculture in the European Union [69,71-73]. These studies use biophysical and agro-economic models to assess the impacts based on the type of event. The impacts expected by 2050 affect agricultural production, trade, agricultural product prices, income, consumption, and rural living standards. Through the use of models and the application of specific scenarios, biophysical changes in production yields and agroeconomic impacts have been identified.

The potential impact of climate change on agricultural production at a global scale could have a significant effect on food security and the well-being of rural communities. Climate change affecting crop growth will directly influence the amount of food produced. The overall impact on food security will depend on the level of exposure of communities to global environmental change and their ability to manage and rebound from it [79]. Food security encompasses accessibility, nutritional and cultural aspects, and stability and sustainability for future generations. Food systems contribute to approximately 30% of total greenhouse gas emissions and have various negative impacts, such as pollution, loss of biodiversity, land degradation, malnutrition, and inequality. Moreover, they are susceptible to climate change and must adapt [83].

Three primary factors impact food safety: microbiological content, chemical element concentrations, and radiation levels [84]. Climate change can affect food safety in several ways [13,36,85], such as changes in the types of food consumed by individuals, changes in chemical and pathogen inputs, and changes in the way food is produced and processed from the field to the final consumer. The figure below illustrates the relationship between the food system and climate.

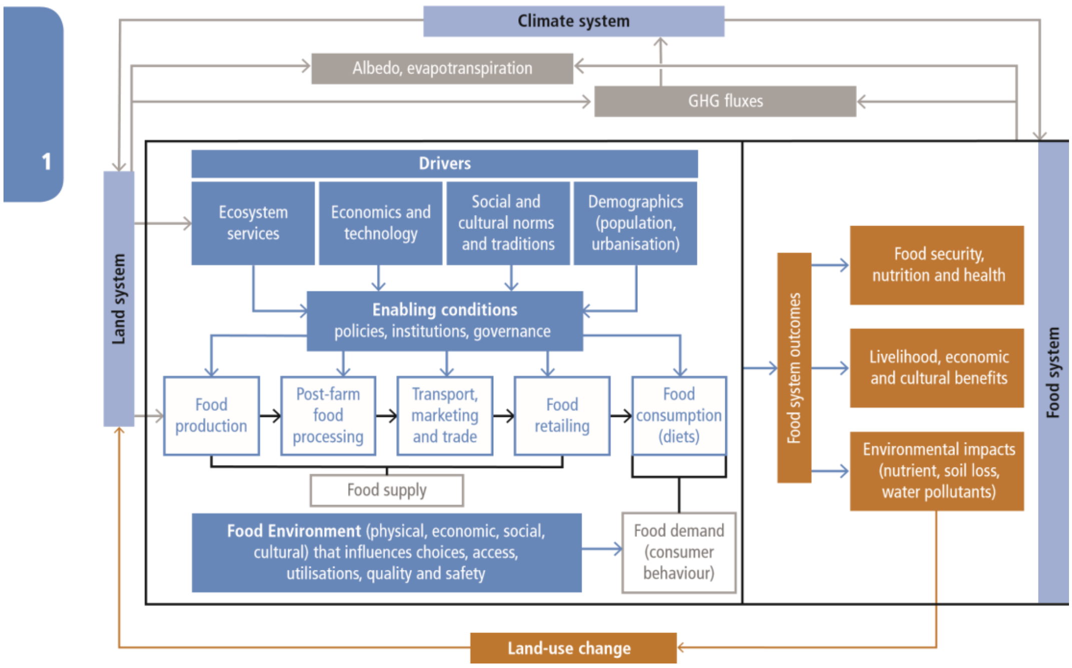

Figure 2 : Food system and its relationship with land and climate [36]

The effects of climate change on agriculture stem from changes in variability and seasonality, shifts in average rainfall and water availability, and the emergence of new pathogens and diseases. These factors are expected to have a greater impact with rising temperatures. The overall impact of climate change on agriculture depends on the interactions among these factors. For instance, new pests, water availability, and temperature thresholds can all interact to influence the outcome [38,77,84].

Numerous reports have focused on crop yield, productivity, and susceptibility to climate change [10,12,30,32,33,40].

Human activity and climate change result in GHG emissions that impact agricultural productivity. However, the overall effect is not yet fully understood, and many of these effects and their interactions have not been reliably quantified, especially on a global scale [33]. The impact of climate change on agricultural crop productivity can be attributed to five main factors [79]: changes in precipitation, temperature, CO_2 fertilization, climate variability, and surface water runoff. This creates a cycle where crop production is directly affected by rainfall and temperature. Precipitation determines the availability of fresh water and the level of soil moisture, which are critical for crop growth. Soil temperature and moisture control the length of the growing season, crop growth, and water requirements. Higher temperatures will shorten the crop cycle and reduce yields in arid and semi-arid areas.

The impact of global warming on agriculture can be understood in three main ways [32,33,45,77]:

1. Increased atmospheric CO_2 concentrations can directly affect the growth rate of plants and weeds.
2. Changes in climate induced by CO_2 can affect temperature, precipitation, and sunshine levels, consequently impacting plant and animal productivity.
3. Rising sea levels may result in the loss of agricultural land due to flooding and increased groundwater salinity in coastal areas.

On the other hand, climate change impacts on plants, soil, insects, and diseases are distinguishable [13,32,45,56]. They are affected by temperature, rainfall, and sunshine changes, which in turn affect agricultural potential, production, land use, soil moisture, soil fertility, soil erosion, and water availability [33,58,64].

There is still limited literature on the potential impacts of climate change on water balance and irrigation [13]. However, the effects of these factors are likely to include reduced water availability in areas affected by declining annual or seasonal rainfall, reduced crop yields and agricultural productivity, and reduced storage of precipitation as snow.

Agriculture is the largest global user of freshwater resources, making it highly vulnerable to climate change. Globally, 70% of available freshwater is used for irrigation, 22% for industry, and 8% for domestic purposes [79]. Water scarcity is a pressing climate-related issue that needs urgent attention. Access to water resources varies widely, leading to alarming levels of water scarcity in some regions [10,12]. Climate change will significantly impact agriculture by increasing water demand, limiting crop productivity, and reducing water availability in areas where irrigation is most needed or beneficial [13]. Irrigation increases total evapotranspiration, adds water vapor to the atmosphere, and reduces daytime surface temperatures in irrigated areas [36].

The warming of the atmosphere, changes in precipitation patterns, and the increasing frequency and severity of extreme weather events will significantly impact agricultural water use. Currently, several regions are facing water shortages, and these shortages may worsen [38]. More intense rainfall will increase surface flooding and soil erosion, placing greater water stress on crops and reducing water security. As a result, agriculture will become more reliant on irrigation [36].

Soil organic matter is crucial for building and maintaining soil fertility, and it influences soil's physical, chemical, and biological properties. Most pest and disease problems are closely linked to crops and their hosts. Potential increases in atmospheric temperature and CO_2 may have significant effects, either directly on the geographical distribution and population growth of harmful insects or indirectly through effects on host plants and natural enemies. This makes significant changes in plant protection problems less likely, although there have been very few studies on the effect of climate change on crop-disease interactions [32].

The impact of climate change on production is influenced by changes in CO_2 concentration and temperature [38]. Intense precipitation events can affect soil CO_2 fluxes, CO_2 uptake by plants, and the carbon cycle in ecosystems. This can lead to decreased soil oxygen levels, which may suppress soil microbial activities and plant roots, and reduce soil respiration, ultimately impacting the carbon cycle [36]. Different types of crops, such as tuber, horticultural, and perennial crops, are influenced by temperature and CO_2 levels, affecting their yield [32]. In forage crops and pastures, changes in yield components and quality criteria can directly and indirectly affect resource availability [38,40], and livestock [60]. However, research on climate change and livestock interaction in developing countries has been relatively overlooked.

There are different ways to categorize the impacts of climate change [38]. Primary impacts include temperature rise, changes in agricultural water availability, and effects on livestock. Meanwhile, secondary indirect impacts, such as increased runoff and soil erosion rates and higher crop losses from insects, diseases, and weeds, can exacerbate production losses.

Climate change can affect soil functions both directly and indirectly. Direct impacts may result from changes in temperature, precipitation, and moisture. Indirect effects may stem from adjustments like irrigation, changes in crop rotation, and tillage practices [66].

Land degradation is a significant issue for ecosystems worldwide. It is caused by unsustainable agriculture and forestry practices, as well as socio-economic pressures like rapid urbanization and population growth. These factors, combined with unsustainable production practices and climate factors, contribute to the problem [36]. The European Commission has identified six major threats that cause soil degradation in Europe: soil erosion, reduction of soil organic carbon (SOC), compaction, reduction of soil biodiversity, salinization, and pollution. On the other hand, soil plays various important roles in society [66]. These roles include food and biomass production, as well as the storage, filtration, transformation, and recycling of water and nutrients. However, certain technologies, such as large machinery, can have adverse environmental impacts by contributing to monoculture and soil erosion [86].

Every year in the EU, there is an estimated average loss of 2.5 tons per hectare, which is significantly higher than the average annual rate of soil formation (around 1.4 tons per hectare) [37]. Global estimates of the total degraded land area vary from 10 million km^2 to over 60 million km^2, with further wide variation in spatial distribution. Although land degradation is a common risk worldwide, poor countries remain most vulnerable to its impacts. Land degradation is of particular concern because of the long period of time required for land restoration. In all future GHG emission scenarios, increasing impacts on land are projected [36].

Changes in the soil water balance will affect the ability of soil to support agriculture and land use distribution [58]. Direct impacts of land degradation are related to changes in water erosion risk due to changes in precipitation, changes in vegetation caused by climate, and impacts on land degradation and coastal erosion [36]. There are also indirect impacts of land degradation that are difficult to quantify due to the many factors involved. The causes of land use change are complex, combining physical, biological, and socio-economic factors [36]. The threats to soil in the EU were investigated in a pan-European project (RECARE) [70], where 14 categories of threats to soil were studied, such as soil erosion, soil organic matter depletion, soil compaction, sealing, and salinization.

In another classification, the effects of climate change are divided into categories based on scenarios and models, connecting them to the quality of life [80]. This classification distinguishes between biological impacts on crop yields, resulting impacts on production and consumption (including prices), and impacts on per capita calorie consumption. There are four ways in which climate would physically impact crops [49]:

- Changes in temperature and rainfall would change the distribution of agroecological zones. - Changes in soil moisture, soil content, and the timing and duration of growing seasons would be affected differently in various parts of the world.
- The effects of CO_2 are expected to have a positive impact due to greater water use efficiency and higher rates of photosynthesis.
- Water availability (or runoff) is a critical factor in determining the impacts of climate change in many places.
- Agricultural losses may result from climate variability and increased frequency of extreme events.

Many reports use models to quantitatively assess climate change impacts and analyze the results for agronomic and agroecological zones [49].

Fisheries are the subject of limited reports [54]. The impact of climate change on the fisheries sector occurs in various ways that bring about significant changes in marine ecosystems and their fish populations, resulting in fluctuations in fisheries production and impacting the livelihood strategies of fishing communities [54]. Extreme climatic conditions have negatively affected aquaculture in South Asia [12]. Global fisheries and aquaculture production will play an increasingly important role in providing food and nutrition in the future. Aquaculture has great potential to feed the world's growing population [87].

2.2 Socio-economic impacts

Three main categories of reports in the literature examine the relationship between climate change/weather impacts and economic activities [17]. The first focuses on biophysical impacts, looking at the connection between climate factors and individual production, such as the effect of weather on crop or livestock yields. The second category examines adaptive responses at the individual or firm level, assessing how farmers or businesses respond to climate impacts. The third considers impacts at regional, national, or sectoral scales, considering both biophysical impacts and adaptation. These reports typically quantify the impacts of climate/weather change on overall economic performance using country/region-level data. They mainly focus on the economic impacts of climate change on agricultural production [10].

Climate change is expected to negatively affect the four pillars of food security—availability, access, utilization, and stability—and their interactions [36]. Different ways are used to measure food security globally. Unpredictable weather patterns worldwide will likely result in reduced agricultural production and increased food prices, ultimately leading to food insecurity [65].

The threat of climate change is increasing the risk of malnutrition, with almost 822 million people currently suffering from undernourishment [36,83]. It is projected that nearly 600 million people will be chronically undernourished by 2030 [85]. The rising frequency of extreme weather conditions may lead to significant increases in food prices and changes in the trade balance between countries. Moreover, climate change is expected to have adverse impacts on social and economic indicators in rural areas. The agricultural sector is influenced by various factors, including market fluctuations, changes in domestic and international agricultural policies, land management practices, terms of trade, technology, and biophysical characteristics.

Agriculture involves managing ecosystems to produce food that meets nutritional needs, making it an integral part of the food system. The scientific debate explores the factors contributing to sustainability and potential future developments in agriculture. Additionally, agriculture serves as an economic sector to support the food needs of a growing global population, and it is increasingly recognized as part of the solution to climate and environmental challenges [37]. However, its role is typically more significant in developing economies than in the developed world [15]. The impacts of climate change will vary across developing countries and regions, depending on local climate, climate changes, market access, and soil conditions. While some developing countries with temperate climates may benefit from warming, others may experience significant temperature increases, loss of rainfall, or challenges in adapting [85,86,88].

Few studies have analyzed the economic impacts of climate change at both the EU and regional levels [57]. Some economic impacts suggest that by 2050, climate change could lead to reductions in crop prices in the EU, which would indirectly affect feed prices and trade, subsequently impacting dairy and meat products [67]. However, the costs of these impacts are partially mitigated by market forces [38].

Assessing the economic impacts of climate change on agriculture in Europe is challenging due to policy and market influences, as well as ongoing technological advancements in agricultural techniques. Climate change may have direct and indirect socio-economic impacts on European agriculture. Direct economic impacts may come from changes in crop productivity and yields, while indirect economic impacts could affect the agricultural sector through alterations in trade flows resulting from changes in crop production and yields [75].

The financial and non-trade consequences of climate change are accelerating and are projected to cost 1.2% of global GDP with a 1°C increase in average global temperature. Furthermore, there is an expected decline in global economic growth of 0.28% per year [89].

By 2050, a global warming of less than 2°C could lead to a 5% increase in total agricultural income in the EU [75]. Due to climate change, the economic impact on agriculture in Europe depends on the emission scenarios, with losses rising as temperatures increase. However, market mechanisms, such as changes in product prices and competitiveness in response to yield changes, can significantly influence these effects. Northern EU Member States have the potential to increase GDP; Central European Member States would experience moderate changes, while Southern European Member States may see a decrease in GDP [75].

The impact of extreme events on agriculture is usually measured by yield losses, which then lead to economic losses [20]. Without climate change, global prices for major agricultural crops such as rice, wheat, corn, and soybeans are expected to rise between 2000 and 2050 due to population, income growth, and demand for biofuels. The annual increase in degraded land area and the resulting loss of total ecosystem services is about 10% of global GDP in 2010 [36]. The reduction in crop yields can result in higher food prices with serious consequences, leading to an annual loss of 0.3% of future global GDP by 2100 [89] or 1.4% by 2080 due to the projected impacts of climate change on agricultural productivity [82]. Another study [12] evaluated the impacts of climate change on farmers using five climate models, two crop models, and one economic model.

Regarding economic costs, some reports suggest that addressing climate change is a manageable issue. The cost of reducing greenhouse gas (GHG) emissions to desired levels is estimated to be around 1% of global gross domestic product (GDP), with a potential range of -2% to 5%, provided that the most effective policies are implemented [90].

Understanding the effects of climate change on the global economy and national incomes, as well as the potential advantages of climate change agreements, is a complex task that requires extensive modeling for a comprehensive and reliable approach. However, projections show a decline in most countries' and regions' GDPs by 2100 under three scenarios and decreases in most of the world's economic sectors [78].

III. The Case of Greece

In Greece, two main studies examine climate change's effects. The first includes reports by the Bank of Greece (BoG) [91] and sectoral reports [92-100]. The second consists of studies by diaNeOsis [101,102], an independent non-profit research and analysis organisation, and additional reports that either directly or indirectly refer to areas of interest in the primary sector [103-107].

The Bank of Greece, through the Climate Change Impacts Study Committee (CCISC), presented a comprehensive report for the first time in 2011 [91]. The report outlines the expected climate and environmental changes up to 2100, covering two time periods (2021-2050 and 2071-2100) compared to the reference period

1961-1990. It assesses the impacts and economic costs of these changes for the Greek economy and the costs of climate change adaptation measures. This study concluded that the impacts on all examined sectors are mostly negative and, in many cases, significantly so. While there were exceptions in specific parts of the agriculture and fisheries sectors, the overall impact was also negative. The estimate of economic impacts should be viewed as indicative and as a threshold for the costs of climate change. This study served as the foundation for subsequent studies on climate change in Greece, and the National Adaptation Strategy to Climate Change (NASCC) [108] in 2016 was primarily based on this. CCISC announced that the 2011 and individual sectoral studies will be updated in 2024.

A study conducted in 2017 [101] analysed the effects of climate change on Greece's development. This study focused on 2046-2065 to simulate future climate conditions for the mid-21st century. The study concluded that climate change would generally negatively impact sectors with significant growth potential, such as agriculture, aquaculture, and coastal and island regions in Greece. However, the intensity of these impacts would vary, and not all regions of the country would be equally affected. It was also noted that some estimated climate changes may have positive effects, such as enhancing solar potential, which could benefit agriculture.

In a study conducted in 2021 [102], researchers explored the impact of climate change on Greece's development model. The study covered the period from 2026 to 2045, spanning 40 years. The study's findings provide detailed estimates of various climate parameters for 2026-2045 and 2046-2065. The study emphasises the significant pressures on both the natural and human-made environment. It indicates that in most of the climate parameters and geographical areas considered, the impact of climate change in Greece is negative. However, the intensity of the impacts varies, and not all regions are equally affected. The study warns that Greece is gradually experiencing a warmer and drier climate, with more intense, frequent, and longer-lasting extreme weather events.

The analysis of all three studies [91,101,102] concludes that climate change will have mostly negative impacts in Greece, which will vary by location and industry. Furthermore, Greece's climate is shifting towards warmer and drier conditions, increasing the frequency of extreme weather events.

3.1 Impact analysis

It is estimated [91,108] that each economic activity, sector, and region will incur damage of millions of Euros. The primary sector and its branches are affected in almost all regions of Greece to varying degrees. This is particularly true for regions where primary production is dominant, such as Eastern Macedonia-Thrace.

According to the CCISC report, agriculture is the sector most likely to be impacted by climate change in Greece. The effects on tourism and coastal systems will also significantly influence the overall economy and household income. The water resources sector is crucial, impacting agriculture and water supply. Therefore, it is essential to focus adaptation policies on these areas [108] and take appropriate actions to mitigate the anticipated adverse effects. Additionally, maintaining strategic reserves of essential food and water to meet the country's basic needs during severe weather events, such as prolonged droughts, should be considered.

Three economic scenarios have been considered for the Greek economy [91]. In the No Action Scenario, where no environmental action is taken to reduce GHG emissions, the total cumulative cost by 2100 is €701 billion. In the Mitigation Scenario, Greece takes action to reduce GHG emissions in line with a global effort to limit average temperatures to 2ºC, with a total cumulative cost of €436 billion by 2100. In the Adaptation Scenario, the total cost is €67 billion.

Over the last 30 years, the observed warming in Greece has negatively affected the productivity of the agricultural sector [61]. Agricultural GHG emissions in Greece amounted to 7.78 million tons of CO_2 equivalents in 2019, accounting for about 8.7% of total emissions in Greece and approximately 2% of total EU emissions from agriculture. This is lower than the EU-27 average of 13% [106].

GHG emission scenarios considered in a UN climate change context [91] include A2, A1B, B2, and B1 Emission Scenarios. Based on the assessment of the environment and the upcoming conditions and climate changes in Greece, the country has been divided into 13 climatic regions using the Emission Scenarios, with an investigation of national-level basis parameters based on previous statistical data.

Several reports have investigated greenhouse gas (GHG) emissions in Greece, including their temporal evolution, their source of origin, and the causes of their change [106,109]. Between 1990 and 2015, GHG emissions from agriculture in Greece decreased by about 18%. The main determinants of emissions during this period were the animal population, the amounts of synthetic nitrogen fertilisers applied to the soil, and the production of agricultural crops. It is projected that between 2020 and 2040, there will be an increase in the use of synthetic nitrogen fertiliser due to the expected economic recovery [109].

The CCISC report of 2011 investigated the following:

- Expected changes in the seasonal and annual mean values of 6 climate parameters for 2021-2050 and 2071-2100, compared to the reference period of 1961-1990.
- Estimation of extreme weather events and their effects on the Greek territory using 12 indicator variables for 2021-2050 and 2071-2100.

Changes in relevant climate indicators for each of the 13 selected climate regions were calculated for two future periods: 2021-2050 and 2071-2100 in comparison to the reference period of 1961-1990. The first future period was chosen to assist policymakers in planning for the near future, while the second was selected to highlight the range of changes expected at the end of the 21st century.
Some key findings from the CCISC report for agriculture:
- The temperature is projected to increase throughout the 21st century for all four emission scenarios studied.
-Overall, annual precipitation across Greece is expected to decrease, with more intense rainfall leading to an increased risk of flooding.
- The annual average relative humidity is predicted to decrease.
- There will be fewer frosty days in various regions of Greece.
- Changes in the germination period duration have been observed, with trends indicating longer periods due to later spring and autumn frosts. This is particularly important for rural areas with vulnerable crops such as citrus.

Various studies [101,102] have drawn the following conclusions about the climate in Greece:
- The average annual temperature is projected to rise, particularly during summer and especially in agricultural areas in Central and Northern Greece. Warm days are expected to increase significantly, particularly in the region of Thessaly and Eastern Macedonia.
- The productivity of plants during their growth phase may be affected by an increase in days when the maximum temperature exceeds 37°C. This impact is forecasted to be especially notable in Thessaly, Central Macedonia, and Eastern Peloponnese.
- Projections suggest a decrease of approximately 30% in the average annual rainfall in Crete, South-Eastern Peloponnese, and Central Greece, with a 10% reduction in summer and winter months.
- Soil moisture distribution in Greece is expected to show significant variability, with the largest decrease anticipated in the summer and spring period and a considerable increase in moisture deficit, mainly in western Thessaly and spatial units in northern Greece.
- An extended growing season is anticipated, which is likely to create more favorable conditions for crops in Greece and lead to longer growing periods.
- The number of frost days is expected to decrease in various regions of Greece.
- Reduction in the number of days with cold episodes may lower the risk of crop damage due to frost in future climate scenarios under study.
- Consecutive wet days, a parameter for studying changes in precipitation, are projected to show relatively small changes, with estimates indicating a decrease for the entire country or localized in western Greece.
- The frequency of flood events, indicated by days with daily rainfall exceeding 20 mm, is expected to increase across all scenarios, particularly in Central, Northern, and Western Greece.
- The drought index is projected to decrease in Western Thessaly and Western Peloponnese, signifying a reduced tendency for soils to become dry.

WWF Hellas [110] has provided the following findings:
- There is an increase in the number of dry days and hot days (>35°C), as well as a decrease in winter precipitation in rural areas.
- Four rural areas, namely Larissa, Serres, Fthiotida, and Pella, have experienced a reduction in the number of days with frost (night frosts).
- Five rural areas, including Heraklion, Larissa, Evia, Fthiotida, and Pella, have seen an increase in autumn rainfall.

The well-being of island countries and their environments depends on four critical sectors: infrastructure (energy, water, transport), agriculture, tourism, and biodiversity. These sectors strongly influence each other and contribute to the balance of island systems [101]. Climate change impacts on agriculture on islands can be categorized as follows [101]:
- Temperature rise can increase plant and animal diseases and pest outbreaks.
- Changes in rainfall patterns can result in soil degradation, lower crop yields, erosion, and possible crop damage.
- Extreme weather conditions can cause damage to crops, livestock, arable land, and related infrastructure.
- Sea-level rise can lead to the loss of arable land and the salinization of irrigation and freshwater systems.

3.2 The risks and impacts of climate change by sector.

Agricultural production is highly vulnerable to climate change, as climate significantly influences the type, quantity, and quality of agricultural products [93,98,108].
The climatic factors that have the greatest impact on crop productivity include air temperature, precipitation, intensity and duration of exposure to solar radiation, atmospheric CO_2 concentration, and the duration and intensity of extreme events [98]. These climate variables are essential for crop productivity. Agricultural production is heavily reliant on climate, as the type and quantity of agricultural products produced largely depend on it.
The key factors that influence crop productivity include the daily minimum and maximum air temperatures, as well as their variability. The average monthly temperature and its variability are also crucial. It's important to

consider the frequency of temperatures exceeding critical points, such as 35°C and 0°C. Temperature also affects soil variables essential for plant growth, such as soil fertility and moisture [91,101]. Increasing temperature leads to higher microbial activity in the soil, resulting in decreased organic matter and soil moisture. Precipitation is also a critical factor for agricultural production. The daily amount of precipitation and its seasonal variability can determine productivity. In addition, atmospheric composition and CO_2 concentration significantly influence crop productivity [91]. Changes in climatic variables are expected to shift favorable zones, affecting crop yields and leading to new types of weed and disease attacks on plants, which will impact food security and sustainability. However, the effects will vary depending on the type of crop.

The impact of climate change on livestock in Greece can be seen in the context of its global impact [38,40,45,111]. There is evidence that an increase in the frequency of extreme weather events will lead to a decrease in the number of livestock [111] and a reduction in plant feed yields [102]. Climate change significantly affects livestock production through its impact on animal growth, milk production, reproduction, metabolic activity, and disease.

The methodology used for assessing the impact of climate change on Greek agriculture [91] was based on the FAO AquaCrop model, which takes into account the effect of water on plant growth and crop productivity. The study utilized data for wheat, cotton, and maize, and for other crops where the model was not applied, previous research results were used. The assessment considered the impact of both climate change and desertification on the production of the crops studied. Furthermore, it was noted that the expected reduction in rainfall and the intensity of extreme events could lead to a potential additional burden of 5-10% on existing forecasts.

The degradation of agricultural soils is expected to play an important role due to the persistence or increase in desertification. The percentage of agricultural land at risk of soil erosion in Greece is 10.2%, which is above the EU average of 6.6% [106]. Dry land covers 33.8% of the Northern Mediterranean countries, while in Greece the figures range between 16% and 62% [36].

The Greek territory was divided into eleven climatic zones: eastern Macedonia-Thrace, western-central Macedonia, central-eastern Greece, western Greece, Ionian, western Peloponnese, eastern Peloponnese, eastern Peloponnese, Cyclades, north-eastern Aegean, Dodecanese, and Crete. For purely practical reasons relating to agriculture, the North Aegean and East Aegean zones have been consolidated.

From the analysis and the application of the FAO AquaCrop model [91], some interesting conclusions can be drawn about the prospects for crop production and the products considered for Greece in the periods covered. Of the three climate scenarios, scenario B2 seems to be the most favorable for crop production. The less negative to positive effects of climate change become more pronounced as we move further north and east, with the result that the climate zones of Eastern Macedonia-Thrace and Western-Central Macedonia are considered more favored or less damaged. The A2 scenario is the least favorable regarding increasing CO_2 concentration, B2 is the most favorable, and A1B is the intermediate.

The most sensitive arable crop is wheat, while cotton production will suffer the greatest reductions in the region of Central and Eastern Greece, including Thessaly. The impact of climate change on the production of tree crops by the middle of the century is expected to be neutral to positive. However, this picture changes sharply to negative at the end of the century, especially in southern and island Greece. Vegetable cultivation will shift further north, away from the currently dominant Crete, and the growing season will be longer than today due to milder-warm winters, resulting in increased production.

It should be pointed out here that around 70 products make up the profile of Greek agriculture, which is highly diversified and is one of its comparative advantages [105].

The Greek viticulture industry is expected to undergo significant changes due to climate change. The extent of these changes will vary depending on the region, the type of grapevines, and the industry's ability to adapt to the new conditions. Climate change will not necessarily reduce the viability of viticulture or crop yields, but it will likely impact the characteristics and quality of grapes and the specific traits of wines. While a rise in temperature can benefit viticulture, excessively high temperatures could have a negative effect on production [101,103,104]. It is predicted that between 2046 and 2065, wine-producing regions in Greece will experience decreasing rainfall and significant increases in moisture deficit. This will create the most pressure for viticulture in regions from Thessaly and further south. Conversely, due to rising temperatures, viticulture may become temporarily more favorable in mountainous wine-growing areas located in the western and northern parts of Thessaly. In the long run, increased irrigation will likely be necessary for crops.

Climate change is expected to impact the growth of plant pathogens and their ability to survive, as well as modify the vulnerability of their hosts, leading to changes in the impact of diseases on various crop species [91]. Changes in climatic conditions affect the physiology of plants and, therefore, the flora and food supply of bees. An increase in temperature causes changes in the biological cycle of bees and also in their annual growth cycle.

The effect of climate change on selected agricultural and livestock areas has been the subject of recent research [102]. The following regional units: Larissa, Heraklion, Evros, Thessaloniki, Fthiotida, Aitoloakarnania, Ilia, Corinthia were investigated for ten crop categories (depending on the region), including olive groves, other cereals, wheat, cotton, maize, tree crops, energy crops, vineyards, vegetables, and fodder, as well as eight categories of livestock: goats, sheep and goats, hens, beehives, cattle, game birds, pigs, horses, and conifers.

The analysis of twelve climate indicators for different areas showed the following conclusions [102]:
- The pressure on the crops and livestock sector is not evenly distributed geographically. It is expected to be particularly significant in the Autonomous Communities of Heraklion, Ilia, Corinth, and Larissa, while it is less significant in the Autonomous Communities of Evros, Thessaloniki, Fthiotis, and Aitoloakarnania. The pressure on the livestock sector depends on reduced yields in feed crops along with higher water consumption demands.
- Olive tree production is generally resistant to high temperatures and drought conditions, but prolonged extreme conditions may limit germination activity. In viticulture, the variation in climatic conditions directly impacts both vineyard yield and wine quality.
- The temperature increase is predicted to positively affect cotton production, while relatively small differences are expected in maize production compared to the reference period.

The assessment of the impact of climate change on various agricultural products in Greece and the EU is reported in several sources [69,91,101]. Depending on the scenario, it is predicted that there will be a 9.33% reduction in bulb crop yields and an increase of up to 12.49% for cereals in Greece. In Thessaly, a reduction in maize yields of up to 20% is expected, with a potential 55% reduction for the entire country. Durum wheat production is anticipated to vary significantly, ranging from a 67% decrease to a 15% increase. Cotton production in Macedonia and Thessaly is projected to decrease by up to 29%, while in Thrace, an increase of up to 21% is expected. The production of vine products is expected to diversify, with potential production changes ranging from a 59% decrease to a 55% increase. The impact on tree crops is expected to be particularly negative in southern Greece and Crete.

The environmental impact of climate change on Greece's agricultural sector leads to economic consequences. Despite facing continuous decline, structural issues, and deviations from the EU average, the agricultural sector is still a crucial part of the Greek economy [91,101,102,106].

Climate change's economic impact on agriculture is linked to changes in productivity, resulting in shifts in agricultural income and employment [98]. Additionally, the chain effects of climate change may influence the price, quantity, and quality of products, impacting trade flows. As a result, agricultural income at both national and European levels is expected to be affected.

The approach to assessing climate change impacts depends on the level at which the assessment is made. There are four levels of assessment [98]:

1. Crop level
2. Individual producers or a community
3. Regional or national level in relation to productivity
4. Global level in relation to agricultural production and prices

Moving to a higher level requires using the results of previous levels as input.

The methodologies developed can be categorized into three categories based on the welfare indicator used (price, cost, or value): pricing, costing, and evaluation [91]. Market methods based on the change in agricultural product outputs on markets are considered the most appropriate methodologies for assessing impacts.

Crops analysis using the FAO model provides an initial projection of the anticipated effects on the agricultural sector in Greece. This analysis is based on climate scenarios and the expected changes in crop yields per hectare and does not consider unforeseen factors such as global production levels. Economic assessments of climate change impacts have also been conducted, highlighting the potential changes in agricultural income based on different climate scenarios, as detailed in table [91,93].

Scenario	No desertification	Desertification	TOTAL IMPACT
A1B	+ 3,26	- 16,91	- 13,63
B2	+ 2,92	- 17,81	- 14,89
A2	+ 13,37	- 10,05	+ 3,31

Table 1 : Change in agricultural income due to climate change by 2100. [91]

All climate scenarios emphasize the importance of combating desertification [91] in adapting to the effects of climate change in Greece. The approved Regional Adaptation Plan to Climate Change (RAPCC) outlines the necessary adaptation actions, reflecting the national dimension of these actions [108].

Adaptation measures are proposed, along with the benefits for 18 crop categories in the administrative regions of Greece. The measures also include an economic assessment of the impacts of climate change and adaptation measures for the period 2021-2050 [55]. The analysis in the report showed that while the agricultural sector in Greece as a whole is negatively affected by climate change, there are some regions where it is positively affected. There is a clear difference between the northern and southern regions of Greece. Similar conclusions were reached by the BoG [91].

Adaptation and mitigation measures are policy measures intended to prepare an integrated multi-sectoral approach to adapt to climate change, which is already affecting Greece and is expected to strengthen by the middle of the 21st century. This poses a major challenge, especially during the current severe economic recession. It requires a revision of Greece's institutional framework to incorporate the dimension of climate change and the development of specific management plans to protect agricultural production [101,102]. The issue of water stress, particularly in the semi-arid Mediterranean, is a key concern [55]. This report also uses a price sensitivity analysis to examine the feasibility of water adaptation measures, such as irrigation. The analysis shows that irrigation can be economically viable in almost all regions and crops, especially with low water prices. Additionally, the report explores climate change adaptation policies and provides examples from EU countries. It also discusses required adaptation actions by sector and industry, including those without economic costs [112].

IV. Discussion

The impact of climate change in the primary sector has a noteworthy two-way relationship with food systems, raising concerns about a potential global food crisis. Assessing the effect of climate change on the primary sector presents challenges due to the inherent uncertainty in global climate patterns [50]. Furthermore, non-holistic scientific methodologies and data gaps contribute to this complexity. Therefore, we must consider various sources of uncertainty, such as future climate trends, demographic changes, economic growth, and technological advancements [91]. As a result, different climate scenarios have been developed and applied globally at the regional or local level.

Various factors influence the impacts on the environment and socioeconomic factors [29,31,113] in agriculture, including crop type and duration, water management, soil quality, livestock and fisheries production, and forest systems and ecosystems management. These also affect the economy by influencing GDP, agricultural product prices, employment, and society as a whole, including population movements, the decline in employment, and deindustrialization.

Thus, efforts to address climate change and its various impacts [67,77] involve measures to either adapt or mitigate its effects [38,63,73,75,89]. Longstanding and continuous strategies and policies are related to this issue at the EU level. Adaptation to climate change is an integral part of the European Green Deal and its external dimension, firmly grounded in the European Climate Law and the new Common Agricultural Policy (CAP).

The EU's approach to climate change initially focused on taking action and adapting to it. In recent years, the emphasis has shifted to addressing the impacts of climate change and adapting all sectors to it. The medium to long-term goal is to strengthen resilience, with the ultimate aim of achieving climate neutrality by 2050 and creating a climate-resilient society fully adapted to the inevitable impacts of climate change. This includes a focus on the primary sector, such as agriculture, forests, and fisheries, as well as interdependent sectors like water management, ecosystems, and food security, with European and national climate change adaptation plans in place. The recent EU Strategy emphasizes sustainable management of natural resources, especially water resources, and reforming policies for agriculture and fisheries to adapt to climate change[68,74,103,107,109,115].

In the 2000s, Greece started evaluating the effects of climate change [91], a process that was strengthened ten years later [55,56,101,103,106]. These impacts vary in type, region, duration, and intensity, with the expectation of more frequent extreme weather events. Greece was slow to respond to the EU strategy in the mid-2010s, with a significant delay in preparing the RASs. Completion and additional studies were scheduled for 2018-2022. Adopting the Regional Adaptation Plan to Climate Change (RAPCC) has also been significantly delayed. The National Strategy (NASCC) focuses on the primary sector, its sub-sectors, and the water sector, emphasizing sustainable water management, an issue also addressed at the EU level [104,108,116,117].

Addressing the multifaceted impact of climate change on Greece's primary sector necessitates comprehensive and adaptive strategies. Future initiatives should focus on enhancing data collection and integration to reduce uncertainties in climate predictions and impact assessments. It is crucial to strengthen collaboration between scientific communities, policymakers, and local stakeholders to develop targeted and effective adaptation and mitigation measures. Further research should explore innovative agricultural practices, resilient crop varieties, and sustainable water management techniques to bolster the sector's resilience. Additionally, investigating the socioeconomic implications of climate change on rural communities and employment patterns will provide valuable insights for creating holistic and inclusive policies. Limitations in current research, such as data gaps and the variability of regional climate models, highlight the need for continuous monitoring and flexible policy frameworks that can adapt to emerging challenges. Ultimately, a proactive and well-coordinated approach will be crucial in ensuring Greece's primary sector's long-term sustainability and resilience in the face of climate change.

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