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Impacts and adaptive capacity as drivers for prioritising agricultural adaptation to climate change in Europe

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ABSTRACT: In the face of likely climate change impacts policy makers at different spatial scales need access to assessment tools that enable informed policy instruments to be designed. Recent scientific advances have facilitated the development of improved climate projections, but it remains to be seen whether these are translated into effective adaptation strategies. This paper uses existing databases on climate impacts on European agriculture and combines them with an assessment of adaptive capacity to develop an interdisciplinary approach for prioritising policies. It proposes a method for identifying relevant policies for different EU countries that are representative of various agroclimatic zones. Our analysis presents a framework for integrating current knowledge of future climate impacts with an understanding of the underlying socio-economic, agricultural and environmental traits that determine a region's capacity for adapting to climate change.

KEYWORDS: Adaptation, adaptive capacity, agriculture, climate change.

JEL classification: Q18, Q54.

Impactos y capacidad de adaptación como factores determinantes para priorizar la adaptación agrícola al cambio climático en Europa

RESUMEN: A la hora de afrontar los potenciales impactos del cambio climático, las administraciones encargadas de la toma de decisiones a cualquier escala territorial deben disponer de herramientas de evaluación que permitan el diseño de políticas relevantes. Los últimos avances científicos han permitido el desarrollo de mejores proyecciones climáticas, pero aún está por ver si éstas se acaban traduciendo en estrategias de adaptación efectivas. En el presente trabajo se utilizan bases de datos existentes sobre impactos climáticos en la agricultura europea y se combinan con una evaluación de la capacidad de adaptación para desarrollar un enfoque interdisciplinar para la priorización de políticas. Asimismo, se propone una metodología para la identificación de políticas relevantes para diferentes países de la Unión Europea representativos de distintas zonas agroclimáticas. Nuestro análisis presenta un marco que permite hacer uso de los conocimientos actuales acerca de los futuros impactos del cambio climático teniendo en consideración los factores socio-económicos, agrícolas, y medioambientales subyacentes que determinan la capacidad de una región de adaptarse al cambio climático.

PALABRAS CLAVES: Adaptación, capacidad de adaptación, agricultura, cambio climático.

Clasificación JEL: Q18, Q54.

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1. Introduction

In recent years climate change science has progressively developed its ability to understand how anthropogenic drivers will contribute to future impacts in different regions (IPCC, 2007; Ciscar *et al.,* 2011; Moss *et al.,* 2010; Giorgi, 2006). Alongside these developments in climate projections there has also been a growing interest in comprehending how future changes will impact human socio-economic systems (Parry *et al.,* 2001; Yohe *et al*., 2006; Lobell and Burke, 2010; Arnell, 2004; Vorosmarty *et al.,* 2010). The proper understanding of impacts and vulnerabilities has led to a vigorous interest in conceptualising adaptive capacity and designing adaptation strategies to reduce the damages and losses associated with global climate change (Parry, 2002; Niang-Diop and Bosch, 2004; Iglesias *et al.,* 2009; Tompkins and Adger, 2004; Lim *et al.,* 2004).

In Europe, agriculture is the main user of land and water and therefore one of the most vulnerable sectors in the region's economy (Iglesias *et al.,* 2007a; Ciscar *et al.,* 2011). This is not to say, however, that climate change impacts will be uniform throughout Europe. On the contrary, climate change is likely to aggravate both risks and vulnerabilities even as it creates opportunities for future gain. In part, the likelihood of risks and opportunities depends upon current, baseline conditions including socio-economic characteristics. It is these socio-economic characteristics which partially determine the extent to which different countries will be able to adapt to projected climate changes (Yohe and Tol, 2002; Reidsma *et al.,* 2007).

Environmental changes are likely to evolve into conflicts among agricultural users which may be aggravated by complex institutional and legal structures that hinder the development of appropriate policies geared towards sustainable management (Iglesias *et al.,* 2009). Therefore there is a need to re-think agricultural policy priorities in Europe. Understanding how socio-economic characteristics influence adaptive capacity, and the extent to which adaptive capacity will modify climate change impacts is of great strategic value for the future development of agricultural policy at the EU level. Under climate change, policies need to keep in mind the different variations within regional climate even though finding common ground between competing regional claims is a serious challenge to the development of regional policy. Nevertheless, this challenge needs to be addressed to ensure the consistency and efficiency of policy measures under a changing climate.

Until recently, however, there have been few specific national-level evaluations that take into account important regional and national differences; exceptions include Quiroga and Iglesias (2009) and Iglesias *et al.* (2010b), among others. Taking our cue from the vast bodies of literature existing on the themes of climate impacts and climate adaptation we propose a method for formulating adaptation strategies for different EU countries that are representative of the region's various agroclimatic zones. More specifically, we present a framework for integrating current knowledge of future climate impacts with an understanding of the underlying socio-economic traits that determine a country's capability for adapting to climate change. The framework's objective is to facilitate the prioritisation of policy innovations that are tailored to specific country needs.

Section 2 bellow describes the methods used in this analysis to evaluate future impacts, adaptive capacity and recommendations on policy measures proposed. The section on results outlines of the outcome of the evaluation, and is followed by a discussion and the conclusions.

2. Methods

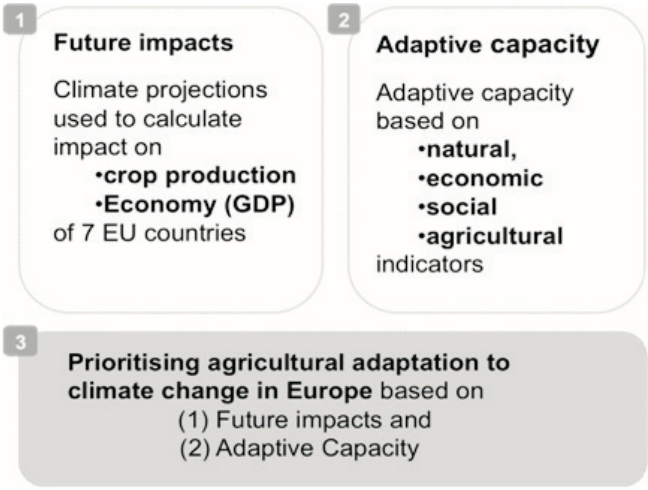
Approach

In this study, we evaluate likely future biophysical and economic impacts of climate change for 2080, using two different future socio-economic scenarios and two climate models for seven different European countries: Romania, Finland, France, Germany, Italy, Spain, The Netherlands. We also develop an adaptive capacity index, based on socio-economic, natural and agricultural factors in order to take a snapshot of the current state of affairs in the countries for which crop productivity and economic changes are projected. Based on the projected biophysical and economic impacts, their relation to adaptive capacity and the weakest component for each country, we propose a number of policy recommendations and mechanisms to facilitate positive impacts or reduce or prevent projected negative impacts.

The methodological framework is presented in Figure 1 and the following section outlines the methodology used for evaluating current-socio-economic status and future climate change impacts.

FIGURE 1

Methodological framework of the study



Source: Own work.

Geographical scope

The focus of the analysis is on 7 European countries, which are representative of major agricultural producers as well as different socio-economic levels and environmental or agricultural zones in Europe. Figure 2 presents an overview of the countries considered in this analysis and the agricultural regional aggregation to which they belong in the PESETA (Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis) study (Ciscar *et al.,* 2009). This aggregation is based primarily on broad climatic conditions in the areas in question. Other aggregations exist (Olesen and Bindi, 2002), generally based also on climatic factors, although different nomenclature may be used. Depending on the study carried out, it may also be relevant to aggregate countries based on economic, social or other environmental criteria. Also provided in Figure 2 is a general overview of the characteristics of the agricultural sector in each country. This particular distribution for analysis provides a comprehensive overview of the likely future impacts of climate change in different regions of Europe.

FIGURE 2

Overview of countries considered in the study, their agricultural region and major characteristics of the agricultural sector

Country	Agricultural regional aggregation (Ciscar et al., 2009)	General overview of agricultural Sector
Romania	Continental South	Important economic sector as shown by population employed and % of gross domestic product (GDP); potential considerable future growth in productivity due to climate change and technology improvements
Finland	Boreal	Low-input, agricultural production. Potential increase in agriculturally suitable land in future and in importance for international cereal production
France	Mediterranean North	One of the world's largest producers of agricultural goods, characterised by very different climates. Difficult to characterise future impacts at the national scale.
Germany	Atlantic Central	Central European country; importance of agriculture for economy and number of farms has fallen continuously in recent decades. The size of the agricultural sector however still makes it an important player internationally.
Italy	Mediterranean South	Highly productive, high-input, intensive agricultural, likely to suffer to varying degree from climate change (north-south).
Netherlands	Atlantic Central	Intensive, high-input, agriculture with high technology use. Grassland and livestock production are important agricultural sectors. Major challenges through erosion, salt-water intrusion, and sea-level-rise.
Spain	Mediterranean South	Considerable regional variation in climate and agricultural production, productivity and intensity of agricultural cultivations. Climate Change poses considerable threat to the agricultural sector in Spain.

Source: Own work.

Projected biophysical and economic Impacts

Climate Change Projections

In order to quantify future impacts of climate change in the chosen countries and regions in Europe, we use databases from the PESETA project (Ciscar *et al.,* 2009; Ciscar *et al.,* 2011), which integrate a set of high-resolution climate change projections and physical models into an economic modelling framework. The projected climate data used in the PESETA project (Ciscar *et al.,* 2009), which forms the basis of this analysis, is derived from the PRUDENCE project (Christensen and Christensen, 2007), which provided a series of high-resolution climate change scenarios for 2071-2100 for Europe based on two global circulation models (GCM):

- the atmospheric model ECHAM of the Max Planck Institute for Meteorology (Roeckner *et al.,* 2003); and
- the atmospheric model HadAM3H of the Hadley Centre for Climate Prediction and Research.

The output from GCMs is quite coarse, so in order to increase resolution, two regional climate models (RCM) were used in the PRUDENCE project (Christensen and Christensen, 2007):

- HIRHAM is based on a subset of the High Resolution Limited Area Model (HIRLAM), a Numerical Weather Prediction (NWP) forecast system (Undén *et al*., 2002); and

- RCAO, the Rossby Centre Atmosphere-Ocean model, developed by the Swedish Meteorological and Hydrological Institute (SMHI).

These models use as their inputs, scenarios that explore the future developments of the global population, Gross Domestic Product (GDP), energy use, land use and emissions of greenhouse gases based on a number of socio-economic and technological considerations or 'storylines' as specified in the Special Report on Emissions Scenarios (SRES) of the Intergovernmental Panel on Climate Change (IPCC). The SRES ensure that inputs to different climate models can be compared based on common assumptions.

A2 and B2 scenarios are used, because data are available for both and because of their contrasting natures. Providing an analysis of both of these storylines allows certain inferences to be made regarding the influence of policies on climate change and its impacts. These scenarios can be described as follows (Nakićenović *et al*., 2000):

- the A2 scenario describes a more heterogeneous, economically oriented, regional growth scenario in which global population is expected to grow to 15.06 billion and CO_2 emissions rise to 29.09 gigatonnes of Carbon (GtC) by 2100 (Nakićenović *et al.,* 2000) and
- the B2 scenario describes a world more focused on environmental sustainability, with intermediate economic development. Population in this scenario would reach 10.41 billion and emissions 13.32 GtC by 2100.

Biophysical and Economic Impact

For the assessment of future changes in crop productivity, data from the PESETA Project ARE used (Ciscar *et al*., 2009) in the DSSAT[1] (Decision Support System for Agrotechnology) model. Based on the statistical relationship between simulated crop responses to a range of climate and management options, crop production functions, are derived and then used to evaluate productivity changes. This analysis uses the previously derived impacts on crop productivity from 109 sites across the seven chosen European countries and aggregates them at country level by averaging the values from these sites for the country in question (Ciscar *et al.*, 2009). One limitation of this approach of averaging the values at national level is that it may hide major regional variations, particularly in larger countries.

To provide an overview of the likely economic impacts of climate change on the agricultural sectors of the countries considered, the Global Trade Analysis Project (GTAP)[2] general equilibrium model (Hertel, 1997) is used. The productivity shock, derived from the crop productivity changes as described above, is introduced into the GTAP model as land productivity- augmenting technical change whereby productivity change is modelled as a shift of the production function, similar to what would happen if there were technology changes.

[1] See http://www.icasa.net/dssat/

[2] See https://www.gtap.agecon.purdue.edu for further information.

The national economic impact, measured by changes into GDP is based on expected regional impacts and the regional agricultural aggregation following Ciscar *et al.* (2009) as shown in Figure 2. Thus the GDP impact for Romania is based on that of the Continental South region; that of Finland on the Boreal region; France on the Atlantic Central and Mediterranean North; that of Germany on the Atlantic Central and Continental North; Netherlands, Atlantic Central; Italy, Mediterranean South and Mediterranean North; and that of Spain on the Mediterranean South.

The source of data and the approach to estimating the biophysical and economic impacts of climate change considered in this analysis presented in Table 1.

TABLE 1

Overview of Biophysical and Economic impacts of climate change

Type of impact variable	Source	Method used to derive the impact variable	Aggregation in this study
Crop production change from baseline in %	Ciscar *et al* 2009; Iglesias *et al*., 2010a;	Validated process based crop models, statistical models (crop production functions);	109 sites aggregated at National level for 7 EU countries
GDP changes from baseline in %	Ciscar *et al*. 2009; Ciscar *et al*. 2011; Nakićenović *et al*., 2000	Based on GTAP, using crop production changes and SRES population changes	6 Agricultural zones of 7 EU countries.

Source: Own work.

Adaptive capacity

Adaptive capacity is defined as the capacity of an economic, social, environmental or other system to cope with or recover from a potentially damaging external shock or influence. This external trigger can be natural or man-made. In terms of climate change, adaptive capacity is generally understood to be the ability of the system to cope with the impacts of climatic changes, including storms, flooding, drought and sea-level rise, among others and an increase in the frequency and intensity of these events. In settings where positive impacts are expected based on climate change, the ability to adapt entails taking advantage of new opportunities.

In this sense, adaptive capacity is the combination of a number of social and economic components (Smit and Wander, 2005; Yohe *et al.*, 2006; Iglesias *et al.,* 2010a; IPCC, 2007). A number of indices of adaptive capacity have been developed (Yohe and Tol, 2002; Ionescu *et al.,* 2009; Yohe *et al*., 2006; Iglesias *et al.,* 2007c) to capture different elements of social and economic vulnerability to climate change. The adaptive capacity index that we present here is modified to mold it to the European context and is based on the one presented by Iglesias *et al*. (2007c). The choice of indicators in the modified adaptive capacity index is less sensitive to developmental concerns and more attuned to capturing country-specific differences within the European context through an aggregate consideration of natural, social, economic,

and agricultural components of adaptive capacity. The value of the index represents a country's potential adaptive capacity, understood as a modifier of climate impacts.

The different components consider different natural, social, economic and agricultural aspects as a way of gauging the extent to which agriculture in different countries is prepared to deal with the impacts of climate change. Firstly, the natural component measures the extent to which environmental changes will impact agriculture. Given the strong evidence for changes in precipitation patterns, the chosen indicators look at the relationship between water and agriculture. The component offers insights into the vulnerability of agricultural sectors to climate change. Secondly, the social component evaluates the associated adaptive capacity of a society through an analysis of some general indicators intended to capture the country's degree of social development. The indicators selected for this component include voter participation (Putnam, 1995), the United Nations Development programme (UNDP) Human Development Index (HDI) and a measure of income inequality (Putnam, 1995; Gupta *et al.,* 2010). The economic component indicates a country's capacity to invest in technologies, food security and income stabilisation. The indicators selected for this component are GDP, the contribution of agriculture to GDP and a measure of net savings. Finally, the agricultural component indicates the strength of the agricultural sector in terms of its productivity, the percent of total active population engaged in agriculture and the level of mechanisation to provide an overview of the sector's capacity at an aggregated country level. The links between agriculture and environment mean that climate change will have a stronger impact on those sectors less able to cope. The indicators chosen for each component are reproduced in Table 2 and were chosen for their relevance for the policy setting under consideration as well as for their availability and ease of calculation, two fundamental criteria in the development of indicators.

To quantify the index we: (a) select the indicators that are policy relevant; (b) normalise the indicators with respect to a common baseline; (c) combine the subcomponent indicators within each policy category by weighted averages; and (d) quantify adaptive capacity index as the weighted average of the components. Ideally, stakeholders would be consulted on how to value the various components of the adaptive capacity index in order to adequately reflect the importance of these and any local and regional variations based on social, political, historical or other factors. However, as this exercise is meant only to be illustrative of the value of assessing adaptive capacity, equal valuation is assumed for the four components.

The scores of the adaptive capacity index range from 0 to 1, with 0 being the situation where it is least developed and 1 where adaptive capacity is most developed. The total index is generated as the average of all components. By looking at the components of adaptive capacity that limit the overall value, the analysis may assist in the formulation of adequate policies to respond to climate change. This difference is especially evident in the case of economic and social capacities (Iglesias *et al.,* 2009).

TABLE 2

Choice of indicators of adaptive capacity by component

Component	Indicators	Source and year of data
Natural	Agricultural Water Withdrawal as % of total withdrawal	FAO[a] (2000)
	Total Water use (% of renewable)	FAO (2002)
	Irrigation area (% of cropland)	FAO (2007, 2002 for Germany)
	Average precipitation depth mm/yr	FAO (2007)
	Adjusted net saving[b]	World Bank[c] (2007)
Economic	GDP per capita (current $)	World Bank (2007)
	Agricultural value added (%of GDP)	FAO (2007)
	Voter Participation	Eurostat[d] (average 99 – 09)
Social	Human Development Index	UNDP[e] (2006)
	Gini coefficient[f] – inequality of income distribution	Eurostat[d] (2007)
	Cereal yield (Kg/Ha)	FAO, World Bank (2008)
Agriculture	Agricultural machinery, tractors per 100sq km arable land	FAO (2007)
	Agricultural employment (% of total)	ILO[g] (2007)

[a] Food and Agriculture Organization (FAO) of the United Nations (UN) from FAOSTAT (http://faostat.fao.org/) and AQUASTAT.

[b] Adjusted net saving, (also known as genuine saving), is a sustainability indicator building on the concepts of green national accounts. Adjusted net savings measure the true rate of savings in an economy after taking into account investments in human capital, depletion of natural resources and damage caused by pollution.

[c] World Bank World Development Indicators, WDI (http://data.worldbank.org/indicator).

[d] Eurostat (http://epp.eurostat.ec.europa.eu).

[e] UNDP Human Development Indicators (http://hdrstats.undp.org/en/indicators/default.html).

[f] The Gini coefficient is a measure statistical dispersion used to determine the inequality of a distribution.

[g] ILO (http://www.ilo.org).

Source: Own elaboration.

The focus of this study is on the agricultural sector and its adaptation to the challenges and opportunities presented by climate change. This focus is reflected in the indicators selected, which are mostly agriculture-related indicators within the different components. Table 3 provides an overview of the agriculture-related indicators used in the evaluation of adaptive capacity for the seven countries considered in the analysis – the source and year of data is listed in Table 2.

Some of the differences between countries, such as the higher water withdrawals in Italy and Spain are intuitive. On the other hand, other figures such as the high number of tractors in Italy require further explanation. In this case, it is due to structure of the agricultural land holdings of the country: Italy is generaly considered to be wealthy country with a large number of relatively small farms: over 60% of it's farms are smaller than 5 hectares (European Commission, 2008). By contrast, in Germany and France this type of farms makes up less than 10% of the total – the greater number of larger farms means that fewer tractors are requiered.

TABLE 3

Selected agriculture related indicators and their values used in the calculation of the adaptive capacity

Country	Agricultural Water With-drawal as % of total with-drawal	Irrigation area (% of crop land)	Agricultural Value Added (% of GDP)	Average Cereal yield (Kg/ha)	Agricultural machinery, tractors per 100sq km ar-able land	Agricultural employ-ment (% of total)
Romania	17.89	6.83	8.97	4530	203	29.5
France	9.81	13.68	2.20	7293	616	3.4
Finland	0.06	3.40	3.00	3655	347	4.5
Germany	2.93	4.04	0.92	7119	646	2.2
Nether-lands	2.96	41.79	2.00	7158		3.0
Italy	45.10	40.71	2.04	5275	2668	4.0
Spain	68.03	21.10	2.91	3584	800	4.5

*For source and year of data please see Table 2.

Source: Own work.

One limitation of the adaptive capacity index is its spatial resolution. In the analysis carried out here, the evaluation at the national level hides major regional and local differences – it is, for instance, difficult to compare the agriculture of southern-Finland to that of northern Finland. In addition, the indicativeness of national data used, such as annual precipitation aggregated at country level, is questionable. The adaptive capacity index can be calculated for smaller spatial scales, but this depends directly on the availability of relevant data.

It should also be noted that some of the indicators of the adaptive capacity (such as precipitation) are independent of any management, economic or social conditions and are therefore beyond the scope of influence of the respective countries or areas whose adaptive capacity is evaluated. However, as shawn bellow, the components that make up the adaptive capacity can aid in indicating specific policy areas could potentially be focused on to improve adaptive capacity and thereby facilitate adaptation to climate change in the future.

Establishing policy priorities

Based on the biophysical and economic results of our analysis and the establishment of the weakest component of the adaptive capacity index, we propose a number of policy priorities and measures in the agricultural and related fields in order to reduce the potential negative consequences and enhance potential positive results of climate change. We assume that the adaptive capacity index that is calculated for the countries in question provides a measure of the current resilience of a country to

future climate change and the changes in crop productivity and economic impacts projected for the future under climate change are a proxy of the likely variation over time under the A2 and B2 SRES scenarios. The policy priorities and measures suggested provide a link between current vulnerability and likely long-term future climate impacts. We focus on EU and national policy measures although many of the suggestions are not spatially explicit.

The first step is to determine impact risk thresholds. These thresholds are based on a qualitative appreciation of the perceived impacts of climate change as they are determined by changes in crop productivity and economic performance. The qualitative methodology utilised is similar to that presented in Iglesias *et al.* (2007b) to establish risk levels. Each impact is classed as neutral, negative or positive based on projected economic and crop productivity changes. The combination of these qualitative scores for both the crop productivity and economic impact is then used to determine the impact risk thresholds (Table 4). Thus, a country projected to suffer future decreases in crop productivity and economic well-being would be allocated a "serious to very serious" impact risk threshold. On the other hand if crop and economic impacts are estimated to be positive, a "none to beneficial" risk threshold would be assigned. The possible combinations are fewer in the "serious to very serious category" as there cannot be a positive impact in either crop or economic impact.

The development of these thresholds is meant to favour simplicity over complexity in order to facilitate for policy development and assessment. Once these thresholds are established, an initial sketch of agricultural vulnerability to climate change begins to emerge. Combining the thresholds with an appreciation of the weakest components of the adaptive capacity allows for policy priorities to be identified.

The logic behind this approach is based on the idea that adaptive capacity is considered to be a reflection of the overall conditions of the area studied (Smit and Pilifosova, 2003; Yohe and Tol, 2002), that local socio-economic context is a primary element that determines how and to what extent a country is capable of adapting to impacts. The impact risk thresholds determine how heavily a given agricultural system will be impacted by climate changes and the extent of potential damage. These thresholds are useful for determining agricultural impact hotspots and to direct the attention of policy efforts to those regions at greatest risk. Having identified potential risks, the next step is to identify which components of adaptive capacity are lagging behind, so as to target policies towards those sectors. In practice this means that different countries will have to adopt very different policies even though they may face the same kind of risk. The combined evaluation of impact risk and adaptive capacity components suggests the need for particular kinds of policies over others.

In order to establish what kinds of policy priority are required we follow the large body of literature on policy typologies developed in different fields of public policy management (Anderson, 1977; Whitehead, 2007; Smit and Skinner, 2002; Dovers, 2005; Yohe and Tol, 2002; Connor and Dovers, 2004). Policy choices are made depending on their feasibility, spatial scope, the degree of intervention required and their intended effect. Therefore, they are ultimately dependant on local context. In establishing priorities we are only delving into the first phases of the policy cycle –

mainly the identification of problems and the conceptualisation of appropriate strategies. This is followed by the implementation and assessment phases of the policy cycle. The discussion section sets out a typology that expands on the types of policy options that are most appropriate for redressing adaptive capacity weaknesses given the urgency and severity of different climate impacts.

TABLE 4

Definition of impact risk thresholds based on projected climate change impacts

Crop productivity	Economic impact	Impact risk threshold
Positive	Positive	None to beneficial
Neutral	Neutral	
Neutral	Positive	
Positive	Neutral	
Negative	Positive	Low to medium
Positive	Negative	
Negative	Negative	Serious to very serious
Neutral	Negative	
Negative	Neutral	

Source: Own work.

3. Results

Biophysical and economic impacts

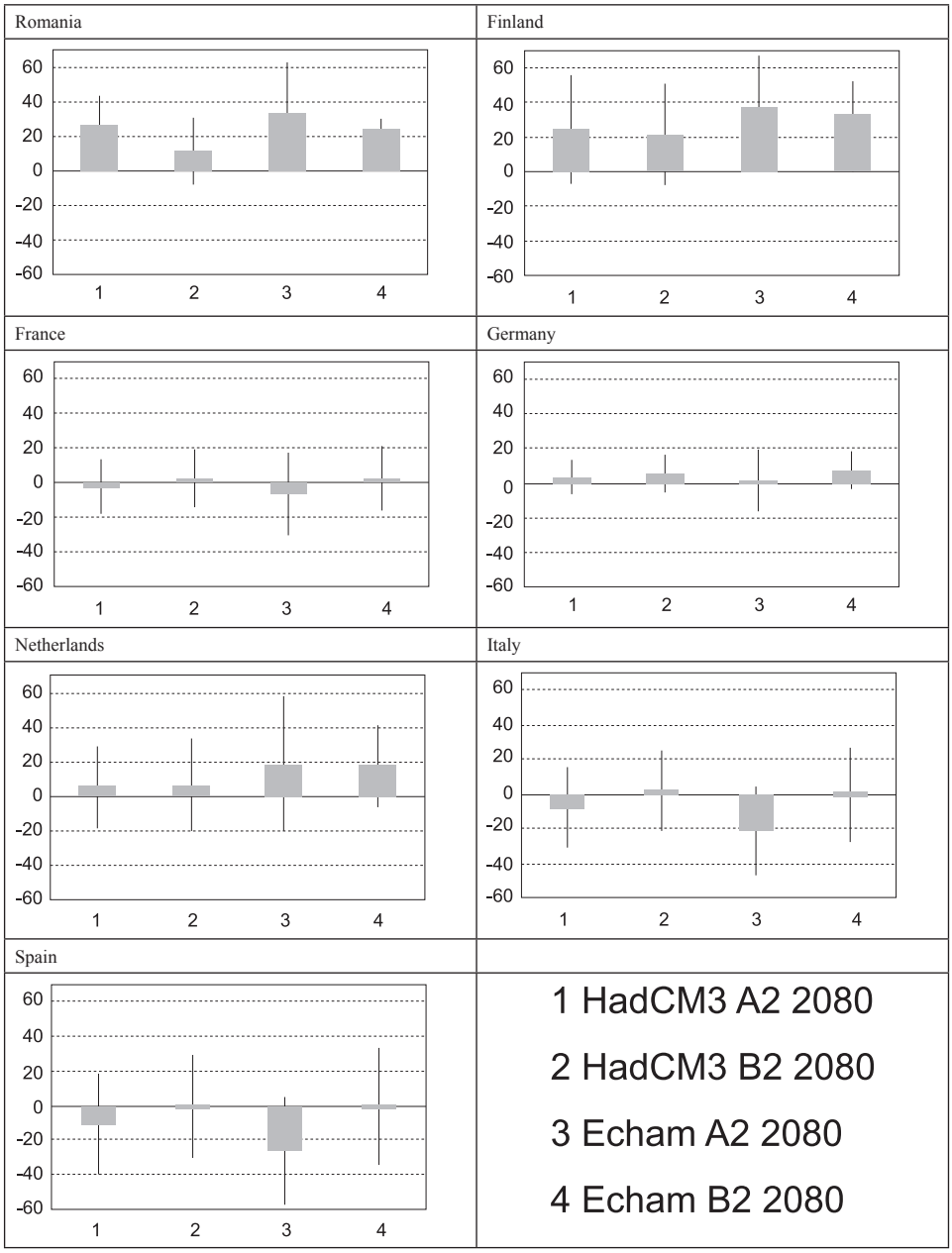
The results of calculating future crop productivity for the two different SRES scenarios (A2 and B2) using the Hadley (HadCM3) and Max Planck Institute of Meteorology (Echam4) climate models are shown in Figure 3 and Figure 4. Figure 3 shows the range of results per country for each of the climate models used whereas Figure 4 shows average values for the four climate models only.

According to these results, clear increases in crop productivity can be expected for Romania and Finland and, to a lesser extent, the Netherlands and Germany. Clear reductions in crop productivity are calculated for the Mediterranean countries of Spain and Italy. The results for France are more ambiguous and closer to zero.

The results for ECHAM A2 are the most extreme, positively for Romania, Finland and the Netherlands, and negatively for Italy and Spain. The HadCM3 A2 results mirror those of ECHAM A2 although the values are more dampened. For ECHAM B2, values are positive and similar to ECHAM A2 for Romania, The Netherlands and Finland; for Germany and France, values are slightly positive and for Italy and Spain they are nearly zero. Finally, values for percentage of productivity change under the B2 scenario of HadCM3 are positive for all countries but less than 5% for France, Italy and Spain.

FIGURE 3

Expected changes in crop productivity for 2071 - 2100 per country in % change from baseline (1971 – 2000 average)

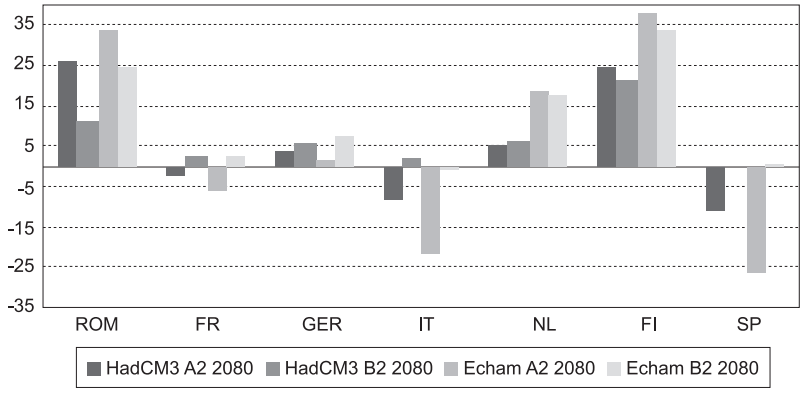


Boxes represent the 1st and 2nd quartile of the range in the values of standard deviation and vertical lines indicate the full extent of standard deviations.

Source: Own work.

FIGURE 4

Expected changes in average crop productivity for 2071 - 2100 per country in % change from baseline (1971 – 2000 average)

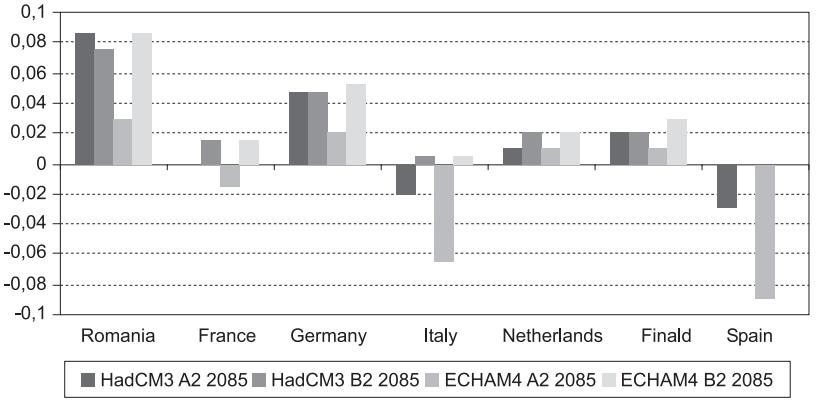


Source: Own work.

The projected percentage change in GDP per year from the 2000 baseline that results from an alteration in productivity, adjusting future population according to the A2 and B2 SRES scenarios are shown in Figure 5. The results mirror the observed changes in agricultural productivity. According to these projections, Romania can be expected to experience the greatest growth, surpassing 0.08% per year for the HadCM3 A2 and ECHAM4 B2 Scenarios whereas Spain can be expected to experience a decline in GDP of more than 0.08% per year for the ECHAM4 A2 scenario. Overall reductions are also projected in Italy for both the HadCM3 and Echam4 A2 scenarios although these stand in contrast to slight increases in the respective B2 scenarios. As in the case for Romania, Germany, and to a lesser extent Finland and the Netherlands, experience positive GDP growth in all scenarios. The results for France are, once again, more ambiguous and are close to zero.

FIGURE 5

Expected changes in GDP in % per year from 2000 baseline for 2071-2100; considering population based on A2 and B2 SRES and changes in agricultural productivity



Source: Own work.

Adaptive capacity

This seccion presents the results of our analysis of the adaptive capacity index under a single scenario, where all components are valued equally (see Table 2).

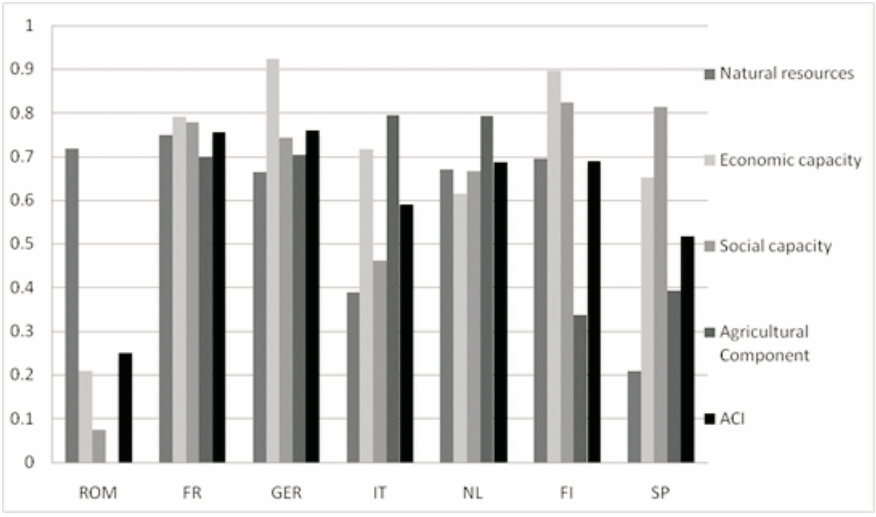
The results of the evaluation of adaptive capacity, as shown in Figure 6 follow, to some extent, what can be expected. France and Germany have the highest adaptive capacity, meaning that they are more likely to posses the economic, social, environmental and agricultural resources and capital needed to adapt to the expected impacts of climate change. The Netherlands, Finland and Italy follow France and Germany in the level of their adaptive capacity. Finally, Spain and Romania have the lowest adaptive capacity levels of the countries considered.

An analysis by components of adaptive capacity reveals that, Finland and Germany have the highest levels for the Economic Capacity component, whereas Romania has the lowest. France, The Netherlands, Romania and Finland have the highest calculated levels for the Natural Resources component and also rank highly in terms of Social Capacity. Spain and Italy have relatively low values for the Natural Resources component. Italy and the Netherlands rank highest in terms of Agriculture, whereas the value for Romania is the lowest for this component.

Finland's relatively low adaptive capacity is attributable, in part, to the design of the adaptive capacity index, which prioritises agricultural production and technology. Since agriculture in Finland is more extensive and less intensive, it also scores lowest in the Agricultural Component of the Adaptive Capacity Index.

FIGURE 6

Calculated adaptive capacity for selected European countries, based on the natural resources component, economic capacity, social capacity and agricultural components



Source: Own work.

Impact Risk Threshold and Adaptive Capacity

As described in the methodology, we propose relevant policy actions based on a combination of the biophysical and economic projections and the weakest component of the calculated adaptive capacity. In order to facilitate the identification of relevant actions, we propose the combination of the impact on crop productivity and GDP into one impact risk threshold per country, rather than an analysis differentiating between A2 and B2 (Table 4). Most countries in our analysis fall into the "none to beneficial" impact risk threshold. Italy and Spain are the notable exceptions and both countries have impact risk thresholds that are estimated to be serious to very serious. Table 5 shows the weakest component of the adaptive capacity of each country (Figure 6) along with its impact risk threshold.

TABLE 5

Impact risk thresholds and weakest component of adaptive capacity for the countries analysed

Country	Impact risk threshold	Weakest component of the Adaptive Capacity
Romania	None to beneficial	Agricultural
Finland	None to beneficial	Agricultural
France	None to beneficial	Agricultural
Germany	None to beneficial	Natural
Netherlands	None to beneficial	Social and Economic
Italy	Serious to very serious	Natural
Spain	Serious to very serious	Natural

Source: Own work.

4. Discussion

The projected biophysical and economic impacts presented in this study, linked to an analysis of adaptive capacity, provide a means for identifying relevant policy priorities and measures to reduce likely adverse impacts and facilitate any potential positive impacts.

The evaluation of changes in crop productivity and future economic impacts places current socio-economic status, natural capital and agricultural development in perspective. The results of our analysis of changes in crop productivity are fairly clear for the countries considered, with Romania and the countries located in Central and Northern Europe clearly benefiting, whereas losses can be expected for Mediterranean countries. In spite of considerable uncertainties in projections of crop production, derived from uncertainties regarding the predictions for climate change, technology development and other factors, which are manifested in the range of values observed, the overall direction of the change seems to be quite clear (Fronzek and Carter, 2007). Similarly, changes in GDP partially mirror those observed for crop productivity. This is, in part, attributable to changes in crop productivity although the trend of decreasing importance of the agricultural sector in the economies of European Union Member States is likely to continue in the future. Changes in future population, which are considered in the calculation of future GDP changes, also plays an important role.

Adaptive capacity at country level hides important regional disparities. Further studies could focus on evaluating adaptive capacity at lower spatial scales, such as river basin level. This will undoubtedly depend on the availability of data at this level of analysis – which still presents a bottleneck to modelling and evaluating in many different fields.

Ideally, the weighting of the components would be adjusted for each country or region in consultation with stakeholders and water managers to reflect the exact

importance of each for the particular level of analysis. This however is beyond the scope of the present study and would make inter-country or region comparison more difficult. In addition, considering that policies to facilitate adaptation are often initiated or promoted at the national level and financing may come from central government, the present approach allows an approximation to be obtained of the overall capacity of a country to adapt. Especially when making future projections, weighting modifications could help to evaluate different routes of development. For example, a plausible scenario may give the social component an additional weight, reflecting the assumption that a society with institutional coordination and strengths for public participation is less vulnerable to climate change (Gupta *et al*., 2010). Again, the difficulty in obtaining data for future projections at national, regional or sub-regional level may present an obstacle to evaluating different future scenarios.

The following section, proposes a number of policy priorities, based on projected economic and agricultural productivity changes, linked to adaptive capacity, we propose a number of policy priorities.

Selection of actions

The impact risk factor, as presented in Table 5 and based on the projected changes in productivity and GDP is used in combination with the Adaptitive Capacity Index to develop possible policy mechanisms, presented in Table 6. The table seeks to provide insights into how policies can be derived from the scientific indicators of impacts and adaptive capacity presented in this paper.

The severity of the impact risk threshold and the weakest component of the adaptive capacity can orient the broad policy focus of the actions that need to be taken. The sample policy mechanisms are derived from a review of policy documents from local, regional, national and EU authorities as well as a close analysis of the actual specific indicators that make up the components of the adaptive capacity index.

It should be clear that all three components socio-economic, natural and agricultural within a particular impact risk threshold level would most likely require policy action. However, taking account of the weakest component of adaptive capacity allows for better targeting of often-limited funds for policy intervention. In the case of a projected impact to risk threshold that is beneficial, focussing resources on the weakest component of the adaptive capacity can also ensure that the potential benefits can be taken advantage of or maximised.

TABLE 6

Summary of possible policy suggestions derived from the scientific indicators

Impact risk threshold	Weakest component of the adaptive capacity	Possible Policies
None to beneficial impact	Social and economic	Investment in Research and Education Evaluation of institutions and public consultation
	Natural	Develop sustainable water use practices, Resource management plans, Consider planned expansion of agriculture areas Invest in ecosystem restoration
	Agriculture	Consultation of Farming Sector to identify needs and problems identification Research and development in agriculture Incentivise innovation in the agricultural sector
Low to medium risk	Social and economic	Institutional reform with public participation Public access to policy Programms to promote public cooperation and confidence
	Natural	Educational campaigns to reduce water use Water use efficiency improvement programs Development of water storage facilities, where appropriate
	Agriculture	Enhance farm advisory service and research and extension services Information and programmes to foment improved cultivars Incentives for agricultural modernisation
Serious to very serious risk	Social and economic	Institutional changes through public consultation and participation Increase government spending on social and educational programms Guarantee basic minimum services, especially in times of crisis
	Natural	Emergency water management planning and implementation, Water use restrictions based on plans and prioritisation Mandatory water efficiency standards
	Agriculture	Consider mandatory adaptation of crops suitable to climate Rural income diversification through training Promote farmer insurance

Source: Own work.

5. Conclusions

This paper combines existing databases on climate impacts and the corresponding economic and biophysical impacts in 7 European countries with an assessment of adaptive capacity at country level to develop an interdisciplinary approach for prioritising policies. The policies presented in the previous section are meant to serve as an example to identify the general orientation of policies based on the weakest component determined by the Adaptive Capacity Index. The grouped indicators used to derive the social end economic, natural and agricultural components of the adaptive capacity index provide the necessary indications to propose the policies in the table.

Numerous policy instruments could be considered to strengthen their role in increasing resilience to projected climate impacts along the lines of the recommended policy focus suggested here. In the European context the EU Common Agricultural Policy (CAP) is capable of ensuring a common but differentiated approach to climate change adaptation in the agricultural sector. As the CAP is reformed, there is a growing need for future policy to take stock of projected climate changes and how they will impact Europe's agriculture. Following the 2008 "Health Check" of the CAP and subsequent public debate, the review process has recognised the importance of facilitating adaptation in the agricultural sector as well as its role in contributing to mitigating future impacts, as manifested in the 2010 Communication of the Commission on the reform of the CAP (European Commission, 2010).

National Adaptation Strategies are additional policy mechanisms, prepared within an international framework, that have been completed by a number of EU countries (including all those analysed in this study except Italy) and all directly address agriculture. These are and can be important instruments for facilitating adaptation in the agricultural and other sectors and should be considered in the European policy development context (Swart *et al.*, 2009; Kallis *et al.,* 2009).

Other policies such as the EU Water Framework Directive (Hering *et al.,* 2010) and specific initiatives to address climate change and adaptation at different spatial scales will also play an important role in facilitating adaptation and reducing potentially adverse impacts. However, it is important that considerations regarding climate change be mainstreamed into general policy development processes that affect agriculture in order to ensure that projects, programms and measures undertaken do not present unnecessary obstacles and to take advantage of any potentially beneficial synergies.

The orientation of policies that address likely future climate change impacts requires a detailed consideration of local conditions in terms of impacts, limitations and opportunities. The type of flexibility required by regional variations in biophysical and socio-economic conditions is a considerable hurdle that makes designing effective common policies inordinately difficult, especially since policies often originate at national or, in Europe, at EU level. That being said, with a close assessment of how climate change will affect Europe, broad principles and guidelines for policy development may be identified. Within appropriate policy instruments, such as the Rural Development Policy of the European Union (Pillar II of CAP), these guidelines could then be used to further define regionally and locally specific measures and policies that reflect the particular needs of farmers likely to be affected.

One of the main complexities in dealing with the climate projections and trying to develop polices from them stems from the uncertainties involved in socio-ecological systems (Reilly and Willenbockel, 2010). Numerous studies have shown that these social systems and the rules, institutions and organisations that underpin them are likely to be more decisive in facilitating adaptation to climate change than technological barriers (Swart *et al.*, 2009). The evaluation of future impacts for the 2070-2100 time-horizon is beyond any feasible policy development time-horizon but can nevertheless provide necessary guidance and information for policy makers in the present regarding the general direction that should be taken given our current understanding

of likely future impacts. Recently, efforts have been made to improve future scenarios (Moss *et al.,* 2010) and these will undoubtedly help to improve projections of future impacts, which can then be used to further define relevant policy approaches.

References

Anderson, C.W. (1977). *Statecraft: An introduction to political choice and judgment*. John Wiley and Sons, New York, NY.

Arnell, N.W. (2004). "Climate change and global water resources: SRES emissions and socio-economic scenarios". *Global Environmental Change*, 14(1): 31-52.

Christensen, J.H. and Christensen, O.B. (2007). "A summary of the PRUDENCE model projections of changes in European climate by the end of this century". *Climatic Change,* 81(1): 7-3.

Ciscar, J.C., Iglesias, A., Feyen, L., Goodess, C.M., Szabó, L., Christensen, O.B., Nicholls, R., Amelung, B., Watkiss, P., Bosello, F., Dankers, R., Garrote, L., Hunt, A., Horrocks, L., Moneo, M., Moreno, A., Pye, S., Quiroga, S., van Regemorter, D., Richards, J., Roson, R., Soria, A. (2009). *Climate change impacts in Europe*. Final report of the PESETA research project. Europea Commission Joint Research Centre - Institute for Prospective Technological Studies; EUR 24093 EN.

Ciscar, J., Iglesias, A., Feyen, L., Szabó, L., Van Regemorter, D., Amelung, B., Nicholls, R., Watkiss, P., Christensen, O.B., Dankers, R., Garrote, L., Goodess, C.M., Hunt, A., Moreno, A., Richards, J. and Soria, A. (2011). *Physical and economic consequences of climate change in Europe*, Proceedings of the National Academy of Sciences doi:10.1073/pnas.1011612108.

Connor, R. and Dovers, S. (2004). *Institutional change for sustainable development*. Edward Elgar.

Dovers, S. (2005). *Environment and sustainability policy: creation, implementation, evaluation*. Federation Press.

European Commission (2010). "The CAP towards 2020: Meeting the food, natural resources and territorial challenges of the future". *COM(2010),* 672.

European Commission (2008). "Agricultural Statistics; main results 2006-2007". *EUROSTAT*.

Fronzek, S. and Carter, T. (2007). "Assessing uncertainties in climate change impacts on resource potential for Europe based on projections from RCMs and GCMs". *Climatic Change,* 81(1): 357-371.

Giorgi, F. (2006). "Climate change hot-spots". *Geophysical Research Letters*, 33, L08707.

Gupta, J., Termeer, C., Klostermann, J., Meijerink, S., Van Den Brink, M., Jong, P., Nooteboom, S. and Bergsma, E. (2010). "The Adaptive Capacity Wheel: a method to assess the inherent characteristics of institutions to enable the adaptive capacity of society". *Environmental Science & Policy*, 13(6): 459-471.

Hering, D., Borja, A., Carstensen, J., Carvalho, L., Elliott, M., Feld, C.K., Heiskanen, A., Johnson, R.K., Moe, J., Pont, D., Solheim, A.L. and De Bund, W.V. (2010). "The European Water Framework Directive at the age of 10: A critical review of the achievements with recommendations for the future". *Science of the total Environment*, 408(19): 4007-4019.

Hertel, T.W. (1997). *Global Trade Analysis: Modelling and Applications.* University Press, Cambridge.

Iglesias, A., Garote, L., Flores, F. and Moneo, M. (2007a). "Challenges to manage the risk of water scarcity and climate change in the Mediterranean". *Water Resources Management*, 21(5): 227-288.

Iglesias, A., Avis, K., Benzi, M., Fisher, P., Harley, M., Hodgson, N., Horrocks, L., Moneo, M. and Webb, J. (2007b). "Adaptation to climate change in the agricultural sector". *ED05334,* Issue 1. Available online at http://ec.europa.eu/agriculture/analysis/external/climate/final_en.pdf.

Iglesias, A., Mougou, R. and Moneo, M. (2007c). "Adaptation of Mediterranean agriculture to climate change". In Battaglini, A. (Ed.): *Key vulnerable regions and climate change*. European Climate Forum, Germany.

Iglesias, A., Cancelliere, A., Cubillo, F., Garrote, L. and Wilhite, D.A. (2009). *Coping with drought risk in agriculture and water supply systems: Drought management and policy development in the Mediterranean*. Springer, The Netherlands.

Iglesias, A., Mougou, R., Moneo, M. and Quiroga, S. (2010a). "Towards adaptation of agriculture to climate change in the Mediterranean". *Reg Environ Change DOI* 10.1007/s10113-010-0187-4.

Iglesias, A., Quiroga, S. and Schlickenrieder, J. (2010b). "Climate change and agricultural adaptation: assessing management uncertainty for four crop types in Spain". *Climate Research,* 44(1): 83-94.

Ionescu, C., Klein, R.J.T., Hinkel, J., Kumar, K.S.K., Klein, R. (2009). "Towards a formal framework of vulnerability to climate change". *Environmental Modeling and Assessment Environmental Modeling and Assessment*, 14(1): 1-16.

IPCC (2007). *Climate Change 2007*. *Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge.

Kallis, G., Kiparsky, M. and Norgaard, R. (2009). "Collaborative governance and adaptive management: Lessons from California's CALFED Water Program". *Environmental Science & Policy*, 12(6): 631-643.

Lobell, D.B. and Burke, M.B. (2010). "On the use of statistical models to predict crop yield responses to climate change". *Agricultural and Forest Meteorology*, doi:10.1016/j.agrformet.2010.07.008.

Lim, B., Spanger-Siegfried, E., Burton, I., Malone, E. and Huq, S. (2004). *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures*. Cambridge University Press, Cambridge.

Moss, R.H., Edmonds, J.A., Hibbard, K.A., Manning, M.R., Rose, S.K., van Vuuren, D.P., *et al*. (2010). "The next generation of scenarios for climate change research and assessment". *Nature*, 463(7282): 747-756.

Nakićenović, N., Alcamo, J., Davis, G., de Vries, B., Fenhann, J., Gaffin, S., Gregory, K., Grübler, A., Jung, T. Y., Kram, T., *et al*. (2000). *Intergovernmental Panel on Climate Change.* Special Report on Emissions Scenarios.

Niang-Diop, I. and Bosch, H. (2004). "Formulating an adaptation strategy. In Lim, B. and Spanger-Siegfried, E. (Eds.): *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures.* Cambridge University Press, Cambridge.

Olesen, J.E. and Bindi, M. (2002). "Consequences of climate change for European agricultural productivity, land use and policy". *European Journal of Agronomy,* 16(4): 239-262.

Parry, M. (2002). "Scenarios for climate impact and adaptation assessment". *Global Environmental Change*, 12(3): 149-153.

Parry, M., Arnell, N., McMichael, T., Nicholls, R., Martens, P., Kovats, S., Livermore, M., Rosenzweig, C., Iglesias, A. and Fischer, G. (2001) "Millions at risk: defining critical climate change threats and targets". *Global Environmental Change,* 11(3): 181-183.

Putnam, R. (1995). Bowling alone: Americas declining social capital. *Journal of Democracy*, 6 (January): 65-78.

Quiroga, S. and Iglesias, A. (2009). "A comparison of the climate risks of cereal, citrus, grapevine and olive production in Spain". *Agricultural Systems*, 101(1-2): 91-100.

Reidsma, P., Ewert, F. and Oude Lansink, A. (2007). "Analysis of farm performance in Europe under different climatic and management conditions to improve understanding of adaptive capacity". *Climate Change,* 84(3-4): 403-422.

Reilly, M. and Willenbockel, D. (2010). "Managing uncertainty: a review of food system scenario analysis and modelling". *Philosophical Transactions The Royal Society B,* 365: 3049-3063.

Roeckner, E., Bäuml, G., Bonaventura, L., Brokopf, R., Esch, M., Giorgetta, M., Hagemann, S., Kirchner, I., Kornblueh, L., Manzini, E., Rhodin, A., Schlese, U., Schulzweida, U. and Tompkins, A. (2003). *The atmospheric general circulation model ECHAM5. Part 1. Model description. Report no. 349*. Max-Planck-Institut für Meteorologie (MPI-M).

Smit, B. and Skinner, M. (2002). "Adaptation options in agriculture to climate change: a typology", *Mitigation and Adaptation Strategies for Global Change,* 7(2002): 85-114.

Smit, B. and Pilifosova, O. (2003). "From adaptation to adaptive capacity and vulnerability reduction". In Smith, J.B.; Klein, R.J.T. and Huq, S. (Eds.): *Climate Change, Adaptive Capacity and Development*. Imperial College Press, London: 9-28.

Smit, B. and Wandel, J. (2005). "Adaptation, adaptive capacity and vulnerability". *Global Environmental Change*, 16(3): 282-292.

Swart, R.J., Biesbroek, G.R., Binnerup, S., Carter, T.R., Cowan, C., Henrichs, T., Loquen, S., Mela, H., Morecroft, M.D., Reese, M. and Rey, D. (2009). "Europe Adapts to Climate Change: Comparing National Adaptation Strategies. (no. 01/2009)". *Partnership for European Environmental Research (PEER)*, Helsinki: 160.

Tompkins, E.L. and Adger, W.N. (2004). "Does adaptive management of natural resources enhance resilience to climate change?". *Ecology and Society,* 9(2): 10.

Undén, P., Rontu, L., Järvinen, H., Lynch, P., Calvo, J., Cats, G., Cuxart, J., Eerola, K., Fortelius, C., Garcia-Moya, J.A., Jones, C., Lenderlink, G., McDonald, A., McGrath, R., Navascues, B., Woetman Nielsen, N., Ødegaard, V., Rodrigues, E., Rummukainen, M., Rõõm, R., Sattler, K., Hansen Sass, B., Savijärvi, H., Wichers Schreur, B., Sigg, R., The, H. and Tijm, A. (2002). *HIRLAM-5 Scientific Documentation*. Scientific Report. Available online from http://hirlam.org .

Vorosmarty, C.J., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S.E., Sullivan, C.A., Liermann, C.R. and Davies, P.M. (2010). "Global threats to human water security and river biodiversity", *Nature*, 467(7315): 555-561.

Whitehead, M. (2007). "A typology of actions to tackle social inequalities in health". *Epidemiol Community Health,* 2007, 61: 473-478.

Yohe, G., Malone, E., Brenkert, A., Schlesinger, M., Meij, H. and Xing X. (2006). "Global Distributions of Vulnerability to Climate Change". *Integrated Assessment Journal*, 6(3): 35-44.

Yohe, G. and Tol, R.S.J. (2002). "Indicators for social and economic coping capacity-moving toward a working definition of adaptive capacity". *Global Environmental Change,* 12(1): 25-40.