Climate change and regulation of agricultural land use
a literature survey on adaptation options and policy measures
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Climate change and regulation of agricultural land use: A literature survey on adaptation options and policy measures

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Abstract

The objective of this working paper is to perform a survey of the climate change literature to establish a policy tool box for regulation of agricultural land use in a changing environment. The policy tool box should serve as a source of inspiration for identifying adaptation options to climatic changes. Adaptation refers to changes in processes, practices or structures to moderate or offset potential damages or to take advantage of opportunities associated with changes in the climate. The working paper addresses the agronomic, socio-economic and environmental impacts of climate change on agro-ecosystems. The focus is on the adaptation options relevant for policy makers, i.e. adaptation measures representing conscious policy options or response strategies aimed at altering the adaptive capacity of the agricultural system or facilitating particular adaptations to climate change. The Working Paper does not make any recommendations between different adaptation options or policy measures but provides a gross list of the suggested options and measures reported in the literature.
Preface

This working paper presents a survey of the climate change literature addressing adaptation options and policy measures for the regulation of agricultural land use. The survey is a contribution to the research project ACCELERATES*) (funded by the EC Fifth Framework Programme). In this research project the impacts of climate change and socio-economic drivers on land use and ecosystems are modelled in an integrated modelling framework and vulnerable areas are identified. In a dialogue with stakeholders adaptation options are evaluated applying the modelling framework. The literature survey presented in this working paper should serve as inspiration for the dialogue with the stakeholders. One of the final results of ACCELERATES will be a recommendation of strategies for sustainable management of land use change and integrated management approaches to conservation at an European and a regional scale.

ACCELERATES is an interdisciplinary research project. Research teams from 8 different institutions within Europe are contributing to the project which is coordinated by professor Mark Rounsevell, Department of Geography, Université catholique de Louvain, Belgium.

The Working paper is prepared by research fellow Jens Abildtrup and senior research advisor Morten Gylling.

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*) ACCELERATES: Assessing Climate Change Effects on Land use and Ecosystems: from Regional Analysis to The European Scale - EVK2-2000-00567
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Summary

The overall objective of this working paper is to perform a survey of the climate change literature to establish a policy tool box for regulation of agricultural land use in a changing environment. The primary use of the policy tool box would be within the research project ACCELERATES (funded by the EC Fifth Framework Programme). In this research project the impacts of climate change and socio-economic drivers on land use and ecosystems are modelled in an integrated modelling framework and vulnerable areas are identified. In a dialogue with stakeholders, adaptation options are identified to mitigate the negative impacts of climate change on land use and ecosystems. The policy tool box presented in this working paper should serve as an inspiration for the dialogue with stakeholders.

The relevance of adaptation to climate change is based on the assumption that climate change, i.e. global warming, is inevitable, even with current and future mitigation initiatives. Adaptation refers to changes in processes, practices or structures to moderate or offset potential damages or to take advantage of opportunities associated with changes in the climate. The working paper focuses on adaptation options relevant for policy makers (joint adaptation), i.e. adaptation measures representing conscious policy options or response strategies aimed at altering the adaptive capacity of the agricultural system or facilitating particular adaptations to climate change. Adaptation options adopted by agents, e.g. farmers, without any need of policy intervention (private adaptation) are only addressed summarily. It is expected that private adaptation will be an important determinant for the impacts of climate change. However, policy intervention may be relevant to remove barriers for agents' autonomous adaptation or to prevent adaptation strategies which are unacceptable from the society point of view. The tools relevant for regulating the adaptation of agricultural land use are, in principle, the standard instruments for land use regulation, i.e. legislative, economic and institutional instruments. The choice of instrument should also be based on the standard criteria for evaluation of policy measures, e.g. effectiveness, efficiency, and flexibility. However, instruments which are flexible to different outcomes of future climate, should be prioritised as the predictions of the future climate changes are highly uncertain. Furthermore, sustainability should constitute an important objective of policy measures as climate change may have important consequences for the future resource bases.

It is suggested that measures which are most in need of immediate implementation should meet at least one of the following criteria: i) address irreversible or costly im-
pacts, 2) be urgent, i.e. reverse trends that make adoption of the measure more difficult over time; or 3) address long-term decisions.

In the appendix to the working paper the literature which is surveyed, is listed, and the suggested adaptation options and policy measures are summarized. The working paper does not seek to make recommendations between different adaptation options or policy measures but provides a gross list of the suggested options and measures reported in the literature. Therefore, some of the adaptation options may seem trivial or irrelevant. Furthermore, what is a relevant option in one region may be irrelevant in another region of Europe.

The overview of adaptation options and potential policy measures suggested in the literature addresses the agronomic, socio-economic, and environmental impacts of climate change. The consequences of future sea level rise caused by increasing global temperatures are ignored in this working paper, i.e. adaptation options and policy implications of global warming in coastal areas are not addressed.

The agronomic impacts include changes in: i) crop growth conditions, ii) livestock production, iii) demand for irrigation, iv) optimal plant protection, and v) soil fertility and erosion. A variety of different adaptation options have been suggested in the literature, including changes in crops or crop varieties, adjustments of external inputs, new tillage practices or housing systems, etc. Most of the agronomic adaptation options are expected to occur autonomously, as farmers will adapt to change in climate without any need of policy intervention. However, existing agricultural programmes and environmental regulations may reduce farmers' capacity or incentives for adaptation. For example, rigid subsidy schemes may hinder changes in crop rotations according to climate changes or rigid restrictions on the applications of pesticides or fertilizers may imply additional cost for farmers. Climate change emphasizes the fact that agricultural programmes should allow a flexible land use and that environmental regulations are evaluated continuously and are based on regional assessment of potential environmental changes. Traditionally, the public sector has supported agricultural research, e.g. crop or animal breeding and research in new farm technologies. Climate change implies that public research funds should be directed at developing new crops and farm practices which are compatible with expected future changes in climate. Due to regional differences in climate change impacts it is important to perform local field experiments as well as targeting the dissemination of the research results. In regions which due to climate change are expected to get drier, implying an increased demand for irrigation, it may be necessary to regulate the use of water to obtain an
optimal allocation of the water resources between different uses. Establishment of a market for water may ensure an efficient use of water. Alternatively, investments in water supply infrastructure, e.g. pipelines, to allocate water from regions with water surplus may be an option.

The economic and social impacts of climate change include i) changes in the optimal farming systems, ii) relocation of farm processing industries, iii) increased economic risk and iv) changes in the rural income and heritage. Changes in the economic performance of different farming systems due to, for example, changed in crop growth conditions, may lead to substantial changes in regional farming systems. Therefore, agricultural policies should be designed to avoid barriers to such changes. In extreme cases climate change would imply incentives to abandonment of land and in other cases cultivation of new land. Changes in farm production, e.g. new crops, imply that the supply of farm products may change regionally. Some agricultural production systems have a close spatial linkage with the processing industry, due to the relative high transportation cost for the raw plant products. Therefore, investment in these - often capital-intensive - industries should be based on long-term forecasts of farm production which take climate change into account. In some climate change studies it is predicted that besides increasing temperatures, we will experience an increasing variability in the weather. Therefore, growing crops which are robust to climatic variability, applying crop diversification strategies or crop insurance programmes represent options to reduce the economic risk of increasing climatic variability. Furthermore, removal of barriers to interregional trade may reduce the sensitivity of farms and industries to the supply of crops for fodder and processing, respectively. In regions where agriculture is still the main income generator, the economic welfare of rural societies depends heavily on economic performance of the agricultural sector. If the competitiveness of agricultural production in such regions decreases, it may have severe negative impact on rural population and may lead to depopulation. Where depopulation is seen as problem government programmes supporting farmers' income or development of alternative employments opportunities in the rural areas may be relevant policy measures. Where traditional farm practices have a value, policies should be designed to support the survival of these farm systems.

The environmental impacts of climate change include changes in nitrate leaching and pesticides pollution and changes in ecosystems and biodiversity. Expected changes in pollution by agricultural production are due to, for example, changes in optimal levels of fertilizer applications, changes in precipitation levels and timing, and changes in demand for plant protection. This underlines the need for continuously monitoring of
pollution levels and consequently revisions of the agri-environmental regulations and norms. Ecosystems would be influenced directly by climate change as the natural distribution of species may change and nutrient cycles may change due to changes in temperature and precipitation etc. Ecosystems may also be influenced indirectly by climate change through changes in land use and emissions of nutrient or pollutants. Reducing stress from pollutants or intensive land use may diminish the sensibility of ecosystems to climate change. The changes in species distributions may cause a risk of extinction for some species, if they are not able to migrate according to the changes in the geographical location of their ecological envelope. Establishment of migration corridors or off site protection represent options to protection of biodiversity. Protection of agro-ecosystems may require that certain land uses are maintained or that the land-use intensity does not exceed certain limits.
1. Introduction

1.1. Background

The management of agricultural land in Europe has profound impacts on the quality of the wider environment through, for example, nutrient dynamics, water resources, and biological diversity. European landscapes have undergone marked changes throughout the second half of the 20th century due to an intensification of agricultural land use. This has led to the fragmentation and loss of habitats and their associated species.

Agro-ecosystems will continue to change in the future caused by the influence of numerous factors like the reforms to the CAP, enlargement of the European Union, globalisation, technological and climatic changes.

To avoid adverse effects of agricultural management on ecosystems various regulations of land use have been implemented. Policy makers and public authorities have employed various instruments, e.g. conservation of ecosystems, subsidizing environmental beneficial farming, excise taxes on pesticides and nitrogen, and provision of information. Future changes in the pressure on ecosystems, including appearance of new threats as well as relief of existing pressures, call for adjustments of land use regulations.

Changes in climate may raise new environmental problems, e.g. changes of ecosystems and loss of biodiversity. The effects of climate change on the environment and biodiversity may be either direct, e.g. changes in the relative performance of different species or loss of soil structure, or indirect through changes in optimal farming systems. Furthermore, negative effects on the economic performance of farming may reduce the income of rural populations and imply loss of cultural heritage.

In the project ACCELERATES one of the objectives is to identify agro-ecosystems vulnerable to changes in climate and socio-economic drivers. Vulnerability of ecosystems is defined in more dimensions, including negative effects on biodiversity, pollution, and economic outcome and sociological patterns. Mitigation and adaptations options are identified in a dialogue with stakeholders. In this working paper the literature on regulation in relation to climate change is surveyed, serving as inspiration for
the dialogue. The consequences of the different policy strategies will be evaluated using the integrated model framework developed within the project.

1.2. Objectives and scope of the working paper

The objective of this working paper is to survey the literature on land use regulation and climate change, thus providing a toolbox for regulation of agricultural land use in a changing environment. The toolbox should support the dialogue with stakeholders concerning the identification of policy measures enhancing adaptation to climate change and mitigating undesirable changes of agro-ecosystems. Adaptation refers to changes in processes, practices or structures to moderate or offset potential damages or to take advantage of opportunities associated with changes in climate (IPCC 2001). It is not the objective to provide a complete database of potential adaptations options available for each stakeholder affected by climate changes but to provide examples of different types of adaptation options. The appendix provides a gross list of adaptation options and policy measures suggested in the reviewed literature. The options included in this list represent very simple and straightforward measures as well as more sophisticated options and measures. Some of the options may only be relevant in a few regions of Europe and some options are only relevant for specific farming systems or ecosystems.

The focus will be on the adaptation options relevant for policy makers, i.e. adaptations representing conscious policy options or response strategies aimed at altering the adaptive capacity of the agricultural system or facilitating particular adaptations to climate change. Adaptation options adopted by agents, e.g. farmers, without any need of policy intervention (autonomous adaptation) are only addressed summarily. However, in many cases there is no clear distinction between options relevant for single agents and for policy makers. Furthermore, information about agents’ adaptation options is a prerequisite for designing policies that facilitate an optimal adaptation from the society point of view. Therefore, the working paper includes an overview of potential adaptation options relevant for private land use decision makers as well.

The consequences of future sea level rise caused by increasing global temperatures are ignored in this working paper, i.e. adaptation options and policy implications of global warming in coastal areas are not addressed. This is justified by the fact that the issues related to sea level rise and coastal areas are excluded in ACCELERATES.
It is not the objective to evaluate or compare adaptation options. Instead, based on the general literature on policy evaluation and the climate change literature a number of criteria for evaluation of policy strategies are formulated.
2. Climate change and land use regulation

In this section we will address the relevance of discussing regulation of land use in relation to climate change. First, we discuss some theoretical aspects of adaptation and why land use regulation is relevant. Next, different types of policy instruments relevant for regulation for land use are presented and finally, criteria for choice of policy instrument are discussed.

2.1. Climate change and adaptation

Mitigation of climate change and adaptation to climate change represent the two main issues occupying researchers and policy makers working with global warming. Mitigation research focuses on measures to reduce the green house gas emissions and the sequestration of carbon dioxide. Researchers working with adaptation assume that climate changes are to some degree inevitable or it may be more efficient to rely on adaptation than mitigation. Adaptation refers to all those responses to climate change that may be used to reduce vulnerability or to actions designed to take advantage of new opportunities that may arise as a result of climate change (Burton et al. 1998). It is generally accepted that the balance between implementing mitigation and adaptation policies should be guided by the relative costs of these policies. Ideally, adaptation and mitigation strategies should be analysed simultaneously because these strategies are interdependent. For example, different adaptation strategies may lead to different emission levels of green house gases. However, in this working paper we address only adaptation policies as our objective is foremost to explore the gross set of adaptation options for agro-ecosystems to improve the basis for integrated modelling of adaptation strategies.

Adaptation to changing environmental conditions is not only linked to human induced climate change. Historically, agriculture and ecosystems have adapted to changes in the environment; human induced or naturally occurring changes. Therefore, the relevance of addressing adaptation does not hinge on the assumption that climate changes are due to human activities.

Different generic types of adaptation have been identified in the literature (see Box 1). The distinction between reactive and anticipatory adaptation is of particular policy relevance. Reactive adaptation measures are those that institutions, individuals, plants, and animals are likely to make in response to climate change after the fact,
whereas anticipatory measures are taken in advance of climate changes, before the
fact (Smith 1997, Burton et al. 1998, Fankhauser et al. 1999), anticipation requires
foresight and planning. Benioff et al. (1996) claim that adaptation options should be
implemented before climate change if they fall into one of two categories: (1) they
produce benefits independent of climate change, or (2) they will be less effective, or
not effective at all, if implemented in reaction to an already occurred climate change.
The latter category is relevant when climate change imply irreversible or catastrophic
impacts, when long-term decisions are considered and when current policy supports

The distinction between reactive and anticipatory adaptation depends in some cases
on the perspective, i.e. the level of decision-making. Farmers’ responses to climate
change, e.g. the decision to grow other crop varieties that are more drought tolerant,
represent a reactive adaptation. On the other hand the government may take anticipa-
tory actions to facilitate reactive adaptations, e.g. support the research in developing
new crop varieties that are drought tolerant.

Fankhauser et al. (1999) and Burton et al. (1998) distinguish also between autono-
mous and planned adaptation. Autonomous adaptation is expected to occur by itself
whereas planned adaptation requires some conscious preparation, i.e. an adaptation
policy has to be formulated. Species that are mobile may be able to migrate fast
enough to adapt to changes in the environment and there is no need for intervention.
In the case of anticipatory adaptation planning is by definition required. Farmers ad-
aptation to climate change is from the view point of the government spontaneous but
from the farmers’ perspective planned.

Relying solely on autonomous adaptations may result in: i) unacceptable impacts or
ii) missed opportunities to mitigate impacts by taking action before climate changes
occur. In the first case, individuals my adapt to climate changes optimally according
to their own private objectives. This may lead to unacceptable results from the soci-
ety's point of view because externalities of individuals’ adaptation options are ignored
or climate change lead to unacceptable distribution of benefits between individuals.
The second case refers to the situation where individuals are not in the position to
choose the optimal adaptation options, due to lack of information, skills, or institu-
tional settings. Therefore, there may be a need for government intervention to facili-
tate an appropriate adaptation behaviour from the point of view of the society. This
lead to another distinction in the characterisation of adaptation: private and joint adap-
tation. Joint adaptation means that measures which have to be taken do not only influ-
ence one agent but several agents, i.e. adaptation is an externality. The distinction between joint and private adaptation is discussed in detail in the next section.

**Box 2.1. Types of adaptation**

<table>
<thead>
<tr>
<th></th>
<th>Timing</th>
<th>Level of conscious intervention</th>
<th>Social dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactive</td>
<td>Anticipatory</td>
<td>Autonomous</td>
<td>Private</td>
</tr>
<tr>
<td>Autonomous</td>
<td>Planned</td>
<td></td>
<td>Joint</td>
</tr>
</tbody>
</table>

In Burton et al (1978, 1998) adaptations measures are classified in 8 categories:

1. **Bear losses**
   If those affected have no capacity to respond in any other ways or if the costs of adaptation measures are considered to be high in relation to the risk or the expected damage, doing nothing may be the adaptation option.

2. **Share losses**
   If the cost and benefit of climate change are unequally distributed there may be a need for policies ensuring redistribution of wealth between single persons or societies. Sharing losses can also be achieved through private insurance.

3. **Modify the threat**
   In the case of global warming there is some possibilities to mitigate the expected changes in climate by reducing the emissions of green house gases. However, even by implementing the most ambitious mitigation policies it is still anticipated that there will be some climate changes in future.

4. **Prevent the effects**
   Changes in climate can be compensated by artificial measures. For example, reductions in precipitation can be compensated by irrigation to avoid drought caused effects.

5. **Change use**
   Changes in the natural environment will change the economic value of use of land. Changes in land use or abandonment of land may therefore be an option to reduce economic losses.
6. **Change location**

Moving the production according to changes in the optimal environmental envelope is expected to be a central measure in agriculture to reduce negative impacts of climate change and taking advantage of new opportunities that may arise as result of climate change.

7. **Research**

Research in new technologies and new methods of adaptation is one of the most cited measures to reduce the vulnerability of climate change. Development of new crops and production systems and better weather forecasts represents examples of important research issues in a changing climate.

8. **Educate, inform, and encourage behavioural change**

Dissemination of knowledge about climate change through education and public information campaigns may facilitate adaptation.

The adaptation options listed in section 3 of this working paper represent all the categories defined above.

### 2.2 Why regulation of adaptation?

Most adaptations may occur autonomously without policy makers have to intervene. Farmers will respond to changes - or expected changes - in the environment for their own benefit and natural dispersal may ensure that species distributions may change according to changing ecological envelopes. Mendelsohn (2000) distinguishes between private and joint adaptation. Adaptation is private if the decision maker is the only beneficiary of adaptation and joint adaptation is when adaptation actions effect the benefits of other individuals, i.e. joint adaptation resembles a public good. In the case of private adaptations we may expect an efficient level of adaptation\(^1\) but in the case of joint adaptation the government will have to intervene to ensure an optimal level of adaptation. Examples of the private adaptation include farmers who optimise the crop rotations according to changes in the environment. Examples of joint adaptation include measures to ensure biodiversity or optimal water use in a changing environment. Even in the case where private adaptation lead to efficient adaptation there may be a need for government intervention because of unacceptable distributions of

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\(^1\) Hannemann (2000) criticizes the often used assumption by economist that private adaptation will lead to efficient adaptation and states with reference to empirical evidences that even when we assumes competition, rules out externalities, and grants the invisible hand as a general tendency in a competitive economy, there can be no guarantee that efficiency is being maximized in every specific choice and on every occasions.
benefits between individuals. The long time horizon of climate change policies implies also that intergenerational considerations as well as issues of sustainable development are of particular relevance.

In principle, the justification for political intervention with reference to climate change is not different from the justification for political intervention in general. However, climate change introduces new challenges and emphasizes that uncertainty, flexibility, and dynamic relationships are central issues to be addressed when designing policy strategies. The foremost rule of the state would be to provide the right legal, regulatory and socio-economic environment to support autonomous adaptation (Fankhauser et al. 1999).

The focus in this working paper is at the need for anticipatory adaptation, i.e. taking action before the climate changes, with respect to European agriculture and ecosystems and in particular the need for governmental policy intervention.

2.3. Policy instruments of regulation

In this section, we provide a brief overview of instruments available for policy makers to secure or enhance adaptation to climate change. In the literature different categories have been used to describe regulation measures (see e.g., US OTA 1995, Russel and Powell 1999). Below, we will distinguish between legislative, economic, and institutional instruments. The appropriate choice of instrument depends heavily on the type of problem to be solved and often a combination of instruments is optimal.

**Legislative instruments**

Legislative instruments or command and control regulations are often referred to as the traditional instruments in environmental regulation. This group of instruments include standards and norms, prohibitions, emission limits, etc. Command and control instruments have often been criticized for being a rigid form for regulation which often fails to adjust to changes in technology, markets and environmental conditions. Application of command and control instruments requires that the regulator has the information needed to design optimal regulations targets etc. and has the capacity to monitor and enforce the compliance to the regulation.
**Economic instruments**

Fees, charges and environmental taxes on the one hand and subsidies or tax relieves on the other hand are very popular measures in current environmental policies. The philosophy is that the need for regulation is due to market failures, i.e. externalities - positive or negative - have no prices. Subsidies or taxes should be set to the value of these externalities and thereby ensuring that the production of externalities corresponds to the optimal level from the point of view of the society. Thus, market-based instruments will often be most cost-effective and efficient incentives to encourage the sustainable use of land and biological resources. However, in many situations it will be necessary to use regulations and restrictions in order to ensure the appropriate level of conservation.

**Institutional instruments**

Institutional instruments represent a broad range of measures, including establishment of markets, information provision, scientific and technical capacity building, and stakeholder involvement. Ensuring competitive markets are generally the most efficient allocation mechanism for private goods, including many of the individual components of land use and biodiversity. At the same time, the assignment of well-defined property rights over land or certain biodiversity resources can overcome uncertainty and provide a long-term incentive for enhancing the overall value of the resource. For example, establishment of an institutional framework which supports adaptation, is a measure to enhance autonomous adaptation and thereby reducing the need for direct policy intervention.

**2.4. Evaluation and choice of policy measure**

In this section we will address some general criteria for evaluating policy measures and then review more specific criteria for prioritising among different adaptation options to climate change.

**2.4.1. Evaluation criteria**

Several criteria have been recommended in the evaluation of policy strategies in relation to climate change (see, e.g., Carter 1996; Downing et al. 1997; Smith 1997). In the environmental economics literature the main criterion for evaluation of policy alternatives is normally welfare economic efficiency, however, a number of different criteria supplements this criteria, e.g. effectiveness, cost effectiveness, equity, and
flexibility (OECD 1997). Meeting these supplementary criteria is in most cases a prerequisite for meeting the economic efficiency criterion but may also be conflicting. An economic efficient policy is cost-effective whereas a cost-effective policy may not be economic efficient. On the other hand, economic efficiency may be reduced by distributional considerations.

**Economic efficiency**

Social cost-benefit analysis is a common tool in the evaluation of policy alternatives. Social cost-benefit analysis is based on modern welfare economics and policies are evaluated according to their effect on social welfare. The changes in social welfare associated with a policy are measured using households' willingness to pay to secure or prevent expected outcomes of the policy. A policy should be implemented if the policy increases the social welfare. Social cost-benefit analysis provides also an appropriate framework for evaluation of the climate change policies. However, lack of information on the choices households make for non-traded commodities that potentially will be affected by climate change and variability, and lack of information about the factor that constrain those choices represent important limitations that plague cost-benefit analysis (Leary 1999). Uncertainty about the costs and benefits of adaptation policies is also due to the lack of information about potential autonomous adaptations by producers and consumers.

**Effectiveness**

A central issue in evaluating the effects of policy instruments is their impact according to the objectives of the policies - how far, and in what way, they achieve the required impact which is the objective of the policy. For example, the effectiveness of environmental policies protecting the groundwater depends on the success in achieving the regulator's objective in pollution control. The effectiveness of policies to reduce nitrate leaching from agricultural production can be measured at a number of levels: i) the production behaviour of farmers, ii) the amount of nitrate leaching at field or farm level or iii) the nitrate concentration in the groundwater. Obviously, the latter level is most appropriate according to the policy objective. However, because nitrate leaching is a non-point pollution problem, i.e. it is impossible or difficult to measure the leaching at the source, criteria for policy success are therefore normally measured as the changes in farm production behaviour.
Cost-effectiveness

In the evaluation of different adaptation options a cost-effectiveness framework is often applied (Mizina et al. 1999). In the cost-effectiveness analysis different options are compared and the option with the lowest cost of achieving a given level of benefit or the option with the highest level of benefit for given level of cost is selected as the most cost-effective option. Cost-effectiveness analysis does not compare the benefit and costs of policies to determine whether or not the society would be better off by implementing a policy but only to find the best policy measure to ensure that some predetermined targets are met. The advantage of the cost-effectiveness criteria is that it is simple and intuitively appealing. Furthermore, some sophisticated valuations of non-market environmental goods may be avoided.

Equity and sustainability

Climate change as well as land use regulations can influence the distribution of costs and benefits of the society. These distribution effects raise the issue of equity and fairness, both within and across generations (Hanley et al. 1997). For example, imposing restrictions on land use to protect biodiversity will increase the costs of agricultural production or even threatening the subsistence of the farmers. On the other hand the whole society may benefit from the protection of biodiversity. The issue whether farmers should be compensated for their losses caused by policy-imposed restrictions on land use is linked to the question of The Polluter Pay Principle (PPP) or the Provider Gets Principle (PGP). The PPP implies that private agents pay some of the costs associated with their production of negative externalities. For example, the loss in society's welfare by groundwater contamination should be paid by the polluter. In practice, using the PPP is not always straightforward. Generally, it is accepted that the PPP does not apply to the negative impacts on the environment, e.g. the groundwater, by agricultural production as long farming does not deviate from what is defined as normal or good farming practices. However, defining normal or good farming practice remains a difficult problem. PGP applies normally to the provision of positive externalities, e.g. extensively grazing of grasslands. This restriction involves that the government is identifying an appropriate level of supply for rural public good, and then directing public funds at the providers of these goods according to the marginal opportunity costs of supply (Hanley et al. 1998). Addressing the distributional effects of policies may also enhance the public acceptability and thereby improve the effectiveness of policy implementation.
In relation to climate change sustainability and in particular the intergenerational equity are important objectives, as the time horizon for climate change policies are very long. Failures in anticipating climate changes impacts may lead to irreversible degradation of natural resources, e.g. loss of soil fertility, affecting future generations' production possibilities.

**Flexibility**

Policy measures should be able to adapt to changes in markets, technology, knowledge and social, political and environmental conditions. Measures that should be implemented to facilitate adaptation to climate change should obviously be flexible as uncertainty about the future impacts is fairly high. Generally, measures that incorporate feedback mechanisms accounting for changes in objectives, markets, climate etc. should be preferred.

### Box 2.2. Evaluation criteria of policy measures

- Economic efficiency
- Effectiveness
- Cost effectiveness
- Equity
- Sustainability
- Flexibility

### 2.4.2. Choice of adaptation option

Several researches have formulated different rules or guidelines for prioritising between different alternative adaptation strategies or options. Smith (1997) suggests that measures which are most in need of immediate implementation should meet at least one of the following criteria: i) address irreversible or costly impacts, 2) be urgent, i.e. reverse trends that make adoption of the measure more difficult over time; or 3) address long-term decisions, such as building infrastructure.

Goklany (1995) suggests the following criteria for selecting or developing adaptation strategies and measures: i) increase the ability to feed, clothe and shelter the world's expanding population regardless of the agent of change; ii) reduce vulnerability of forests, habitats and biological diversity, also regardless of the agent of change; iii) be compatible with strategies to limit climate change; iv) be independent of results from site specific impacts assessments, which are unlikely to be available with sufficient confidence at appropriate temporal and spatial resolutions for several years, for either
their justification or implementation; v) be implementable in short order; and vi) be beneficial now and in the future.

Generally, those strategies that make sense for society even without climate change risk - the so-called "low regret" strategies - are of particular importance (Toman and Bierbaum 1996). These strategies could include reforms of agricultural programmes, improvement of efficiency in irrigation and water management, and protection of ecosystems. In principle low regret strategies should be implemented disregarding climate changes. However, these strategies are included in the group of climate change adaptation options because climate change may be the factor initiating the implementation of the strategies.
3. Adaptation options and policy measures

This section provides a survey of potential adaptation options to climate change impacts on agro-ecosystems as well as a review of potential policy initiatives to facilitate an efficient adaptation. The survey is based on the adaptation options and policy measures reported in the climate change literature.

In the literature there has been a number of attempts to make global inventories of adaptation options to climate change and of potential policy implications (see e.g. Markham and Malcolm 1995; IPCC 1996, 2001; Feenstra et al. 1998). Other studies address measures relevant for local areas or specific types of impacts (e.g. Smit et al. 1993; Erda 1996; Hartig et al. 1997). This section summarizes both types of studies and Appendix 1 offers an overview for the literature addressing adaptation options and policy strategies. A gross list of adaptation options and policy measures is provided. A wide range of options and measures are listed, including options that may seem trivial from farmers or policy makers perspective as well as more sophisticated options. For example, to change crop rotations according to changes in climate may seem very banal reaction to climate change for most farmers. However, in areas dominated by perennial crops changing crop rotation is a non-trivial decision. Furthermore, farmers’ managerial capacity to optimise crop rotations according to changes in climate varies from region to region in Europe, implying that in some regions some intervention may be necessary to ensure an optimal adaptation of crop rotations. The survey includes studies which analyse adaptation outside Europe since experiences from other regions may easily be extended to an European framework. On the other hand adaptation measures and policies which exclusively address tropical areas or/and less developed countries, are ignored in the present working paper.

Climate change is one of several environmental factors that may alter the future state of European agricultural ecosystems. It may often be convenient to address the impacts of different environmental stressors simultaneously because they are interrelated, e.g. are changes in climate and changes in CO$_2$ concentrations linked. However, the survey is structured according to the types of climate change impacts on agricultural production and on ecosystems; the structure is to some extent inspired by the analysis of climate change impact in Parry (2000), Markham and Malcolm (1995) and Easterling (1996)$^2$. First, we address the agronomic impacts of climate change, then

$^2$ Based on Drabenstott (1992).
the economic and social consequences, and finally the environmental impacts the of climate change.

3.1. Agronomic impacts

3.1.1. Changes in crop growth conditions

Changes in temperature and in the level and timing of precipitation may influence the yield of agricultural crops. It is expected that in some areas crop production will generally suffer from the changes whereas in other areas crop production will benefit from the changes. In some areas heat or water stress will reduce the yields of certain crops, whereas other crops will benefit from the changes in climate, implying that the relative productivity of different crops will change. Furthermore, the frequency of extreme meteorological events may change, causing higher yield variability. Increased levels of CO₂, technological changes, plant breeding, etc., will also influence the future crop production.

Adaptation options

Changes in sowing and planting dates
Earlier sowing or planting will increase the growing season and thereby yields as the negative effects of summer droughts may be reduced. In some regions two cultivars per season may be possible if the climate gets warmer.

New crops or crop varieties
According to changes in growing conditions new crops or crops varieties, e.g. heat or drought tolerant crops, can be introduced. This may reduce the potential negative impact of climate change or enhance the increase of yield in the case of improved growing conditions including increased concentrations of CO₂. Plant breeding (including genetic engineering) aiming at developing new plant varieties and research on farming systems will increase the capacity of adaptation. To account for increased variability in climate better weather forecast and more robust crops or crop varieties should be considered. An increased demand for the development of new crop varieties emphasizes that protection of existing gene resources is important. Therefore, establishment of gene banks may increase the adaptation capacity in the long run.
Box 3.1. Changes in crop growing conditions

**Adaptation options**
- Changes in planting and sowing time
- Growing new crops
- Growing new crop varieties
- Investing in crop breeding
- Investing in seed banks
- Using short- and long-range weather forecasts

**Policy measures**
- Reforming agricultural policy to encourage flexible land use
- Assembling, preserving and characterising plant genes
- Support research in new crops and crop varieties
- Develop (regional) centres to store genetic varieties
- Make seed banks sustainable
- Enhance the development of weather forecasts

**Policy implications**
Most benefits of farm adaptations are internal in the sense that the farmers themselves benefit directly from adaptation, implying that there may be no need for policy intervention. Existing regulations of land use or agricultural production may, however, hinder an economic adaptation. Examples are rigid agricultural programmes which subsidize certain crops in certain areas. Such programmes may reduce the flexibility of land use changes, implying that crop rotations which are not optimal in a changed climate, are maintained (Lewandrowski and Brazee 1993).

There is a tradition of public support for agricultural research because farms are generally too small enterprises to perform their own research and because the research results often have character of public goods. The state support of the research can either be direct by establishing state research institutions or indirect by encouraging the formation of research cooperatives. In either case it is important that policy-makers are aware of new issues raised by changes in climate when allocating research funds. Dissemination of research results is another example of activities where public agencies have been involved to facilitate the application of the newest scientific results in the production at (small) farms. Climate change emphasizes the need for dissemination of research results about impacts and adaptation measures. Due to local or regional differences in the changes in climate it is important to make local research and
experiments as well as targeting the information flows, e.g. offering local workshops for farmers (Mizina et al. 1999).

### 3.1.2. Livestock production

Animal production is influenced directly by weather through, for example, extreme weather events which have impact on animal health, growth, and reproduction and changes in the distribution of livestock diseases. The climate influences livestock production indirectly through the impact on yield of forage crops and pastures.

#### Adaptation options

*Changes in animal housing systems and forage production*

Higher temperatures may reduce the need for winter housing of livestock, which may reduce the capital costs of buildings. In areas with a warm climate housing should be constructed to mitigate negative effects of a warmer climate, e.g. by installing sprinklers in livestock buildings or in feedlots. Changes in climate may also imply that the carrying capacity of rangeland may change wherefore changes in the optimal stocking rates may change. If yield variability of forage crops increases, establishment of fodder banks can moderate the consequences for the animal production of years of bad crops.

*Animal breeding and gene banks*

Besides the direct effects on husbandry of climate change new diseases may appear or the occurrence or outbreak of diseases may be more frequent. Animal breeding have to take this into account, implying that the protection of genes may be relevant as in the case of plant breeding.
Box 3.2. Livestock production

Adaptation options
- Adjustment of animal stocking rates at range land
- Adjustment of grazing systems
- New forage crops in dairy farming
- Use feed conservation techniques and fodder banks
- Sprinklers in feedlots
- Adapted housing systems
- Breeding management

Policy measures
- Assembling, preserving and characterising animal genes
- Supporting animal breeding
- Prepare animal health services to cope with spread of new diseases and parasites
- Supporting research on alternative feed crops

Policy implications
Farm programmes regulating or subsidizing livestock production systems should be designed to allow a flexible adaptation of buildings to a changed climate. Investments in livestock housing represent typically irreversible long-term investments. This emphasises the importance of research in climate change and dissemination of research results to decision makers. Alternatively, investment in flexible housing systems or capital extensive housing systems should be promoted.

Public animal health programmes and research should be directed at future diseases and parasites. Animal breeding should be directed at new conditions, e.g. changes in forage crops, grazing systems and diseases.

3.1.3. Increased demand for irrigation
For most regions the demand for water for irrigation is projected to rise in a warmer climate, implying an increased competition between agricultural and urban as well as industrial users of water. The demand for irrigation changes because climate change modifies rainfall, evaporation, runoff, and soil moisture storage. An increased use of irrigation implies also in some regions a higher risk of salinisation of soils.
Adaptation options

Practices to reduce water stresses
Changes in tillage practices which reduce water runoff and improve water uptake can improve the available water for crops. Planting of hedges may reduce evaporation and introduction of drought resistant crop varieties represent other options to reduce the impact of water stress.

Efficient water use
An increased demand for irrigation will lead to an increased competition for a scarce water resource. Therefore, measures that ensure an efficient allocation of water resources to different uses should be implemented, i.e. only crops with a high marginal product of irrigation should be irrigated. Changes of irrigation systems or improvement of the efficiency of existing systems, e.g. optimising the timing of the irrigation, represent options to improve the efficiency of irrigation.

Box 3.3. Increased demand for irrigation

Adaptation options
• Practices to conserve soil moisture
• New drought and heat resistant crops or crop varieties
• Drought management
• Application of irrigation
• New water efficient irrigation systems
• Apply methods to avoid salinisation

Policy measures
• Reforming water markets to encourage more prudent use of water
• Promote agricultural drought management
• Develop large scale watershed programmes

Policy measures
Policy measures include support of research in water conserving farm practices, e.g. new tillage methods or breeding aiming at drought resistant crops. Public intervention to improve the water supply infrastructure, e.g. pipelines, to allocate water from regions with water surplus to areas with water deficiency may be relevant in some areas. In other areas, it may be necessary to regulate the use of irrigation to ensure a
sustainable water management, e.g. defining which crop types are allowed to be irrigated and to what extent.

Property rights of water and establishment of markets for water may in some cases ensure an efficient use of and a sustainable management of the water resource. However, ensuring property rights to water is only a tractable path when all externalities may be internalised by development of a water market. If for example, ecosystems are affected by the use of water, there may still be need for regulation of the water use.

3.1.4. Changes in the optimal plant protection

Higher temperatures may increase the need for plant protection (Chen and McCarl 2001). The conditions are more favourable for the proliferation of insects and pests in warmer climates. The growth of weeds is influenced by temperature as well as increased levels of CO₂, implying that control of weeds may be more difficult. However, the effects of climate change on the need for plant protection will vary from case to case.

Adaptation options

The dose-response functions of different measures of plant protection should be continuously evaluated to reveal climate induced change and the plant protection should be adjusted accordingly. Application of forecasts on agricultural pest and disease outbreaks and integrated control of pests represent sustainable strategies to cope with a potential increased need for plant protection.

Box 3.4. Changes in the optimal plant protection

Adaptation options

- Changes in application of pesticides and herbicides
- Develop forecasts on agricultural pest and disease outbreaks
- Integrated control of pest and diseases

Policy measures

- Avoid rigid regulation of the application of plant protection measures
- Encouragement of integrated control of pests and diseases
Policy measures

Research in new plant protection measures should be stimulated to increase the capacity of farmers to adjust the plant protection optimally in a changing climate. Furthermore, it is important that existing norms or regulations of the pesticides application are continuously evaluated to be compatible with a changing demand for plant protection as well as for the protection of the environment.

3.1.5. Soil fertility and erosion

Warmer conditions are likely to speed up the natural decomposition of soil organic matter and to increase the rates of other soil processes. This has in particular importance for peat soils (Parry 2000). The demand for fertilizers, e.g. nitrogen, may change. Higher yields due to changes in climate or CO₂ concentration increases the demand for fertilizers. Furthermore, the cycling of carbon, nitrogen, phosphorus, potassium and sulphur in the soil-plant-atmosphere system is likely to accelerate under warmer conditions. An increased application of nitrogen fertilizers may increase the risk of losses to the environment. Where the climate gets dryer, there may be an increased risk of wind erosion and in areas with strong gradients and where the rainfall increases there may be an increased risk of soil erosion.

Adaptations options

Adjustment of level of external inputs
Changes in yield should be followed by adjustment in the application of fertilizers. This implies that norms should be adjusted continuously based on field experiments. It underlines the importance of using updated research data in the agricultural advisory service.

Changes in tillage practices and farm systems
Application of conservation tillage, i.e. leaving some or all the previous season's crop residues on the soil surface, may protect the soil from wind and water erosion and retain moisture by reducing evaporations and increasing infiltration of precipitation into the soil. Establishment of windbreaks or agroforestry systems represent other options to mitigate an increased risk of soil erosion.
Land abandonment

Some areas may not be feasible for agricultural production due to increased risk of soil erosion or leaching of nutrients. The best solution may in some cases be to convert these areas to extensive grazing or to withdraw such areas from cultivation.

**Box 3.5. Soil fertility and erosion**

**Adaptation options**
- Improved nutrient management
- Changes in optimal application of fertilizers
- New land field techniques (tillage)
- Establishment of windbreaks

**Policy measures**
- Avoid distorted prices on fertilizers
- Research in new tillage practices
- Organising workshops on cultivation techniques
- Discourage the use of marginal land and protecting areas that are degraded
- Develop agroforestry systems

**Policy implications**

Stimulate research in and experiments with new tillage practices and facilitate the dissemination of updated research results. Environmental norms and standard defined in regulations and political action plans should be revised according to changes in the optimal application of external inputs. Subsidizing or compensating farmers for abandonment of agricultural land may in some areas be justified. On the other hand subsidies encouraging increased use of external inputs or maintaining the cultivation of degraded land should be abandoned.

3.2. Economic and social impacts

In areas where climate change implies decreasing productivity the income from farming is expected to decrease, whereas the income from farming is expected to increase where conditions for agricultural production improve. The economic consequences of changes in productivity depend on the effects of climate change on world demand and supply of agricultural products. If world market prices of food increases compared to other products, productivity losses may be offset by increasing prices. However, the
uneven geographical distribution of productivity effects implies that there will be changes in the relative income from agriculture between different regions.

3.2.1. Changes in optimal farming systems

Changes in the relative productivity of different crops and livestock systems imply that the economic optimal farming system in a given area changes. This may imply new investments in, e.g., housing, machinery, and managerial skills of the farmer, or that the agricultural land use are abandoned.

Adaptation options

Farming systems that are robust to changes in climate should be selected. In some areas it may be optimal to abandon the agricultural land use whereas it may be optimal to take in new land for cultivation in other areas.

Box 3.6. Changes in optimal farming systems

Adaptation options

- Changes in the allocation of land for different uses
- Land abandonment or cultivation of new land

Policy measures

- Support research in alternative farming systems
- Provide farmers with mid- and long-term loans to aid them in adaptation to changes in climate and markets.
- Improving institutions for a free market and unsubsidised trade
- Avoid tying subsidies or taxes to type of crop and acreage
- Decentralizing of decision making
- Reallocating farming resources to different regions

Policy measures

Government programmes, e.g. investment subsidies and price support, and other regulations should be adjusted according to changes in the optimal farming systems. Income support of farmers should be independent of farming system, i.e. that the programmes are non-distortional, to minimize the risk of supporting non-adapted farming systems (Lewandrowski and Schimmelphennig 1999).
Crop insurance programmes should be designed to encourage farmers to react quickly to climate change. Crop insurance programmes, however, may reduce the incentive to adapt, as the costs of growing climate incompatible varieties are reduced (Smit et al. 1993).

Due to regional differences in the relative impacts of climate change on the economic performance of different farming systems, it is important that agricultural policies are geographically differentiated to account for such differences. Decentralizing of the policy formulation may ensure this.

### 3.2.2. Relocation of farm processing industry

Some agricultural production systems have a close spatial linkage with the processing industry, e.g. sugar beets for sugar production, potatoes for starch production, tomatoes for canning, and oranges for processing. The linkage is due to the relative high transportation costs for the raw plant products. Spatial changes in the areas where such crops are grown imply therefore costs of relocating these - often capital-intensive - processing industries.

**Adaptation options**

Long-term investments in capital-intensive industries and infrastructures should be based on long-term projections of changes in climate changes and agricultural policies and if possible, irreversible investments should be avoided. Changes in the geographical distribution of the agricultural production may require changes in the agricultural infrastructure, i.e. transportation systems, agricultural advisory service, education of labour for farming and processing industry.

**Box 3.7. Relocation of the farm processing industry**

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<th>Adaptation options</th>
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<td>Relocation of the farm processing industry</td>
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<td>Changes in agricultural infrastructure (transport, education, etc.)</td>
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<th>Policy measures</th>
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<tr>
<td>Reallocating farming resources to different regions</td>
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<td>Long-term regional industrial policies</td>
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</table>
Policy measures

Public interventions to ensure an efficient infrastructure may mitigate the negative impacts of changes in the geographical distribution of the agricultural production. Long-term regional industrial and labour policies are important to mitigate social consequences of relocation of the farm processing industry.

3.2.3. Increased (economic) risk

Some studies have considered possible changes in the variability of climatic variables. Where certain varieties of crops are grown near their climatic limits, extreme weather events may have dramatic effects on agricultural production (Parry 2000). This may consequently influence the variability of the economic outcome of farming and increase the risk of agricultural investments.

Adaptation options

Insurance against the effects of extreme weather events may reduce farmers' economic vulnerability to increased climatic variability. However, increasing damage costs will lead to increasing insurance fees. Crop diversification has also been identified as an option to mitigate the effects of increased climatic variability.

Box 3.8. Increased (economic) risk

Adaptation options
- Crop diversification
- Crop insurance

Policy measures
- Develop long-term food reserves to be used to meet dietary needs in poor crop production years
- Improve transportation, distribution, and market integration to provide the infrastructure to supply food during crop shortfalls
- Foster the development of markets that allow farmers to hedge their risk
- Support adaptation of crop insurance and disaster assistance programs
- Removal of insurance programmes that discourage farmers to adapt to new environmental conditions
- Social security programmes to provide insurance against local supply changes
**Policy measures**

Public intervention may be necessary to facilitate a market for crop insurance. On the other hand, insurance programmes that reduce the incentives for adaptation should be removed or modified. This is the case where insurance fees are not adjusted accordingly to changes in the risk of economic loss. Public disaster programmes should continuously be evaluated during a changing climate. If these programmes make up the losses to farmers after disasters, there will be no incentive for farmers to adapt to the change in the risk of disasters.

Barriers to free trade should be removed to mitigate the effects of local shortfalls in the supply of food. Integration of markets of, for example, cereal and concentrates for livestock production may decrease the dependence of livestock production on local variability in the crop yields. However, international food trade may increase the vulnerability of local farms to changes in yield as the price will not increase due to low yields. In economic vulnerable areas policy intervention may be relevant to provide social insurance programmes and facilitate the development of long-term food reserves to be used to meet dietary needs in poor crop production years.

**3.2.4. Loss of rural income and cultural heritage**

In some regions of Europe agriculture is the main income generator, implying that economic welfare of rural societies depends heavily on economic performance of the agricultural sector. In regions where climate change reduces the competitiveness of agriculture it may have severe negative social impact on the local population and may cause an increased depopulation of the rural areas. Traditional farming practices have in some areas a value as regional or cultural symbol. Changes in farming systems induced by climate change may threaten these symbols.

**Adaptation options**

Farmers in areas where agricultural production is affected adversely by climate change have in principle two options to compensate for the economic losses. They can either improve the relative competitiveness by increasing productivity or they have to leave the agricultural sector to get alternative employment.
3.3. Environmental impacts

3.3.1. Nutrient leaching and pollution by pesticides

Climate change may in some regions increase the risk of leaching of nutrients, i.e. primarily nitrogen, caused by changes in precipitation patterns, increased optimal levels of fertilizer applications and higher temperatures. However, the mechanisms determining the risk of leaching are very complex, implying that the effects of climate change are ambiguous.
Increased demand for pesticides due to either intensification of the agricultural production or due to increased stress from weeds, pests, or diseases may increase the risk for contamination of the groundwater, food, and natural habitats with pesticides.

**Adaptation options**

There are several different farm management options which can be employed to reduce the leaching of fertilizers from farmland, e.g. reduction of the rates fertilizer application, changes in crops or farm systems. Several of these options are employed today due to agricultural or environmental regulations or demand for "green products" by the consumers.

**Box 3.10. Nutrient leaching and pesticides pollution**

**Adaptation options**
- Adjustment in fertilizer application rates
- Changes in crop selection and crop rotation management
- Crop breeding
- Improved techniques for spreading of fertilizer and manure
- Precision farming
- Reduction of atmospheric nutrient pollution
- Establishment of buffer zones
- Organic farming

**Policy measures**
- Research in climate change impacts
- Monitoring climate change effects on leaching
- Changes in regulation of fertilizer application
- Restrictions on the use of polluting chemicals (pesticides etc.)

**Policy measures**

There is a need for monitoring the impact of climate change on nutrient leaching. Increasing risk of leaching may demand adjustment of existing regulations of the application of fertilizers and manure or require introduction of new regulations. Some agro-ecosystems may be more sensitive to nutrient enrichment, e.g. due to changes in the carbon cycle, implying that ecosystem specific measures, e.g. buffer zones, should be implemented.
Introduction and approval procedures of new pesticides compatible to new climate induced changes in demand for plant protection should be flexible. Furthermore, policy objectives and action plans to reduce the application of pesticides should be adjusted to changed climate and farming practices.

### 3.3.2. Biodiversity

According to the Convention on Biological Diversity, biological diversity (biodiversity) means the variability among living organisms and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (United Nations 1992). Climate change may influence the biological diversity of Europe directly and indirectly. Climate change influences ecosystems and single species directly through changes in temperatures, precipitation patterns, and the occurrence of extreme weather events. Changes in CO₂ concentrations may also have direct influence on ecosystems. The indirect influence of climate change includes changes in land use or in the pressure on ecosystems from changes in environmental stress factors. The climate change impacts may disrupt the present ecological balances of the ecosystems, change the natural distribution of species and habitats, and in some cases lead to extinction of species or varieties. This may lead to reductions in the supply of ecosystem services and irreversible loss of genetic information. Climate change may also increase the stress from or risk of invasion of exotic non-native species, which disturb the natural balances of ecosystems.

#### The adaptation options

*Reducing environmental stresses on ecosystems*

In cases where ecosystems are stressed by climate change one option may be to reduce other environmental stresses. For example, active raised bogs represent ecosystems that may be affected negatively by climatic change as the peat may start decomposing due to higher temperatures. The pressure from climate change on raised bogs is expected to increase by nitrogen deposition (Vestergaard 2000). Therefore reducing the nitrogen deposition may reduce the negative impacts of climate change on active raised bogs. Establishing buffer zones around sensitive ecosystems is one possible measure to reduce other environmental stresses. Other measures include reduction of general emission levels from agriculture, industry and the transport sector, either through reduced production intensity or through emission reducing technological changes. Some agro-ecosystems are sensitive to intensive agricultural land use and
climate change may increase this sensibility, implying additional constraints on the land use

*Enhancing migration*

In Europe the ecological optima of species and ecosystems are, generally, expected to shift northward, i.e. the distribution of species is expected to change. To which extent species will move geographically according to changes in ecological conditions depends on the possibilities of migration. Situations may arise where the survival of a species may depend on the species' ability to migrate accordingly to changes in its ecological optimum. However, in landscapes fragmented by human activities, e.g. intensive agricultural land use and urbanisation, opportunities for migration will be limited and restricted to only a portion of the species pool. Therefore, measures to enhance migration, e.g. corridors, should be considered as a measure for protection of biodiversity (Markham and Malcolm 1996).

*Off site protection*

In cases where changes in the ecological conditions imply that habitats of certain species disappear, there will be a risk of extinction of species. To maintain the genetic information represented by endangered species different offsite protection measures are relevant, e.g. establishment of seed banks, zooparks etc. (Markham and Malcolm 1996).

*Land use*

One of the most direct threats of ecosystems and biodiversity are changes in land use or increased land-use intensity. Therefore, regulation of land use represents a key measure in the protection of biodiversity. Where climate change influences the land use, the optimal land use regulation may change.
**Box 3.11. Ecosystems and biodiversity**

### Adaptation options and
- Remediation of ecosystems
- Establishment of buffer zones
- Enlarge wildlife habitats to ensure species survival
- Controlling water levels in wetlands
- Food and water provision for wildlife
- Irrigation or drainage of natural habitats
- Control of diseases
- Increased fire protection in dry ecosystems
- Enhance methods to protect biodiversity off-site
- Project and enhance migration corridors
- Removal of impediments to migration and colonisation
- Changes in the optimal set of tree species for any site
- Transplant seed and seedlings to appropriate locations
- Control of alien and invasive species

### Policy measures
- Research on climate impact on biodiversity and monitoring
- Base policies on regional assessment
- Integrate ecosystem planning and management
- Appointment of migration corridors
- Legal protection of existing habitats and species
- Geographically targeted or horizontal regulations of land use
- Restriction on emissions from human activities, e.g. agriculture
- Removal of adverse subsidies
- Subsidizing environmentally beneficial farming, e.g. organic farming
- Improved efficiency in food production
- Voluntary agreements about biodiversity protection
- Education in biodiversity protection

### Policy measures

There is a large number of different instruments that may be relevant to ensure the protection of biodiversity, including, e.g., voluntary agreements, subsidizing environmental beneficial farming, restrictions on land use, taxes on land use, and eco-labelelling. In most cases these instruments are employed today. The implications of climate change will be a need for adjustment of these instruments. If, for example, climate change stresses an ecosystem stronger restrictions on land use may be required to avoid damage of the ecosystem.
Rapid changes in climate may imply that the migration of some species cannot keep pace to the changes in their distribution. Therefore, relocation of species artificially or establishment of corridors may be relevant options. Programmes for protection against invasive species or establishment of gene banks represent other measures to cope with changes in the natural distribution of species.

Generally, it will be relevant to assess and monitor the local impacts of climate change on biodiversity and adjust the policy measures accordingly. However, impacts on biodiversity and protection of the gene resources should also be viewed in a larger scale as species distributions may change inter-regionally.

Improving the efficiency in agricultural production may reduce the demand on marginal land and degraded land, as the demand for food is relatively inelastic, i.e. demand does not increase very much by lower prices. However, this option should only be designated to carefully selected agricultural areas in order not to counteract other measures to protect vulnerable ecosystems.
4. Conclusion

An increasing body of literature is reporting studies on adaptation to climate change. In the agricultural sector the potential of adaptation is recognised as an important strategy to reduce the costs of - or increase the benefit of - climate change. In many cases adaptation may occur autonomously without any need of policy intervention. This reduces the role of policy makers to the task of removing barriers, e.g. rigid farm programmes, for adaptation or enhancing the adaptation capacity of land users, e.g. supporting research and dissemination of research results. Due to externalities of (agricultural) land use there may, however, be a need for policy intervention to ensure that adaptation occur optimally according to objectives of the society. This includes regulating the use of land to avoid soil degradation, groundwater contamination and other unsustainable land uses. It may also include the establishment of institutions to ensure property rights of water resources and development of water markets, ensuring an efficient use of water resources. Investments in larger infrastructural projects, e.g. building of dams for irrigation purposes, may also require governmental intervention to ensure financing and facilitating the coordination of a typically large number of small landowners involved in such projects.

The working paper list about 60 adaptation options to climate change impact on agricultural land use and ecosystem protection. We do not maintain that the list is a complete list of adaptation options but it represents an illustration of potential options. In most situations, there will be no need for public intervention to ensure adoption of these measures by land users. However, it is important that policy makers recognize the whole range of adaptation options available and design policies accordingly.

The working paper record also about 60 policy measures constituting the toolbox for policy makers to cope with climate change adaptation. As in the case of adaptation options we do not maintain that the policy measures listed represent a complete list. However, we believe that the list is representative and may be a source of inspiration to policy makers.

It is generally recommended that policy measures mitigating irreversible or catastrophic impacts, influencing long-term projects and breaking unfavourable trends making adaptation more difficult should be given a high priority. Furthermore, "low-regret" strategies which yield positive benefit even without climate change should be prioritised.
According to the survey on policy measures support of research on adaptation and dissemination of the results should constitute a central role for increasing the capacity of adaptation. Development of new technologies and education of land users will, beside reducing cost of adapting to climate changes, increase land users’ capacity to adapt to other changes in production conditions, e.g. socio-economic changes.
References


Appendix 1

Literature reporting adaptation options and policy measures

The appendix provides an overview of the literature surveyed in this working paper and lists summarily the adaptation options and policy measures suggested. Adaptation options and policy measures are in separate tables. Adaptation options are actions that can be undertaken to mitigate negative impacts of climate change or to take advantage of new opportunities that may arise as a result of climate change. Policy measures are actions that policy makers and regulators can employ to enhance adaptation capacity or mitigate adverse consequences of autonomous adaptation. Furthermore, adaptation options and policy measures addressing the agricultural sector and the ecosystem protection are in separate tables.
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<td>Provide farmers with mid- and long term loans to aid them in the adaptation to changes in climate and markets.</td>
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Table 2A. Potential policy implications for the agricultural sector - continued

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<td>Removal of insurance programmes that discourage farmers to adapt to new environmental conditions</td>
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Table 3A. Adaptation options for ecosystem protection

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### Table 4A. Potential policy implication for ecosystem protection

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<td>Basing policies on regional assessment</td>
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<td>Integrate ecosystem planning and management</td>
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<td>Incentive measures for establishment of buffer zones</td>
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# Working papers
Statens Jorbrugs- og Fiskeriøkonomiske Institut

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<td>Empirisk analyse af generations-skifter i landbruget</td>
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<td>Jens Abildtrup and Morten Gylling</td>
<td>Climate change and regulation of agricultural land use: A literature survey on adaptation options and policy measures</td>
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<td>Philip D. Adams, Lill Andersen and Lars-Bo Jacobsen</td>
<td>Does timing and announcement matter? Restricting the production of pigs within a dynamic CGE model</td>
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<td>Henrik Bolding Pedersen og Steffen Møllenberg</td>
<td>Gartneriets økonomi 1995-99 med særligt henblik på omkostninger til pesticider og biologisk bekæmpelse</td>
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<td>Jayatilleke S. Bandara and Wusheng Yu</td>
<td>How Desirable is the South Asian Free Trade Area? - A Quantitative Economic Assessment</td>
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<td>Kim Martin Lind</td>
<td>Food reserve stocks and critical food shortages – a proposal based on Sub-Saharan Africa needs</td>
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<td>Christian Bjørnskov and Ekaterina Krivonos</td>
<td>From Lomé to Cotonou The new EU-ACP Agreement</td>
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13/01 August 2001  Søren E. Frandsen, Hans G. Jensen, Wusheng Yu and Aage Walter-Jørgensen  Modelling the EU Sugar Policy
A study of policy reform scenarios

12/01 August 2001  Poul P. Melgaard  En afviklingsstrategi for den direkte støtte i EU’s fælles landbrugspolitik
- muligheder og begrænsninger

11/01 Juli 2001  Steffen Møllenberg  EU’s regnskabsstatistik for jordbrug

10/01 Maj 2001  Jørgen Dejgård Jensen, Connie Nielsen og Martin Andersen  ESMERALDA som formodel til makromodellen ADAM
Dokumentation og anvendelser

9/01 Maj 2001  Jens Hansen  Overskuds- og indkomstbegreber i regnskabsstatistikken for landbrug


7/01 May 2001  Aage Walter-Jørgensen and Trine Vig Jensen  EU Trade Developing Countries

6/01 April 2001  Søren Marcus Pedersen og Morten Gylling  Lupinproduktion til fermenteringsindustrien – vurdering af teknologi og økonomi

5/01 April 2001  Mona Kristoffersen, Ole Olsen og Søren S. Thomsen  Driftsgrensøkonomi for økologisk jordbrug 1999
4/01 February 2001  Søren Marcus Pedersen and Morten Gylling  The Economics of producing quality oils, proteins and bioactive products for food and non-food purposes based on biorefining

3/01 Januar 2001  Lars Otto  Metoder til atakonstruktion i Bayesianske netværk – udvikling af beslutningsstøttesystem til sundhedsstyring i svinebesætninger

2/01 January 2001  Søren Marcus Pedersen, Richard B. Ferguson and R. Murray Lark  A Comparison of Producer Adoption of Precision Agricultural Practices in Denmark, the United Kingdom and the United State

1/01 January 2001  Chantal Pohl Nielsen, Karen Thierfelder and Sherman Robinson  Consumer Attitudes Towards Genetically Modified Foods The modelling of preference changes

17/00 December 2000  Hild Rygnestad, Jørgen D. Jensen og Tommy Dalgaard  Målrettede eller generelle politiske virkemidler? Økonomiske analyser i geografisk perspektiv

16/00 December 2000  Stine Hjarnø Jørgensen og Jørgen Dejgaard Jensen  Estimation af priselasticiteter for gødnings- og pesticidkomponenter

15/00 December 2000  Søren E. Frandsen and H.G. Jensen  Economic Impacts of the Enlargement of the European Union. Analysing the importance of direct payments
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