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Perspective

Impact of Climate Change on the Primary Agricultural Sector of Greece: Adaptation Policies and Measures

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Abstract: The wide acceptance that Climate Change (CC) is a reality, often taking extreme forms, has led to the development of strategies to mitigate climate change and the need to adapt to the new climate conditions. Greece has already developed a National Strategy for Adaptation to Climate Change (NSACC), which has started to be implemented in 2016 in the 13 regions of the state by implementing relevant projects. The Primary Sector of Agriculture (PSA) is one of the most vulnerable sectors to CC in Greece. This analysis describes the main points of the national strategy for mitigation and adaptation, focusing on the adaptation strategy for the PSA. Most of the information included in the analysis comes from a multidisciplinary study organized by the Bank of Greece (BoG), which was used as a guide for the formulation of the NSACC. The analysis includes a comprehensive summary of the PSA adaptation policy to CC, an assessment of climate evolution in Greece with emphasis on the characteristics related to the PSA, estimations of the CC impact on plant and animal production, and the whole organization of the national effort for adaptation to CC. The entire organization of the work followed the framework of the BoG study and the methodologies used in this paper.

Keywords: climate change; food security; adaptation to climate change; agriculture; Mediterranean climate; greenhouse gases; climate projections

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1. Introduction

The general acceptance that Climate Change (CC) exists, often expressed through extreme weather events, has led to the need for the adoption and implementation of strategies and action plans for its mitigation and adaptation to the new conditions. The adaptation processes have been framed by many initiatives and decisions, including the Sustainable Development Goals (SDGs) [1], the Paris Agreement [2], the European Green Deal [3], and both European [4] and National [5] Climate Laws, all aimed at the mitigation and adaptation to CC. The mitigation framework states that by 2030, CO_2 emissions should be reduced by 55% compared to the year 1990, to achieve climate neutrality (zero emissions) by 2050, and to limit the average air temperature increase by 1.5 °C above the pre-industrial period's temperature of 13.5 °C.

A sector with significant involvement in human activities affecting climate change is the Primary Sector of Agriculture (PSA). For example, in the EU-27, the agricultural sector contributed to the total GHG emissions for the year 2019, 10.55% of total emissions. The most significant share of emissions comes from the energy (77.01%) and industry (9.10%) sectors, while the lowest share is from waste management (3.32%) [6]. In this context, the European countries must design their national strategies for mitigation and adaptation to the new climate conditions, i.e., to take appropriate measures to prevent or minimize the effects or even exploit the opportunities that may arise from the CC on different sectors of economic and social activities. Greece is among the countries that have already developed a National Strategy for Adaptation to Climate Change (NSACC) since 2016, which has started to be implemented in the 13 regions of the state through the Regional Strategies for Climate Change Adaptation (RSACC). The implementation of the NSACC is under the supervision of the newly established Ministry of Climate Crisis and Civil Protection. This analysis aims to present the main topics of the NSACC, focusing on the PSA, the obligations and consequences resulting from the adaptation, and to provide some proposals for the more effective PSA adaptation to CC.

The paper includes the main points of a study sponsored by the BoG [7], aiming at the presentation of the impacts of climate change and the adaptation strategy with a focus on the Primary Sector of Agriculture, and is enriched with information from the international and national scientific literature. The purpose is to highlight the main features related to climate change, their main impacts on the PSA, and to formulate some opinions and proposals on the indicated measures and actions for the adaptation of the PSA to the new climate data. In this sense, it is not a research paper but a critical presentation of a study, on which the development of the strategy of the adaptation of PSA to climate change in Greece was based.

2. Conceptual Frame

2.1. Climate and Primary Sector of Agriculture (PSA)

2.1.1. Climate and Plant Production

Essential functions of plant physiology, such as photosynthesis and respiration, depend primarily on climatic conditions [8]. However, there is a great diversity between plants in terms of their particular climatic preferences. In terms of the fundamental physiological function of photosynthesis, the CO_2 of the atmosphere, nutrients, and water through soil, and the contribution of solar energy are combined to produce organic substances, i.e., crop production. Based on the function of photosynthesis, the plants are distinguished into two major categories—the plants C3 and C4 [9,10], depending on the processes of binding the CO_2 of the atmosphere. Among these categories, there are substantial differences in the carbon cycle within the plants, which is essential for understanding their behavior against changes in climatic parameters, and thus for adopting measures and policies to adapt to the CC. Some of the substantial differences between C3 and C4 plants related to climatic parameters are the following [9,10]:

(1) Photosynthesis and, therefore, carbon binding in C3 plants is slow and less effective than in C4 plants due to the physiological process called photorespiration, which occurs in C3 plants but not in C4 plants.

(2) C3 plants have much less water use efficiency because, during photosynthesis, they have water losses by transpiration unlike C4 plants, which can photosynthesize without transpiring water. This fact means that C4 plants are more capable of coping in scorching areas than C3 plants, i.e., C4 plants are better adapted to hot and dry environments than C3 plants.

(3) The optimum temperature of the atmosphere for the development of C3 plants is between 20 and 25 °C, while for C4 plants, it is between 30 and 45 °C. The optimum soil temperature for the growth of C3 plants is 4–7 °C, while for the C4 plants, it is 16–21 °C.

The C3 category includes the vast majority of plants on the planet. Although C3 crops include only 3% of plant species, they account for about 25% of terrestrial photosynthesis [11]. The most important crops of this category in Greece are cereals (wheat, barley, oats, rye, rice), cotton, sugar beets, tobacco, sunflower, most fruit crops, and many vegetables, such as tomatoes, cucumbers, spinach, peppers, aborigines, carrots, and potatoes.

Class C4 includes maize and a few vegetables, such as cabbage, broccoli, and cauliflower. Under conditions of increasing temperature and to avoid water loss, C3 plants reduce CO_2 capture, and thus produce organic compounds, i.e., their yields of photorespiration. In contrast, C4 plants, in which photorespiration is minimized, do not reduce their yields when the temperature is increased. This is why C4 plants are advantageous over C3 plants at elevated atmospheric temperatures. Therefore, to predict the impact of CC on crop yields, it is essential to know the evolution of the atmospheric temperature [11].

2.1.2. Climate and Animal Production

Climate change significantly affects livestock production through animal growth, milk production, breeding, pasture status and food availability, water availability, and diseases [12]. The increase in temperature leads to stress and decreased food consumption, reducing the animals' weight and meat and milk production [13,14]. In dry and semi-arid environments, the breeding of animals is reduced due to the reduced plant biomass production in pasture areas and reduced water availability, leading to the need to move animals over longer distances to find food and water.

Climate change also leads to a redistribution of geographical and phenologic pathogens and insects, increasing disease susceptibility and risks. The rising temperature and heavy rains are the two most noticeable effects. In all these effects of the CC, animals react by trying to adapt through developing mechanisms that affect their function and, ultimately, their production capacity in meat and milk, as well as greenhouse gas (methane) emissions [15].

Ruminant farming systems are an essential part of the milk and meat production sector in the Mediterranean region. A significant proportion of these systems exists in less favored areas, where no other viable agricultural production systems could exist, and in this respect, ensuring their sustainability is fundamental [16]—A framework towards resilient Mediterranean eco-solutions for small-scale farming systems, Agriculture and Food Security. As these production systems rely on rangelands, maintaining their productivity becomes crucial. The productivity of rangelands is expected to be significantly affected by climate change. Recent research has shown that the main influencing factors are precipitation (affects mainly herbaceous plants), and CO_2 concentration (affects primarily tree and bush plants). Thus, the factors on which the productivity of the pastures depends must receive special care and monitoring [17].

3. The National Strategy for Adaptation to Climate Change (NSACC) of Greece

Greece has formulated a national strategy for adaptation to climate change since 2016. The strategy was based substantially on a study organized by the Bank of Greece (BoG) and supervised by a multidisciplinary scientific committee [7]. The study covered a wide range of issues, including the description of the climate of the East Mediterranean and Greece, the risks and impacts of CC per sector, the economics of CC in Greece, the road map for an economy with low emissions, and a description of the strategy for climate change mitigation and adaptation. The responsible body for implementing the adaptation strategy is the Ministry of Climate Crises and Civil Protection through the National Council for Adaptation to CC, which brings together many delegates from various institutions. Regarding the PSA, the council's representative comes from the Ministry of Rural Development and Food (MRDF).

The adaptation to CC is based on three scenarios: (a) the Non-Action Scenario (NAS), (b) the Mitigation Scenario (MS), and (c) the Adaptation Scenario (AS). These three scenarios result in quite different cost impacts. In the NAS, it was estimated that Greece's Gross National Product (GNP) will decrease annually by 2% by 2050 and 6% by 2100. The total adaptation cost in this scenario is estimated at EUR 701 billion (at constant 2008 prices). In the MS, where the temperature increase is intended to be kept at 2 °C, the total cost up to 2100 is estimated at EUR 436 billion, i.e., 40% lower than the NAS. Finally, the total cost of the AS is estimated to be EUR 577 billion, consisting of the impact of the CC and the adaptation cost, which is estimated at EUR 67 billion. For the implementation of the NSACC, several actions and measures have been scheduled, which are described in detail in the pre-mentioned BoG study.

3.1. The Climate of Greece

According to the Hellenic National Meteorological Service (see http://www.emy.gr/emy/el/climatology/climatology, accessed on 20 July 2023), Greece's climate is typically Mediterranean with mild and humid winters, relatively warm and dry summers, and in general, long periods of sunshine during most of the year. In the context of Mediterranean climate, there is a wide variety of climate types due to the topographical configuration of the country, which is characterized by significant differences in altitude between the mountain ranges along the central area of the country and other mountain ranges, as well as in land and sea rotation. In general, in the territory of Greece, there are four climate types [18]: (a) the sea Mediterranean type, in the western coasts of Greece and the Ionian islands, with mild characteristics of a temperate climate, (b) the terrestrial Mediterranean type, including the south-east region and parts of Sterea Hellas, East Peloponnese, the islands of Central Aegean and Crete with drier summers and colder winters, (c) the continental type, in part of Thrace, Macedonia, Epirus, and part of Thessaly with characteristics of continental climate, and (d) the mountainous type with alpine characteristics in winters. Generally, the year is divided into the cold and rainy winter season (mid-October and until the end of March) and the hot and dry season lasting from April to October. The coldest months are January and February, with an average minimum temperature of 5–10 °C in the coastal areas, 0–5 °C in the continental regions, and below zero in the northern areas. The number of rainy days is small and mostly occurs in the winter season, while there are long periods of sunshine. The warmest period is the last 10 days of July and the first of August, with an average maximum temperature from 29 °C to 35 °C.

3.2. Projections of Climate Change Characteristics Associated with PSA

The forecast of the evolution of the climate characteristics related to the PSA was based on the scenarios set by the IPCC in the AR4, which are summarized as follows: (a) A2 (increase up to 850 ppm in the atmospheric concentration of the CO_2 by 2100), (b) A1B (increase in the CO_2 concentration will reach 720 ppm by 2100), (c) B2 (CO_2 concentration will increase up to 620 ppm by 2100), and (d) B1 (CO_2 concentration will increase up to 550 ppm by 2100) [19].

The Science Academy of Athens planned the adaptation measures in cooperation with the National Observatory of Athens through the LIFE17 IPC/GR000006 project [20]. The projections have been divided into two future periods 2031–2006 ('near future') and 2071–2100 (distant future), which are compared to the 1971–2000 ('present climate') reporting period. The climate projections are based on the following three Greenhouse Gas (GHG) mitigation scenarios of the UN Intergovernmental Panel on Climate (IPCC) (RCP-Representative Concentration Pathways): (a) the severe mitigation scenario (RCP2.6), according to which global emissions will reach the maximum value by 2020 and then decrease significantly by 2100, while the temperature will increase to 1.0 °C by 2020, (b) the intermediate mitigation scenario (RCP4.5), with a forecast of a temperature increase of 2.2 °C by 2040 and then a significant decrease in GHGs by the end of the century, and (c) the extreme mitigation scenario (RCP8.5) with a forecast of a temperature increase of 3.7 °C and a continuous increase in GHGs by the end of the century.

Below is the presentation of projections for the key climate parameters of Greece related to the PSA based on the two mitigation scenarios, RCP2.6 and RCP8.5.

3.2.1. Air Temperature

In Figure 1, the projection of the air temperature under the two scenarios, RCP2.6 and RCP8.5, in the near future is presented.

Figure 1 shows that under the severe mitigation scenario (RCP2.6), the average annual temperature will increase from 1.2 to 1.44 °C in most areas of the country and to 1.68 °C in very few areas of the central and northern parts. The average minimum temperature will increase from 0 to 1 °C and the average maximum from 1.0 to 1.82 °C. In contrast, in the extreme scenario (RCP8.5), the average annual temperature will increase from 3.52 to 5.0 °C, the average minimum from 3.0 to 4.0 °C, and the average maximum from 3.46 to 5.19 °C.

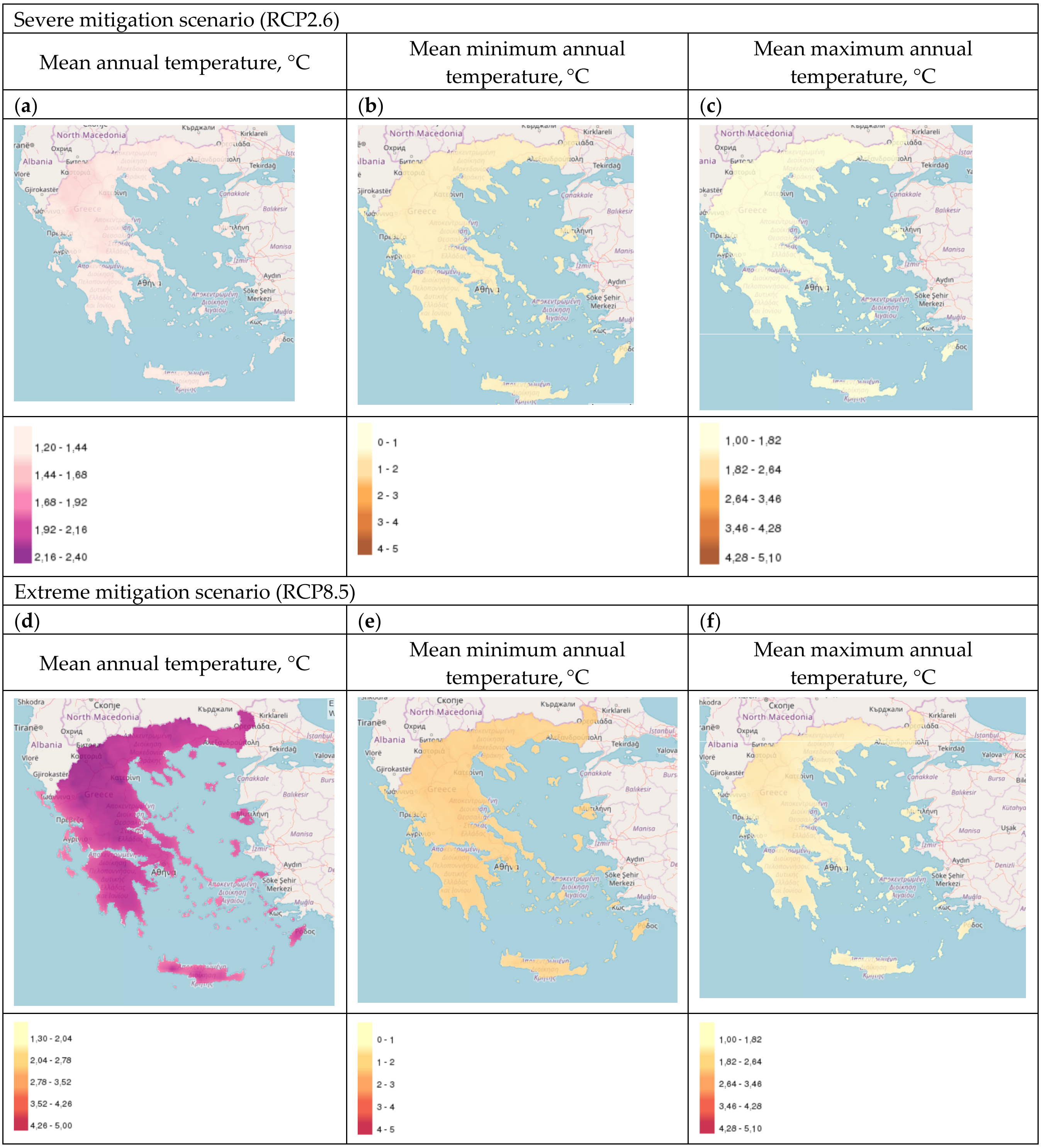


Figure 1. Projection of air temperature under the two scenarios, RCP2.6 and RCP8.5.

3.2.2. Rainfall

Projections show that in the RCP2.6 scenario in the near future, the average annual rainfall will decrease from 10 to 40 mm, rainfall days will decrease from 6 to 30, and rainfall-free days will fall from 6 to 18. The most substantial changes will occur in Northern and Western Greece. In the RCP8.5 scenario, the average annual rainfall is expected to decrease from 20 to 40 mm, rainfall days will reduce from 12 to 40, and rainfall-free days from 14 to 20 in the same areas, as in the severe scenario (Figure 2).

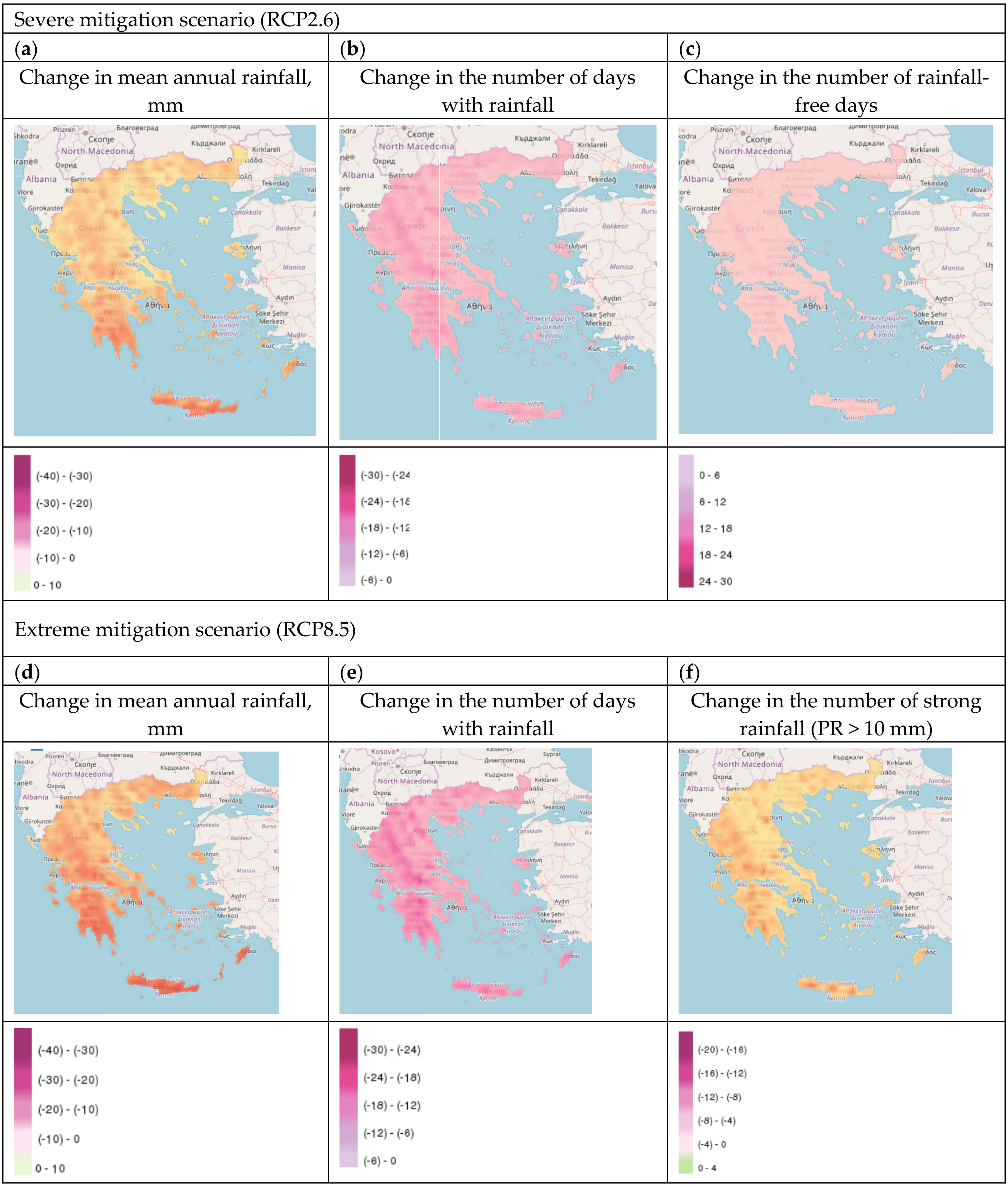


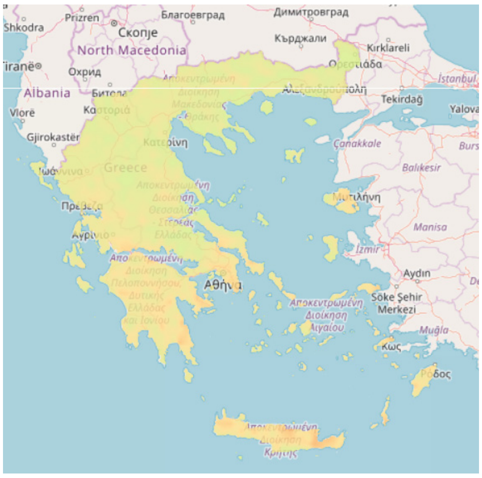
Figure 2. Projection of rainfall under the two scenarios, RCP2.6 and RCP8.5.

3.2.3. Drought, Rainfall-Free Days, Relative Humidity

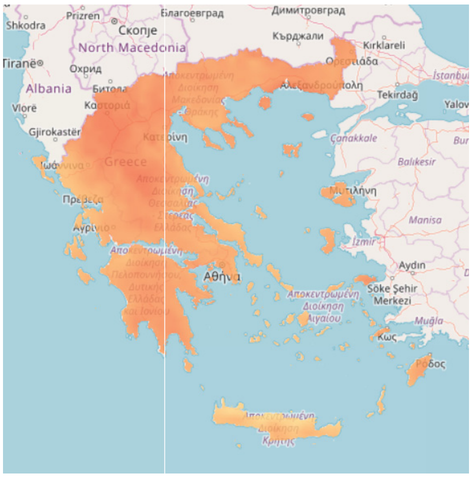
Projections of drought, rainfall-free days, and relative humidity in the near future are shown in Figure 3.

Severe mitigation scenario (RCP2.6)

(**a**) Change in mean duration of drought (PR < 1 mm)

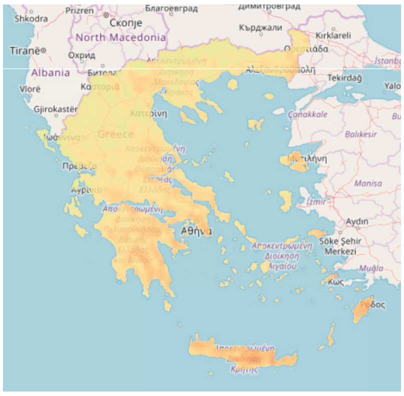


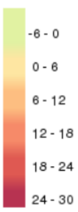
(**b**) Change in mean annual relative humidity, %



Extreme mitigation scenario (RCP8.5)

(**c**) Change in mean duration of drought (PR < 1 mm)





(**d**) Change in mean annual relative humidity, %

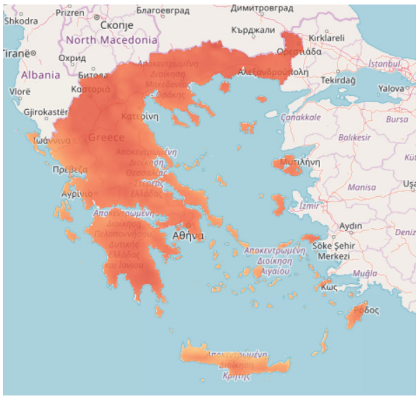


Figure 3. Projections of drought, rainfall-free days, and relative humidity.

Under the severe scenario (RCP2.6), the average drought duration (drought is defined as the condition when Precipitation (PR) is less than 1 mm) will increase by up to 6 days, the number of rainfall-free days will increase by 6–18 days, and the relative humidity will decrease by 2–4%. Under the extreme scenario (RCP8.5), the average drought duration and the increase in the number of rainfall-free days appear to be distributed uniformly throughout the country. At the same time, the decrease in relative humidity seems to occur mainly in the mountainous areas. In the extreme scenario, the increase in days with PR > 1 will increase by 6–12 days, and the number of rainfall-free days will increase by 6–18 days, mainly in the mountainous areas. The average annual humidity will decrease from 3 to 5%, with the most significant decreases being recorded in the areas with higher altitudes.

3.2.4. Sunshine

Sunlight, which is a form of electromagnetic energy (electromagnetic waves or photons that transmit their energy in the form of wave packages), supplies plants with the energy needed for photosynthesis, i.e., the primary physiological function of plants, through which CO_2 of the atmosphere is captured and converted by the involvement of water and nutrients in organic compounds (carbohydrates) [21]. The processes that take place are carried out on the leaves of particular organs, the chloroplasts, containing chlorophyll, in which the absorption of the solar energy converted to chemical energy is carried out and stored in the form of carbohydrates (starch, sugars, polysaccharides). Through this process, almost all of the living organisms on the planet are fed. Therefore, the significance of the sunshine upon which the amount of solar energy arrives on Earth and is used by plants for photosynthesis is evident [22]. The requirements of the different plant categories concerning sunlight differ significantly. For example, plants of the C4 category need more solar energy to form carbohydrates than those of the C3 category. There is no reference in the BoG study for this important parameter. Further research is needed on this evolution in Greece to design adaptation measures.

3.2.5. Concentration of Carbon Dioxide (CO_2) in the Atmosphere

Carbon dioxide concentration is another important climate parameter in which plants react differently. For example, C3 plants under low CO_2 concentrations reduce photorespiration and increase photosynthesis compared to C4 plants. On the other hand, under high temperatures, high sunshine, and high CO_2 concentrations, C4 plants photosynthesize better than C3 plants. In Greece, CO_2 emissions have increased significantly in recent decades. According to World Bank data [23], the year 2000 was 8.74 tons/person, but there has been a continuous decrease in recent years, being 6.0 tons/person in 2019. The evolution of this climate parameter depends on the intensity of activity of the various sectors of the economy, with the building sector at the top [24]. Therefore, this climate parameter should also be studied more extensively in the country's circumstances before the PSA adaptation measures in the CC are formulated.

3.2.6. Desertification

Desertification is a parameter that, although there are no predictive models for its evolution, has been taken into account in the formulation of the National Strategy for Adaptation to Climate Change (NSACC). This phenomenon degrades large areas of land, thus reducing agricultural production. Desertification is seriously threatening Greece [25]. It is estimated, in particular, that 30% of agricultural land has already been deserted and that the remaining 49% faces a risk of desertification [26]. In the BoG study, it was considered that desertification will result in a 5–10% reduction in agricultural production.

4. Materials and Methods

In the BoG study, both of the results from recent research as well as models have been used to assess the impact of CC on the agricultural production. The FAO mechanical AquaCrop model combined with research data on wheat, cotton, and maize crop development were used and the results from previous survey studies were considered for horticultural, arboreal, and other crops. The AquaCrop model was chosen because it combines the effect of water on plant growth and crop productivity, uses a smaller number of parameters compared to other models, is simple to use, and has higher accuracy and lower probability of error. For horticultural, arboreal, and other crops for which no relevant models exist, the results from recent research have been used.

The reference period was the 1991–2000 decade, and the results of this period were compared with the CO_2 concentration and temperature forecast scenarios of the atmosphere A1B, A2, and B2 of the 20141–20250 and 2091–2100 periods. The primary climatic and meteorological data affecting crop growth (maximum and minimum daily temperature, daily precipitation, and daily evaporation) have been provided and analyzed by the Academy of Athens, which has a well-organized meteorological database.

A basic assumption was adopted with respect to the cultivation works (sowing, irrigation, fertilization, harvesting, etc.) that will be kept stable, while the possible impact of competition from weeds and diseases will not be considered. This was necessary because otherwise the system would become chaotic. It was also assumed that desertification will add 5–10% to the economic impacts, which is considered a realistic estimation. It is noted that there is no relevant model for the assessment of desertification on crop production.

For the BoG study, the country was divided into 13 climatic regions based on their special climatic and geographical characteristics. These regions are 1 Western Greece (WG), 2 Central and East Greece (CEG), 3 Western and Central Macedonia (WCM), 4 East Macedonia-Thrace (EM-T), 5 Western Peloponnese (WP), 6 East Peloponnese (EP), 7 Attica (AT), 8 Crete (CR), 9 Dodecanese (DO), 10 Cyclades (CY), 11 East Aegean (EA), 12 North Aegean (NA), and 13 Ionian (IO). However, for the particular part of the adaptation of the PSA, these regions are reduced to 11 with the merging of regions 2 and 7, and 11 and 1 as shown in Figure 4.

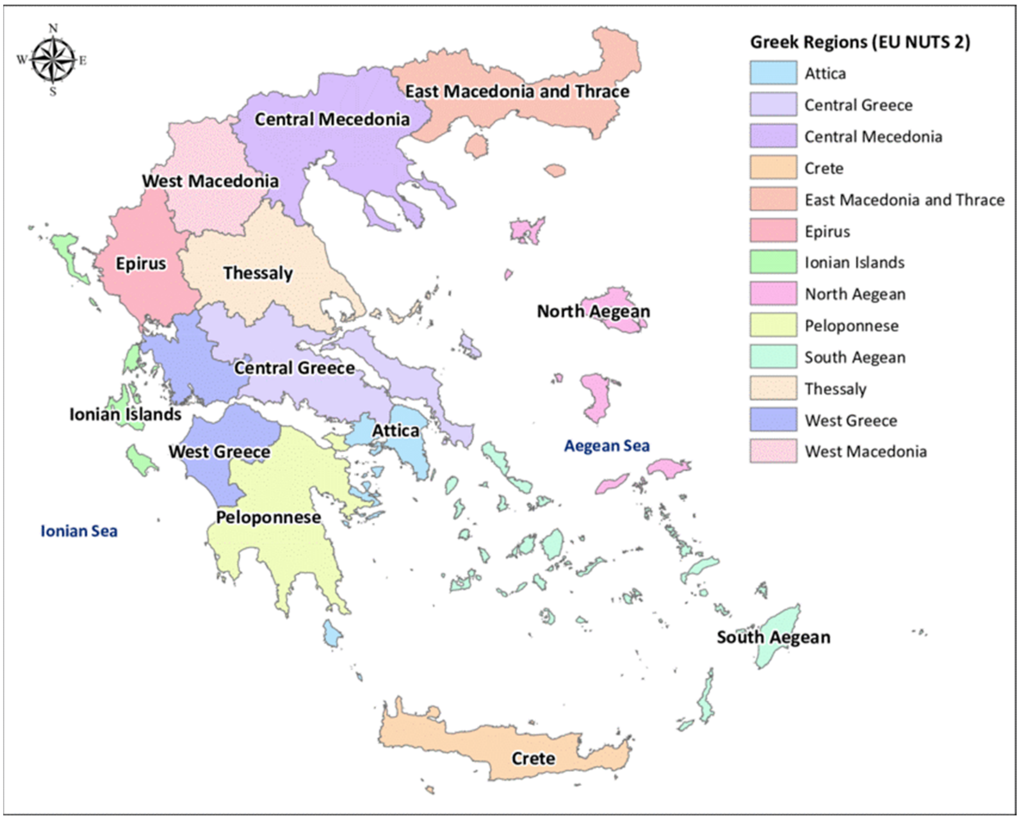


Figure 4. Map of the Greek regions [Source: the Greek Ministry of Interior, Decentralisation and E-government-Open Public Data (geodata.gov.gr)].

In this figure, it is noticed that the BoG study did not consider changes in some factors affecting significantly plant production, such as the impact of weeds and pests and possible modifications in pollinator efficiency. The study did not include an analysis of the livestock sector or drought farming, i.e., agriculture is based exclusively on atmospheric precipitation, which accounts for a significant proportion of the PSA of Greece.

5. Results

5.1. Climate Change Impacts on Plant Production

As stated above, the impact of climate change on the country's main crops was assessed using the AquaCrop model for the three climate change scenarios, i.e., A1B (intermediate), A2 (Intense), and B2 (Mild). The results drawn for the main crops of the country are presented below in Tables 1–6 as compiled from the data provided by the BoG study:

Table 1. The anticipated effects of CC on cotton yield.

Climate Area/Scenarios	A1B		A2		B2	
	2041–2050	2091–2100	2041–2050	2091–2100	2041–2050	2091–2100
East Macedonia-Thrace	Increase					
West-Central Macedonia						
Central-East Greece						
Western Greece						

Legend: green: Increase > 10%; grey: Increase < 10%; brown: Decrease 10%; yellow: No change.

Table 2. Climate change impacts on cereal yield.

Climate Area/Scenarios		A1B		A2		B2	
		2041–2050	2091–2100	2041–2050	2091–2100	2041–2050	2091–2100
East Macedonia-Thrace	Wheat						
	Maize						
West-Central Macedonia	Wheat						
	Maize						
Central-East Greece	Wheat						
	Maize						
Western Greece	Wheat						
	Maize						
Western Peloponnese	Wheat						
	Maize						
East Peloponnese	Wheat						
	Maize						

Legend: green: Increase > 10%; grey: Increase < 10%; brown: Decrease 10%; yellow: No change; red: Decrease > 10%; white: no data.

Table 3. Climate change impacts on the production of horticultural crops.

Climate Area/Scenarios	A1B		A2		B2	
	2041–2050	2091–2100	2041–2050	2091–2100	2041–2050	2091–2100
East Macedonia-Thrace						
West-Central Macedonia						
Central-East Greece						
Western Greece						
Ionian						
Western Peloponnese						
East Peloponnese						
Cyclades						
North Aegean						
Dodecanese						
Crete						

Legend: green: Increase > 10%; grey: Increase < 10%; brown: Decrease 10%; red: Decrease > 10%; yellow: No change.

Table 4. Climate change impacts on arboreal crops.

Climate Area/Scenarios	**A1B**		**A2**		**B2**	
	2041–2050	**2091–2100**	**2041–2050**	**2091–2100**	**2041–2050**	**2091–2100**
East Macedonia-Thrace	grey	green	grey	grey	grey	green
West-Central Macedonia	grey	grey	grey	grey	grey	green
Central-East Greece	yellow	brown	yellow	brown	yellow	grey
Western Greece	grey	grey	grey	yellow	grey	grey
Ionian	grey	grey	grey	brown	grey	grey
Western Peloponnese	yellow	yellow	yellow	brown	yellow	grey
East Peloponnese	yellow	yellow	yellow	brown	yellow	yellow
Cyclades	yellow	brown	yellow	red	yellow	brown
North Aegean	grey	brown	grey	grey	grey	grey
Dodecanese	yellow	brown	yellow	red	brown	grey
Crete	yellow	brown	yellow	red	brown	brown

Legend: green: Increase > 10%; grey: Increase < 10%; brown: Decrease 10%; red: Decrease > 10%; yellow: No change.

Table 5. Climate change impact on olives yield.

Climate Area/Scenarios	**A1B**		**A2**		**B2**	
	2041–2050	**2091–2100**	**2041–2050**	**2091–2100**	**2041–2050**	**2091–2100**
East Macedonia-Thrace	grey	green	grey	grey	grey	green
West-Central Macedonia	grey	grey	grey	grey	grey	green
Central-East Greece	yellow	brown	yellow	brown	yellow	green
Western Greece	grey	grey	grey	yellow	grey	green
Ionian	grey	yellow	grey	yellow	grey	green
Western Peloponnese	yellow	yellow	yellow	yellow	yellow	grey
East Peloponnese	yellow	brown	yellow	brown	yellow	yellow
Cyclades	yellow	brown	yellow	red	yellow	yellow
North Aegean	grey	yellow	grey	grey	grey	dark green
Dodecanese	yellow	brown	yellow	brown	yellow	grey
Crete	yellow	brown	yellow	brown	yellow	yellow

Legend: green: Increase > 10%; grey: Increase < 10%; brown: Decrease 10%; red: Decrease > 10%; yellow: No change.

Table 6. Possible effects of climate change on vines.

Climate Area/Scenarios	**A1B**		**A2**		**B2**	
	2041–2050	**2091–2100**	**2041–2050**	**2091–2100**	**2041–2050**	**2091–2100**
East Macedonia-Thrace	grey	green	grey	grey	grey	green
West-Central Macedonia	grey	grey	grey	grey	grey	green
Central-East Greece	yellow	brown	yellow	brown	yellow	grey
Western Greece	grey	yellow	grey	yellow	grey	green
Ionian	grey	yellow	grey	yellow	grey	green
Western Peloponnese	yellow	yellow	yellow	yellow	yellow	grey
East Peloponnese	yellow	brown	yellow	brown	yellow	yellow
Cyclades	yellow	brown	yellow	brown	yellow	yellow
North Aegean	grey	yellow	grey	grey	grey	green
Dodecanese	yellow	brown	yellow	brown	yellow	grey
Crete	yellow	brown	yellow	brown	yellow	yellow

Legend: green: Increase > 10%; grey: Increase < 10%; brown: Decrease 10%; yellow: No change.

5.1.1. Cotton

The anticipated effects of the CC on cotton cultivation in Greece are recorded in Table 1.

From the data in this table, it appears that in almost all possible climate evolution scenarios, CC will favor cotton production, which is expected to increase its yield to more than 10%. The exception is Central and East Greece, where the yield will remain the same or decrease by about 10% under the A1B and A2 scenarios. This is attributed to the cotton plant physiology pattern. It has been found that when the concentration of CO_2 increases with a simultaneous increase in temperature, cotton plant performance increases sharply unless the temperature increase is very high; therefore, the yield of the plant at an increased concentration of CO_2 decreases. The minimum temperature for cotton growth is 12–15 °C, and the optimum is 26–28 °C; the maximum temperature depends on the duration of exposure. Even short periods of above-optimum temperatures may injure the young fruits [27]. Drought is an abiotic stress that severely affects cotton [28]. The areas where cotton is expected to be most impacted are Central and East Greece, where most of the total cotton quantity in the country is produced.

5.1.2. Cereals

The possible effects of CC on cereals are presented in Table 2.

Cereals appear to be the most vulnerable crops in scenarios A1B and A2. The most sensitive area is Central and East Greece, where significant reductions in wheat cultivation are expected to amount to up to 10% or more. Only in the medium B2 scenario does wheat production appear not to be affected in all regions of the country. The situation for wheat is similar in both Western Greece and West-Central Macedonia in scenarios A1B and A2, where yields are also anticipated to fall by about 10%. In the case of maize, the picture is similar but somewhat better. At the European level, estimates are that for a temperature increase from 1.5 to 2 °C, the decrease in wheat yields by 2050 will be up to 49% and corn between 1 and 29% [29].

5.1.3. Horticulture

The impact of the CC on the horticultural sector is summarized in Table 3.

In the horticultural sector, the effects of climate change on its production appear to be considerably milder compared to the cereal crops sector. Under scenario B2, a decrease in yields is expected only in the Cyclades, while in the rest of the regions, the yields are expected to increase. The areas in which horticultural production seems to be favored due to climate change are the northernmost of the country (East Macedonia-Thrace and Western Macedonia), where significant increases in yields are predicted under all scenarios. The situation appears to be similar in Western Greece and the Ionian Sea, where an increase in yields by less than 10% is also expected. In Central Greece, in scenarios A1B and A2, a significant yield reduction is predicted towards the end of the century, at a level of greater than 10%. Similarly, the impact on the production of the horticultural sector in the Western Peloponnese is milder, while on the Eastern side of the Peloponnese, the reductions are predicted to be greater than 10%. In the region of the North-East Aegean, an increase in yields is expected at the end of the century at a level of less than 10%. Finally, climate change seems to have devastating effects on the horticultural crops in the Dodecanese and Crete areas, in which in all scenarios, the reductions in yields will be significant, at a level of greater than 10%. Some increases are predicted at levels of less than 10% only in the B2 scenario at the end of the century.

5.1.4. Arboreal Crops

The predicted consequences of CC in the nut and fruit production sectors are shown in Table 4.

In this crops sector, the northern regions of Macedonia-Thrace and West-Central Macedonia, as well as Western Greece, the Ionian, and the North-East Aegean, seem to be favored by CC as an increase in yields of up to and greater than 10% is expected, under all the scenarios, except for the A2 in the Ionian and the A1B in the North-East Aegean at the end of the century. In Central Greece, under scenarios A1B and A2, a decrease in yields is expected at the end of the century, but not in the B2 scenario, in which an increase or no effect of CC is expected. The Peloponnese as a whole does not seem to be significantly affected by CC in this category of crops. The situation appears to be much worse in the Cyclades, Dodecanese, and Crete, where the yields of these tree crops are expected to decrease significantly under scenarios A1B and A2, and to a smaller extent under scenario B2.

5.1.5. Olives

The possible effects on the country's very important crop, the olive, are presented in Table 5.

Positive effects are expected for the olives, a crop that is cultivated across the whole country in the northern parts of the country, East Macedonia-Thrace, and West-Central Macedonia, where the yields are expected to increase by more than 10%. Similar are the predictions for Western Greece, Ionian, and North Aegean regions but with less yield increase. The most significant adverse effects for olives are expected in the rest of the parts of the country. Recent research has confirmed the impact of climate change on olive cultivation in Greece. For example, Grillakis et al. 2022 [30], in a study in Chalkidiki area, reported that for the RCP4.5 and RCP8.5 scenarios, chill accumulation will be reduced by 12.0–22.7%, respectively, for the near future (2021–2060) and 22.7–70.9% for the far future (2061–2100) compared to the reference period 1979–2019. In addition, flowering will occur 6–10 days earlier in the near future and 12–26 days earlier in the far future, depending on the elevation and the climate change scenario. Another recent study in the same area [31] reported that due to the future projection of the increase in temperature, especially in the winter period, the flowering during spring is expected to decrease, which will lead to the reduction in the quantity and quality of olives and oil.

5.1.6. Vines

The predicted effects of CC on the vine are presented in Table 6.

In the case of vines, the picture is similar to olives. The North-East regions of Macedonia-Thrace, West-Central Macedonia, Western Greece, Ionian, and North-East Aegean seem to be favored by the CC with an increase in yields up to over 10%. In contrast to Central-East Greece, Ionian, Western Peloponnese, and East Aegean seem not to be significantly affected by the CC. In the Peloponnese, the Cyclades, the Dodecanese, and Crete are expected to have appreciable yield reductions.

The above-described effects on essential crop production are beneficial for planning and implementing measures against the expected changes in the climatic parameters, rainfall, and temperature in plant growth. However, as mentioned above, other climatic parameters also play an important role in plant growth and yield, such as solar radiation (duration and exposure), atmospheric CO_2 concentration, extreme weather events (intensity and duration), and desertification (degradation of agricultural soils and land). These parameters are not included in the BoG study or the NSACC. This gap could be filled through the regional adaptation plans to CC using local research data and the experience of specialists.

5.1.7. Impact of the CC on Livestock Production

Livestock farming is an essential branch of the PSA, where the impact of the CC has not been viewed similarly to that of plant production. However, the effect of the CC on livestock production is significant and should be taken into account accordingly in the planning of adaptation measures and policies in the CC [32]. Livestock breeding is in a two-way relationship with the CA. On the one hand, livestock produces significant amounts of GHG emissions, and at the same time, CC has serious effects on the animals' growth and production [33]. Thus, under the changes occurring in the climate, livestock farming must be designed to reduce GHG emissions and the impact of CC on itself. In Greece, small-scale livestock farms constitute a large proportion of livestock farming, which are of particular value as low-imputed farms provide much of their feed from pastures. Therefore, appropriately managing grasslands becomes crucial in adapting to climate change [34].

6. Discussion

The results presented above show that climate impacts differ significantly in the regions of Greece. This is due to the significant variability of the soil−climate characteristics that lead to different vulnerabilities to climate impacts.

6.1. Vulnerability of the Primary Agricultural Sector by Region

Climate change does not have the same intensity and direction across the country. As mentioned above, the country is highly diversified in terms of climate characteristics, which leads to a different response to the CC. Therefore, before taking any mitigation and adaptation measures, it is necessary to investigate the sensitivity to CC and the vulnerability of the different regions, so that the measures can be scaled up accordingly.

According to the BoG study [7], the PSA is considered the most sensitive sector to the CC in Greece. The regions with the highest vulnerability are Central Macedonia, the Peloponnese, Western Greece, Thessaly, East Macedonia, and Thrace and Crete. More specifically, Table 7 shows the vulnerability of the country's regions.

Table 7. Primary sector of agriculture vulnerability in the regions of Greece.

1 *	2	3	4	5	6	7	8	9	10	11	12	13
9 **	13	4	6	10	3	11	7	5	12	1	2	8

* 1: East Macedonia-Thrace, 2: Central Macedonia, 3: Western Macedonia, 4: Epirus, 5: Thessaly, 6: Ionian Islands, 7: Western Greece, 8: Central Greece, 9: Attica, 10: Peloponnese, 11: North Aegean, 12: South Aegean, 13: Crete, ** The numbers in this line show the degree of vulnerability. The higher the number, the higher the vulnerability.

From the data in Table 8, it seems that the regions of the country with the greatest vulnerability are Central Macedonia-Thrace, the Peloponnese, the North Aegean, and Thessaly.

Table 8. Impact of the CAP on agricultural income up to 2010, % of GNP.

Scenario	Without Desertification	With Desertification	Total Impact
A1B	+3.26	−16.91	−13.63
B2	+2.92	−17.81	−14.89
A2	+13.37	−10.05	+3.31

6.2. Economic Consequences of the CC on the PSA

As discussed above, the change in climatic parameters affects crop and animal productivity and, ultimately, farm income and employment. Tables 1–6 summarize the impact of the CC on the main crops of Greece. The economic assessment of these effects is carried out using various methodologies. The authors of the BoG study used the output of agricultural products on the market to assess the impact of the CC on agriculture. The assessment of the economic impact of the CC was approached as the product of the change in agricultural production due to the CC and the price of the farm product. For the crops referred to in Tables 1–6, the average quantity of the product was considered to be that produced in the period 1990–2000, based on estimates of AquaCrop (version 3.1, 2010) software with processing data on the amount of production and the prices provided by the Ministry of Rural Development and Food (MRDF). Producer prices were adjusted for 2009, and a discount rate of 1% were used, assuming that climatic events will evolve as the models predict, adding to the impact of desertification. It is noted that these estimates did not take into account changes in weeds, pests, and pollinators. In regards to the accuracy of forecasts, it should be noted that this overall approach incorporates several uncertainties related to the forecasting of climate data, price developments, economic analysis, developments in international food markets, the choice of discount rate, etc. Based on the above, the BoG study concluded that the CC had an impact on agricultural income, as shown in Table 8.

This table shows that despite the adverse effects of the CC, in some regions of Greece, as shown in Tables 1–6, the economic impact on agricultural income is expected to be positive in the period 2010–2100. The importance of desertification in the impact on agricultural income is also highlighted, ranging from 10.5% of GDP (scenario A2) to 17.81% (scenario B2), and the urgent need for immediate action [35].

6.3. Characteristics and Weaknesses of the PSA

The Primary Agricultural Sector of Greece is characterized by several special characteristics that should be taken into account when any action or measure is going to be applied, in order that they are successful. The PSA of Greece is characterized by serious weaknesses, the most important of which are related to the small farm size, the old age and low education of the farmers, and the low technical level of the infrastructure. A good description of the PSA characteristics in Greece was concentrated in a study sponsored by the Piraeus Bank (former Agricultural Bank of Greece) [36]. They are summarized below:

The PSA in Greece uses 4.85 million out of about 13.2 million ha (data from 2010) of the country's land area (approximately 37%) and employs around 500,000 employees, 88% of which are permanent. The total number of agricultural holdings is approximately 4.5 million (2016 data), of which 77% have an area of less than 5.0 ha, 12% 5.0–10.0 ha, 6% 10.0–20.0 ha, 1.5% 30.0–50.0 ha, and just 0.2% greater than 100.0 ha. Additionally, 33.5% of the employees are over 65 years old, 27,4% are 55–64, and only 3,7% are under 35. Fifty percent of farms generate an annual production value of less than EUR 4000, 17,7% less than EUR 8.000, 14% less than EUR 15,000, 8.5% less than EUR 25.000, 7% less than EUR 50,000, and just 0.1% up to EUR 500.000. The larger areas of the PSA are used for C3 plants (cereals, cotton, tobacco, olives, citrus fruit, fruits, and vegetables), which are very sensitive to the CC. Chiefs in the largest proportion of farms (61%) are over 55 years old.

Furthermore, according to Mylonas (2015) [37], it is stated that the market share of cooperatives is only around 20% when the respective shares of the Netherlands are 70%, Finland 75% of Italy, Spain more than 40%, and Portugal about 30%. The overall percentage of trained farmers is only 7%, while the Mediterranean countries have 35% and the EU has 45%. Irrigated areas in Greece account for 51% of the total area cultivated, which is quite higher than Italy, Spain, and France by 39%, 25%, and 8%, respectively. The annual quantities of water pumped from the groundwater aquifer are 60%, with 54% of the cost being recovered, whereas in Italy, it is 50% to 50%, in Spain 30% to 50%, and in France 76% to 85%. The funding of agricultural research and innovation in Greece is only EUR 1.1 per ha, while in the Mediterranean countries, it is EUR 2.6 per ha, in the EU-28, it is EUR 3.3 per ha, and worldwide EUR 0.19 per ha. However, the physical characteristics of agricultural land are better than the mean value of EU-28 (index 164 versus 100), the Netherlands (164 versus 96), and Israel (164 versus 89).

7. Conclusions and Proposals

Climate change is now a fact, and it has a significant, adverse impact on national economies, forcing countries to set it up alongside CC mitigation policies and climate change adaptation plans. Greece is among the countries that have formulated a National Strategy for Adaptation to CC (NSACC), attempting to implement it in the 13 regions of the state through the Regional Strategy for Adaptation to Climate Change (RSACC). Climate projections show that significant changes in temperature, precipitation, and drought are expected, which will generally harm the yield of key crops, such as cotton in Central Greece. Moreover, cereals throughout the country, vegetables, olives, and vines in the central southern regions of the country will be significantly affected, with severe economic impacts. For the adaptation to be effective to the greatest extent possible in the future, the following should be seriously taken into account:

- The MRDF, which is the responsible body for implementing the Convention to Combat Desertification [38], should take a key role in the implementation of the NSACC.

- The National Strategy for Adaptation to Climate Change (NSACC) needs to be reevaluated and enriched by including the livestock sector and dryland agriculture, which are not included in the BoG study.
- The division of the country into climatic zones should be improved since it seems to be based on administrative criteria rather than representative agroecological characteristics. An agroclimatic zoning is needed, within which the agricultural activities will be performed.
- The governmental policy on protecting agricultural land has to be changed entirely. The existing, very complex legislation that does not protect the productive agricultural land needs to be replaced by a new one that will protect it from land takeover.
- A restructuring of crops, considering the new climatic data along with the soil and water factors, is required.
- The complete implementation of the Convention to Combat Desertification which was flagged many years ago.
- Boosting agricultural research, which has been downgraded in the last years, is a prerequisite for expecting positive results in the whole mitigation and adaptation efforts.

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Abbreviations

AS	Adaptation Scenario
AT	Attica
BoG	Bank of Greece
CEG	Central and East Greece
CAP	Common Agricultural Policy
CC	Climate Change
CM	Central Macedonia
CR	Crete
CY	Cyclades
DOD	Dodecanese
EA	East Aegean
EM-T	East Macedonia-Thrace
EP	East Peloponnese
GHG	Green House Gas
GNP	Gross National Product
IO	Ionian
IPCC	Intergovernmental Panel on Climate
MRDF	Ministry of Rural Development and Food
MS	Mitigation Scenario
NA	North Aegean
NAS	Non-Action Scenario
NSACC	National Strategy for Adaptation to Climate Change
PSA	Primary Sector of Agriculture
RSACC	Regional Strategies for Adaptation to Climate Change Adaptation
RCP	Representative Concentration Pathways
SDGs	Sustainable Development Goals
WCM	Western and Central Macedonia
WP	Western Peloponnese

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