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THE EFFECTS OF CLIMATE CHANGE ON (THE EUROPEAN) AGRICULTURE

Agriculture plays a special role in climate change. Nevertheless, European agriculture faces some serious challenges in the coming decades. It is important to know, that opportunities for farmers may also arise as a consequence of climate change. The study surveys the possible agricultural impacts of global warming in the European context. This sector is both a significant victim and a mitigating factor in the carbon emission problem. The focus of the survey is on the adjustment capabilities of EU agricultural policy.

KEYWORDS: AGRICULTURE, GLOBAL WARMING, EU, CAP

JEL O13, Q16, Q18, Q54, Q58

1. INTRODUCTION

The history of agriculture has clearly shown a significant ability to adapt to changing conditions coming from different sources. Most of them occurred autonomously and there were no need for conscious response by farmers and agricultural planners (Brooks et al., 2005). Although one should notice that the current changes (global warming, variable weather, natural disasters, etc.) are far beyond the natural adaptation abilities of agriculture. Not only farmers, but also policy makers have to do their best to maintain the quantity and quality of agricultural production. Of course, the extent of these problems differs from country to country. While most of the developing countries are facing with both of them, developed countries were able to get rid of the problem of insufficient production and in some cases they suffer from overproduction, especially the European Union.

Agriculture plays a special role in climate change since, on the one hand, it causes it in many ways, but on the other hand suffers from it. Agricultural production requires various inputs including significant amount of water, pesticides, fertilizers, fodder, etc. Industrial agriculture uses more chemicals and pollutes air and soil, contributes to erosion, salinization, loss of forests and biodiversity, etc. However, plants are able to absorb CO2 and different ingredients from the soil and create food, feed or biofuels. But the latter topic is controversial itself. It is not clear, namely, what costs and benefits come from producing of biofuels and the energy

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balance of the total process is very doubtful.[1] In addition to these, agriculture may contribute to the conservation of the water base.

The general symptoms of climate change are more or less the same in every continent. Climatic zones are moving, weather is becoming warmer with huge anomalies in precipitation, which may induce water shortages. Climate change will have many impacts on agriculture and this will lead to many risks and opportunities. To minimize the negative impacts of climate change on European agriculture, and to take advantage of the potential benefits, adaptation efforts will need to be introduced at all levels and may need to be coordinated across the EU. Changes at the level of an individual farmer, relating to tillage practice, cultivar variety, planting date can also contribute to the efficient adaptation to climate impacts. However, farm businesses are unlikely to be able to adapt to the extent, speed and severity of impacts of changing climatic patterns and extreme events, leaving European agriculture increasingly unstable and vulnerable. Owing to this overall rules for farm support, Rural Development policy and crisis management will play important roles in the future CAP.

Nevertheless, European agriculture is going to face serious challenges in the coming decades. These are the loss of comparative advantage in relation to international growers, competition for international markets, declining rural populations, land deterioration, competition for water resources, rising costs due to environmental protection policies, but the most threatening one is undoubtedly the climate change. Demographic changes are causing water shortages and agricultural production fall short in many areas, involving serious consequences at local and regional levels. Population and land-use dynamics, and the overall policies for environmental protection, agriculture, and water resource management, are the key drivers for possible adaptation options to climate change.

Despite climate change is always made appear as having negative consequences, it is important to know that opportunities for farmers may also arise as a consequence of climate change. There may be regions where the higher average temperature will result in increased yield of current crops, or might allow the cultivation of new ones. These favorable changes of conditions could increase farm incomes. In some parts of the EU, farmers may benefit if they have access to capital or knowledge that will enable them to adapt their farming practices to take advantages of these potential opportunities. The most important role of the various measures of the future CAP should be to support these actions in order to translate the opportunities into benefits, just as to mitigate the potential effects of the expected risks. For the most vulnerable farming communities in Europe, the realization of any opportunity that might arise could have critical importance to their economic survival (European Commission 2009b).

1 According to some studies (led mainly by University of California, Berkeley) this picture is rather negative, for example in case of ethanol production using corn grain required 29% more fossil energy than the ethanol fuel produced (Pimentel-Patzek, 2005). Biofuel production has an influence on food production as well. The increasing demand for both food and biofuels might result in shortages on both fields (Pimentel et al., 2009).

2. AGRO-CLIMATIC ZONES IN EUROPE

Of course, not all effects will come up equally in all regions of Europe. Since the states have various climate and so agricultural profiles, they will face the consequences of climate change also in different form and on a different scale. To demonstrate these different effects, zones with similar climatic attributes are needed to be set up.

In several studies, so-called "agro-climatic" zones of the EU have been used to differentiate estimated climate change impacts. For the analysis in the study Adaptation to Climate Change in the Agricultural Sector (Iglesias et al. 2007) nine agro-climatic zones were determined, which were modified by applying climate change scenarios, so the future changes caused by climate change have been taken into account. The nine agro-climatic zones and the incorporated states are as below *(Table 1)*.

Table 1. Agro-climatic zones in Europe

Agro-climatic zone	Countries or areas of countries within the region
Boreal	Norway, Northern Sweden, Finland, Latvia, Estonia
Atlantic North	Scotland and Ireland
Atlantic Central	England and Wales, The Netherlands, Belgium, Luxemburg, Northern France, Western Germany, Denmark and Southern Sweden
Atlantic South	Portugal, North-West Spain, Western France
Continental North	Eastern Germany, Poland, Lithuania, Belarus, Czech Republic, Slovakia, Northern Ukraine and Eastern Austria
Continental South	Hungary, Serbia, Romania, Moldova, FYROM, Southern Ukraine and North-Eastern Turkey
Alpine	Switzerland, Western Austria, Slovenia
Mediterranean North	Northern Spain, Southern France, Corsica, Northern Italy, Croatia, Bulgaria, the Macedonian region of Greece, North-Western Turkey
Mediterranean South	Southern Spain, Sardinia, Southern Italy, Albania, Greece (except Macedonia), South-Western Turkey

Source: Iglesias et al. (2007, p. 28).

Going down in table 1, the anticipated effects of climate change will become worse. The next table gives on overview of the risks and opportunities on the level of agro-climatic zones *(Table 2)*.

As the table 2 shows, risks relate mainly to potential changes in precipitation patterns in the Alpine, Boreal, Atlantic North and Atlantic Central and Continental North zones with projected increases in winter rainfall and decreases in water availability in summer. Therefore strategies are needed to reduce the effects of winter flooding, water logging and reduced water quality, while implementing measures for capturing and storing water to ensure adequate supply during the summer (European Commission 2009a).

Table 2. Risks and opportunities by agro-climatic zones

Description	Bor	Atl N	Atl C	Atl S	Cnt N	Cnt S	Alp	Md N	Md S
Risks									
Crop area change due to decrease in optimal farming conditions		M	M	M	M	M	M	M	H
Crop productivity decrease		M	M	M	M	M	M	M	M
Increased risk of agricultural pests, diseases, weeds	H	M	H	H	H	H	M	H	H
Crop quality decrease			M	M	M	M		M	H
Increased risk of floods	H		H		H		H		
Increased risk of drought and water scarcity		H	H	H	H	H	H	H	H
Increased irrigation requirements				M		H		H	H
Water quality deterioration	H	H	H		H		H		
Soil erosion, salinization, desertification	H			M		H	H	H	H
Loss of glaziers and alteration of permafrost	M						H		
Deterioration of conditions for livestock	H	H	H	L	H	L	H	L	M
Sea level rise	H	H	H	H	H			H	H
Opportunities									
Crop distribution changes leading to increase in optimal farming conditions	H	H	H	M	H	H	H	M	
Crop productivity increase	M	H	M	M	M		H		
Water availability	H	M	H	H	H		M		
Lower energy costs for glasshouses	M			M	M	M		M	
Improvement in livestock productivity	H	H	H		H		H		

H=High M=Medium L=Low
Source: Iglesias et al. (2007, p. v).

In the Continental North areas total annual rainfall is expected to increase, with precipitation increases in the winter while reduction in summer could occur in several areas. The increased rainfall is predicted to lead to a greater number of intense rainfall events and to increase the risk of flooding, which may be particularly severe as this area has large areas of low-lying land vulnerable to flooding from rivers. A warmer climate may lead to an increase in the northern range over which crops such as soya, sunflowers may be grown and potential increases in yield from the longer growing season (Iglesias et al. 2007).

In the Boreal, there will be potential for cultivating new areas and crops due to much longer growing seasons. Yields could increase under limited warming, but agriculture could suffer from new pests and diseases. The warmer climate could aggravate the problems of water quality in the Baltic Sea.

The increasingly extreme weather events will affect vulnerable mountain areas. Mountain Alpine regions are particularly vulnerable as temperature increases are expected to be above average and other climate change impacts, such as decreased snow cover may have further impacts on hydrological cycles and reduce biodiversity in many river basins (European Commission 2009a). In the Alpine, Boreal, Atlantic, and Continental North agro-climatic zones, a lengthened growing season and an extension of the frost-free period may increase the productivity of some crops and enhance the suitability of these zones for the growth of other crops (Iglesias et al. 2007). However, these changes will only be possible if there is sufficient water available.

Rising sea levels are a particular risk in the Atlantic central zone, requiring either improved defenses or the abandonment of land. Hard defenses are extremely expensive and not cost-effective. The greater intensity of winter precipitation and warmer temperatures in this area are expected to increase the frequency of storms and flooding, especially because there are several large rivers in this zone. Summers are predicted to become dryer and hotter. The longer growing season is forecasted to increase yields of wheat. There is also likely to be an increase in the northern range, where crops such as soya and sunflowers may be grown (Iglesias et al. 2007). The greatest problem to be faced by agriculture in this zone may be rising sea level, which may affect low-lying land in Eastern England and the North Sea coasts of Belgium, the Netherlands and Germany, some of the most productive agricultural areas in those countries. Reduced water resources during summer may lead to conflicting demands between agriculture and other users.

Although new pests and diseases present a high risk in the Boreal, Atlantic Central, and Continental North zones, there is likely to be considerable opportunity in these zones for increased agricultural production. The yields of current crops are set to increase, together with the area of potentially productive land. There are also opportunities for the introduction of new crop types, and may be potential for increased livestock production in some zones. However, there is also a possibility that optimal growing conditions may shift from areas that have a large proportion of fertile soils towards those where soils are less fertile and, therefore, less able to produce higher yields.

In the Atlantic South, Continental South and Mediterranean zones, the greatest risks could arise from reduced crop yields and conflicts over reduced water supply. Strategies need to be developed to adopt cultivars or crops better suited to water and heat stress (Kurukulasuriya–Rosenthal 2003). Also, a greater risk of forest fires has been identified in this area. Problems from new pests and diseases are also considered a high risk in these zones. These changes are expected to reduce the diversity of Mediterranean species. There are few opportunities, although in parts of the Continental South zone, there may be some scope for the introduction of new crops.

The delineation of agro-climatic zones in Europe is demonstrated below *(Table 3.)*. The shift of these zones may lead to loss of some indigenous crop varieties, regional shifts in farming practices and to shifts in optimal conditions for pest species and disease types.

Table 3 The delineation of agro-climatic zones in Europe

Agro-climatic area	2006	2080
Boreal	Sweden, Finland, Latvia, Estonia, Norway	EU: Sweden, Finland, Norway
Atlantic north	Ireland, Scotland	Ireland, Scotland
Atlantic central	England & Wales, Benelux, Central and Northern France, Western Germany, Denmark, Southern Sweden	England & Wales, Benelux, Central and Northern France, Western Germany, Denmark, Southern Sweden, Southern Norway, Southern Finland
Atlantic south	Northern Portugal, Galicia, Western France	Northern Portugal, Galicia, Western France
Continental north	Eastern Germany, Poland, Lithuania, northern Ukraine, Czech Republic, Slovakia, Eastern Austria, Belarus	Eastern Germany, Poland, Lithuania, Latvia, Estonia, Northern Ukraine, Czech Republic, Slovakia, Belarus
Continental south	Hungary, Romania, Serbia, Moldova, FYROM, Southern Ukraine, North-Eastern Turkey	Hungary, Romania, Eastern Austria, Serbia, Moldova, FYROM, Southern Ukraine, North-Eastern Turkey
Mediterranean north	Northern Spain, Southern France, Corsica, Northern Italy, Bulgaria, the Macedonian region of Greece, North-Western Turkey, Croatia	North-Western Spain, Southern France, Corsica, Northern Italy, Bulgaria
Mediterranean south	Southern Spain, Southern Italy, Greece, Southern Turkey	Central Spain, Southern France
Alpine	Western Austria, Slovenia, Switzerland	Western Austria, Slovenia, Switzerland

Source: Iglesias et al. (2007, p. 12–13).

Climatic changes, in general, are likely to shift the zones of optimal production areas for specific crops in the EU. Temperature increases tend to speed the maturation of annual crops, therefore reducing their total yield potential. When the optimum temperature is exceeded, plant growth tends to be reduced. The optimum temperature varies between species, but most of the crops are sensitive to high temperature. Crop yield and quality may decrease, causing loss of rural income due to the problems of pests and diseases as well. The mitigation of these problems may lead to a decrease in water quality from the increased use of pesticides.

In turn, such changes in productivity may affect the total agricultural output of the EU and its share of international commodity trading. Varying seasonality and inter-annual variability will affect crop cycles and farm management, affecting yields and rural economies. Temperatures are expected to rise beyond the optimum growing conditions for many common crop species, and also increased concentrations of tropospheric ozone are expected to reduce crop yields.

In some regions a positive relationship between temperature and crop yield is forecasted, with higher temperature and increased CO2 concentration producing more yields. However, an insufficient supply of water or nutrients, coupled with increased weed competition is expected to frequently negate the fertilizing impact of higher CO2 levels (Iglesias et al. 2007).

New crops such as soya could be grown in future conditions to produce livestock feed. Warmer and drier climatic conditions may also reduce forage production leading to changes in optimal farming systems and a loss of income in areas dependent on grazing agriculture (DG AGRI 2008a). Decreased availability of water may lead to insufficient water being available for irrigation resulting in crops suffering moisture stress. For crop production, a change in the seasonality of precipitation may be even more important than a change in the annual total. Inter-annual variability of precipitation is a major cause of variation in crop yields and yield quality. Crop yields are most likely to suffer if dry periods occur during critical developmental stages. In case of most grain crops flowering is especially sensitive to water stress. Increasing demand for water is likely to lead to increased groundwater abstraction and thus depletion of those resources. Excessively wet years may also cause yield declines due to waterlogging and increased pest infestations (DG AGRI 2008a). Heavy rainfall may damage younger plants.

Lower levels of winter rainfall will lead to decreased water quality. Other changes in crop growth, such as reduced yields and in consequence of this use of extra fertilizer and manure, will extend the problem of water quality. Increased salinity, as a result of drought or sea level rise, may lead to land becoming unsuitable for cropping and being abandoned (EEA 2008b). In extreme cases this may lead to desertification. Increased intensity of precipitation is likely to cause erosion and increase the occurrence of storm flooding and storm damage and lead to greater incidences of waterlogging.

A warmer and drier climate may reduce forage production leading to changes in optimal farming systems and a loss of income in grazing agriculture. In some northern areas, a warmer climate and therefore an extended growing season has the potential to increase forage production. A shift in the location of optimal conditions for specific crop or livestock production systems may lead to loss of rural income and soil deterioration in the areas where those modes of production can no longer be maintained. Such losses of farming practices may lead to loss of cultural heritage, land abandonment and increased risk of desertification (European Commission 2009a). Rising sea levels may also lead to land use changes and land abandonment.

The need for increased spending as a result of damage caused by extreme weather events will lead to a loss of rural income and economic imbalances between the more and less prosperous parts of Europe.

3. IMPACTS OF CLIMATE CHANGE

The four most influential factors of climate change on agro-ecosystems are CO2, temperature, rain and wind. They have different and sometimes controversial effects on the ecosystem. As it was mentioned above, higher CO2 content may increase yields, though weeds can grow faster too. It is more or less the same with temperature: it will have good effects on crops in the colder parts of the continents (e.g. Northern America, Northern Europe, etc.), but negative effects on the originally warmer parts of the continents (Southern Europe[2], Africa, etc.). Increased precipitation may occur in some areas, while other areas will face with much less rain, but water quality and quantity problems (early spring runoff peaks vs. higher winter flows) can be expected everywhere (Falloon–Betts 2010). The table below shows the most probable influence of these factors on the agro-ecosystem *(Table 4)*.

Table 4. Influence of CO_2, temperature, rainfall and wind on various components of the agro-ecosystem

Component	Influence of factor		
	CO_2	Temperature	Rain/wind
Plants	Dry matter growth Water use	Growth duration	Dry matter growth
Animals	Fodder yield	Growth and reproduction	Health
Water	Soil moisture	Irrigation demand Salinization	Groundwater
Soil	SOM turnover*	SOM turnover Nutrient supply	Erosion by wind and water
Pests/diseases	Quality of host biomass	Generation time Earliness of attack	Transmission of diseases
Weeds	Competition	Herbicide efficacy	–

* Soil Organic Matter concentration
Source: Olesen–Bindi (2004, p. 40).

Climate change will manifest itself in various forms. One of the most important consequences are that temperatures will rise all over Europe, especially during winter. According to the IPCC, global warming will cause a temperature increase of 1.8°C to 4°C over the next century compared to 1990 levels (IPCC 2007). Besides annual total precipitation may increase, but so may inter-season variability as well, while summer rainfall is likely to be lower throughout Europe, with periods of intense rainfall becoming more common and less winter precipitation falling as snow. Although difficult to forecast, the incidences of extreme weather events is likely to rise in a warmer climate. This will mean more flooding, higher winds, destructive precipitation events and longer periods of drought. Sea level is predicted to rise by as much as 5 meters (EEA 2008b). One of the effects of this is likely to be the salinization of water resources in coastal areas. And in addition, we must not forget that the atmospheric levels of CO_2 and ozone will rise.

The combination of long-term changes and the greater frequency of extreme weather events are likely to have adverse impacts on the agricultural sector. It will directly impact agricultural production and production methods. Reductions in crop yield (or increased yield variabilities) and quality as the result of reduced

2 It is to be mentioned that climate change will cause enormous changes in energy demand as the projected temperature increases will result higher need for cooling (EEA 2008a). The opposite can be predicted for Northern Europe, where heating demand will be lower.

water availability and precipitation variability could result in loss of rural income. This loss of income will be further worsened by the need for increased spending as a result of damage caused by extreme weather events.

On the one hand, heavier winter rain and the decreased proportion of winter precipitation falling and being stored as snow will increase the occurrence of floods, damaging crops at vulnerable stages of development and disrupting farm activity. Excessively wet years may cause declining yields as a result of waterlogging and increased pest and disease problems (DG AGRI 2008b). Intense rain and hailstorms can affect the yield and quality of vulnerable crops, such as soft fruits. Sea level rise will directly impact some agricultural land, contribute to greater pressures via changes in land use around urban areas and increase the salinity of some of the water resources. Increased salinity may result in land abandonment as it becomes unsuitable for cropping.

Table 5 Climate change and related factors relevant to agricultural production at global scale

Climate and related physical factors	Expected direction of change	Potential impacts on agricultural production	Confidence level of the potential impact
Atmospheric CO_2	Increase	Increased biomass production and increased potential efficiency of physiological water use in crops and weeds. Modified hydrologic balance of soils due to C/N ratio modification. Changed weed ecology with potential for increased weed competition with crops	Medium
		Agro-ecosystems modification	High
		N cycle modification	High
		Lower yield increase than expected	Low
Atmospheric O_3	Increase	Crop yield decrease	Low
Sea level	Increase	Sea level intrusion in coastal agricultural areas and salinization of water supplies	High
Extreme events	Poorly known, but significant increased temporal and spatial variability expected. Increased frequency of floods and droughts	Crop failure. Yield decrease. Competition for water	High
Precipitation intensity	Intensified hydrological cycle, but with regional variations	Changed patterns of erosion and accretion. Changed storm impacts. Changed occurrence of storm flooding and storm damage. Increased water logging. Increased pest damage	High
Temperature	Increase	Modifications in crop suitability and productivity. Changes in weeds, crop pests and diseases. Changes in water requirements. Changes in crop quality	High
	Differences in day/night temperature	Modifications in crop productivity and quality	Medium
Heat stress	Increases in heat waves	Damage to grain formation, increase in some pests	High

Source: Iglesias et al. (2009b, p. 10).

On the other hand, reduced water availability caused by drought may lead to insufficient water available for irrigation, crops suffering from heat and drought stress, and increased competition for water resources may result in higher prices and regulatory pressure (DG AGRI 2008a). As a consequence of drought, the quality of land resources will be worsened by soil degradation, which will lead to a decrease in yields and subsequently weak food security.

As a response to reduced nutrient uptake, increased manure and fertilizer may be applied. This may lead to a reduction in water quality as nutrients will not be sufficiently diluted by rainfall. *Table 5* summarizes climate and related physical factors relevant to agricultural production.

As it can be seen from the table above, the possible effects of these various factors can be very different, but most of them will increase yield variability and require instant actions. The only factor with mostly positive influence on production is the rising atmospheric CO_2 via increasing photosynthesis. Although Grace et al. 2002 argued that temperature has much more (negative) effects by limiting photosynthesis over a certain temperature range than CO_2 has. Investing in more resistant crops is important, but it can not answer all the challenging physical factors. Regional differences have to be kept in mind. The northern and the southern parts of the Earth will benefit from higher precipitation and warmer weather, while the central (especially tropical and sub-tropical) areas will suffer from them. It will affect the productivity of both crop and livestock sectors, which is even more of a vital problem for African (non-oil exporting) countries, where agriculture is undoubtedly the most important sector measured either by its contribution to the national GDP or to export revenues.

According to the Global Environmental Outlook of the United Nations Environment Programme,[3] different continents will face with different problems:

- Africa has the worst perspectives as the main problems are lower yields and desertification . It will lead to food insecurity, as well as increased malnutrition and hunger. Especially lake fish production will decrease due to rising water temperature (UNEP 2007). Increased water stress can cause additional problems. The problems of the key sector in the majority of the countries will have serious financial consequences in terms of lower export incomes.
- Asia will also have to face adverse effects. Higher yields and more utilized agricultural areas available are expected in the Northern part, while the Southern part will have lower yields and less agricultural area available. In addition to these, higher sea level (especially in the mega-delta regions) and more extreme weather events will cause further problems.
- Australia will experience overall balanced impacts. However, the loss of biodiversity seems to be unavoidable.
- Europe will have more or less the same prospects as Asia: better opportunities on the Northern part and worse situation on the Southern part.
- North America's perspectives are similar to Asia's and Europe's. The winner is expected to be Canada on this continent.

3 More details at http://www.unep.org

- South America has to be prepared for worse agricultural conditions caused by the climate change. Although the yield decrease may be in a reasonable range and can be compensated by plant breeding and technological interventions in the intervening period (Jones–Thorton 2003).

4. MODELING THE IMPACTS OF CLIMATE CHANGE ON AGRICULTURE

Forecasting the possible effect of climate change on agriculture is a very topical issue. Modeling is very important as it can help identify the key problems and proper adaptation measures and give answers to several questions by pointing out the direction and magnitude of changes.[4] They can be divided into two parts: global and regional climate models (GCMs and RCMs). It is to be mentioned that these models are very sensitive to the initial data, especially to variation in temperature and rainfall, and GCMs often require detailed regional spatial analyses (Olesen et al. 2007).

There are at least three model families in use: process-based crop models, empirical statistical models and production functions. Naturally, all of them have strengths and weaknesses. Table 6 shows the main characteristics of the most commonly used models.

Table 6. Summary of the characteristics of process-based crop models, empirical models and crop production functions

Type of methodological approach	Description and use	Strengths	Weaknesses
Process-based crop models	Calculate crop responses to factors that affect growth and yield (i.e., climate, soils, and management). Used by many agricultural scientists for research and development.	Process based, widely calibrated, and validated. Useful for testing a broad range of adaptations. Test mitigation and adaptation strategies simultaneously. Available for most major crops.	Require detailed weather and management data for best results.
Empirical statistical models	Based on the empirical relationship between observed climate and crop responses. Used in yield prediction for famine early warning and commodity markets.	Present day crop and climatic variations are well described.	Do not explain causal mechanisms. May not capture future climate crop relationships or CO_2 fertilization.
Production functions derived from crop models and validated with empirical data	Based on the statistical relationship between simulated crop responses to a range of climate and management options. Used in climate change impact analysis.	Allow to expand the results over large areas. Include conditions that are without the range of historical observations. Allow to simulate optimal management and therefore estimate possible adaptation.	Causal mechanisms are only partially explained. Spatial validation is limited due to limitations in the database.

Source: Iglesias et al. (2009b, p. 17).

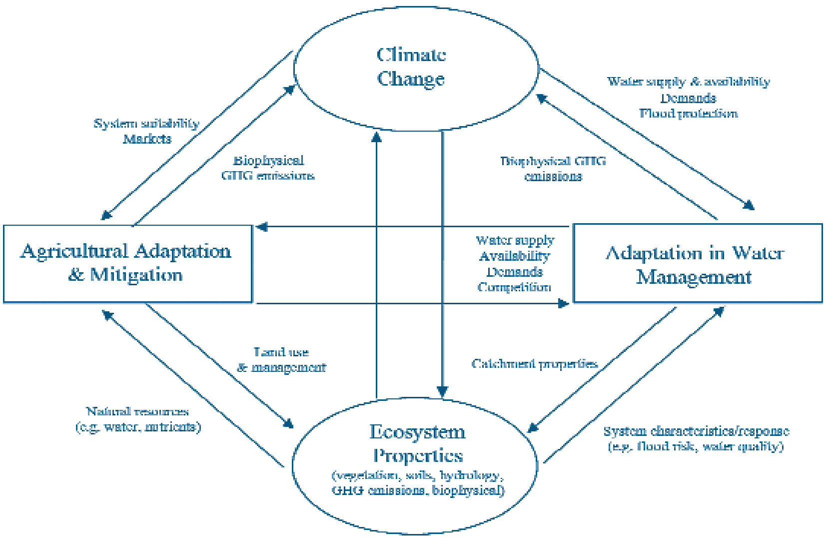
4 From this aspect, the results of IMPACCT (**I**ntegrated **M**anagement O**p**tions for **A**gricultural **C**limate **C**hange Mi**t**igation), a project organized by the University of Hertfordshire, are interesting: a working greenhouse gas (GHG) emission counter. It may be used on national, regional or farm level in order to identify GHG reducing actions. More details at http://sitem.herts.ac.uk/aeru/impacct.

The model suitable for analyzing the given problem always depends on the situation at hand and on the aims of the modeler.

5. ADAPTATION MEASURES

In agreement with many authors (e.g. Olesen–Bindi 2004), adaptation means long term issues, because in the short run we may speak only about adjustments. Some elements of production may be changed easily and immediately (e.g. optimized production, timing, fertilizer use, change in varieties, water conserving practices), but the introduction of irrigation or structural changes (e.g. land use patterns) take time. Sustainability should also be highlighted as an important element of adaptation measures. It is not only in line with long term objectives, but also helps reduce the vulnerability to climate change by enhancing adaptive capacity and increasing resilience (UNEP 2007).

It must be stressed that adaptation and mitigation require integrated approach as none of the important elements can be handled separately. Interactions between climate change, adaptation and ecosystem properties are extremely important. Each element of this system has effect on all the others and vice versa *(Figure 1.)*.



Source: Falloon–Betts (2010, p. 5668).

Figure 1. Interactions between climate change, adaptation/mitigation in agriculture, adaptation in water management and ecosystem properties

It also should be kept in mind that the likelihood of various impacts are different. In addition, the expected negative effects are often accompanied by further negative impacts (e.g. in case of lack of irrigation, less precipitation causes lower yields). Obviously, the adaptive capacity of agriculture depends on the nature and magnitude of changes. Table 7 shows the most relevant impacts on the agro-ecosystem, their uncertainty levels, impacts and adaptive capacity.

Table 7. Characterization of agronomic and farming sector impacts, adaptive capacity, and sector outcomes

Impact	Uncertainty level	Expected intensity of negative effects	Socioeconomic and other secondary impacts	Adaptive capacity
Changes in crop growth conditions	Medium	High for some crops and regions	Changes in optimal farming systems; Relocation of farm processing industry; Increased economic risk; Loss of rural income; Pollution by nutrient leaching; Biodiversity	Moderate to high
Changes in optimal conditions for livestock	High	Medium	Changes in optimal farming systems; Loss of rural income.	High for intensive production systems
Changes in precipitation and availability of water	Medium to low	High for developing countries	Increased demand for irrigation; Decreased yield of crops; Increased risk of soil salinization; Increased water shortage; Loss of rural income.	Moderate
Changes in agricultural pests	High to very high	Medium	Pollution by increased use of pesticides; Decreased yield and quality of crops; Increased economic risk; Loss of rural income.	Moderate to high
Changes in soil fertility and erosion	Medium	High for developing countries	Pollution by nutrient leaching; Biodiversity; Decreased yield of crops; Land abandonment; Increased risk of desertification; Loss of rural income.	Moderate
Changes in optimal farming systems	High	High for areas where current optimal farming systems are extensive	Changes in crop and livestock production activities; Relocation of farm processing industry; Loss of rural income; Pollution by nutrient leaching; Biodiversity.	Moderate
Relocation of farm processing industry	High	High for some food industries requiring large infrastructure or local labor	Loss of rural income; Loss of cultural heritage.	Moderate
Increased (economic) risk	Medium	High for crops cultivated near their climatic limits	Loss of rural income.	Low
Loss of rural income and cultural heritage	High	Not characterized	Land abandonment; Increased risk of desertification; Welfare decrease in rural societies; Migration to urban areas; Biodiversity.	Moderate

Source: Iglesias et al. (2009b, p. 35).

As it can be seen from the table above, some of the problems are expected to be occurred in special areas, regions or countries. For the most part, developing countries are in danger (e.g. water availability, soil fertility and erosion, etc.). Some of the changes have serious impacts on rural environment, rural life (loss of rural income, outmigration, loss of cultural heritage, etc.) as additional effects. Although one might notice that the adaptive capacity is mostly on moderate/high level.

The different agro-climatic zones will not only face different impacts, risks and opportunities, but will also have different adaptation options for the same risks because of different adaptive capacities. Southern regions should increase the capture and storage of water to ensure adequate supplies. Water storage capacity need to be increased to capture a greater proportion of winter rainfall. As an opposite, Northern states are receiving a large proportion of their annual precipitation in summer. Differences can be seen at farm level too. Intensive farming systems, which are very common in Western Europe, are less sensitive to climate change because the impact on their production is lower, while low input farming systems are in danger (Chloupek et al. 2004). Another aspect of production is specialization. Climate change has higher effects on specialized farms than on mixed farms (Olesen–Bindi 2002). In case of livestock sector, methane emission can cause problems by contributing to greenhouse effects. The suitable solution is already in use, but biogas production can not be an issue in case of low scale farming (e.g. small farms with a few cows).[5]

There is a higher need for irrigation due to the drought in the Southern Mediterranean zone than in the North. Therefore extensification of production would be advisable in the Southern part of Europe, while the Northern part will be more suitable for intensive production (Olesen–Bindi 2004). As a consequence of this, there is a higher awareness of climate change impacts and a higher willingness to take adaptive measures and to seek alternative modes of production in the Southern agro-climatic zones than in the Northern ones (European Commission 2009a).

Farmers have always adapted to changes in climate. The challenge now is to adapt within very short periods of time to potentially extreme impacts, and new risks and opportunities. This will be achieved through a combination of managerial, infrastructural and technical measures (European Commission 2009b). Diversification is also an important tool in farmers' hand, especially from financial point of view. Many of the possible adaptation measures to address the risks and opportunities identified in the nine agro-climatic zones can be applied at farm level, with correct management. But there is a need for EU measures as well to help farmers cope with the forecasted loss of agricultural production. While in a global economy it might be argued that the market should be left to resolve such issues, it must also be remembered that social and environmental issues are closely affected by this one, which may fail without any support. Insurance needs to be considered to allow farmers to increase their adaptation to climate change.

The current CAP measures are only partly adequate to adapt the new conditions. Several changes need to be done in the future CAP in order to make the instruments appropriate and flexible enough to ease the Europe-wide different adaptation. Short-term measures involving policy development and knowledge

5 In the case of biogas production, the proper use of gas is also an important issue. Local use is essential as biogas cleaning is very costly and therefore it makes almost no sense to do it in order to pump the biogas into the gas supply system.

transfer must be put first in place. Existing CAP mechanisms can be used to stimulate and facilitate adaptation and other mechanisms must also be used, such as insurance and partnerships (European Commission 2009a).

The Good Agricultural and Environmental Condition (GAEC) standards provide the Member States with the required flexibility to use locally appropriate management practices. However the instrument could be improved by indentifying each Member State's major environmental threats, which should be focused on.

Member States should be required to make farmers aware of climate change issues, particularly for new entrants such as young farmers. Developing the role and scope of the Farm Advisory System (FAS) would be a feasible option for effective knowledge transfer. For the best result, the use of FAS should even be obligatory for farmers.

The Rural Development Programs have the potential to support the adaptation by obligating Member States to consider the impacts of future climate change across all axes. The aim of the mitigation of climate change would be achieved better by linking funding to cross-compliance (Iglesias et al. 2007). Adjusting the criteria for those eligible for rural development support for areas with high vulnerability to climate change may be an option to facilitate their adaptation. But it should mentioned that the European Union has already recognized the importance of proactive actions and funded numerous projects related to climate change adaptation (e.g. see Policy Research Corporation 2009, Annex III.).

The actual state of adaptation differs from country to country. More developed and/or affected countries are playing a leading role in the process. The following table gives an overview of the actual state of adaptation strategies in Europe *(Table 8).*

Table 8. Summary of national adaptation strategies in the EU-27 and other European countries

Status of the national adaptation strategies	Countries
Developed	Finland, Spain, France, Sweden
Under preparation, to be published in the near future (EU-27)	The Netherlands, UK
Under preparation, to be published in the near future (other European countries)	Norway
First steps	Rest of the countries

Source: Iglesias (2009, p. 159).

As a key area of addressing climate change, adaptation researches has quite an old history. Most of the possible answers are well known, but only some of them are widely used. Introducing them requires not only time and money, but also changes in people's attitude towards public goods, (positive) externalities, education and in some cases strong political will. The following table contains suggested policies to support adaptation of European countries *(Table 9).*

Table 9. Suggested resource based policies to support adaptation of European agriculture to climate change

Resource	Policy
Land	Reforming agricultural policy to encourage flexible land use. The great extent of Europe cropland across diverse climates will provide diversity for adaptation.
Water	Reforming water markets and raising the value of crop per volume of water used to encourage more prudent use of water. Water management, that already limits agriculture in some regions, is crucial for adapting to drier climate.
Nutrients	Improving nutrient use efficiencies through changes in cropping systems and development and adoption of new nutrient management technologies. Nutrient management needs to be tailored to the changes in crop production as affected by climate change, and utilisation efficiencies must be increased, especially for nitrogen, in order to reduce nitrous oxide emissions.
Agrochemicals	Support for integrated pest management systems (IPMS) should be increased through a combination of education, regulation and taxation. There will be a need to adapt existing IPMS's to the changing climatic regimes.
Energy	Improving the efficiency in food production and exploring new biological fuels and ways to store more carbon in trees and soils. Reliable and sustainable energy supply is essential for many adaptations to new climate and for mitigation policies. There are also a number of options to reduce energy use in agriculture.
Genetic diversity	Assembling, preserving and characterizing plant and animal genes and conducting research on alternative crops and animals. Genetic diversity and new genetic material will provide important basic material for adapting crops species to changing climatic conditions
Research capacity	Encouraging research on adaptation, developing new farming systems and developing alternative foods. Increased investments in agricultural research may provide new sources of knowledge and technology for adaptation to climate change.
Information	Enhancing national systems that disseminate information on agricultural research and technology, and systems encourages information exchange among farmers. Fast and efficient information dissemination and exchange to and between farmers using the new technologies (e.g. internet) will speed up the rate of adaptation to climatic and market changes.
Culture	Integrating environmental, agricultural and cultural policies to preserve the heritage of rural environments. Integration of policies will be required to maintain and preserve the heritage of rural environments which are dominated by agricultural practices influenced by climate.

Source: Easterling (1996) modified by Olesen–Bindi (2002, p. 255).

6. CAP BEYOND 2013 AND THE ADAPTATION

The 2003 CAP reforms were a first step towards a framework for the sustainable development of EU agriculture. The central objective of the reforms was to promote a competitive and market-responsive agricultural sector. High standards for the environment, the public, animal and plant health, and animal welfare were key issues during the reform. Decoupling helped reach greater market responsiveness, while higher standards were achieved through cross-compliance. When improving the CAP measures, the focus should be on the aim to be better suited to climate change adaptation. Fortunately, the challenges represented by the climate change are widely known among the developers of the future CAP. The direction of the CAP beyond 2013 is going to be built on the 2003 reforms, with a continued shift from market intervention and further decoupling. In order to create well targeted measures it is also necessary to elaborate the good allocation of resources. For this reason, the current reform of the CAP must be accompanied in time by the creation of the new Multiannual Financial Framework (MFF).

The CAP 2020 Presidency Conclusions (Council of the European Union 2011) clearly establish that "the CAP already includes significant green elements". While cross-compliance with GAEC standards promotes the reduction and control of undesirable impacts of agriculture on the natural environment, the so-called agro-environmental schemes under the second pillar benefit conservation and landscape management efforts.

As put forward in the CAP 2020 Presidency Conclusions, further greening "must be based upon the experience of the CAP's current green policy measures". The bipolar structure, i.e. cross compliance and the second pillar's agro-environmental payments, has proven its worth Europe-wide. However, additional values and a certain extent of fine-tuning are welcome.

At the discussion of the Commissions proposal on the CAP beyond 2013 there were two approaches in the further greening of the CAP. Some MSs proposed a cross-compliance-focused solution, i.e. to refine the GAEC standards to meet additional or higher environmental values. On the other hand, there were hints that the Commission is devoted to give greening a "targeted" priority and couple green payments with certain environmental performance. According to the Commission's proposal on the Multiannual Financial Framework 2014–2020 (European Commission 2011) the Commission intends to couple 30% of the direct payments to green measures. This approach, in spite of the good intention, carries the possibility of complication (instead of simplification) and an interference with pillar two agro-environmental measures.

This sort of greening measures have different impacts on holdings that are located in designated areas (e.g. Natura 2000) and also on those that are not. Evidently, such location implies natural and administrative burdens on the economical efficiency of production. Carrying out environmental efforts is, in some cases, perfectly proportional with size in terms of variable costs or opportunity costs. However, certain limitations of the farming activity (e.g. altered grazing or mowing periods) come across as quality losses which may have a more severe impact on small-scale farms. Not only the different size of holdings, but also the diverse conditions in MSs have different consequences in terms of economic performance of apparently similar holdings. For this reason the flexibility provided for the MSs is crucial. As for the proportionality with efforts to achieve CAP objectives, the objectives must be translated into proper measures and programs, and then no doubt the farmers participating in the different measures will get only the amount of support they deserve for their activity and ambitions. This would lead to the efficient and well targeted allocation of the reduced resources which were indicated by the new MFF.

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