ECONADAPT

The Economics of Adaptation

Funded by the European Union

Report on major uncertainties related to climate impacts and socio-economic costs, and policy recommendations related to the effectiveness of adaptation options

Authors: Tatiana Emolieva[1], Anne Biewald[2], Esther Boere[1], Petr Havlik[1]

Deliverable number	D7.3
Work Package Number	WP7
Submission date	28.04.2016
Type of Activity	RTD
Nature	R = Report
Dissemination level	Public

[1] International Institute for Applied Systems Analysis (IIASA).
[2] Potsdam Institute for Climate Impact Research (PIK).

Document information

Title:	Overview report on major uncertainties related to climate impacts and socio-economic costs, and policy recommendations related to the effectiveness of adaptation options
Authors:	Tatiana Emolieva (IIASA), Anne Biewald (PIK), Esther Boere (IIASA), Petr Havlik (IIASA)
Other Contributors	-
Date:	28.04.2016
Contact details	ermol@iiasa.ac.at
Work Package Number	WP7
Deliverable number	D7.3
Filename:	ECONADAPT_Deliverable_D7.3.docx
Document history:	Final version 1
Type of Activity	RTD
Nature	R = Report
Dissemination / distribution level	PU = Public
Citation:	Emolieva, T., Biewald, A., Boere, E., Havlik, P., 2016, Overview report on major uncertainties related to climate impacts and socio-economic costs, and policy recommendations related to the effectiveness of adaptation options ECONADAPT Deliverable 7.3.
Copyright:	ECONADAPT Project

The ECONADAPT project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 603906.

To find out more about the ECONADAPT project, please visit the web-site: www.econadapt.eu

For further information on the ECONADAPT project contact Alistair Hunt at: ecsasph@bath.ac.uk

The views expressed in this publication are the sole responsibility of the author(s) and do not necessarily reflect the views of the European Commission. The European Community is not liable for any use made of this information.

Executive Summary

Climate change is expected to have a substantial impact on European agriculture over the next decades. In light of this, the current distribution of money through the Common Agricultural Policy (CAP) might not be the most efficient way to support the adaptation of farmers to climate change. Policy makers are therefore faced with the challenging situation of distributing large money flows to different kinds of policy measures to reduce climate impacts. However, because of the uncertain degree of a changing climate on agriculture, the effectiveness of the measures remains unclear. Against this background, the objective of this report is to assess different financial and structural CAP policies in terms of their individual and combined costs and benefits for producers, consumers and the environment, both within and outside the European Union, in light of the uncertainties posed by climate change.

In order to do so, we use the stochastic agro-economic model GLOBIOM and compare effects with its deterministic counterpart. GLOBIOM is a global recursive-dynamic, partial-equilibrium model running at the level of major countries and world regions. The model integrates the agricultural, bioenergy, and forestry sectors allowing for a policy analysis on global and regional issues concerning land use competition and land use transformations driven by increasing demands for food, feed, water, and biofuels. The deterministic model uses a scenario-by-scenario analysis of potential climatic shocks to derive scenario-dependent policy advice regarding adaptation measures. The stochastic version employs uncertainty in yields to simultaneously account for different policies and derive measures that are optimal (robust) with respect to all the scenarios.

The CAP is organized into two pillars, the first pillar covering direct payments and market-related expenditures and the second pillar covering rural development. The CAP measures of Pillar 1 and Pillar 2 intend to provide a basis for climate change mitigation and adaptation in EU in the face of inherent uncertainties and risks. The direct payments of Pillar 1 offer a buffer in case farmers incur income losses. In this report we evaluate direct payments in three ways: (1) based on historic entitlements; (2) equal flat-rate payments; (3) a robust distribution allocated by production allocation profile calculated using stochastic GLOBIOM. The structural measures of Pillar 2 are analyzed using the example of storage facilities. The demand for storage is estimated as a production “shortfall” in locations where current production does not meet the demand. Each measure and their combinations are evaluated using such indicators as land use, demand and water use.

Results show that the robust recommendations of the stochastic model, compared with a deterministic model, can save a considerable amount of maladaptation and sunk costs. Using a deterministic model, an extreme shock may lead to a large uptake in cropland, which may imply large irreversible costs. By taking into account years with good and bad yields, the stochastic model provides a middle way in terms of uptake of cropland between an average yield deterministic model and an extreme shock deterministic model. Furthermore, differences between alternative direct payment schemes are generally small, as is consistent with the literature. Under all direct payment schemes more land is allocated to cropland, managed forest, and natural land, and less land to primary forest and grassland compared with a situation without direct payments. There is a strong synergy between financial and structural measures. The introduction of direct payments is therefore analyzed together with the introduction of storage facilities. The introduction of both direct payments and storage facilities decrease water demand and save investments into irrigation expansion, implying a substitution effect between policy measures.

Two main recommendations stand out in analyzing the effects of optimal combination of CAP policies in light of climate change: (1) It is essential to assess policy measures using a variety of possible outcomes as a result of climate change in order to overcome irreversible costs of maladaptation. (2) Agricultural policies are interdependent and crop and location specific. Agricultural systems are characterized by a strong nexus among the systems at regional and global levels, e.g. through trade, supply-demand, price, food-water-energy-environmental (FWEE) security goals. The optimal combination of policies should not only maximize benefits to producers and consumers, but also optimize environmental parameters like water use, fertilizer use, land cover change, and greenhouse gas emissions.

The case of Stochastic GLOBIOM applied in this study provides an example of how Integrated Assessment Models (IAMs) can assess the costs and benefits of different adaptation options. IAMs can add to standard approaches of impact assessment to ensure a transparent, comprehensive and balanced assessment of policy impacts. This study identifies four ways in which IAMs can contribute to Policy Impact Assessment (PIA): (1) through the inclusion of risk and uncertainty; (2) through the interlinkages between systems; (3) by analyzing on different levels; (4) by analyzing over multiple time periods. We conclude with some policy recommendations related to the inclusion of IAMs in the PIA guidelines of the European Commission.

Table of Contents

1. Introduction

1.1. The impact of climate change

Climate change is in progress; average global temperatures are currently around 0.8°C above pre-industrial levels and continue to rise (EEA, 2012). Its effects are felt in many locations. Much of the debate on climate change has been based on an assertion that climate changes gradually. However, recently it has been accepted that major losses from climate changes associate, in particular, with increasing frequency and variability of natural disasters as well as changing seasonal weather patterns, which introduce considerations of uncertainties and risk into climate change policy debate. Natural disasters are rare events with major impacts; for example, weather-related disasters such as floods, hurricanes, and droughts. These events may cause severe losses, which are highly correlated through space, depending on timing and geographical patters of catastrophes, e.g. clustering of precipitation (floods) or droughts due to persistence in climate (MacDonald 1992). The losses can be exacerbated by past and current risk mitigation and adaptation decisions or when societies do not take proper actions to mitigate the risks (e.g. hurricane Katrina).

Climate change can induce also cascading (systemic) catastrophes of a natural-anthropogenic nature, e.g. such as black-outs in power supply due to intensive water use (pumping) for agriculture in drought periods. High "endogenous" systemic losses due to climate change related disasters associate with incoherent policies, which in interdependent systems lead to cascading systemic failures and risks with catastrophic consequences.

Thus, the impacts and risks associated with climate change are real and taking place in many systems and sectors essential for human livelihood, including water resources, food security, coastal zones and health.

1.2. Need for adaptation

Adaptation to climate change, defined as the response to climate change that seeks to reduce the vulnerability of social and biological systems (UNFCCC, 2016), is an indispensable complement to climate mitigation. Because of the vulnerability to climate change and the huge importance for sustainable developments, adaptation to climate change is essential for the agricultural sector. However, adaptation in the face of climate change uncertainties and risks is a challenging methodological task. From a methodological point of view, traditional economic models and approaches used for the appraisal of adaptation options are based on scenario-by-scenario deterministic evaluations, which do not account for the potential variability of possible future scenarios, and are not flexible enough to balance inherent risks.

Approaches to explicitly account for treatment of risks, also of catastrophic nature, have been developed and are available from other scientific communities (e.g. operations research, statistics, and engineering). In the face of uncertainties and multiple feasible (future) scenarios (climate changes, yield shocks, etc.), the most promising approaches are those providing robust policy advice, making society better-off independently of what scenario materializes. This includes approaches to robust decision-making, robust optimization, robust solutions for dealing with uncertainties (including irreducible, deep catastrophic risks), safety, reliability, and security criteria (see Deliverable 4.2 for further discussion).

In the context of the ECONADAPT project we develop a stochastic partial equilibrium price-endogenous Global Biosphere Management Model (GLOBIOM), which is able to explicitly account for various types of uncertainty (see sections 2.1-2.4), (systemic) risks and climate variability. Contrary to scenario-specific analysis, the model enables the evaluation of robust policy conclusions which leave land use systems better-off independently of what scenario materializes. Stochastic GLOBIOM is used for the analysis of new CAP measures intended to support EU farmers in dealing with climate change and production risks.

1.3. Evolution of the CAP: increased focus towards climate change and mitigation

Upon its establishment, the main goal of the Common Agricultural Policy (CAP) was based on the idea of food security and free trade on a European scale, while ensuring a reasonable income for farmers. In order to achieve these twin aims, a number of common market-control regulations were introduced: tariffs on food imports and export subsidies to protect the internal market and to keep internal market prices high and stable. Over the following decades, a gradual shift in the position and implementation of the CAP took place. Several rounds of reforms followed, aimed to control supply and replace price support by direct income payments with an increasing focus on sustainable agricultural production (Silvis and Lappere, 2010).

Each round of reforms had its own specific objectives. The 1992 MacSharry reform laid the foundation for the transition from market protection and price support to direct payments. The 2013 CAP reform specifies three main objectives: (1) viable food production; (2) sustainable management of natural resources and (3) climate action and balanced territorial development. It is organized in two pillars, the first pillar covering the direct payments and market-related expenditures and the second pillar covering rural development. The total budget of the CAP is around 408.31 billion Euro for the period 2014-2020 (European Commission, 2013a). The first pillar comprises about three quarters of the total budget, with direct payments taking up the majority. The second pillar comprises structural and regional measures and takes up the remainder of the total budget.

1.3.1. Pillar I

Direct payments offer subsidies directly to farmers, conditional upon certain practices (cross-compliance) but decoupled from production. They therefore mainly aim to support farmers' incomes and incentivize them towards good environmental behavior.

The 2014-2020 CAP introduced a basic payment scheme that would eventually provide the same level of support to every hectare of agricultural land within a region, independent of the type of farm or crop grown – it is a flat rate payment. In addition, producers can be compensated for providing public goods in the form of environmentally-friendly farming practices – a so-called greening component that is added to the basic payment if farmers are in compliance. An arable (i.e., crop) producer must meet three basic practices to qualify for green payments (European Commission, 2014):

1. Permanent grassland, defined as land that has been in pasture for at least five years, must be maintained. At a national level, the ratio of permanent grassland to total agricultural area cannot decrease by more than 5%.

2. The producer must diversify his crop portfolio if farmland exceeds 10 hectares. For farms with less than 30 hectares of arable land, there must be at least two crops. For farms with more than 30 hectares of land, at least three different crops must be grown. In both cases, the largest crop cannot be planted on more than 75% of the land; and, for farms larger than 30 hectares, the largest two crops cannot account for more than 95% of land in cultivation.

3. To improve biodiversity on farms, ecological focus areas should be established. For farms larger than 15 hectares, at least 5% of the land must be designated as an ecological focus area. This could take the form of land lying fallow, buffer strips, afforested and agro-forestry areas, or through the use of catch crops, winter green cover and nitrogen-fixing crops.

1.3.2. Pillar II

Pillar II structural measures are focused on the improvement of farmers' incomes and livelihood through investments into structural measures targeted to rural development (rural development programs).

Under the 2014-2020 CAP reform, the second pillar with rural development policies remains unaltered. The second pillar was introduced as part of the CAP reform 'Agenda 2000'. The main goal of the second pillar is to promote growth and employment by promoting sustainable rural development. Policies are aimed at balancing regional growth and environmental sustainability and at building more resilience towards climate change. Member states have more flexibility in designing their own policies of rural development programs targeted to the local environment. At least 30% of the budget of the second pillar must go to voluntary measures that aim to improve the environment and combat climate change. These may be agri-environmental schemes, Natura 2000 areas, forestry measures and investments that improve the environment or climate, such as storage facilities (both for grain and water).

Grain storage is important for transferring grain from good to bad years. Grain markets are characterized by fairly stable (inelastic) demand and uncertain supply, which can fluctuate widely from one year to the next depending on climatic conditions. Grain storage therefore is critical to even out fluctuations in market supply, which in turn smooths out fluctuations in market prices (FAO, 2009). As storage limits production risks, it also reduces the demand for other climate change adaptation and risk hedging measures, both financial and structural, e.g. by reducing the commitment of arable land used in production (Ben-Yehoshua, 2005), thereby also reducing the impact of agriculture on the environment. Availability of storage also reduces the demand for water and for irrigation capacities/investments, as it is also discussed in section 4.

Irrigation projects (improvements) are being discussed in the context of new CAP as an important structural adaptation measure. Agriculture is one of the major water consumers, placing major burden on available water resources and threatening water security issues. Thus, although irrigation may add more stability in yields under variable weather conditions, it can lead to negative impacts especially in water scarce areas with multiple water-dependent systems (IEEP 2000), where overconsumption of water by one (e.g. agricultural sector) can lead to water shortage and systemic failures in other sectors (e.g. energy) (Free-press-release.com, 2014; The Automatic Earth, 2012).

Thus, it is very important to achieve a consistent balance between different water preserving and water demanding technologies. Main water-related instruments in the CAP are: (1) improving irrigation techniques and infrastructures under the rural development pillar; and (2) river basin management plans and water pricing policies as part of the Water Framework Directive (Kahil et al., 2015; European Commission, 2015).

1.4. Integration of climate change adaptation in CAP

The importance of adaptation has been recognized by the European Commission, who adopted an EU strategy on adaptation to climate change in 2013. This strategy focuses on three objectives: (1) promoting actions by member states through guidelines and findings; (2) promoting better informed decision making and (3) adaption in key vulnerable sectors such as agriculture and fisheries. An important part of the adaptation strategy is the facilitation of the climate proofing of the Common Agricultural Policy (CAP). In order to ensure that climate change adaptation objectives are embedded in the CAP, the EU has integrated four broad types of instruments:

1. An improved framework to sustainable management of natural resources, such as the “green” payments as part of the income support.
2. Financial support for rural development policies providing targeted support to a large array of adaptation measures, including implementing actions (e.g. insurance).
3. Promoting enhanced research and innovation for building bridges between research, innovation, advisors and farmers
4. Knowledge transfer for enhancing the adaptive capacity of farmers

The CAP measures of Pillar 1 and Pillar 2 intend to provide a basis for climate change mitigation and adaptation in the EU in light of inherent uncertainties and risks. The direct payments of Pillar I offer a buffer in case farmers incur income losses. Moreover, the cross-compliance and greening requirements may help to hamper climate change. The structural measures of Pillar II imply more straightforward measures that are supposed to improve and adapt rural areas in response to climate changes, such as water and grain storage. The direct payments of Pillar I can be seen as instant adaptation measures, since they provide a yearly flow of money. The measures of Pillar II can be seen as structural adaptation measures, since they provide a large initial investment from which benefits can be derived over a large number of years.

Table 1 below shows an overview of the identified measures and their potential contribution to climate mitigation.

Table 1: Identified CAP measures and their contribution to climate change adaptation in light of inherent uncertainties and risks.

Policy	Meaning	Potential impact on climate mitigation
Pillar I measures		
Direct payments	Lump-sum payment for every hectare of land that has been maintained in good agricultural condition.	Provide a yearly secured flow of money and thereby offer a buffer in case farmers incur income losses.
Greening payment	Top-up on the direct payments in case farmer meets the three requirements with respect to permanent grassland, crop rotation and ecological focus area as indicated in section 1.3.1.	Greening requirements may help to hamper climate change and provide a yearly secured flow of money and thereby offer a buffer in case farmers incur income losses.
Pillar II measures		
Storage	Storage facilities	Catastrophe pools to buffer production shortfalls and fulfill regional and global Food-Energy-Water-Environment Security (FEWES) requirements when extreme events occur.
Irrigation	Irrigation infrastructure	Provide a way to decrease yield variability caused by increased weather variability.

1.5. Nexus between systems

Agricultural systems are characterized by a strong nexus among the systems at regional and global levels, e.g. through trade, supply-demand, price, food-energy-water-environment-security (FEWES) goals. The interdependencies between systems are expected to further increase driven by increasing demands and vulnerability of supplies. The way in which climate change adaptation and risk management strategies will evolve in one region can have significant implications for other regions and globally. Implementation of adaptation measures in CAP can alter regional land uses and trigger changes in other regions' FEWES[3], e.g., through tightening agricultural markets, changing trade balances, increasing price volatility, land grabbing, increasing soil and water pollution, and diverting water for irrigation.

There is also a strong nexus between Pillar I (instant) and Pillar II (structural) measures. This may lead to trade-offs between Pillar I and Pillar II measures. The direct payments or otherwise

[3]Here, security is defined as the ability to deal with risks and uncertainties for meeting dietary, water, energy, environment needs and norms. The main concern of security management is how to ensure the FEWE requirements under all circumstances without substantial increase of costs (Ermolieva et al., 2015).

available income support (also in the form of state or private insurance, subsidies, etc.) can guarantee some income and compensate (part of) potential production losses. Therefore, farmers are less concerned with production risks, which can discourage them from building longer-term (structural) measures that adapt to production vulnerability in the face of (possibly deep) climate change uncertainties. One can argue that ensuring security of production by means of a structural measure may completely eliminate the need in other measures. On the other hand, if climate change and production risks associated with e.g. weather vulnerability are not as severe as expected, the investments used to implement the adaptation may have been lost. Figure 1 below schematically depicts how Pillar I and Pillar II CAP measures are intertwined and together affect changes in FEWES.

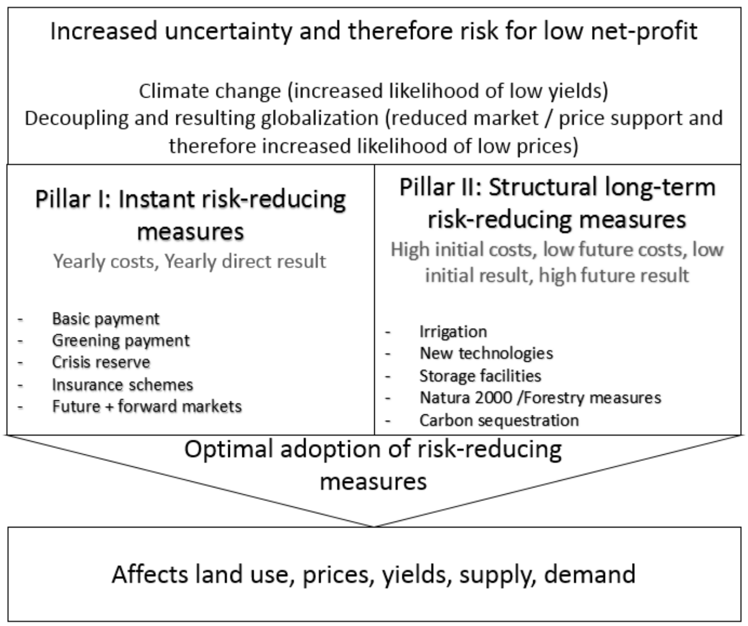


Figure 1: Schematic display of how pillar I and pillar II reduce uncertainty and risk and affect FEWES.

1.6. Objective of this study

Policy makers are faced with the challenging task of distributing large money flows to different kinds of policy measures. Given the uncertain degree of climate change and its effect on agriculture, the effectiveness of policy measures on the structure of the production systems, their risk exposure and vulnerability remains uncertain. For example, the distribution of direct payments can discourage and slow down effective environmentally-friendly and risk-averse producers and encourage marginal businesses with limited potential for improvement to remain active; thereby increasing insecurity in the sector and the chance of systemic failures. This could lead to a decrease of "self-sufficiency", an increase of import dependence, changes in trade balance and market structure, an increase in market risks, a decrease in food security, and socio-economic instabilities. Moreover, direct payments may lead to a reduction in investments in structural adaptation measures, such as the ones offered under Pillar II. The evaluation and approval of the

Pillar II measures also require serious attention as these measures require huge upfront investments, thereby possibly diverting capital (funds) from other projects. Such measures can incur sunk costs if climate change or weather variability is not as severe as expected.

Hence, there are strong synergies (nexus) among Pillar I and Pillar II measures, which need to be accounted for in the analysis of optimal allocation of CAP funds among and within the Pillars at different levels. The current distribution of CAP funds to countries and Pillars might not be the most efficient way to support farmers to adapt to climate change. The objective of this report is therefore to assess different financial and structural CAP policies in terms of their individual and combined costs and benefits for producers, consumers and the environment, both within and outside the European Union, in light of the uncertainties posed by climate change. We therefore analyze how adaptation options integrated into the CAP 2014-2020 and the entire policy can be improved towards an even better climate change adaptation strategy. The optimal combination of policies should not only maximize benefits to producers and consumers, but also optimize environmental parameters like water use, fertilizer use, land cover change, and greenhouse gas emissions.

1.7. Methodological elements in CAP appraisal

Potential costs and benefits and the related economics of adaptation have been assessed in many studies and summarized in a review by UNFCCC (2009) and more recently by Watkiss (2015, Watkiss et al. 2015). In order to appraise a policy targeted at adaptation, it is necessary to weigh the benefits of these measures against their costs. The resulting costs and benefits substantially depend on the methodology applied for policy appraisal. Four elements can be distinguished that are essential in selecting the appropriate methodology to appraise the optimal combination of policy measures in the CAP in light of climate change: (1) the necessity to assess various policies at the same time; (2) the possibility to include both monetary and non-monetary costs and benefits; (3) the issue of time dependence and temporal heterogeneity; (4) the ability to take uncertainty and risks into account.

1.7.1. Necessity to assess various policies at the same time

Often, the analysis of adaptation measures concentrates on single responses (e.g. hard measures such as building dykes), covering insufficiently the potential and need for several measures. Climate change impacts and costs of mitigation and adaptation are then estimated in a scenario-by-scenario manner using a deterministic model. However, there might not be one unique adaptation measure, but a combination of adaptation measures may lead to the most optimal outcome. When trying to mainstream adaptation into the CAP, several money flows and different policy implementations have to be regarded (see Deliverable 4.2 for a more detailed discussion).

1.7.2. Monetary and non-monetary costs and benefits

Costs and benefits of climate adaptation measures can be monetary or non-monetary. Adaptation measures are often evaluated in the context of a financial assessment, based on a cost-benefit analysis. This is designed to show whether the total benefits exceed total costs. This approach ignores the costs and benefits that cannot be reflected in monetary terms. It is often discussed that monetary valuation is unethical in dealing with issues where no distinct price or loss/cost can be associated with one outcome, e.g. risk to human wellbeing. The greater the uncertainty, the more difficult it can be to attach a meaningful “monetary” value to different management options/strategies. In this situation, there is no straightforward assessment of policy options. This is similar to the situation with two alternative land uses that can take place on a certain parcel of land: to measure the costs and benefits of each individual use for a parcel of land is a much more difficult task than to determine the optimal use for a parcel. This is the underlying principle of robust decisions: the evaluation of the robust optimal decisions is achieved without exact evaluation of all possible alternatives. The notion of the robustness explicitly accounts for safety, flexibility, and optimality criteria of all agents against multiple potential scenarios of uncertainties or/and risks. Foremost, the robustness is associated with the safety criteria (Ermoliev and Hordijk, 2003).

1.7.3. Time dependence and temporal heterogeneity

Climate adaptation is subject to inter- and intra-generational justice. In case of intra-generational justice, discount rates are a key issue, as they represent the extent to which today’s society values costs and benefits for future generations. Thus, discounting imposes time preferences of investments, in order to evaluate adaptation projects. Benefits are however highly uncertain. For example, how to justify investments or maintenance in dike construction to prepare against a flood, which may occur on average once in 300 years? This flood, however, can occur and cause catastrophic losses in 1 year, in 50 or 100 years, or not at all. In relation to the random occurrence of the flood (and losses), the disadvantage of standard deterministic discounted criteria is that it does not reveal the temporal variability of the potential catastrophes and associated cash flows (including random losses). Two alternative cash streams (e.g., associated with a system of river channels or a dam) may have the same NPV despite the fact that in one of them all the cash is clustered within a few periods, but in another it is spread out evenly over time. This type of temporal heterogeneity is critically important for dealing with high losses from possible climate change related catastrophes (e.g., floods, hurricanes, etc.), which occur suddenly as a “spike” in time and space (Ermolieva and Ermoliev 2005; Ermoliev et al. 2008).

Although costs of adaptation occur today, benefits accrue in the future. In the traditional appraisal approach, costs and benefits are discounted. This can lead to a very low incentive to invest into adaptation today. As a result, there has been a shift to consider timing and phasing of adaptation. This means that appraisal methods should focus on low-regret actions today combined with an evaluation and learning process to improve future strategies. An appropriate discount rate is especially difficult to define when decisions involve a time span beyond the planning horizon of the current generation, as market interest rates do not reflect the preferences of future generations (Arrow et al. 1996). The discount rate is one of the most important parameters defining CBA, PCBA, NPV, and dynamic GEs evaluations. All studies assume a discount rate exogenous to the economic problem, and construct discount rates in different ways. A comparison of the different ways in which discount rates are constructed can be found in Annex A1.

1.7.4. Ability to take uncertainty into account

Many studies assessing the economics of adaptation have used scenario-based costs-benefits assessments, starting with plausible future socio-economic scenarios and climate model projection to assess impacts and costs from climate change. These studies do not explicitly consider the uncertainties and risks inherent in climate change and are unable to account for increasing variability and frequency of catastrophic risks, as they are highly stylized and focus on adaptation as a response to a (deterministic) defined future projection.

Implementing adaptation with respect to a single (climate change or a catastrophe) scenario is associated with the risk of irreversibility and sunk costs if a different scenario materializes. With respect to potential risk of maladaptation, the analysis explicitly recognizes that the problem should be more accurately framed as sequential decision making under uncertainty. The trade-off is between how much to act now and how much to act when more information about uncertainties reveals (Chichilnisky and Heal 1993). This is a natural framing of the problem involving uncertainty, irreversibility and the potential for learning about climate change. Here, the main issue is how to properly factor in irreversible (sunk) costs (O'Neill et al. 2006).
For proper appraisal of long-term strategic adaptation measures with long pay-back periods in front of climate change uncertainties and risks it is necessary to investigate a mix of several measures with different time horizons oriented to hedge different climate change related events. One could think of floods with different reoccurrence periods or floods and droughts. Only when accounting for various risks and multiple adaptation measures with different time horizons, using both monetary and non-monetary measures (costs and benefits) under different degrees of uncertainty, is it possible to deal with issues of interdependent (systemic) risks, sunk costs of maladaptation, and the costs of reversing decisions (e.g. if other than expected scenario occurs).

1.8. Methodology used in this study

In the face of climate uncertainties and risks, and in order to reduce the negative impacts of wrongly implemented adaptation measures, it is important to focus on methods and models which account for potential maladaptation and reversibility costs (Arrow and Fisher 1974). An optimal adaptation strategy also very much depends on the uncertainties associated with future population and economy development. Taking these inherent uncertainties into account is therefore essential for deriving robust conclusions regarding adaptation options.

In this report, as an example of designing robust policy decisions under uncertainties, maladaptation and irreversibility, we use a stochastic partial equilibrium price-endogenous land use model (Global Biosphere Management Model, GLOBIOM) based on the principles of a two-stage (two types of solutions) stochastic optimization framework. This approach enables coherent analysis of both ex-ante measures (taken in front of uncertainties) and ex-post measures (to adjust initially taken decisions when additional information becomes available). The approach minimizes total costs of the decisions providing policy makers with flexibility for revising the measures in light of newly acquired knowledge about uncertainties (O'Neill et al. 2006).

Stochastic GLOBIOM is applied for the analysis of CAP measures intended to support EU farmers in dealing with climate change and production risks. The model explicitly accounts for various types of uncertainties, (systemic) risks and climate variability. The set of ex-ante (strategic) measures comprises production allocation, storage capacities, where the ex-post operational decisions concern the level of demand, trading, and storage control. In Ermolieva et al. (2016) the model is applied to the case of increased storage facilities, which can be viewed as catastrophe pools to buffer production shortfalls and fulfill regional and global FEWES requirements when extreme events occur. Expected shortfalls and storage capacities have a close relation with Value-at-Risk (VaR) and Conditional Value-at-Risk (CVaR) risk measures.

1.9. Layout

The remainder of this deliverable is structured as follows: In the next section we identify four different types of uncertainty to assess the optimal combination of CAP policies in light of climate change. In section 3 we present the data and methods used in this study. In section 4 we describe the results, which can be divided into results from the deterministic and stochastic version of GLOBIOM, with respect to Pillar I and Pillar II measures individually as well as combined. In section 5 we conclude upon the results and discuss how this report fits into the existing research on the economics of adaptation and how such an analysis can contribute to the guidelines on Policy Impact Assessment (PIA) of the European Commission.

2. Uncertainty in climate change and policy assessment

Uncertainties can be distinguished as natural and anthropogenic. Natural uncertainties result from the inherently stochastic nature of interactions in earth and climatic systems. Anthropogenic uncertainties result from our inability to completely understand and analyze complex interdependencies and behavior of anthropogenic systems in response to potential exogenous (natural) and endogenous (policy-driven) shocks and threats. For example, anthropogenic uncertainties can be related to various characteristics of future technologies, abatement rates, and adaptability of future societies to altering climate.

2.1. Uncertainty in climate change

Significant uncertainties associate with different facets of climate change, their impacts and socio-economic costs. There have been several surveys on uncertainties in climate change studies, in particular, including Heal & Kristrom (2002). One of the examples of natural systems uncertainties relevant to ECONADAPT was mentioned in the Climate Change 2007 report on “Impacts, Adaptation and Vulnerability” and it refers to the difficulties of exact estimation and prediction of water availability and supply. The precipitation patterns exhibit natural variability which scientists fail to correctly describe. Other examples of natural uncertainties refer to uncertainties in responses of soil to changing precipitation and temperature regimes, and uncertainties of bio-physical and plant growth processes resulting in e.g. yields variability.

An example of climate change anthropogenic uncertainties associates with possible outcomes of incoherent climate change adaptation policies, which can result in systemic risks propagating through land use systems (LUS). Various studies demonstrate that massive deforestation and increase of GHG emissions in Indonesia, Malaysia, and Africa is due to rapidly increasing expansion of palm oil plantation being driven by biofuel targets in Europe (Coyle 2007; Koh and Wilcove 2007; Fitzherbert et al. 2008). The costs of climate change adaptation in this case should include also the costs of reverting the harmful consequences (reversibility and maladaptation costs), i.e. high investments and the costs of expensive projects devised to compensate for ongoing large scale human-made changes to ecosystems (Butler et al. 2009; Koh et al. 2009; Wicke et al. 2011).

These examples show that because of interdependencies, the way in which climate change adaptation policies evolve in one system and/or region (e.g. EU) can cause changes not only within the system or region, but in other systems, regions, and globally.

2.2. Uncertainty in agricultural production

In the agricultural sector, uncertainty relates to yield shocks in response to climatic or other shocks, leading to e.g. price variability. Increased output price volatility does not necessarily imply changes to the level and variability of income, because income also depends on input costs and yields, and the correlation between them (Pennings et al., 2010). More specifically, a producer faces different kinds of uncertainty: production uncertainty, due to uncontrollable elements such as weather; price uncertainty, because the output price is unknown at the time decisions have to be made; technological uncertainty; and policy uncertainty (Moschini and Hennessy, 2001).

Depending on the correlation between different kinds of uncertainty, the resulting uncertainty in producers' incomes may lead to rising income risk (Hardaker et al., 1997).

2.3. Uncertainty in policy making

The EU's reduced intervention in agricultural markets has led to increasingly volatile output prices and more income uncertainty. At the same time, the introduction of direct payments may decrease downside risk by securing a minimum amount of wealth (Hennessy, 1998). This may alter the decision-making process of producers and their exposure to risk.

There is an extensive literature on the evaluation of effects that the decoupled payments of the 2003 Mid-Term Review had on farmers' decisions (for a review see Bhaskar and Beghin, 2009). These include impacts on investment decisions caused by increased access to credit (Sckokai and Moro, 2009), changes in on- and off-farm labor allocations (Key and Roberts, 2009; Hennessy and Thorne, 2005), changes to inputs or other activities that would increase output (Hauser et al., 2004), increased land and rental prices (Brady et al., 2009), and, related to prices, competition for land between agricultural markets (Gohin, 2006). On a broader scale, direct payments impacted land abandonment and biodiversity (Brady et al., 2009; Mosnier et al., 2009; Baskar and Beghin, 2009; Key and Roberts, 2009), affected prices/markets (Balkhausen et al., 2008; Gohin, 2006), and led to the distortion of subsidies on production (Dewbre et al., 2001; Burfisher and Hopkins, 2003).

From the studies relying on traditional economic theory without accounting for uncertainties and risks, it has been concluded that in general moving to a flatter rate across farmers and member states will have a rather marginal effect on production within the EU (Hennessy and Thorne, 2005; Sckokai and Moro, 2009; Koundouri et al., 2009; Key and Roberts, 2009), certainly in comparison to other support mechanisms (Dewbre et al., 2001; Burfisher and Hopkins, 2003). I.e., Moving payments from one farm to another (or one country to another) will affect relative incomes but not outputs.

2.4. Structural differences between models

In reality, the level of production depends not only on the cost-efficiency of producers (region), but also on their risk exposures, security targets, and the set of feasible policy measures including trade, storages, irrigation technologies. In this section we provide a short overview of traditional economic (multi-sectoral) models applied for estimation of climate change impacts and adaptation costs in economic sectors. The results significantly differ across the models, caused by structural differences between the models, such as the sectorial representation, constraints, and, of course, the way climate change scenarios (shocks) are defined in terms of impacts on costs and benefits.

2.4.1. Differences caused by different model structures

To get an insight into potential sources of discrepancies across models, let us shortly describe the differences between Integrated Assessment Models (IAMs) applied in studies of climate change impacts on the agricultural sector (Nelson et al., 2013). We specifically focus on the models IMPACT (Rosegrant, 2012), ENVISAGE, GCAM, GLOBIOM (Havlik et al., 2011), GTEM, MAGNET, MAgPIE, and AIM (Nelson et al., 2013).

Among the economic models (Nelson et al., 2013) ENVISAGE and GTEM are CGE models, GLOBIOM is a partial equilibrium model of land use systems; MAGNET is a "modular" global CGE model; MAgPIE is a global land use allocation model with exogenous demand and trade scenarios; AIM is a large-scale computer simulation model; and IMPACT is a partial-equilibrium model.

The diversity of the model results reflects the diversity of problems for which the models were designed. For example, models focusing on policies affecting energy security, energy access, and air pollution usually have a detailed energy component, but an underrepresented agricultural and land use sector. Models focusing more on agricultural developments generally have richer agricultural sector components, enabling a better representation of food-feed production, but an underrepresentation of interdependencies and feedbacks with other LUS sectors and/or less flexibility regrading energy-LUS interactions.

One of the significant sources of divergence is trade representation in the models. Some models (e.g., GLOBIOM, GCAM, and IMPACT) rely on an integrated world market representation, which could overstate the degree of trade response, whereas others use the Armington trade model (based on elasticity of substitution between products of different countries calculated based on historical data), one-market model, demand-production-trade scenarios, or a restricted role of trade.

Spatial land resolutions also differ largely between models. Within partial-equilibrium models, GLOBIOM and MAgPIE have a full representation of land use and allocate it through an optimization process with high spatial resolution, whereas IMPACT only considers cropland and assumes it can be expanded without constraints. Within general-equilibrium models, land representation also varies strongly, from the simplified structure of substitution found in GTEM or ENVISAGE that does not consider land expansion into forest to MAGNET that relies on a land supply curve calibrated on a biophysical model.

But even within the same model differences may occur. For example, IMPACT links its multi-market economic model with water and crop models (DSSAT model). In Nelson et al. (2009), the combined IMPACT2009-DSSAT analysis results in two climate models for the A2 scenario of the IPCC's Fourth Assessment Report: the National Center for Atmospheric Research, US (NCAR) model and the Commonwealth Scientific and Industrial Research Organization, Australia (CSIRO) model. Substantial differences in IMPACT estimates between the two climate models occurred. Figure 2 displays discrepancies between model-predicted yield projections derived with alternative bio-physical models for the same geographical region.

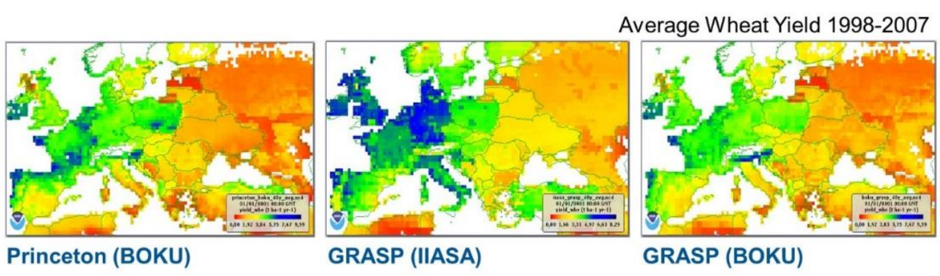


Figure 2: Yield differences between existing biophysical models.

2.4.2. Estimated costs and benefits from climate change between models

Estimates of adaptation costs in the presence of uncertainties and risks will vary depending on: representation of uncertainties, risks, and security considerations; representation of possible maladaptation and the need to reverse actions; the nexus between adaptation and mitigation; the nexus between short- vs long- term decisions as defined in the structure of models.

Estimates of climate change costs and benefits are incorporated into different legislations. Often the costs are included through the social cost of carbon (SCC) of global warming. The use of SCC as a global warming cost estimate has been established by Interagency Working Group (IAWG) in 2010. It is being drawn from three simple commonly-used IAMs of climate change and the global economy, DICE (Nordhaus, 2008), FUND (Anthoff et al, 2009), and PAGE (Hope, 2006)[4]. The IAWG models produce a relatively narrow "distribution" of SCC values, as can be seen from Figure 3 where the distribution of 2010 IAWG SCC estimates from all three models for a discount rate of 3% are represented. In Moyer et. al. (2013) it is shown that one of the main reasons for this is that the IAWG models do not properly include spatio-temporal propagation of costs through economic sectors, i.e. economic growth continues despite substantial climate damages. All IAMs cost estimates are derived with an assumption that climate changes gradually and incrementally. Therefore, these models fail to account for spatio-temporal heterogeneities of uncertainties, variability and risks inherent to climate changes.

[4]For a broad list of IAMs see Kelly and Kolstad, 1999). The SCC is an estimate of the economic damages associated with a small increase in carbon dioxide emissions, conventionally one metric ton, in a given year ($21/tCO). This dollar figure also represents the value of damages avoided for a small emission reduction (i.e. the benefits of a CO2 reduction). The methodology for estimation of SCC became a framework for examining issues in modeling the cost of climate change. The IAWG's central SCC estimate (IAWG, 2010) must be used in cost-benefit analysis of any regulation that affects carbon dioxide emissions. IAMs try to capture interactions between complex, highly non-linear, non-stationary systems. The systems are characterized by deep (often unresolvable) uncertainties regarding direct and indirect interactions (nexus), response delays, risk exposure, vulnerability, resilience, etc. The heterogeneities related to spatio-temporal timing of impacts. However, IAMs are not designed to represent the very fine details, they were designed to provide "strategic" insights, which may considerably affect their reliability regrading impacts and costs estimates. As they say, IAMs are like climate models which are not supposed to forecast weather.

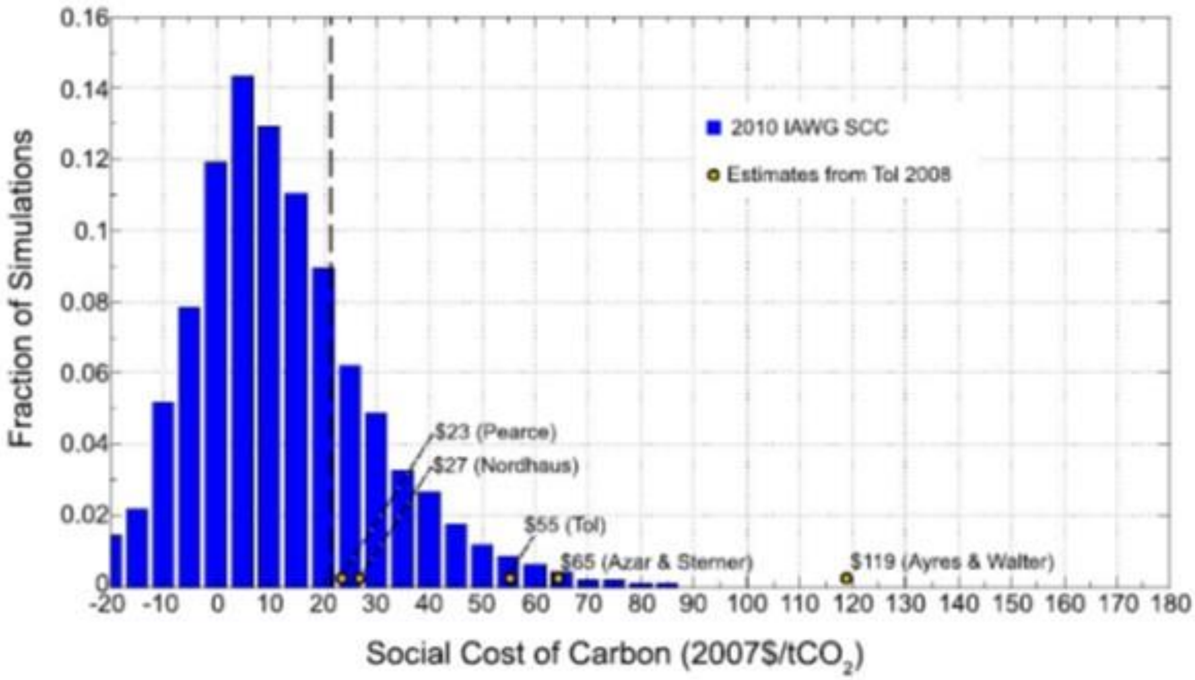


Figure 3: (Source Moyer et. al., 2013): Distribution of 2010 IAWG SCC estimates from the DICE, FUND and PAGE model for a 3% discount rate. Data were digitized from Figure A8 of IAWG (2010). (Raw SCC data are no longer available.) Dashed line is mean value across models, \$21/tCO2. Mean (median) SCC values for DICE, PAGE, and FUND are \$28 (\$25), \$30 (\$12), and \$6 (\$0.5) /tCO2, respectively (IAWG (2010) Tables A3 and A5). Negative SCC values imply that climate change is net beneficial to society; all are confined to FUND, which assumes gains in the agricultural sector under moderate warming (Greenstone et al, 2013). Dots show all SCC estimates from the Tol (2008) review with 3% discount rate, as average values from each study.

3. Data and Methods

Instead of using a traditional deterministic scenario-by-scenario analysis of climate changes, as it has been done in Nelson et al. (2013), this study uses stochastic GLOBIOM which simultaneously makes use of all relevant uncertainty scenarios and based on this derives optimal decisions. In particular, the stochastic GLOBIOM enables to investigate a robust combination between Pillar 1 and Pillar 2 measures of the new EU CAP accounting for the synergies between different types of measures and for the interdependencies between multiple sectors and regions. In this section we provide some details of the model and data applied for this study. Before discussing the stochastic aspects and investigating new CAP measures, we provide a conceptual description of the general (deterministic) GLOBIOM (section 3.1). Further details of the model formulation and the underlying assumptions can be found e.g. in Havlik et al. (2011).

3.1. Standard version of GLOBIOM

GLOBIOM is a global recursive-dynamic, partial-equilibrium model running at the level of major countries and world regions. The model integrates the agricultural, bioenergy, and forestry sectors allowing for policy analysis on global and regional issues concerning land use competition and land use transformations driven by increasing demands for food, feed, water, and biofuels. Endogenous demands, prices and trade flows are computed at the level of all countries and/or 30 aggregate world regions, while decisions on production and land use allocation are taken at simulation units of about 50 km2 resolution. The main land uses distinguished are crop land, grass land, forest (managed and non-managed) land, fast-rotation forest plantations, and natural land. Land use change alternatives are limited by explicit food, feed, energy, water, and environmental security constraints.

The supply of crops (i.e., agricultural production) needs to cover food and feed demands. The food security constraint ensures that the energy intake from food cannot be lower than the minimum amount of kilocalories needed to satisfy dietary requirements in cereals, vegetable, and animal products (meat and dairy products) measured in kilocalories per capita (James and Schofield 1990; WHO 1985). Feed sources for livestock comprise crops, grass, and biofuel co-products (feed cakes). Feeds produced for livestock cannot be lower than the minimum livestock dietary requirements in energy measured in mega-calories. First-generation biofuels from crops and second-generation biofuels from lignocellulosic biomass (woody crops) and agricultural residues have to fulfill biofuel production targets. Food security constraints and biofuel security targets introduce competition for limited natural resources (land and water) among different land uses.

Forestry resources are used for the production of saw logs, pulp logs, and other industrial logs. Forest production also includes biomass for woody energy and traditional fuel wood. The energy biomass can be converted through i) combined heat and power production, ii) fermentation for ethanol, heat, power and gas production, and iii) gasification for methanol and heat production. Woody biomass for energy can also be produced from short-rotation tree plantations. Thus, agriculture and forestry have binding bioenergy targets which induce systemic risks similar to those in the example discussed in section 2.2 (Havlík et al. 2011). Environmental[5] security

[5]Discussions of environmental security have been evolving since 1970 (Mayers 1993). Several definitions of environmental security have been adopted by a few countries and international organizations. An overview of the definitions is summarized in The Millennium Project, http://millennium-project.org/, Fiksel and Hecht (2012).

constraints are introduced as targets on GHG emissions from land use and land use changes (Valin et al. 2013).

Product supply functions are included implicitly and are based on detailed, geographically explicit Leontieff production functions. The Environmental Policy Integrated Model (EPIC) model (Liu et al. 2007) is used to simulate climate- and management-related yields for 20 crops, which represent more than 80% of the 2007 harvested area as reported by FAO (2009). The GLOBIOM model is formulated as a linear optimization problem. The objective function of GLOBIOM maximizes the sum of producer and consumer surpluses subject to food security, biofuel targets, GHG emissions, and resource constraints. For further details on GLOBIOM, the reader is referred to Havlík et al. (2011) where all assumptions on exogenous drivers (i.e., population, economic, environmental, and technological development parameters, etc.) are also presented in detail.

3.2. Stochastic GLOBIOM

The deterministic model uses a scenario-by-scenario analysis of potential climatic shocks to derive scenario-dependent policy advice regarding adaptation measures. The stochastic version employs all relevant uncertainty scenarios to simultaneously account for different policies and derive measures that are optimal (robust) with respect to all the scenarios. An analytic description of a stylized two-regional (two-producer) model, which enables to understand the main difference between the deterministic and stochastic versions of GLOBIOM can be found in Annex AI. A more detailed description can be found in Ermolieva et al. (2016).

As a simple example to highlight the advantages of the stochastic model compared with the deterministic model, consider two crops, A and B, and two scenarios of nature (climate), e.g., a wet and dry season. Crop A is better than crop B in a wet season, and B is better than A in a dry season. At the time planting decisions have to be made, we do not know whether there will be a wet or dry season. In a deterministic scenario-specific model, we would either assume a wet or a dry season, and based on this crop A or crop B is chosen as the optimal production strategy. Therefore, the deterministic approach may result in maladaptation if crop A is planted and dry season occurs (or crop B in case of a wet season). A robust solution may be crop C (or a combination of A and B), which is neither better than crop A in wet or crop B in dry season; however, it is better when faced with uncertainties about the season. Robust solutions may also involve a proper balance between domestic production and imports of shortfalls, as it is discussed with an example in Annex AI. Therefore, the set of feasible solutions of the stochastic model is larger and qualitatively different than of the deterministic counterpart.

Thus, robust solutions minimize the costs associated with decisions taken in the light of uncertainties as well as the costs of correcting these decisions after information on uncertainties becomes available. The so-called value of the stochastic solution (VSS) indicates the magnitude of losses associated with implementing a deterministically derived solution in a stochastic environment (Birge and Louveaux, 1997).

At the level of EU countries, stochastic GLOBIOM allows us to investigate the effects of different Pillar 1 payment schemes and derive a robust solution based on the combination of economic, social, agricultural and risk (security) principles. Using calculations of geographically-detailed “profiles” of risk-adjusted production and prices derived from stochastic GLOBIOM, we define the so-called robust policy mixes based on the estimated demand for storages in different locations and analyze the effects of storages on demand, price, land, water consumption, etc.

In section 2 different kinds of uncertainty have been identified. In this deliverable we focus on the effect of climate change on agriculture and the optimal mix of CAP policies in light of mitigating climate change. Therefore, uncertainty is specified in stochastic GLOBIOM by variability in yields. However, because demand, supply, price and trade flows are endogenous in GLOBIOM, variability in e.g. prices due to increased uncertainty in yields is incorporated as well.

3.3. Implementation measures

Section 3.2 explained the methodological differences between the deterministic and stochastic GLOBIOM model. In this section we present the selected measures used to analyze the difference between the deterministic and stochastic models.

3.3.1. Deterministic versus Stochastic GLOBIOM

Both the deterministic and the stochastic model run for a time horizon of 40 years (from 2010 to 2050) with time steps of 10 years. Stochastic yields are represented by a finite set of historical yield scenarios from 1960 to 2015, analyzed in Figure 4. In the calculations, we use food, feed, water, environmental and biofuel security constraints by requiring that, in each yield scenario, the demand for food, feeds, and biofuels is not less than the exogenously given target levels. Water security is introduced through a constraint on the total admissible water consumption of the following activities: crop production and processing, animal farming, forest production and processing, and biofuel production and conversion. Greenhouse gas (GHG) emissions targets from land use systems are included as environmental security constraints.

Results of stochastic GLOBIOM will be compared with results of deterministic GLOBIOM using the “Value of Stochastic Solution,” (VSS). VSS is calculated based on values of the objective functions, where the optimal solution of the deterministic GLOBIOM under the average yield scenario is compared with the robust solution of the stochastic model. The comparison shows about 25% difference between the two values, which indicates the importance of including uncertainties when designing robust solutions.

For comparing policy recommendations with and without uncertainties we study the following cases:

C1: Deterministic model (GLOBIOM) is run in a “what-if” manner using alternative, including average, yield shock scenarios. For each yield scenario, the model derives scenario-specific estimates of production, profits, demand, costs, prices, trade, land use, etc., and, therefore, provides scenario-dependent optimal solutions. The analysis of results shows considerable variability of model outcomes (production, profits, demand, land use, etc.) across the yield shock scenarios (cc scenario). In this case, GLOBIOM assumes that a spatio-temporal yield scenario occurs with probability 1, and there is no need to adjust to shocks. When all is known in advance, LUS are managed ex ante without ex post responses.

C2: Stochastic GLOBIOM is run with planning under uncertainty; the so-called strategic (ex-ante) decisions on land allocation between crops and management systems are made in the face of uncertainties, i.e. before information on stochastic yields becomes available. The costs of these decisions are minimized together with the costs of respective operational (ex-post) decisions (trade, storage withdrawals, water use, prices) after the actual yield is observed, thus ensuring the coherency and robustness of strategic and operational decisions.

Robust solutions of stochastic GLOBIOM comprise ex-ante strategic decisions (land allocation by crops, management systems, regions and storage capacities) and related adaptive decisions (trade, storage withdrawals, prices, demands).

3.3.2. Pillar I measures

Under the 2003 reforms, direct payments were decoupled from production but linked to eligible farmland, although coupling elements were retained in some programs, notably dairy, cereals, sugar beet and starch potatoes. Countries could choose eligible farmland to be based on (1) farm-specific historical reference amounts, (2) regional reference margins, or (3) a hybrid of the historic regional references. While the European Commission expressed a preference for (2), the majority of countries opted for (1) (Matthews et al., 2013). Under the historic approach, only lands growing specific crops were considered eligible for fixed payments (€/ha) that varied by crop based on historic 2000-2002 yields. Because payments were based on farm-specific entitlements, their size differed significantly by type of farm and across farms (Helming and Peerlings, 2014). Pillar I direct payments are applied per hectare of cultivated land in three ways:

D1: Direct payments as they were allocated for the average hectare of cultivated land by country.

D2: An alternative allocation based on the same level (flat-rate) of aid per hectare to all farmers in the EU. In the model we calculate the average level of direct payments at the level of EU-27 to be around 150 – 160 EUR/ha (in these studies we exclude grass land from the analysis), i.e. we assume the EU flat rate is about 155 EUR/ha cultivated area (Scheme 2)[6].

D3: Using production allocation "profile" calculated by stochastic GLOBIOM, we define the so-called Robust (Scheme 3) payment rates per hectare eligible land.

Thus, using stochastic GLOBIOM, we are able to achieve a more equitable and risk-adjusted redistribution of decoupled payments among Member States and among farmers (land) in order to enhance the effectiveness of direct payments in supporting farmers' income and contributing to secure and sustainable provision of food and other basic goods. One of the reasons why we do not consider grassland is because of uncertainties and missing values in spatially-detailed grassland data. As the purpose is to compare the outcomes from deterministic (traditional) and stochastic approaches, in these studies we include only the basic payments schemes (BPS) and do not consider "greening" payments, although the structure of GLOBIOM permits accounting for main greening principles such as compliance with "management requirements and good agricultural conditions" (cross compliance) and "agricultural practices beneficial for the climate and environment" (greening payments).

3.3.3. Pillar II measures

Pillar II structural measures are tailored to the local context. Explicitly, we implement only one of the measures, i.e. grain storage, which, however, does allow us to analyze the interdependencies between different measures. Namely, introduction of storage can significantly decrease the

[6] Other approaches to "exogenous" allocation of payments can be tested ("MAX" or "MIN" rate), however, these schemes do not account for risk considerations either.

demand for other structural measures, such as expansion of irrigated land or investments in advanced irrigation systems. Pillar II measures can be applied in two ways:

S1: Grain storage in a region (location) is introduced by accounting for the frequency of potential production shortages vs security constraints, costs, and benefits associated with the introduction of the storage in the region (location). The demand for storage is estimated as a production “shortfall” in locations where current production does not meet the demand (no self-sufficiency) and the trade is either not possible or too expensive.

S2: The demand for irrigation infrastructure (and, in general, water storage), is estimated similar to grain storage, i.e. in locations where water supply does not meet the demand. The water shortfall determines the demand for water saving technologies, storage, etc., able to stabilize production and welfare of farmers at required level.

In this study we illustrate the interdependencies between the two measures. Without the explicit introduction of water storage, we analyze by how much grain reserves (calculated with stochastic GLOBIOM) can decrease overall agricultural water demand. In this case, grain storage may especially be useful for climate change adaptation in water-scarce areas characterized by competition for water among multiple users.

Finally, stochastic GLOBIOM allows to incorporate economic, social, agricultural, and risk criteria for defining an optimal distribution of Pillar 1 payments among member states.

3.4. Data

3.4.1. Stochasticity of yields

Climate change uncertainties and variability are included in stochastic GLOBIOM using stochastic scenarios of crop yields. Instead of using yield scenarios from bio-physical crop models (e.g. EPIC), we use information on empirical yield shock distributions calculated based on available FAO data. Prior to introduction in the model, the data have been de-trended and normalized by 2012 yield. Analysis of data shows remarkable yield variability attributed to weather conditions. The effect of weather on agricultural productivity differs by region. Histograms of wheat yields based on 52 years (from 1960 to 2012) data series are depicted in Figure 4 for major grain producing countries.

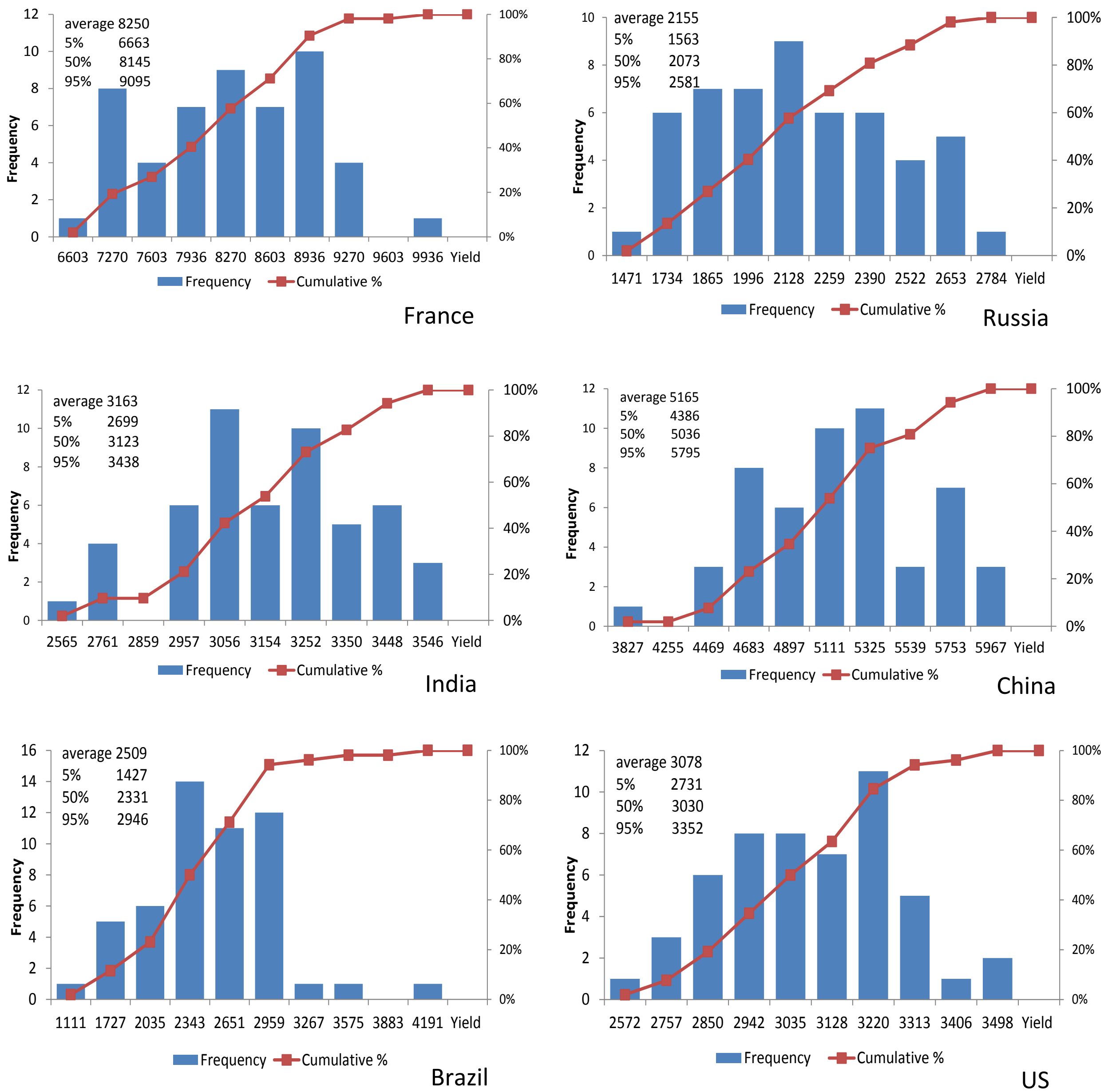


Figure 4: Empirical wheat yield distribution by selected grain producers, 1960-2012 (source: FAO, 2016). Horizontal axis denotes yield (in kilograms per hectare of harvested land) and vertical axis shows the number of years (frequency) the corresponding yield occurred in the 1960-2012 period. Cumulative distribution refers to the percentage of total of the yield occurrences at or below the value on the horizontal axis.

As can be seen from the figure, yield distributions are characterized by multimodal shapes, precluding the use of mean-variance criteria and indicators. Figure 4 shows average and main (5th, 50th, 95th) percentiles of yield distributions. Countries such as France and China are characterized by higher yields and smaller yield variability. For example, in France, 50th percentile equals 8145 (kg), and 5th and 95th are in the range of [-17; 11] percent around the 50th; in China, the 50th percentile is about 5036 (kg), and 5th and 95th are within [-16; 15] percent ranges. In the US, the 5th and 95th percentiles deviate from the 50th by -13 and +10 percent, respectively. In Russia, Ukraine, and Kazakhstan, the yields are smaller and the variability is larger, 50th percentile is 2050 (kg), and the ranges are -24 and +27 percent for 5th and 95th percentiles respectively. In Australia, the 5th and 95th percentile yields are within [-41; 22] percent ranges around the 50th percentile.

3.4.2. Pillar I Measures

The current distribution of direct payments leads to significant differences in average payment by country, as can be seen from Figure 5, which gives the average payment per hectare by country before the 2013 CAP reform.

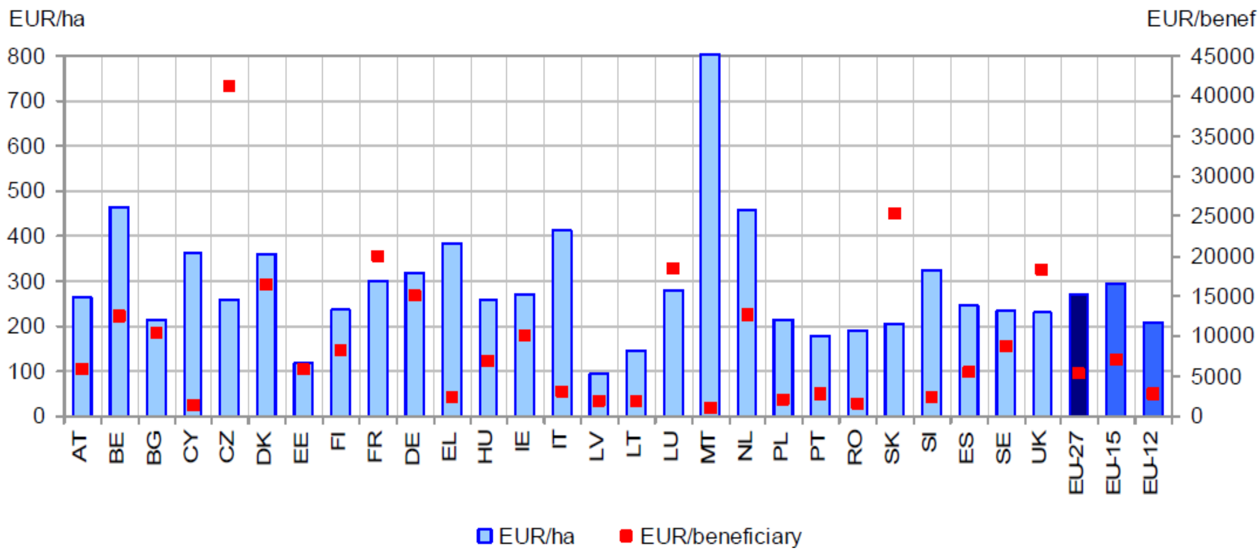


Figure 5: Average direct payment per beneficiary and per hectare in EU Member states (Source: DG AGRI).

Part of the 2013-CAP reform is a basic payment scheme that would eventually provide the same level of support to every hectare of agricultural land within a region, according to the regulations described in section 1.3.1. This may also lead to a more equal distribution between countries. An equal distribution between member states would amount to €267 per hectare of cultivated land.

3.4.3. Pillar II Measures

Grain storages in a region (location) are introduced by accounting for the frequency of potential production shortages versus security constraints, costs and benefits from the introduction of the storage in the region (location). The demand for storage capacity depends on the distribution of production shortfalls (shocks) in the region, agricultural self-sufficiency[7] policies in the EU (other

[7]Stochastic GLOBIOM allows for the analysis of the question: Does the EU really need food self-sufficiency as a guarantor of food security. Food self-sufficiency is defined as the proportion of domestic consumption met from domestic production. For example, **the deficit of EU protein crop production** has been identified as one of the current challenges (see discussion in Annex A3).

regions), FEWES requirements, and storage maintenance (including running) costs vs import costs. Let us illustrate this with a typical example of rice production in Japan. In Japan, as a part of the governmental control, rice imports are banned with the rational that self-sufficiency in rice is important for food security. In the absence of imports, downward yield shocks lift prices[8]. Adequate storage introduce flexibility in supply-demand relations by reducing the dependence on ex-post imports.

Thus, introduction of storage in stochastic GLOBIOM can serve as a tool for revealing and relaxing tight policies (levels of self-sufficiency, security, GHG targets) and restrictions causing systemic risks in LUS. Similar to the example of strict rice policies in Japan, analysis of the demand for storages in EU (section 4) allows us to investigate the feasibility of (high) bio-fuel targets under production risks and inelastic demand for wheat, corn, rape, sunflower, i.e. biofuel sources.

3.5. Indicators for policy appraisal

The following indicators are used to evaluate CAP policies in the light of climate change:

The Value of Stochastic Solution (VSS), which is used to measure the overall importance of applying the stochastic model (Birge and Louveaux, 1997) for the analysis of policy recommendations in the presence of uncertainties and risks. Or, in other words, the VSS reflects the possible gain associated with the application of the stochastic model.

Land (production) allocation by different land use and management systems: Land expansion under the current set of measures indicates the demand for new measures. For example, in the absence of grain storage, managing food security (maintaining a certain production level) can lead to rapid land expansion. For catastrophic scenarios, absence of grain storage may can cause expensive and possibly irreversible land use transformations, and unnecessary technological investments.

Demand: Robust long-term planning of land management in combination with trade, precautionary savings of grain, and other measures, lowers prices and increases demand.

Environmental parameters: water use, and land cover change to analyze e.g. deforestation in the set of land cover changes.

[8]http://www.canon-igs.org/en/column/macroeconomics/20131001_2136.html. Rice production in Japan in 2003 was poor, “crop situation index” was about 90. As a result, the rice price increased by 30% from the 2002 year, which is also reflected in stochastic GLOBIOM.

4. Results

In this section we evaluate the different policies identified in Section 3 individually and together in order to analyze the optimal combination of CAP policies for producers, consumers and the environment, both within and outside the European Union, in the light of the uncertainties posed by climate change. In particular, we start by analyzing the main differences between policy recommendations derived with deterministic and stochastic GLOBIOM in section 4.1, continued by the assessment of direct payments and storage facilities in the subsequent sections. We end the results section with an appraisal of the optimal combination of CAP policies in light of climate change.

4.1. Deterministic versus stochastic GLOBIOM

In this section we illustrate the main qualitative differences between policy recommendations derived with deterministic and stochastic GLOBIOM to highlight the importance of incorporating climate change uncertainties, introduced as alternative yield shock scenarios, for the analysis of robust policy recommendations. Treatment of stochastic variables (e.g. yields) as deterministic parameters, ignoring variability and uncertainties in production conditions simply by averaging them, is equivalent to dealing with only one scenario of evaluations.

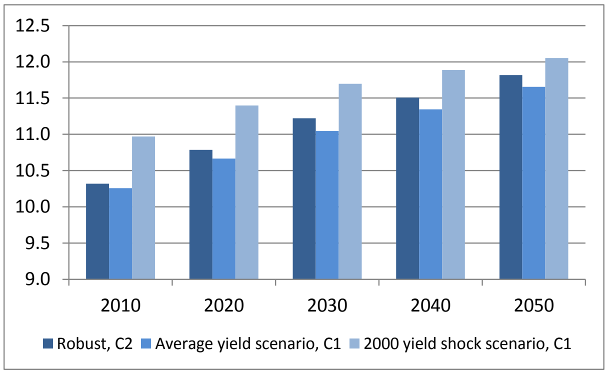
Implementation of scenario-specific decisions may lead to maladaptation, sunk costs and the costs to adjust or reverse the decisions if another scenario occurs, i.e., the deterministic model. This does not account for potential reversibility costs if another scenario occurs, i.e., allowing no trade-offs between strategic and operational measures. In general, there may be a vast variety of scenarios. Stochastic GLOBIOM allows us to find strategies which are robust against all eventualities, leaving us better off independently of which scenario occurs.

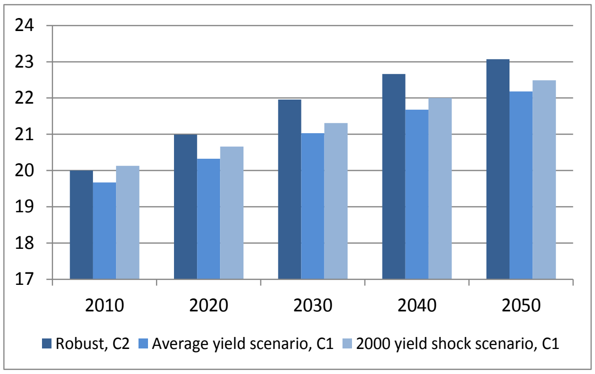
4.1.1. Effects on land use

Scenario-specific deterministic analysis of yield shocks produces scenario-dependent solutions similar to the example in section 3.2 (two crops and two seasons). Thus, for each yield scenario, the deterministic GLOBIOM model calculates different optimal land requirements, crop portfolios and production allocation by management systems, trade flows, demand, prices, which can significantly differ across scenarios. Therefore, the implementation of a scenario-specific solution can lead to maladaptation and require adjustments, such as conversion of forest into crop land or additional irrigation capacities if, for example, a drier than anticipated year occurs. Consider Figure 6, which presents the percentage of land in different LUS in C1 and C2 cases at the global level. Traditionally, the majority of policy recommendations are based on results derived from a model using an “average” scenario. Therefore, the deterministic, average yield scenario can be seen as the base case in the comparison of model structures. Compared with the average yield scenario, the 2000 yield shock scenario shows a larger percentage of land allocated to cropland and grassland, but a smaller percentage allocated to natural forest, planted forest, and natural land, and an equal percentage allocated to managed forest. This implies a large loss of biodiversity.

Hence, the average yield scenario would considerably underestimate land demand, as well as production technologies that are able to limit production risks. Various explanations may be given for this. For example, “2000 yield shock scenario” (corresponding to the year 2000 historical yields) is characterized by rather low yields due to simultaneous occurrence of droughts in

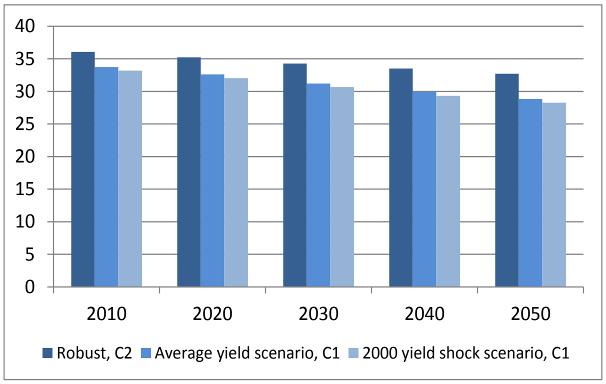
Australia, China, India, Russia, etc. If deterministic GLOBIOM uses the “2000 yield shock scenario”, the model correspondingly calculates the requirements in crop and grassland, production and trade (and other variable), which enable to fulfill food and feed security norms, biofuel targets, environmental pollution goals, etc. Because of low yields, the land demand in “2000 yield shock scenario” is higher then, e.g., in the “average yield” scenario (average yield is calculated as a sum of possible yield values divided by the number of values)[9] as well as in many other scenarios.

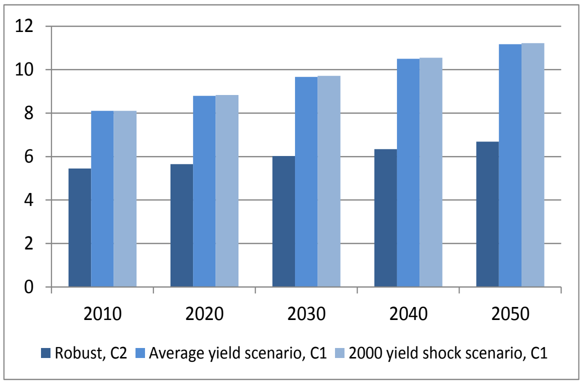




a. Crop land

b. Grass land

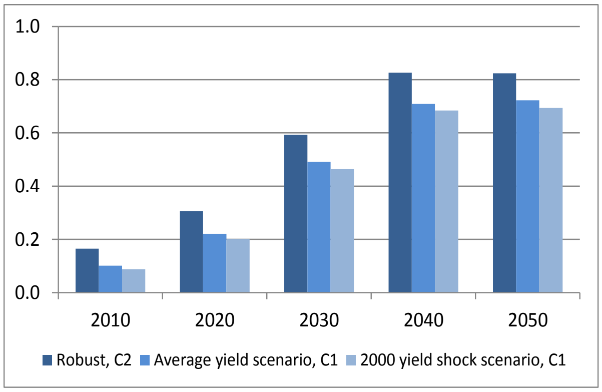


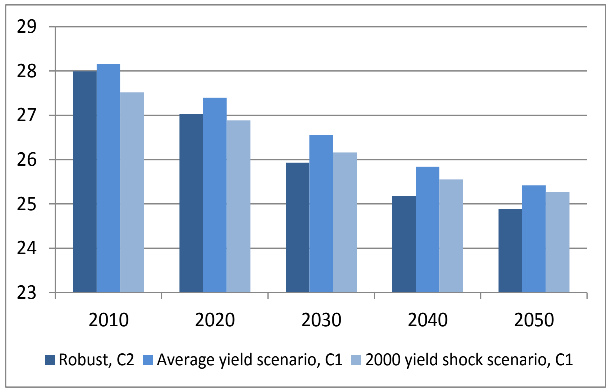


c. Natural forest

d. Managed forest

[9]Average scenarios are traditionally used in deterministic modelling. Average yield value is calculated as a sum of possible yield values divided by the number of values.





e. Planted forest

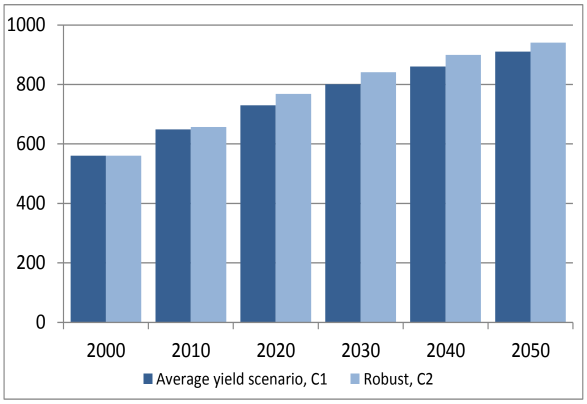
f. Natural land

Figure 6: Percentage of total land occupied by different LUS at the global level calculated using stochastic GLOBIOM (Robust, C2), deterministic GLOBIOM under the average yield scenario (Average yield scenario, C1), and deterministic GLOBIOM under extreme shock scenario (2000 yield shock scenario, C1). Horizontal axis labels simulation year and vertical identifies percent.

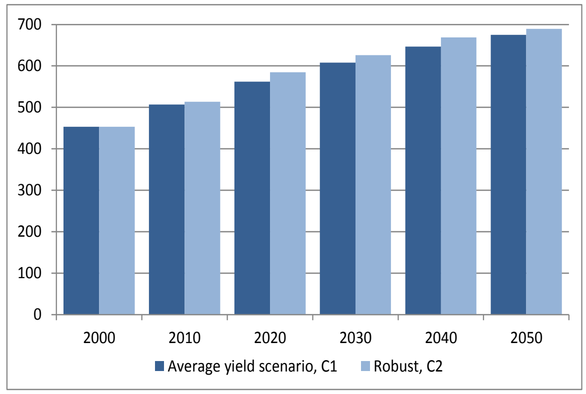
Stochastic GLOBIOM incorporates in the analysis all yield shocks simultaneously and derives solutions accounting for yield variability. Having possibility of flexible ex post adjustments to all potential scenarios, stochastic GLOBIOM recommends qualitatively different solutions. For example, natural ecosystems should be preserved, the conversion of natural forests into managed should slow down, grass land should be protected as an important feed source for livestock (see panels b and c in Figure 6). At the same time, it calculates a higher percentage of short-rotation tree plantations to fulfill bioenergy goals (Figure 6, panel e). All conversions come primarily from natural land (Figure 6, panel f). It is critically important that robust strategic decisions on land allocation among LUS are supplemented with adaptive scenario-specific trade decisions. Stochastic GLOBIOM accounts for spatial dependencies between yield shocks (FAO, 2011) and suggests scenario-specific geographical diversification of trade across uncorrelated (or negatively correlated) regions and commodities.

Stochastic GLOBIOM balances global systemic risks, which influence land use and thereby prices and demand for crops. To facilitate a crop-specific analysis, we focus on the crops as wheat, corn, rice, rape, sunflower and soya. We select these crops because they take up a large portion of arable land. Moreover, soya is important for livestock feeds and is in deficit in the EU. Rape and sunflower are highly demanded for bio-diesels, and are inelastic crops. Wheat, rice and corn are the main staple crops.

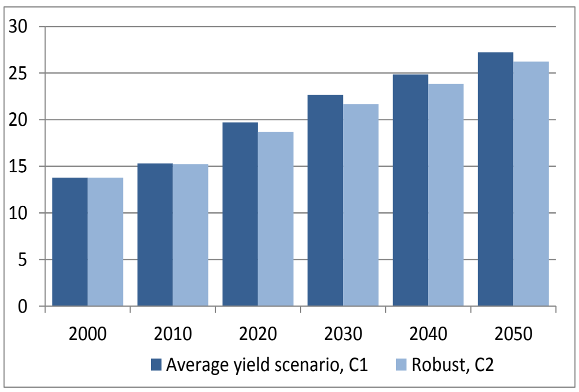
Figure 7 shows the global demand for rice, wheat, rape and sunflower. As can be seen from the figure, stochastic GLOBIOM allows that rice and wheat demand are increased by about 4.5% and 6%, respectively, compared with the deterministic average yield model. On the other hand, the model suggests that production of rape and sunflower be decreased by about 5% and 6%, respectively. Hence, under stochastic GLOBIOM there is a larger demand for staple crops, which may be due to the food security requirement.



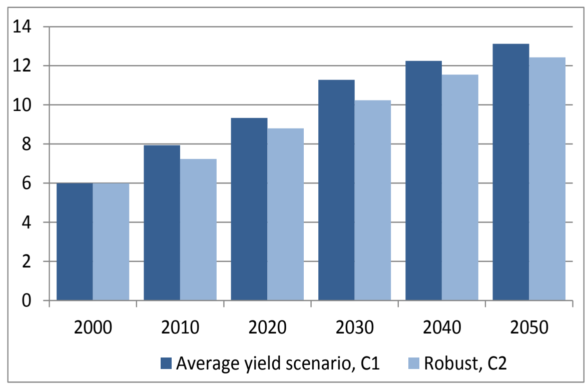
a. Rice



b. Wheat



c. Rape.



d. Sunflower.

Figure 7: Global demand for selected agricultural commodities calculated using deterministic GLOBIOM under the average yield scenario (Average yield scenario, C1); using stochastic GLOBIOM (Robust, C2). Horizontal axis identifies simulation years and vertical axis shows the demand level in thousand tons.

4.2. Pillar I Measures

4.2.1. Direct payments

As many farms and agricultural enterprises heavily depend on income stabilization measures, the design of the Pillar 1 payments (now decoupled from production) can have impacts on producers' behavior and profitability of farmers' businesses. Currently, the Pillar 1 payments in many EU countries still reflect historical patterns of production. Traditional economic theory argues that moving from historical (D1) to the flat distribution of payments will not affect production. However, the example in Annex A1 shows that the level of production depends not only on the cost-efficiency of producers (region), but to a major extent it depends on risk exposures, security targets, and the set of available (or feasible) measures including trade, storage, irrigation technologies, etc.

Stochastic GLOBIOM can be used for designing robust and fair allocation of payments (D3), accounting for risk-exposures, economic, social, agricultural, and self-sufficiency and security criteria for defining a distribution of Pillar 1 payments among member states. The country-specific rates of D3 are calculated in such a way that the average per hectare payment rate over all countries equals to the flat rate (D2). The Robust payments can be further adjusted for other economic and social indicators reflecting, e.g. levels of rural incomes, working hours etc. Figure 8 displays three alternative payment schemes: historical (D1), flat (D2), and robust (D3), in EUR per hectare eligible land.

Figure 8: Alternative schemes for distribution of Pillar I payments across EU countries, in EUR/ha.

Table 2 and Table 3 show the demand for respectively corn and wheat under the three different direct payment schemes compared with the scenario without subsidies. In Table 2, only very small changes between the different scenarios occur. Under the scenario without subsidies, EU_Central East fluctuates a bit. Initially a slight increase until 2030 is observed, followed by a decrease. This is mostly due to EU_CentralEast and EU_South. Under a flat rate direct payment, demand increases with 18.5% between 2010-2050 for EU-North, and decreases for all other regions. The historic scenario is very similar to the flat-rate scenario, which is in line with the literature on direct payment reform. Under the robust scenario, the size of increase and decrease in demands lies between the flat-rate and historic scenario. The demand for wheat (Table 3) shows positive changes in demand over time for all regions except for Baltic and Central-East. Under the no-subsidy scenario, a very large increase in demand for wheat in EU South is observed. Under the flat, historic and robust subsidy scenarios, the largest increase in wheat demand is observed for the EU-North region (between 24 and 27%). This is in line with the higher subsidies for Northern regions under both the historic and robust scenario's (Figure 8).

Similar effects are observed also for other commodities, barley, rice, etc. It is important to mention that currently stochastic GLOBIOM incorporates rather moderate shocks; therefore, it is expected that in case of possible stronger shocks, the effects of subsidies on production can be more profound.

Table 2: Corn demand under alternative allocation schemes of Pillar 1 payments for stochastic GLOBIOM, by EU region, in thousand tons.

EU Region	2010	2020	2030	2040	2050	% change
No subsidies						
EU_Baltic	44.0	42.8	40.8	39.2	36.6	-16.8
EU_CentralEast	6341.1	7167.6	5798.7	4780.6	5451.4	-14.0
EU_MidWest	4662.2	4260.4	4235.2	4377.8	4492.7	-3.6
EU_North	1357.4	1377.6	1458.5	1309.2	1377.5	1.5
EU_South	3042.9	2841.0	2744.6	2824.7	2935.0	-3.5
Total	15447.5	15689.5	14277.9	13331.7	14293.3	-7.5
Flat						
EU_Baltic	53.9	81.4	124.7	75.3	45.0	-16.5
EU_CentralEast	5798.5	6566.2	6195.6	4795.9	4800.8	-17.2
EU_MidWest	4785.6	4306.6	4361.1	4521.1	4678.1	-2.2
EU_North	1420.1	1664.4	1853.3	1631.5	1683.2	18.5
EU_South	3890.1	4005.7	4033.0	3280.4	3160.9	-18.7
Total	15948.2	16624.3	16567.8	14304.2	14367.9	-9.9
Historic						
EU_Baltic	53.5	81.7	122.7	75.7	43.5	-18.7
EU_CentralEast	5779.8	6578.7	6315.0	4962.1	4888.9	-15.4
EU_MidWest	4784.6	4447.4	4371.3	4511.9	4672.8	-2.3
EU_North	1420.1	1680.2	1864.8	1684.0	1717.2	20.9
EU_South	3910.6	4076.5	3336.2	3329.9	3184.2	-18.6
Total	15948.7	16864.4	16010.0	14563.5	14506.6	-9.0
Robust						
EU_Baltic	53.3	81.8	123.8	75.2	42.1	-21.0
EU_CentralEast	5851.2	7010.5	6301.3	4951.2	4862.1	-16.9
EU_MidWest	4785.4	4453.8	4371.3	4527.9	4693.5	-1.9
EU_North	1420.1	1663.6	1861.1	1652.6	1692.7	19.2
EU_South	3910.6	3999.0	4035.6	3316.0	3182.5	-18.6
Total	16020.6	17208.6	16693.0	14523.0	14472.9	-9.7

Table 3: Wheat demand under alternative allocation schemes of Pillar 1 payments, by EU regions, in thousand tons.

EU Region	2010	2020	2030	2040	2050	% change
No subsidies						
EU_Baltic	766.3	735.3	640.9	650.9	659.4	-14.0
EU_CentralEast	15229	15027.2	14177.3	15066.9	14931.3	-2.0
EU_MidWest	22844.7	21862.7	19513.3	22434.3	23963.6	4.9
EU_North	10050.6	10124	8800	10936.6	11835.1	17.8
EU_South	11304.9	15769.2	18067.6	18745.2	19198.7	69.8
Total	60195.4	63518.3	61199.1	67833.9	70588.2	17.3
Flat						
EU_Baltic	787.4	740.8	687.5	687.8	652.4	-17.1
EU_CentralEast	15178.8	15199.3	14562.1	14744.1	14913	-1.8
EU_MidWest	23080	22958	21433.8	26366	25875.4	12.1
EU_North	10915.9	11700.6	12940.4	13702.6	13544	24.1
EU_South	18222.5	19472.4	20160.9	19911.7	19886.3	9.1
Total	68184.5	70071.1	69784.7	75412.2	74871.1	9.8
Historic						
EU_Baltic	787.6	737.5	687.4	688.1	652.5	-17.2
EU_CentralEast	15166.3	15293.9	14522.7	14729.3	14660.1	-3.3
EU_MidWest	23083.8	22976.4	21433.8	23563.8	25977.8	12.5
EU_North	10888.5	11733.4	13203.7	13704.3	13826.8	27.0
EU_South	18217.9	19443.6	20144.3	19837.4	19790.9	8.6
Total	68144.1	70184.8	69991.9	72522.9	74908.1	9.9
Robust						
EU_Baltic	787.6	740.9	688.7	691.1	652.4	-17.2
EU_CentralEast	15140.6	15344.1	14642	14754.8	14924.7	-1.4
EU_MidWest	23118.7	23018.5	21469.8	23650	25986.7	12.4
EU_North	10934	11696.6	13342.8	13767.9	13855.8	26.7
EU_South	18227	19475	20165.1	19880.9	19899.5	9.2
Total	68207.8	70275	70308.4	72744.8	75319.2	10.4

Table 4 shows the global demand for corn, rape, soya and wheat. Demand increases for all crops over time. For the crops rape, soya and wheat there is almost no difference between schemes in terms of percentage change over time. For corn, the difference in percentage change between crops is a bit larger; and is the largest under the robust scheme.

Table 4: Global demand for selected crops under alternative allocation schemes of Pillar 1 payments, in thousand tons.

Crop	Scheme	2010	2020	2030	2040	2050	% change
Corn	Flat	211783	251444	293252	25129	367082	73.3
Corn	Historic	211812	252808	293271	337748	355071	67.6
Corn	Robust	206458	252898	302917	337251	372917	80.6
Rape	Flat	16521	20252	21085	34001	27637	67.3
Rape	Historic	16521	20308	21030	25112	27607	67.1
Rape	Robust	16523	23664	21085	28656	27812	68.3
Soya	Flat	60575	69127	78632	88080	108750	79.5
Soya	Historic	60578	69125	78607	87303	108838	79.7
Soya	Robust	60585	69123	78619	88061	108786	79.6
Wheat	Flat	519198	556110	604626	635775	678451	30.7
Wheat	Historic	504545	556008	604858	635642	661105	31.0
Wheat	Robust	504542	556408	605108	635877	661405	31.1

Change in land use

Table 5 shows the area of land allocated to the crops corn, wheat, rape and soya under different allocation schemes over time. Under the scenario without direct payments, a decrease in land for corn and wheat and an increase in land for rape and soya is observed. When subsidies are introduced (flat, historic and robust), the area allocated to corn increases instead of decreases. The areas allocated to wheat, rape and soya remain similar.

Under the robust scheme, soya is allocated to more land than under historic and flat payments. Here, the acreage of land under corn production is higher than in the flat-rate case and lower than in historic scenarios, while under wheat it is in the robust case higher than in the historic and lower than in the flat scenario. It is interesting to note that when storage possibility is added, land under rape production decreases and under corn, wheat and soya it increases. The largest relative increase in land is always related to soya, ranging between 174 and 210%.

Table 5: Acreage of land under different crops and alternative allocation schemes of Pillar 1 payments, at EU level, in thousand hectares.

Crop	Scheme	2010	2020	2030	2040	2050	% change
Corn	NoSubs	9365	9989	10215	9666	9010	-3.8
Wheat	NoSubs	23107	20769	18740	17266	16832	-27.2
Rape	NoSubs	5672	7242	8432	8103	8167	44.0
Soya	NoSubs	920	1345	1705	2225	2520	173.9
Corn	Flat	9272	10022	10660	10578	10573	14.0
Wheat	Flat	23022	20365	18733	17048	16691	-27.5
Rape	Flat	6862	8728	9640	9313	9343	36.2
Soya	Flat	727	1225	1630	2128	2083	186.5
Corn	Historic	9279	9979	10659	10632	10809	16.5
Wheat	Historic	23007	20396	18814	17046	16608	-27.8
Rape	Historic	6862	8763	9648	9331	9350	36.3
Soya	Historic	727	1223	1645	2186	2254	210.0
Corn	Robust	9286	10026	10623	10501	10569	13.8
Wheat	Robust	23029	20394	18956	17050	16635	-27.8
Rape	Robust	6859	8732	9637	9445	9536	39.0
Soya	Robust	728	1226	1638	2213	2117	190.8
Corn	Rob+Stor	9523	10289	10813	10757	10773	13.1
Wheat	Rob+Stor	23116	20693	19068	17442	16925	-26.8
Rape	Rob+Stor	5742	7311	8449	8057	8232	43.4
Soya	Rob+Stor	920	1402	1650	2186	2230	142.4

Table 6 shows the area of land by type of land use allocated under different allocation schemes over time. In Figure 6 the deterministic version of GLOBIOM was compared with the stochastic version. Compared with the deterministic model, it was shown that natural ecosystems were more preserved, the conversion of natural forests into managed forests slowed down, and grassland, planted forest and natural land increased. When subsidies and storage are added, only minor changes in land allocation by type occur. Compared with the case without subsidies, there will be a bit more land allocated to cropland (around 600 hectares by 2050). This mostly goes at the cost of grassland.

Table 6: Area under different land uses and different payment schemes, at EU level, in thousand hectares.

Land Use	2010	2020	2030	2040	2050	% change
No subsidies						
CropLnd	60304	58790	57392	55985	54611	-9.4
MngFor	82221	56448	58306	60363	61210	-25.6
PriFor	56187	81960	80102	78045	77198	37.4
PltFor	682	5539	10253	14831	18722	2645.2
GrsLnd	59260	57884	56645	55455	54801	-7.5
NatLnd	37066	35099	33022	31041	29179	-21.3
Total	295720	295720	295720	295720	295720	0.0
Flat rate						
CropLnd	60304	59115	57895	56493	55239	-8.4
MngFor	82221	56584	58422	60695	61509	-25.2
PriFor	56187	81824	79986	77713	76900	36.9
PltFor	682	5539	10263	14806	18786	2654.5
GrsLnd	59260	57497	56073	54917	54057	-8.8
NatLnd	37066	35161	33081	31097	29231	-21.1
Total	295720	295720	295720	295721	295722	0.0
Historic						
CropLnd	60304	59118	57911	56506	55230	-8.4
MngFor	82221	56572	58414	60733	61549	-25.1
PriFor	56187	81836	79994	77675	76860	36.8
PltFor	682	5539	10263	14806	18800	2656.6
GrsLnd	59260	57505	56068	54914	54060	-8.8
NatLnd	37066	35150	33071	31087	29222	-21.2
Total	295720	295720	295721	295721	295721	0.0
Robust						
CropLnd	60304	59115	57890	56487	55232	-8.4
MngFor	82221	56602	58434	60754	61565	-25.1
PriFor	56187	81806	79974	77654	76843	36.8
PltFor	682	5539	10263	14805	18811	2658.2
GrsLnd	59260	57531	56109	54953	54066	-8.8
NatLnd	37066	35128	33050	31067	29203	-21.2
Total	295720	295720	295720	295720	295720	0.0
Robust + storage						
CropLnd	60304	59058	57758	56361	55164	-8.5
MngFor	82221	56396	58259	60458	61309	-25.4
PriFor	56187	82012	80149	77950	77099	37.2
PltFor	682	5539	10261	14818	18779	2653.5
GrsLnd	59260	57648	56300	55120	54217	-8.5
NatLnd	37066	35067	32993	31013	29153	-21.3
Total	295720	295720	295720	295720	295720	0.0

Water use

Table 7 shows the irrigated area under different payment schemes. Under D3 (robust scenario), the demand for irrigated land in 2010 to 2040 is lower than under historic (D1) and flat (D2) schemes. This can be explained by the fact that stochastic GLOBIOM under robust subsidies identifies more efficient water management technologies and activities, which reduce the demand for water. Thus, irrigated crop production under D3 requires by about 2-3% less water at EU level than under other subsidizing schemes. Another reason for the fact that a much larger percentage increase in irrigated area over time can be observed from the no-subsidy scenario compared with the scenarios including subsidies is that support measures may substitute each other. For example, the possibility of storage reduces the demand for irrigation.

Table 7: Irrigated area under different payment schemes, by EU regions, in thousand hectare of basin irrigation.

EU Region	2010	2020	2030	2040	2050	% change
No subsidies						
EU_Baltic	5.2	5.5	2.7	3.6	9.8	88.5
EU_CentralEast	2817.4	3888.8	4856.3	5786.4	6610.2	134.6
EU_MidWest	1379.3	1858.1	2601.4	2615.5	3283.3	138.0
EU_North	408.5	622.4	819.6	1049.2	1312.5	221.3
EU_South	2233.8	2832.7	3634.1	4308.5	5192.1	132.4
Total	6844.2	9207.5	11914.2	13763.1	16407.7	139.7
Flat						
EU_Baltic	4.2	3.9	2.7	3.6	4.8	14.3
EU_CentralEast	2554	2712	2859.3	2383.5	1759.2	-31.1
EU_MidWest	1013.2	1093.4	1107.6	993.3	789.1	-22.1
EU_North	411.1	268.5	282.6	362.5	409.4	-0.4
EU_South	2013.5	2028	2051	2107.6	1922.7	-4.5
Total	5996.1	6105.8	6303.3	5850.5	4885.2	-18.5
Historic						
EU_Baltic	4.2	3.9	5.8	3.5	4.5	7.1
EU_CentralEast	2559.1	2928.4	2822.5	2326.3	1793.2	-29.9
EU_MidWest	1013.2	1067.4	1107.8	993.3	795.1	-21.5
EU_North	411.1	388	371	358.4	406.4	-1.1
EU_South	2002.1	2024.4	2065	2074.1	1987	-0.8
Total	5989.8	6412	6372.1	5755.7	4986.2	-16.8
Robust						
EU_Baltic	4.2	3.9	2.7	5.3	4.8	14.3
EU_CentralEast	2565.8	2675.8	2879.4	2406.4	1840.2	-28.3
EU_MidWest	1013.2	1094	996.5	850.4	786	-22.4
EU_North	411.1	338.3	279.4	358.2	406.4	-1.1
EU_South	2008.1	2026	2061.6	2078.4	1928.1	-4.0
Total	6002.5	6137.9	6219.6	5698.7	4965.6	-17.3
Robust + storage						
EU_Baltic	4.2	5.3	2.7	3.6	4.6	9.5
EU_CentralEast	2373.8	2353.3	2513.1	2127.6	1523.9	-35.8
EU_MidWest	1103.4	890.8	702.5	821.5	795.2	-27.9
EU_North	415.2	426.9	469.5	439.4	411.4	-0.9
EU_South	1963.6	2026	2041	2074.7	1982.8	1.0
Total	5860.2	5702.3	5728.8	5466.8	4717.9	-19.5

Table 8 shows the water use at EU level for D1 and D2 as a percentage of D3 and D3 as a percentage of D3 plus additional storage facilities. Total water for irrigation under D3 is less then under D1 and D2. The model calculates also by how much water use differs by crops under different allocation schemes. Positive numbers (e.g. in “Flat versus robust” row) identify by how much, in percentage terms, water consumption is higher under flat as compared to robust payments allocation scheme.

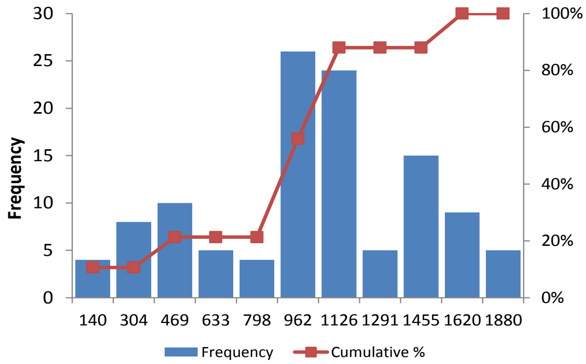
Table 8: Water use under different Pillar I payment schemes, at EU level, in percentage terms difference from D3 (Robust).

Total water	Flat_vs_Rob	0.3	3.4	1.6	2.7	2.6
	Hist_vs_Rob	0.3	10.7	17.1	7.1	8.7
	Rob_vs_Rob+Stor	2.9	0.9	-0.1	-0.7	-0.3
Wheat	Flat_vs_Rob	0.1	1.6	0.1	5.0	11.8
	Hist_vs_Rob	0.3	10.7	17.1	7.1	8.7
	Rob_vs_Rob+Stor	3.8	4.1	9.8	-0.3	-0.6
Corn	Flat_vs_Rob	2.3	3.2	3.6	0.1	6.5
	Hist_vs_Rob	1.4	13.7	7.7	2.5	0.1
	Rob_vs_Rob+Stor	6.4	-0.7	-12	-8	-0.6
Soya	Flat_vs_Rob	0	0	-0.1	-0.1	-0.2
	Hist_vs_Rob	0	0	0	0.1	6.8
	Rob_vs_Rob+Stor	-10	-15	-0.2	-0.5	-0.9

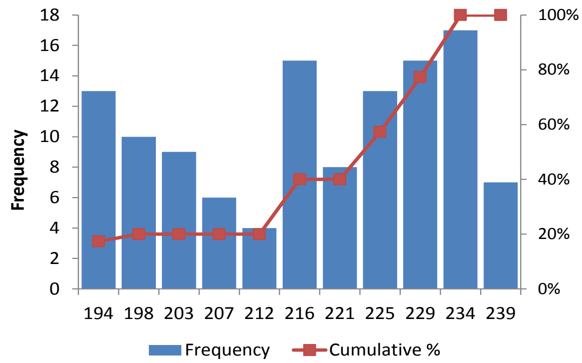
Pillar II measures: Storage facilities

Grain reserves can effectively buffer instantaneous shortages of domestic production and imports due to natural events in combination with trade bans and/or tariff policies. In stochastic GLOBIOM, the demand for storage is estimated using expected production shortfall characterizing the systemic risks and vulnerability of production, as it is illustrated with an example in Annex A1. By varying parameters reflecting costs of storage, it is possible to achieve reliable predictions on domestic grain savings vs interregional trade, i.e., the model decides if precautionary grain stocks are cheaper then ex-post importing. Storage is also important to avoid large investments into irreversible decisions, e.g., irrigation systems.

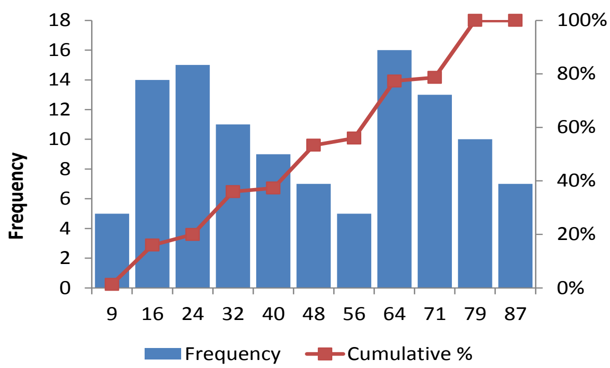
Robust solutions of stochastic GLOBIOM in the presence of grain storage increase the feasibility of various environmental and (bio)fuel targets. For example, storage capacities (Figure 9) of about 80 and 300 thousand tons for rape and sunflower, respectively, modulate the instantaneous demand for cropland caused by a yield shock (similar to the year 2000, as in Figure 9, panel a), and decrease the investments in and conversion of rain-fed land into irrigated land to sustain rare high-impact shocks. In particular, global reserves (Figure 9) of about 1000, 250, 60, and 300 thousand tons of rice, wheat, barley, sunflower, respectively, can obviate the need for investment in the irrigation of about 3545 thousand hectares of agricultural land globally.



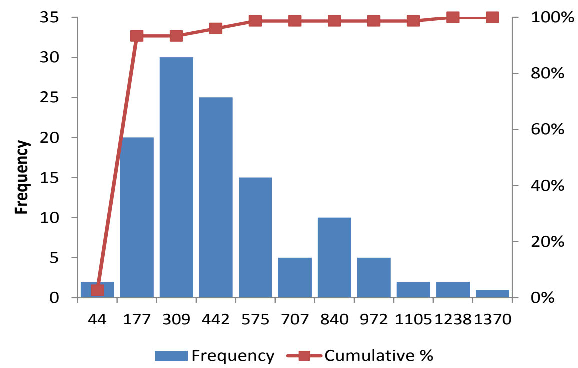
a. Rice.



b. Wheat.



c. Barley.



d. Sunflower.

Figure 9: Distribution of storage withdrawals, in thousand tons, at the global level. Frequency refers to the absolute number of withdrawals within a range identified on the horizontal axis. Cumulative refers to the percentage of total of the withdrawals at or below the value on the horizontal axis.

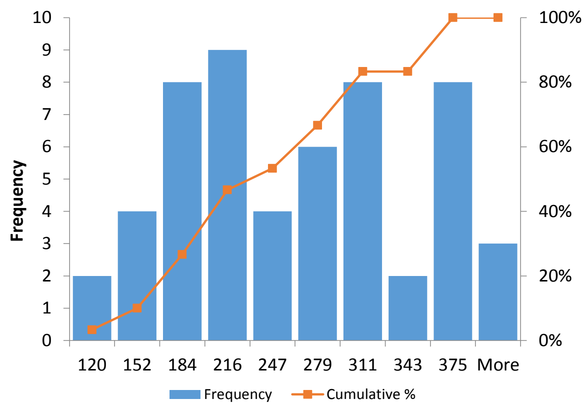
Introduction of storage further increases the supply and demand by buffering production shocks in bad yield years. Storage is particularly essential (for self-sufficiency at the EU level) to cover food-feed-(bio)-fuels demand when trading is restricted or limited because of a direct or indirect (induced) yield and price shocks, or when land and water resources are scarce, or advanced water management technologies are not available. Thus, storage can be viewed as insurance in cases where no other sources of supply, domestic or foreign, are available. In this sense, storage capacities measure the systemic risks and (in)security.

Figure 10 depicts distribution of storage withdrawals corresponding to robust (D3) allocation of subsidies.

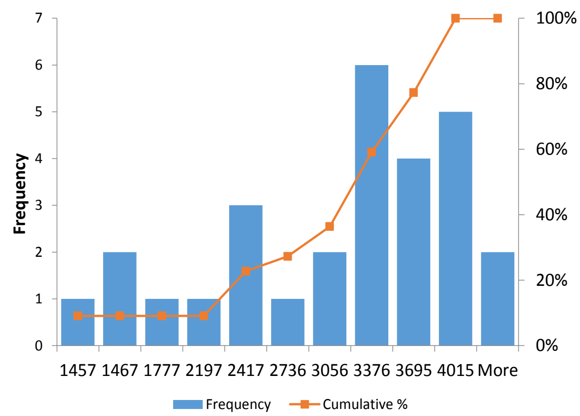
Storage facilitates the decrease of demand for land in bad yield scenarios. In particular, with storage as in Figure 10, the demand for irrigated land is by about 5.5% to 7.5% lower than in the scenario without storages.

EU grain reserves of about 240, 10, and 3376 thousand tons of rape, soya, and sunflower (Figure 10), respectively, can avoid investment in irrigation by about 300-400 thousand hectares of agricultural land, at EU level. Robust grain storage calculated with stochastic GLOBIOM can increase the feasibility of various environmental and (bio)fuel targets. On the other hand, it can also indicate that the targets are too high and can cause grain shortfalls, increase of prices and increased risk of food security.

Thus, in locations where introduction of storage enhances production and increases profits, the rate of Pillar 1 subsidies can be decreased to enable compensation for storage costs (construction and maintenance costs).



a. Rape



b. Sunflower

Figure 10: Distribution of storage withdrawals, in thousand tons, at EU level. Frequency refers to the absolute number of withdrawals within a range identified on the horizontal axis. Cumulative refers to the percentage of total of the withdrawals at or below the value on the horizontal axis.

Pillar II measures: Water infrastructure

In this report we do not model optimal Pillar 2 water management (infrastructure) projects. The goal is to show that water provision policies highly depend on other policies and measures, and, therefore, require special analysis of interdependencies (nexus) at local scales. As it has been discussed in the previous section, robust design of subsidies and availability of grain storage can substantially reduce the overall water demand and the need for irrigation investments, i.e. reduce the demand for water infrastructure, which is especially important in locations with scarce water resources and/or multiple water users.

4.3. Optimal mix of CAP policies in light of climate change

In this report we discussed interdependencies between different types of CAP measures. We have compared different Pillar I and Pillar II measures in terms of their effects on demand for selected crops, uptake of land by type and water use.

4.3.1. Pillar I measures

It was hypothesized that moving from the historic Pillar 1 payments (D1) to a country-specific flat-rate system (D2) can shift payments from less risk exposed to more risk exposed (see Annex A2) countries (and vice versa), which would affect production of some necessary commodities such as wheat, corn, rape, sunflower, and soya. The results have shown very small changes in the demand and acreage of land allocated to specific crops. Also in terms of irrigated land and land by land use type, very small changes between D1 and D2 are observed. This may be because these crops can be characterized as inelastic, i.e., there is high demand for wheat and rape as main sources of biofuels; soya is in high demand in the livestock sector as an important protein crop (Annex A3). Production decrease of these crops would necessitate the implementation of other measures such as subsidies and new trade policies (as it happened with protein crops after "the General Tariff and Trade Agreement (GATT) and the Blair House Agreement"). These measures might include expansion of the production area (also in other countries), introduction of new irrigation capacities, grain storage, etc. The introduction of robust subsidies (D3) leads to similar crop demands and supply compared with other subsidy scenarios. However, some difference between scenarios with direct payments and no direct payments can be observed. Only with direct payments will there be an increase in the area for corn. Moreover, the irrigated area will go down. This may mean that subsidies alone can lead to inefficient agricultural management, leading to more extensive agriculture and a decrease of irrigated area.

4.3.2. Pillar II measures

In addition to robust subsidies, rather moderate grain storage, such as displayed in Figure 9, can further increase the adaptive capacity of EU regions towards climatic risks and uncertainties. The storage would further reduce water demand by agriculture; under a scenario of robust subsidies (D3) combined with storage facilities, the irrigated area decreases by 19.5% over time, which is the largest percentage across scenarios. This indicates that policy measures are interdependent and may substitute each other.

The analysis of interdependencies could be easily extended by including the effects of investments into advanced irrigation systems, for example. However, in this case more detailed location-specific data on the stochastic properties of climatic variables, such as e.g. distribution of precipitation, temperature, etc., is required for deriving robust policy conclusions. Also, currently in the EU water management is highly regulated by different users. It tends towards more organized water distribution with user rights and charges and/or even the formation of user groups to manage water in the collective interest (which needs to be more narrowly defined for specific locations). The design of water infrastructure and water provision among water users involves also environmental indicators such as point and non-point water pollution, which are usually involved in determining water quotas. These issues can be considered in stochastic GLOBIOM, however they require additional attention beyond this deliverable.

5. Conclusions and discussion

This deliverable is guided by the assertion that “The costs of taking action to address climate change can be much lower than the cost of inaction over long and medium term (European Commission 2009a)”. However, such action needs to be well-targeted and needs to account for various climatic outcomes. The question addressed in this report is therefore “How to take action to address climate change which would cost less than inaction”.

Climate change is an essential production limiting factor that agriculture has to cope with. Recently, it has been accepted that for many economic sectors and foremost for agriculture, major impacts will result from the frequency and intensity of the occurrence of extreme events (heavy precipitation, droughts, etc.) and changing (seasonal) patterns of climatic indicators (precipitation, temperature, etc.). The increased incidence of extreme events leads to greater variability of production, contributing to increased volatility of prices and changes in trade flows. However, farmers’ decisions are also substantially limited by other factors, which are often associated with agricultural reforms. In particular, farmers’ decisions will significantly depend on the new CAP policies and the way they are implemented. A set of measures comprising the CAP 2014-2020 have been approved with an intention to support farmers’ adaptation to climate change and production risks. Pillar I decoupled payments (income-stabilization measures implemented on an annual basis) mainly aim at environmental protection and are exercised in terms of per hectare payments. Pillar II measures imply structural changes and investments into structural mitigation and adaptation, including water and grain storage, as well as advanced irrigation infrastructures.

The combined effects of policies and climate change, as well as their interactions necessitate the need for a proper appraisal of policies with respect to climate change adaptation. The objective of this report was to assess different financial and structural CAP policies in terms of their individual and combined costs and benefits for producers, consumers and the environment, both within and outside the European Union, in light of the uncertainties posed by climate change. We therefore analyzed how adaptation options integrated into the CAP 2014-2020 and the entire policy can be improved towards an even better climate change adaptation strategy.

Traditionally, impacts, costs, and benefits of adaptation measures have been evaluated by deterministic models in a scenario-by-scenario manner assuming that climate changes gradually. These approaches do not account for costs associated with maladaptation and the need to reverse decisions in case an unexpected scenario occurs. Therefore, the key methodological issue raised in this deliverable is how to appraise policy measures in the face of uncertainty of future climate changes so that the reversibility costs are minimized. Major attention is paid to the design of robust strategies, which contrary to scenario-specific policy-recommendations, provide information which are robust against multiple future scenarios.

Analysis of synergies and interdependencies among different climate change adaptation measures, financial and structural, is based on the stochastic partial equilibrium price-endogenous Global Biosphere Management Model (GLOBIOM). GLOBIOM enables the study of interdependencies due to its features as a partial equilibrium, price-endogenous, multi-sectoral, multiregional model with explicitly defined trade policies (i.e. quotas, tariffs, bans, etc.), food-energy-water-environment-security (FEWES) requirements, and pollution targets. The stochastic version of the model evaluates the robustness of the feasible policy portfolios with respect to all stochastic yield shocks. The conclusions of this report can be grouped into two aspects: (1) what are the trade-offs between the deterministic and the stochastic version of the model; and (2) what are the recommendations regarding trade-offs between Pillar I and Pillar II (instant and structural) EU CAP measures.

5.1. Recommendations derived from modelling results

The main conclusion from applying the stochastic model, as compared to its deterministic counterpart, is that robust recommendations of the stochastic model can save a considerable amount of maladaptation and sunk costs related to investments into adaptation projects appraised using scenario-by-scenario deterministic analysis. For example, under a deterministic scenario, an extreme shock may lead to a large uptake in cropland, which may imply large irreversible costs. By taking into account years with good and bad yields, the stochastic model provides a middle way in terms of uptake of cropland between an average yield deterministic model and an extreme shock deterministic model. This implies that a robust adaptation requires less natural resources than scenario-dependent adaptation. Because they take into account a range of possible options, robust portfolios do not require instantaneous revisions (often very costly or even irreversible) if additional information becomes available and are thereby more efficient.

The CAP reform has moved from a historical distribution of Pillar I payments (in terms of per hectares of eligible land) to a flat-rate system of payments, decoupled from production level and type of crop. Existing literature has showed that moving to a flatter rate across farmers and member states will have a rather marginal effect on production within the EU (Hennessy and Thorne, 2005; Sckokai and Moro, 2009; Koundouri et al., 2009; Key and Roberts, 2009). In this deliverable, we analyzed three ways of implementing direct payments: based on historic entitlements (D1), flat rate payment (D2) and a robust distribution based on a combination of economic, social, agricultural and risk (security) principles (D3). Differences between direct payment schemes are generally small, as is consistent with the literature. However, a robust payment scheme leads to more demand for wheat within Europe, and a higher demand for wheat and corn globally. Under all direct payment schemes more land is allocated to cropland, managed forest, and natural land, and less land to primary forest and grassland compared with a situation without direct payments. The reduction in grassland may not represent the reality because we assumed that direct payments are only allocated to hectares of arable land in this deliverable, whereas in reality they are also allocated to grassland. Direct payments also lead to a reduction in irrigated area, implying that direct payments lead to a larger focus on crop production using land instead of water.

We found strong synergies and trade-offs between instant and structural measures. In some regions, the introduction of rather moderate grain storage can not only increase adaptive capacity towards climatic shocks, but also decrease water demand and save investments into irrigation expansion. Under a scenario of robust subsidies (D3) combined with storage facilities, irrigated area decreases by 19.5%, which is the largest percentage across scenarios. This indicates that policy measures are interdependent and may substitute each other; the adoption of one policy (storage) reduces the need for other policies (irrigation).

Two main recommendations stand out in analyzing the effects of optimal combination of CAP policies in the light of climate change:

1. It is essential to assess policy measures using a variety of possible outcomes in order to overcome irreversible costs of maladaptation. A good example is the uptake of cropland. Under a deterministic scenario that does not take yield variability into account, the uptake of cropland is too small. Under a deterministic scenario that takes a shock in yield into account, the uptake of cropland is too large. Taking into account the various scenarios resulting from climate change leads to a middle way.

2. Agricultural policies are interdependent and crop and location specific. Direct payments lead to an increase in terms of demand and cropping area for some regions and crops,

whereas they lead to a decrease for other regions and crops. Moreover, effects differ when analyzing direct payments alone or together with other policy measures such as storage capacities. The clearest example here is the demand for irrigated land. The demand for irrigated land reduces when direct payments and storage facilities are provided. Hence, different policy measures may act as substitutes in different regions.

Our recommendations are of a rather general character because there are still many (irreducible) uncertainties, and exact prediction is impossible. The challenge might be summed up as the need, in a situation of considerable uncertainty and risks, to produce sufficient food and feeds in response to an expanding population while reducing water consumption, reducing greenhouse gas emissions and protecting biodiversity., i.e., consideration of FEWES is a cornerstone of agricultural and rural developments in response to climate changes, in the face of uncertainty, variability and extreme shocks.

5.2. Improving policy appraisal

In this section we will discuss how an advanced economic analysis of adaptation improves the reliability of the results and the quality of policy advice, and how such an analysis can be profitably included into the policy assessment process of the European Union.

5.2.1. Advancing the economics of adaptation

The literature on the economics of adaptation focuses on three main methodological approaches for assessing adaptation measures (UN 2011). Cost-benefit analysis, when efficiency is the only decision making criteria; cost effectiveness analysis, when objectives of adaptation are hard to measure in monetary terms; and multi-criteria analysis, when it is possible to assess different adaptation options against a number of criteria. All of the approaches above have the shortcoming that they do not integrate the different kinds of uncertainty related to socio-economic and biophysical development, as well as the effectiveness of implemented adaption options, and that they do not take into account the complex interdependencies of different sectors and biophysical processes. But most importantly, they can only be applied to local analysis where the specific impacts and adaptation options can be clearly identified. Applying them to a larger level on continental or global scale will not work well, as using averages of costs and benefits of adaptation would hide specific costs and adaptation possibilities. For assessing policies on the European level, the above mentioned methodologies are therefore not suitable.

A more sophisticated, but also substantially more resource consuming way, of assessing the costs and benefits of different adaptation options is the utilization of integrated assessment models (IAMs). IAMs have become a common tool for addressing the strategies to cope with the negative effects of climate change. In these models factors of analysis of climate change are greenhouse gas emissions, changes in temperature, radiation and precipitation and in the case of agriculture yields, production, demand, and trade. There have been several ways to include adaptation in IAMs (a more detailed description can be found in Patt et al. 2008). The first is implicit adaptation where e.g. farmers react to changes in yield by shifting to more profitable crops in order to maximize profits. This approach has come under criticism for 2 main reasons: (1) Applied in a partial equilibrium approach it does not consider changes of prices of different commodities, e.g. the greater need for irrigation water, (2) It does not take into account the additional costs from changing from one production system to another.

As a further step, adaptation has been implemented into IAMs as an explicit control variable (see e.g. de Bruin et al. 2009). While these models make an important progress in the analysis of adaptation as they consider the complex interactions of different sectors and economic development, they still do not model concrete adaptation options, but base their analysis on aggregate measures. Impacts and adaptation are only considered for the average of large world regions, thus neglecting local impacts, but also local adaptation options. They focus on a narrow set of engineering adaptation options, excluding soft measures, as well as short term "low regret" adaptation options. Scenario-specific IAMs analyze an idealized response to an individual future climate change simulation (even if they repeat these simulations for several times). This approach is called predict–and–optimise (Watkiss 2015) and presents information on how adaptation changes across a range of future projections. As a tool for policy appraisal this is only of limited value, as decision makers need concrete estimates to base their decisions on. Using mean values such as weighted expected values does not address this uncertainty as it cannot take into account variations (Watkiss 2015). The IAMs can only measure the economic costs and benefits of adaptation, non-monetary costs such as the avoidance of deforestation are often not included (Watkiss 2015, Füssel and Klein 2006, Ranger et al. 2010, Watkiss and Hunt 2011).

Our analysis is an IAM analysis as it focuses on both biophysical and economic processes, but it is still partial as it simulates only the agricultural and forestry sectors. GLOBIOM can be efficiently linked with other sectorial models such as e.g. an energy sector model MESSAGE. As the partial equilibrium model GLOBIOM is based on spatially explicit biophysical input data on water availability and yields, it is possible to model climate impacts, as well as the concrete adaptation options in a much more realistic way. Although not exhaustive, we model reversible "low regret" adaptation measures that are short term and address current climate variability, such as different direct payment measures, and autonomous adaptation of switching to less impacted and more profitable crops. More structural, long term measures may relate to the construction of irrigation schemes or storage facilities. All these measures are part of the Common Agricultural Policy, meaning that estimating their costs and benefits are an important part of the policy appraisal and do not require additional public expenditures. Finding the optimal mix and level of these measures means also finding the maximal synergies between existing agricultural policies which aim at supporting farmers and providing ecosystem services and the optimal level of adaptation and reduction of negative climate change impacts, and finally understanding how a given public money flow can be transformed in the most efficient way. Mainstreaming adaptation options into existing policies is an important step in advancing the economics of adaptation and has not been done yet on a larger than national level (Watkiss et al. 2015).

GLOBIOM covers also the complexities of the economic interaction between sectors, countries and continents. All modelled measures and impacts are influenced by production and demand in other regions through trade policies. This dimension is important to take into account for a policy appraisal as it might impact the effectiveness of concrete adaptation options. Availability of grain and water storage may increase regional adaptive capacity and self-sufficiency and reduce the need for trade. The integration of local adaptation options into a global analysis is tackling one of the major shortcomings of recent studies in economics of adaptation, as it can account for continental or global drivers such as supra-national policies, changes in population, demand or economic growth, while at the same time analyzing concrete local adaptation options.

In the model, climate change related shocks and systemic risks of various kinds are explicitly covered and can be analyzed and mitigated in all their interactions. The model incorporates different land use sectors and therefore enables to assess complex producer-consumer interactions and competition for, often scarce, financial (investments) and natural (land, water) resources between agriculture, bioenergy, and forestry at regional and global scales.

Our analysis assumes that the goals of the CAP such as secure food provision, sustainable management of natural resources and balanced territorial development are in harmony with the goal of adaptation to reduce the negative impact of climate change on agricultural production. But this is not necessarily the case under existing technologies. A sustainable management of natural resources might require new (not yet implemented or/and existing) technologies for sustainable land use management and food-energy-water-environment security. The stochastic GLOBIOM, as it has been discussed with the example of storage facilities, estimates the "deficit" (shortfall) of such technologies.

In these studies, some new CAP policies, e.g. the direct payments, are implemented only for arable land. In reality, direct payments are also provided for grassland. However, this does not affect the conclusion that implementation of adaptation measures, as e.g. the distribution of direct payments, has to depend on risk exposure, profitability, and adaptive capacities (availability of resources, technologies, trade, etc.) of regions, countries, farmers.

Systemic interconnectedness between regions (e.g., through markets or food chains or through producers of a certain commodity) is often considered beneficial. However, as it is shown, it can increase the vulnerability to shocks if interconnectedness is too strong and a vital component is suddenly damaged and no alternative is readily available. Thus, using two regions as an example, Annex A2 shows that, instead of choosing most cost-efficient technologies and regions, stochastic GLOBIOM calls for proper risk diversification between various kinds of technologies in different regions.

Stochastic GLOBIOM includes systemic risks and security (safety) criteria enabling to buffer various shortfalls and meet FEWES requirements at regional and global levels, which is important for planning agricultural development policies. The criteria include also targets and norms on emission of greenhouse gases, water and fertilizer utilization norms. Accounting for the variability of various uncertainties and risk scenarios, security is defined as the ability to deal with the uncertainties and risks to assure the necessary supply of food, feed, water, land, and environmental quality under all scenarios without a substantial cost increase (Ermoliev and von Winterfeldt 2012).

Considering a set of concrete adaptation options that aim to mitigate future climate change impacts, turns this analysis into a policy-first approach (Ranger at al. 2010) as promoted e.g. by Watkiss et al 2015. Instead of using scenarios and investigating several possible futures, stochastic GLOBIOM employs all relevant uncertainty scenarios with respect to yields to simultaneously account for different policies and derive measures that are optimal (robust) with respect to all scenarios. This provides policy makers with one instead of a multitude of suggestions on which they can base their decision.

5.2.2. How to include integrated framework modelling into the policy impact assessment guidelines of the EC

Watkiss (2015) identifies two major recent strands in the literature of the economics of adaptation: 1. Scenario-specific impact assessments which focus on technical adaptation measures, and 2. Policy oriented studies that focus on early low regret options or decision making under uncertainty. This report combines these two strands, by analyzing policies individually as well as combined. The economics of adaptation and the mainstreaming of integrated model-based analysis under uncertainties and risks into climate change policy impact assessment (PIA) can be substantially advanced based on this report.

Recognizing that a well performed policy appraisal is a key part of good policy making, the EC provides Policy Impact Assessment Guidelines (PIA) for preparing policy proposals (European Commission, 2009b). These guidelines define six steps: 1. Identifying the problem; 2. Defining the objectives; 3. Developing main policy options; 4. Analyzing the impact of options; 5. Comparing options; 6. Outlining policy monitoring and evaluation. In the following we analyze where IAM, as undertaken in this study, can enrich PIA guidelines for climate change adaptation projects.

5.2.2.1. The role of integrated assessment modelling of adaptation for PIA

Stochastic integrated assessment modelling (IAM)[10] of climate change adaptation in the EU aims to appraise policies in such a way that they can ensure security in food, water, energy and environmental standards, while at the same time avoiding increases in price volatility, soil and water pollution, diversion of water for irrigation, etc. IAM for PIA can be conducted from different perspectives and at different scales involving multiple systems and stakeholders with often conflicting goals. In general, IAM can enable a dialogue in the form of a Decision Support System among various stakeholders for robust decisions ensuring sustainable development. IAM can add to standard approaches of impact assessment (cost-benefit-analysis, cost-effectiveness analysis and multi-criteria analysis as explained above) to ensure a transparent, comprehensive and balanced assessment in four ways: (1) through the inclusion of risk and uncertainty; (2) through the interlinkages between systems; (3) by analyzing on different levels; (4) by analyzing over multiple time periods.

Inclusion of risk and uncertainty: In the context of Policy Impact Assessment (PIA), IAM can support the inclusion of uncertainty and risk in the assessment of policies and can therefore reduce the likelihood of irreversible costs and maladaptation. This is an improvement compared to traditional risk assessment and predictions that often analyze policy impacts on a scenario-by-scenario basis.

Interlinkages between systems: Traditional PIA cannot integrate the interconnected natural and anthropogenic systems and various interdependencies. They do not take interlinkages between systems into account and thereby cannot analyze the result of a policy scenario on the stability of systems. Therefore, they do not reflect the actual costs and benefits to society, because they focus on only one sector, not including externalities that occur in other sectors. Advanced IAM enables to address these issues by designing robust solutions using model-based analysis of complex systemic interactions and risk exposures evaluated with respect to various (including FEWES) targets.

Multi-level analysis: Among the main concerns of economic analysis is how to ensure policies "not" leading to negative consequences. For example, policies or measures are often implemented at local levels, i.e. farms, rural communities, etc., without accounting for negative implications which they may cause at regional or national levels. Thus, construction of a dam or a water supply (irrigation) system in a location can impact water quality in the whole region; lead to imbalanced distribution of water among water users; cause systemic failures such as electricity black-outs due to insufficient supply of water to other (than agricultural) systems, etc. On the other hand, policies at global and national levels, e.g. regarding biofuel targets, can require substantial local adjustments beyond local natural and financial potentials. An IAM analysis which considers impacts on different scales, as well simulates interactions between those, can substantially improve policy relevance.

[10] We will refer to this as IAM in the rest of the text

Multi time-period analysis: The trade-off between different policy measures is highly dependent on the time-horizon at which it is analyzed. Under a short time-horizon, low initial costs are essential. Under a long time-horizon, initial costs may be higher if the resulting benefits can be reaped for a large number of years. Therefore, under a short time horizon optimal policies often enforce current trends, while longer time horizons they enable the analysis of more structural measures and new technologies. An IAM such as stochastic GLOBIOM applied in this study evaluates optimal policy measures at 10 year time-steps, allowing analysis at both the medium and long term.

5.2.2.2. How should the design of PIA be modified to incorporate advanced results of advanced IAM?

Although an IA of a specific project, measure or a portfolio of measures is very case-specific, each IA process is based on answering a clear objective which can be directly related to solving an identified problem. Several examples outlined in this report and also in Deliverable 4.2 identify major issues that are important for an IA of climate change adaptation policies. By default, an IA should have a detailed description of the challenges ahead that necessitate EU legislation. In this study, this was the effect of climate change and the increased variability in yields. To analyze the effects of policies targeted at climate change adaptation, it is essential to take current policies (in this report the current decoupled payments) as well as various alternative policies (robust payment schemes and structural measures) into account. To complement standard PIA with advanced IAM, the four points mentioned in the previous section can be broken down in specific design considerations:

Inclusion of risk and uncertainty: Various policy alternatives and their trade-offs have to be accounted for in an IA, e.g. a trade-off between various types of strategic long-term (ex ante in front of uncertainties) and adaptive short term (ex post) after learning about uncertainties. Systemic (dependent) risks, and ways to deal with them, as well as risk criteria have to be included.

Inclusion of interlinkages between systems: Climate change policies are likely to have significant impacts in economic, environmental and social domains and on a wide range of stakeholders. It is therefore essential to take potential side-effects of the policy on other levels into account.

Inclusion of multi-level analysis: A level of analysis for the IA needs to be defined. But the impacts on other level are of also of uttermost importance and need to be included.

Inclusions of multi-time period analysis: Short-medium and long-term impacts of a policy need to be defined. Random horizons of climate change, including possible occurrence of catastrophic events, versus life-spans of adaptation measures has been taken into consideration;

5.2.2.3. What are the methodological aspects that need to be considered?

A proper selection for evaluation criteria: Adoption of proper safety, security, reliability and environmental criteria in IAM for practical PIA of climate change adaptation measures, as it has been done in engineering, insurance industry, operations research (Ermolieva et al. 2016; IAEA 2001; IAEA 1992; Jansen 1988).

A proper way of accounting for uncertainty: By including a yield variability this study provides a first attempt towards the inclusion of uncertainty, but this can be further elaborated towards uncertainty in the entire system and how producers experience this uncertainty. A cross-sectorial analysis of demand and competition for (scarce) natural and financial resources under security criteria and inherent uncertainty and risks is therefore essential (Xu et al. 2015).

Inclusion of different methodologies: As explained in section 5.1, there are different methods to analyze policy impacts. While IAMs such as GLOBIOM add to the evaluation of measures it is important to consider that IAMs are also based on a set of assumptions inherent to the model used, such as maximizing producer and consumer surplus in the case of GLOBIOM. Considering PIA from different perspectives, with illustrative models and examples may throw light on differences between model assumptions.

In modeling technological changes for climate change adaptation, the trade-offs between the choices of time horizons is as follows. A short time horizon enforces current trends, while longer time horizons enable the analysis of new technologies. In many economic models, technological innovations (new technologies) are introduced exogenously independently of policies and other variables, e.g. climatic shocks. In reality, technological changes are endogenous (see discussion in Gritsevskyi and Nakicenovic 2000). They can be affected by deliberate policies related to urgent socio-economic, environmental and safety/security issues in response to e.g. climate change. Whereas traditional economic appraisal tools focus such as CBA, PCBA, NPV and dynamic GEs define a discount rate equal to the rate of return in capital market, this study combines the trade-off between ex-ante strategic and ex-post adaptive measures thereby applying an endogenous form of discounting (see Annex A1) (Ermoliev et al. 2010; Ermolieva et al. 2013).

The approach can provide a basis for a dialogue with stakeholders involved in IA. The idea is that at the beginning of a time horizon (can be infinite) a model (e.g. similar to stochastic GLOBIOM) evaluates strategic and operational two-stage decisions. The decisions can be implemented until some random time (stopping time) when important information about climate (climate changes faster) or systemic changes (prices increase) reveals. The new information provides the basis for revision of parameters and uncertainty scenarios perceived at the beginning of the time horizon. With respect to new scenarios, adjusted two-stage robust decisions are derived. The problem can be formally defined as decision making under learning based on dynamic two-stage moving time horizon model, in which reevaluation of decisions occurs when additional information on critical parameters or performance indicators becomes known.

5.2.2.4. When, and in what form, is IAM as PIA tool likely to be useful in other sectors than agriculture?

Agriculture is the only policy that is fully integrated at a European level. It is therefore a central part of the Treaty and justifies EU action. This means that diverse countries that differ in importance and types of agricultural sectors all have to make use of the same policy. It is therefore necessary to conduct an analysis of PIA in agriculture at both the country and the European level. Each agricultural sector, as well as differences in the characteristics of farmers and the landscapes on which they operate need to be taken into account in order to assess the costs and benefits of different policy measures. Moreover, uncertainties and risks should be an important component of the PIA to ensure proper livelihoods both in urban and rural areas. Planning sustainable agricultural production and secure food provision in the face of climate uncertainties and various risks is of a strategic importance.

In this study, analysis of agricultural policies in the EU and globally relies on a stochastic GLOBIOM model, which is an example of an integrated model that incorporates most of the central issues in climate change adaptation necessary for a proper IA, i.e. such as interdependencies between sectors and regions, possibility of systemic risks, abrupt catastrophes, treatment of irreversibilities and learning, safety and security requirements, and robustness of decisions. The model enables integrated robust land use planning under systemic risks accounting for interdependencies among main land use systems on global, national, and grid-cell levels. The model incorporates stochastic climate change related shocks (crop yield shocks) facilitating analysis of induced systemic risks on crop production and food, energy, water provision. The model is spatially detailed, enabling a detailed analysis of geographic and temporal occurrence and clustering of shocks, as well as their implications for risk sharing and robustness of risk management. In the deliverable, the model has been used for the analysis of new CAP policies. The studies identify potential impacts from the policies, the results are computed at rather aggregate levels. The assessment at finer scales is possible, however would require more detailed problem specification.

We have already shown that the integration of an advanced stochastic IAM into PIA is relevant in order to appraise policies which take into account all aspects mentioned above. This is of course also true for other sectors. Even if agriculture is the only sector which is fully integrated into the European level, other sectors and related policies also require such an extensive assessment, which integrates adaptation as well as the different kinds of uncertainty.

5.2.2.5. What is the potential of PIA for mainstreaming adaptation?

Mainstreaming climate change adaptation under uncertainties into practical PIA substantially depends on awareness and risk perception of policy makers and the ability of their dialogue with involved stakeholders at different levels, e.g. scientists, farmers, water authorities, local and central governments. Better understanding of the problem will lead to faster mainstreaming. Wrong evaluation and implementation of a policy in an economic system is less visible (at the beginning), then e.g. a car crash, however in the end it affects large communities and territories (as it happened with first generation biofuels).

"Integrating adaptation into EU key policy areas" (European Commission 2009a) as identified by the EC as one of the four pillars of the EU adaptation framework is important for guaranteeing that the different economic sectors are able to carry on with their tasks even within the circumstances of a changing climate (Altvater et al., 2011). Adaptation to climate change is therefore included in the PIA guidelines, one of the questions in Table 3 in the section on" Analyzing the impact of the options" asks: "Does the option affect our ability to adapt to climate change?" The impact assessment guidelines are therefore seen as an important instrument to ensure mainstreaming adaptation (Altvater et al., 2011).

It lies in the nature of the PIA guidelines, which have to be applicable to each policy developed and implemented by the EU, to be very general. The PIA guidelines rather concentrate on conventional tools for PIA which can be applied to a broad range of policies. But as shown above the conventional ways to assess mainstreaming of adaptation into existing policies entails flaws. We have shown that in the case of mainstreaming adaptation into the CAP, using a stochastic integrated assessment model has clear advantages over the usages of conventional assessment tools such as CBA. But in the current PIA of the EC, the application of such a tool is not foreseen. We therefore suggest to integrate stochastic IAM as one of the tools for comparing impacts of different policy options (section 9.1.), besides the traditional tools.

Additionally, and contrary to the way policies are traditionally assessed with the help of with the tools proposed in the PIA guidelines and for reasons explained above, the analysis in this report does not consider single policies and assess their effectiveness in regards to defined criteria, but uses an overall objective (such as maximizing demand and minimizing water resource use in order to find an optimal mix of policies. It also does not assess the risk of the different measures (as described in section 5.5. in the PIA guidelines), but includes the uncertainty of measures as well as climate change uncertainty in the analysis and bases its outcomes on the inherent uncertainties. The analysis as implemented above can also not be framed in any of the traditional analyses described in sections 9.1. and in in the PIA guidelines (CBA, CEA or MCA), as an already existing policy is investigated, which means no additional costs occur but the transformation of an already existing large money flow is analyzed. We therefore also suggest to include a section in the PIA guidelines in which the focus is not on the assessment of single policies, but rather on targeting a certain goal (such as improving adaptation in agriculture) and assessing which combination of (already existing) policies might best meet this target. This provide relevant information on where support for policies should be increased and where support should be faded out. Such a complex analysis is now possible when applying stochastic IAM in the way described above.

Relevant here is the impact analysis as defined in part 8.2 of the PIA where in three major steps several impacts are analyzed. Such an in depth analysis is the strength of an integrated framework model because many of the economic, social and environmental impacts can be analyzed with a consistent framework. This has clear advantages over using single and unrelated tools for assessing the different impacts. The specific strength of the analysis in this report for example is the ability to analyze aggregate impacts on European level, disaggregate impacts on national level as well as the impact on third countries outside of the EU.

5.2.2.6. Time and resources required for IAM of adaptation in PIA

There is no one-size-fits-all solution, however, depending on the Policy Impact Assessment (PIA) maker, stochastic IAM of adaptation as a tool to appraise policies can be incorporated in the PIA within a reasonable time frame provided available relevant data, resources and the necessary technological tools are available. Different steps have to be taken to produce an impact assessment, which can be incorporated into a PIA as foreseen by the EC. In the following we use as an example the stochastic IAM GLOBIOM.

1. Compilation of data with respect to the base year: this takes costs, revenues, production and demand at a very local level, as well as trade at a global level into account. In GLOBIOM the base year is 2000 and most of the subsequent data is readily available.

2. Deduction of the level of EU-support from the base year. A proper IA includes both a ‘business as usual’ scenario which considers the current policy as well as a ‘no action taken’ scenario, which includes no interference from the EU. To facilitate the latter one, the current level of support has to be excluded from the base scenario.

3. Establishing uncertainty scenarios. Stochastic GLOBIOM is an example of a model for planning land use developments under uncertainties and risks. The model bridges decision oriented economic theory with risk theory and catastrophe (yield shocks) modelling. In stochastic GLOBIOM, risk management decisions are evaluated from the long-term perspectives of the welfare growth in regions (e.g. EU).

4. Analysis of various scenarios. Alternative policy scenarios are implemented in GLOBIOM, both individually and collectively.

As general rule, the European Commission assumes 12 months to produce an IA, which includes an iterative process between stakeholders and the IA analysis (European Commission, 2009a). Stochastic GLOBIOM is ideal for this process because it can create model assumptions and alternative policies based on discussions with stakeholders and can take feedback from stakeholders into account using new model runs with alternative policies. Further model elaborations may include linking the model to other sectorial models such as e.g. an energy sector model MESSAGE, to give policy advice regarding coherent land use and energy sector developments.

References

Altvater, S., Benjamin Görlach, Daniel Osberghaus, Sabine McCallum,Thomas Dworak, Judith Klostermann, Kaj van de Sandt, Jenny Tröltzsch, AnaFrelih Larsen (2011): Recommendations on priority measures for EU policy mainstreaming on adaptation – task 3 report, Ecologic Institute, Berlin.

Anthoff, D., C.J.Hepburn, and R.S.J.Tol (2009), Equity weighting and the marginal damage costs of climate change, Ecological Economics, 68, (3), pp. 836-849.

Arrow, K.J. and Fisher, A.C., 1974. Preservation, uncertainty and irreversibility. Quarterly Journal of Economics 88, 312–319.

Arrow, K.J., Cline, W.R., Maler, K.G., Munasinge, M., Squitieri, R., Stiglitz, J.E. 1996. 'Intertemporal Equity, Discounting, and Economic Efficiency' Bruce, J.P., H. Lee and E.F. Haites (eds.). Climate Change 1995: Economic and Social Dimensions of Climate Change. Cambridge University Press: Cambridge. Ch. 4, pp. 125-144.

Balkhausen, O., Banse, M., and Grethe, H., 2008. Modelling CAP Decoupling in the EU: A Comparison of Selected Simulation Models and Results. Journal of Agricultural Economics 59(1): 57-71.

Ben-Yehoshua, S. 2005. Environmentally Friendly Technologies for Agricultural Produce Quality, Shimshon, Taylor and Francis group, New York.

Bhaskar, A. and Beghin, J.C., 2009. How coupled are decoupled farm payments? A review of the evidence. Journal of Agricultural and Resource Economics 34(1): 130-153.

Birge, J.R., Louveaux, F., 1997. Introduction to stochastic programming. Springer.

Brady, M., Kellermann, K., Sahrbacher, C., and Jelinek, L., 2009. Impacts of Decoupled Agricultural Support on Farm Structure, Biodiversity and Landscape Mosaic: Some EU Results. Journal of Agricultural Economics 60: 563-585.

Burfisher, M.E., and Hopkins, J., 2003. Decoupled Payments: Household Income Transfers in Contemporary U.S. Agriculture. Agriculture Economic Report No. 882. Market and Trade Economics Division, Economic Research Service, U.S. Department of Agriculture.

Butler, R., Koh, L. P., & Ghazoul, J., 2009. REDD in the red: palm oil could undermine carbon payment schemes. Conservation Letters, 2(2), 67–73.

Cline WR (1999) Discounting for the very long term. Discounting and intergenerational equity 131–140.

Coyle, W., 2007. The future of biofuels. Economic Research Service, Washington, D.C.

de Bruin, K. and Ansink, E. (2011). Investment in flood protection measures under climate change uncertainty. Climate Change Economics, 2(4), 321–339

Dewbre, J., Anton, J. and Thompson, W., 2001. The transfer efficiency and trade effects of direct payments. American Journal of Agricultural Economics 83(5): 1204–1214.

Ermoliev, Y., Hordijk, L., 2003. Global changes: Facets of robust decisions. In: Marti, K., Ermoliev, Y., Makowski, M., Pflug, G. (Eds.), Coping with uncertainty: Modeling and policy issue. Springer Verlag, Berlin, Germany.

Ermoliev, Y., Ermolieva, T., Fischer, G., Makowski, M., Nilsson, S. and Obersteiner, M. (2008) Discounting, catastrophic risks management and vulnerability modeling. Mathematics and Computers in Simulation, 79 (4). pp. 917-924.

Ermoliev Y, Ermolieva T, Fischer G, Makowski M (2010) Extreme events, discounting and stochastic optimization. Annals of Operations Research 177:9–19.

Ermoliev, Y., von Winterfeldt, D., 2012. Systemic risk and security management. In: Ermoliev, Y., Makowski, M., Marti, K. (Eds.), Managing safety of heterogeneous systems: Lecture notes in economics and mathematical systems. Springer Verlag, Berlin, Heidelberg, Germany, 19–49.

Ermolieva T, Ermoliev Y, Obersteiner M, Makowski M, Fischer G (2013) Dams and Catastrophe Risk: Discounting in Long Term Planning. Integrated Catastrophe Risk Modeling. Springer, pp 73–92.
Ermolieva, T., Filatova, T., Ermoliev, Y., Obersteiner, M., de Bruijn, K. M. and Jeuken, A. (2016) Flood Catastrophe Model for Designing Optimal Flood Insurance Program: Estimating Location-Specific Premiums in the Netherlands. Risk Analysis. (In Press).
Ermolieva T, Havlík P, Ermoliev Y, Mosnier A, Obersteiner M, Leclère D, Khabarov N, Valin, H, Reuter, W. (2016). Integrated management of land use systems under systemic risks and security targets: a stochastic Global Biosphere Management Model. J Agricultural Economics. (In Press).
European Commission, 2009a Adapting to climate change: Towards a European framework for action. White Paper. Brussels, 1.4.2009 COM (2009) 147 final.
European Commission, 2009b. Impact Assessment guidelines. http://ec.europa.eu/smart-regulation/impact/commission_guidelines/docs/iag_2009_en.pdf Last accessed: 30-04-2016.
European Commission, 2013. Overview of CAP Reform 2014-2020. Agricultural Policy Perspectives Brief. No. 5, December 2013. http://ec.europa.eu/agriculture/policy-perspectives/policy-briefs/05_en.pdf. Last viewed at 17/12/2015.
European Commission, 2014. Regulation No. 1307/2013 of the European Parliament and of the Council establishing rules for direct payments to farmers under support schemes within the framework of the common agricultural policy and amending Annex X to that regulation. C(2014) 1476 final. http://ec.europa.eu/transparency/regdoc/rep/3/2014/EN/3-2014-1476-EN-F1-1.Pdf. Accessed August 2014.
FAO, 2009. The state of food insecurity in the World. Rome.
FAO, IFAD, IMF, OECD, UNCTAD, WFP, the World Bank, the WTO, IFPRI, UNHLTF (contributors), 2011. Price volatility in food and agricultural markets: Policy responses (downlodable from: http://www.oecd.org/tad/agricultural-trade/48152638.pdf).
FAO, 2016. http://faostat3.fao.org/browse/Q/QC/E. Last accessed: 29-04-2016.
Fitzherbert, E. B., Struebig, M. J., Morel, A., Danielsen, F., Bruhl, C. A., Donald, P. F., and Phalan, B., 2008. How will oil palm expansion affect biodiversity? Trends in Ecology & Evolution 23, 538–545.
Free-press-release.com 2014. “Electricity and power shortage holding India back”.
Füssel H. M. and R. J. T. Klein (2006) Climate Change Vulnerability Assessments: An Evolution of Conceptual Thinking. Climatic Change 75: 301-329.
Glauber, J.W. (2004). Crop insurance reconsidered. American Journal of Agricultural Economics 86(5): 1179-1195.
Gohin, A. (2006). Assessing the CAP reform: Sensitivity of modelling decoupled policies. Journal of Agricultural Economics 57: 415–440.
Gritsevskyi A, Nakićenovic N (2000) Modeling uncertainty of induced technological change. Energy Policy 28:907–921.
Havlík P., U. A. Schneider, E. Schmid, H. Boettcher, S. Fritz, R. Skalský, K. Aoki, S. de Cara, G. Kindermann, F. Kraxner, S. Leduc, I. McCallum, A. Mosnier, T. Sauer, and M. Obersteiner, 2011. Global land-use implications of first and second generation biofuel targets. Energy Policy 39, 5690-5702.
Hardaker, J.B., Huirne, R.B.M., Anderson, J.R., Lien, G., 1997. Coping with risk in agriculture. http://www.cabi.org/cabebooks/ebook/20043056174. Last Accessed: 10-03-2016.
Hauser, R.J., Sherrick, B.J. and Schnitkey, G.D., 2004. Relationships among government payments, crop insurance payments and crop revenue. European Review of Agricultural Economics 31: 353-368.
Heal G, Kriström B (2002) Uncertainty and climate change. Environmental and Resource Economics 22:3–39.

Helming, J. and Peerlings, J., 2014. Economic and environmental effects of a flat rate for Dutch agriculture. NJAS 68: 53-60.
Hennessy, D.A., 1998. The production effects of agricultural income support policies under uncertainty. American Journal of Agricultural Economics 80(1): 46-57.
Hennessy, D.A. and Thorne, F.S., 2005. How decoupled are decoupled payments? The evidence from Ireland. EuroChoices 4(3): 30-35.
Hope, C. 2006. The Marginal Impact of CO2 from PAGE2002: An Integrated Assessmnt Model I ncorporating the IPCC's Five Reasons for Concern. Integrated Assessment 6: 19-56.
IAEA 2001. Applications of probabilistic safety assessment (PSA) for nuclear power plants. International Atomic Energy Agency http://www-pub.iaea.org/MTCD/Publications/PDF/te_1200_prn.pdf. Last accessed: 20-03-2016.
IAEA 1992. The Role of probabilistic safety assessment and probabilistic safety criteria in nuclear power plant safety. International Atomic Energy Agency, http://books.google.at/books?id=J-ZSAAAAMAAJ. Last accessed: 30-04-2016.
IAWG, 2010. Technical support document: social cost of carbon for regulatory impact analysis under executive order 12866. Interagency Working Group on Social Cost of Carbon. United States Government.
James, W.P.T. & Schofield, E.C. 1990. Human energy requirements. A manual for planners and nutritionists. Oxford, UK, Oxford Medical Publications under arrangement with FAO.
Jansen RB (ed) (1988) Advanced dam engineering for design, construction, and rehabilitation. Van Nostrand Reinhold, New York
Koh, L. P., Levang, P., Ghazoul, J., 2009. Designer landscapes for sustainable biofuels. Trends in Ecology & Evolution, 24(8), 431–8.
Koh, L. P., Wilcove, D.S., 2007. Cashing in palm oil for conservation. Nature 448, 993–994.
Liu, J., Williams, J.R., Zehnder, A.J.B., Yang, H., 2007. GEPIC – modelling wheat yield and crop water productivity with high resolution on a global scale. Agric. Syst. 94, 478–493.
Kahil, M., Connor, J., Albiac, J., 2015. Efficient water management policies for irrigation adaptation to climate change in Southern Europe. Ecological Economics. 120: 226-233.
Kelly, D. and Kolstad, C., 1999, 'Integrated assessment models for climate change control' in Folmer, H. and Tietenberg, T. (eds), International Yearbook of Environmental and Resource Economics 1999/2000: A Survey of Current Issues, Cheltenham, UK.
Key, N. and Roberts, R., 2009. Nonpecuniary benefits to farming: Implications for supply response to decoupled payments. American Journal of Agricultural Economics 91(1): 1-18.
Koundouri, P., Laukkanen, M., Myyrä, S. and Nauges, C., 2009. The effects of EU agricultural policy changes on farmers' risk attitudes. European Review of Agricultural Economics 36(1): 53-7.
MacDonald G.J., 1992. Persistance in Climate, JSR-91-340, The MITRE Corporation, McLean, Verginia, 22102-3481.
Matthews, K.B., Buchan, K., Miller, D.G., and Towers, W., 2013. Reforming the CAP – With area-based payments, who wins and who loses? Land Use Policy 31: 209-222.
Moschini, G. and Hennessy, D.A., 2001. Chapter 2 Uncertainty, risk aversion, and risk management for agricultural producers. Handbook of Agricultural Economics 1. Elsevier Science B.V: 87-152.
Mosnier, C., Ridier, A., Képhaliacos, C. and Carpy-Goulard, F., 2009. Economic and environmental impact of the CAP mid-term review on arable crop farming in South-western France. Ecological Economics 68: 1408-1416.
Moyer, Elisabeth J., Mark D. Woolley, Michael Glotter, and David A. Weisbach. 2013. Climate impacts on economic growth as drivers of uncertainty in the social cost of carbon. University of Chicago Coase-Sandor Institute for Law & Economics Research Paper 652.

Nelson, G.C., Rosegrant, M., Koo, J., Robertson, R., Sulser, T., Zhu, T., Msangi, S., Ringler, C., Palazzo, A., Batka, M., Magalhaes, M., Lee, D., 2009. Climate Change: Impact on Agriculture and Costs of Adaptation. International Food Policy Research Institute, Washington, DC.

Nelson, G.C., Valin, H., Sands, R., Havlík, P., Ahammad, H., Deryng, D., Elliott, J., Fujimori, S., Hasegawa, T., Heyhoe, E., Kyle, P., Von Lampe, M., Lotze-Campen, H., Mason d'Croz, D., van Meijl, H., van der Mensbrugghe, D., Müller, C., Popp, A., Robertson, R., Robinson, S., Schmid, E., Schmitz, C., Tabeau, A., Willenbockel, D. 2013. Climate change effects on agriculture: Economic responses to biophysical shocks. PNAS. Vol. 111., pp. 3274-3279.

Nordhaus, W. D. 2008. A Question of Balance: Weighing the Options on Global Warming Policies, Yale University Press, New Haven, CT.

O'Neill, B. C., Crutzen, P., Grübler, A., Ha Duong, M., Keller, K., Kolstad, C., Koomey, J., Lange, A., Obersteiner, M., Oppenheimer, M., Pepper, W., Sanderson, W., Schlesinger, M., Treich, N., Ulph, A., Webster, M., Wilson, C. 2006. Learning and Climate Change. Climate Policy, Vol. 6, pp. 585–589.

Patt, A., van Vuuren, D., Berkhout, F., Aaheim, A., Hof, A., Isaac, M., Mechler, R., 2008. Adaptation in integrated assessment modeling: where do we stand? Climatic Change, 2010, 99,3: 383-402.

Pennings, J., Garcia, P., and Oskam, A., 2010. Private market and price stabilisation methods. In: A. Oskam, G. Meester and H. Silvis (eds), EU policy for agriculture, food and rural areas. Wageningen: Wageningen Academic Publishers: 183-189.

Ranger, N. et al. 2010. Adaptation in the UK: a decision-making process, Policy Briefing prepared for the Adaptation Sub-Committee of the UK Climate Change Committee.

Rockafellar, R.T., Uryasev, S., 2000. Optimization of Conditional Value-at-Risk. Journal of Risk 2, 21-41.

Rosegrant., M.W., IMPACT Development Team. 2012. International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description. International Food Policy Research Institute, Washington, DC.

The Automatic Earth 2012. India power outage: The shape of things to come?

Sckokai, P. and Moro, D., 2009. Modelling the impact of the CAP Single Farm payment on farm investment and output. European Review of Agricultural Economics 36(3): 395-423.

Silvis, H., Lapperre, R., 2010. Market, price and quota policy: half a century of CAP experience. In A. Oskam, G. Meester and H. Silvis (eds), EU policy for agriculture, food and rural areas. Wageningen: Wageningen Academic Publishers: 165-182.

UN, 2011. United Nations Framework Convention on Climate Change, Assessing costs and benefits of adaptation options: an overview of approaches

UNFCCC, 2009. Potential costs and benefits of adaptation options: A review of existing literature. Technical paper. FCCC/TP/2009/2. http://unfccc.int/resource/docs/2009/tp/02.pdf. Last accessed: 27-04-2016.

UNFCCC, 2016. Glossary of Climate change acronyms, http://unfccc.int/essential_background/glossary/items/3666.php. Last accessed: 27-04-2016.

USDA, 2005. A Preliminary assessment of the effects of Katrina and drought on U.S. Agriculture. USDA/OCE, Washington, DC, USA.

Valin, H., Havlík, P., Mosnier, A., Herrero, M., Schmid, E. & Obersteiner, M. 2013. Agricultural productivity and greenhouse gas emissions: trade-offs or synergies between mitigation and food security? Environmental Research Letters 8 (3).

Watkiss, P. and A. Hunt, 2011: Method for the UK Adaptation Economic Assessment (Economics of Climate Resilience). Final Report to Defra. May 2011. Deliverable 2.2.1

Watkiss, P., 2015. A review of the economics of adaptation and climate - resilient development. Centre for Climate Change Economics and Policy, Working Paper No. 231, Grantham Research Institute on Climate Change and the Environment Working Paper No. 205.

Watkiss, P., Hunt, A., Blyth, W., and Dyszynski, J. (2015). The use of new economic decision support tools for adaptation assessment: A review of methods and applications, towards guidance on applicability. Clim. Change 132, 401–416.

WHO. 1985. Energy and protein requirements: Report of a joint FAO/WHO/UNU expert consultation. WHO Technical Report Series No. 724. Geneva.

Wicke, B., Sikkema, R., Dornburg, V., Faaij, A., 2011. Exploring land use changes and the role of palm oil production in Indonesia and Malaysia. Land Use Policy, 28(1), 193–206.

Xu, X., Gao, J., Cao, G.-Y., Ermoliev, Y., Ermolieva, T., Kryazhimskii, A.V. and Rovenskaya, E. 2015. Systems analysis of coal production and energy-water-food security in China. Cybernetics and Systems Analysis, 51 (3). pp. 370-377.

Annex A1: Comparison of construction of discount rates amongst studies

Many studies assume the intergenerational discounting rate equal to the rate of return in capital market, which means that for a modest interest rate of 3.5% the expected duration of evaluation time horizon does not exceed 30 years (Ermoliev et al. 2008). Thus this rate orients the policy analysis on a 30-year expected time horizon, which has no correspondence with expected, say, 100- or 300-year extreme events. (Ramsey 1928) argued that to apply a positive discount rate to discount values across generations is unethical. (Koopmans 1966) contrary to Ramsey argued that zero discount rate would imply unacceptably low level of current consumption. According to (Arrow et al. 1996) “the observed market rates of interest refer to how individuals are willing to trade off consumption over their own life. These may or may not bear a close correspondence to how a society is willing to trade off consumption across generations”.

The “perspective” approach tends to generate relatively low discount rates and thus favors mitigation measures and the wellbeing of future generations. The “descriptive” tends to generate higher discount rates and thus favors less spending on mitigations and the wellbeing of the current generation. The constant discount rate has only limited justification (see further overviews in (Chichilnisky 1997; Frederick et al. 2002; OXERA 2002). The recent literature argues that discount rates vary with time. As a compromise (see discussion in (Cline 1999) between “prescriptive” and “descriptive” approaches there is an argument for a declining in time discount rate of 5% for the first 30 years, and 1.5% beyond this.

There have been proposals for other schedules and attempts to justify the shape of proper decline. Papers (Weitzman 1999; Newell and Pizer 2003) shed some light on how uncertainty about the rate of return produces a certainty equivalent discount rate which will generally be declining with time. (Weitzman 1999) proposed to model interest rates by a number of exogenous time dependent scenarios. He argues for rates of 3-4% for the first 25 years, 2% for the next 50 years, 1% for the period 75-300 years and 0 beyond 300 years. (Newell and Pizer 2003) analyzed uncertainty of historical interest rates by using data on the US market rate for long-term government bonds. They proposed a different declining discount rate justified for a random walk model.

It can be shown that the choice of discounting associates with the occurrences of a “stopping time” event, determining a finite random horizon of evaluation (Ermoliev et al. 2008; Ermoliev et al. 2010). Extreme events might affect discount rates, which in turn alter the optimal mitigation efforts that ultimately close the feedback loop impacting the frequency of extreme events. This endogeneity of discounting and induced complexity calls for exploration of equivalent undiscounted evaluations and stochastic optimization methods. In this connection it is important to discuss the implications of uncertainties and catastrophic risks on the choice of discounting. Especially, this concerns catastrophic risks and projects protecting against these risks (e.g. floods – dams, reservoirs, etc).

Annex A2: A fragment of stochastic GLOBIOM

Let us analyse a stylized two-regional (two-producer) model, which enables to understand the main difference between the deterministic and stochastic versions. The example shows the emergence of systemic risks between interdependent regions, sectors, producers. The example does not include the discussion of direct decoupled payments explicitly, however the effects of allocation and redistributing the payments among regions and producers in the deterministic and stochastic versions are conceptually different. In this report they will be discussed only at qualitative level (and with more details in other paper).

The objective function of stochastic GLOBIOM maximizes total expected net benefit (benefits-costs) of consumers and producers under endogenously calculated prices. In the simple example below we ignore the elasticity of the demand, reducing the model to minimizing the total cost subject to a demand constraint. Namely, we analyze the effects of existing interdependencies and the emergence of systemic risks in a simple social planning model with only two regions cooperating on a market (e.g. for bio-ethanol production from corn and wheat), $i=1,2$, to meet exogenous inelastic demand d.

Systemic risks are induced through interdependencies between decisions of regions and supply uncertainties under demand security constraint. Let x_i denote production (or land) in region i, and c_i is a unit cost (per production unit or per hectare).
We assume that in the case of production shortage, the goods can be purchased on a market with a per unit price of b. Assume the first producer is the cheapest, $c_1 < c_2 < b$.

2.2.1. *Absence of uncertainty.* In the absence of uncertainty (i.e., using average values and ignoring variability), the deterministic model is formulated as the minimization of the total cost function

$$c_1 x_1 + c_2 x_2 + by \tag{1}$$

subject to the supply-demand security constraints

$$x_1 + x_2 + y \geq d \ , \ x_1 \geq 0, x_2 \geq 0 . \tag{2}$$

The optimal solution to the problem is $x_1^* = d$, $x_2^* = 0$, $y^* = 0$, that is, the degenerated solution of the deterministic model (1)-(2) leaves all production to the most efficient region.

2.2.2. *Systemic risk, cooperation, and risk sharing.* Consider the more realistic situation of planning production under uncertainty due to yield variability, which may reduce production x_1, x_2. In this case, the endogenous supply (2) is transformed to a constraint

$$a_1(\omega)x_1 + a_2(\omega)x_2 + y(\omega) \geq d , \tag{3}$$

where $a_1(\omega)$ and $a_2(\omega)$ are random shocks to production x_1, x_2, for example, due to weather variability, $0 \leq a_i(\omega) \leq 1$, $i=1,2$. We do not specify the structure of uncertain events ω, which may affect both regions simultaneously or independently. In general, we can think of a vector $\omega = (\omega_2, \omega_2)$, where ω_1 and ω_2 can be dependent random variables (e.g., yield shocks), simulated by a Monte Carlo model producing a sequence of potential scenarios $\omega = \omega^s$, for example, weather events, $s = 1,2,...,$ with components ω_i^s, $i = 1,2$, which are then used in the EPIC model to calculate the yields shocks $a_1(\omega)$ and $a_2(\omega)$. Often, ω is characterized by a finite number of scenarios (Kall and Mayer 2004). Decisions on production $x = (x_1, x_2)$ at stage 1 have to be made before observing exact values $a_1(\omega)$ and $a_2(\omega)$. If supply $a_1(\omega)x_1 + a_2(\omega)x_2$ falls short of demand d, the residual amount $d - a_1(\omega)x_1 - a_2(\omega)x_2$ must come from purchasing $y(\omega)$ on the market at stage 2 at per unit price b.

The concept of two-stage modeling with strategic (ex ante) x_1, x_2 and adaptive (ex post) decisions $y(\omega)$ is critically important for robust land use planning, as these decisions ensure the security constraint (3) for any event ω. The deterministic model (1)-(2) is now formulated as a linear two-stage stochastic optimization (STO) model: minimize the cost function

$$c_1x_1 + c_2x_2 + bEy(\omega) \tag{4}$$

subject to security constraint (3) for all potential scenarios of uncertainty ω, where $Ey(\omega)$ is the expected value of the shortfall $y(\omega)$, that is, $Ey(\omega) = \sum_s p_s y(\omega^s)$, for discrete scenarios ω^s and their probabilities p_s, $s = 1,2,...$ (In the absence of knowledge about p_s, scenarios ω^s can be assumed equally probable). In this simple example, the optimal stage 2 decision $y(x,\omega)$ satisfying constraint (3) for any fixed vector $x = (x_1, x_2)$, $x_1 \geq 0$, $x_2 \geq 0$ and ω can be found analytically as $y(x,\omega) = \max\{0, d - a_1(\omega)x_1 - a_2(\omega)x_2\}$. Therefore, optimal strategic decisions x_1 and x_2 minimizing function (4) also minimize

$$F(x) = c_1x_1 + c_2x_2 + bE\max\{0, d - a_1(\omega)x_1 - a_2(\omega)x_2\}, \tag{5}$$

where $E\max\{d - a_1(\omega)x_1 - a_2(\omega)x_2\}$ is the expected shortfall characterizing the systemic risks and vulnerability of the supply x_1, x_2. It is important to emphasize that the model (5) does not directly include any measure of risk in the objective function. The risk aversion arises through the coexistence of ex ante x and ex post $y(x,\omega)$ decisions in the form of Value-at-Risk (VaR) quantile-based risk constraint (Ermoliev and Norkin 1997). Let us show that robust x_1^*, x_2^* satisfy quantile-based risks constraints induced by interdependencies between uncertainties $a_1(\omega)$ and $a_2(\omega)$, decisions $x = (x_1, x_2)$, security requirements (3), and the costs. Assume that only the efficient region is at risk (i.e., $a_2 = 1$). Region 2 may be viewed as an inefficient region $(c_1 < c_2)$. Yet, we shall see that this region, due to the interdependencies, is the key player in terms of securing the supply. Let function $F(x)$ have continuous derivatives; for example, the distribution function of $a_1(\omega)$ has a continuous density. This assumption avoids the use of more sophisticated non-smooth stochastic optimization techniques (Ermoliev and Wets 1988). The optimal positive solution $x_1^* > 0$, $x_2^* > 0$ exists in the case when $F_{x_1}(0,0) = c_1 - bEa_1(\omega)$ and $F_{x_2}(0,0) = c_2 - b$ are negative, where $Ea_1(\omega)$ is the expected value of $a_1(\omega)$. The efficient region 1 is inactive in the case $c_1 - bEa_1(\omega) > 0$, leaving production entirely to region 2. Both regions are active only in the case when $c_1 - bEa_1(\omega) < 0$. Somewhat surprisingly, inefficient region 2 is active unconditionally because $c_2 - b < 0$.

It is important to derive the optimal production level $x_2^* > 0$ of the inefficient producer. Using optimality conditions of type $F_{x_2}(x) = 0$ for stochastic minimax models (see Ermoliev and Wets 1988; Ermoliev and Norkin 1997), it is defined by the equation

$$Prob(d - a_1(\omega)x_1^* \geq x_2^*) = c_2/b, \qquad (6)$$

that is, the optimal production x_2^* of the risk-free region 2 is a quantile of the probability distribution characterizing the contingencies $a_1(\omega)$ of region 1. Equation (6) shows that the ex ante first-stage decisions x^* cover only a fraction of the risks determined by the quantile c_2/b, whereas second-stage decisions hedge the rest of the exposure (i.e., the production shortfall). Although not at risk, region 2 is affected by systemic risks characterized by the structure of the whole supply system, that is, demand d, shocks $a_1(\omega)$, cost function c_2, import prices b, robust decisions x_1^* and x_2^*, and the security constraint (3). These risks can be regulated by adjusting parameters c_1 and c_2 on local (regional) and b and d on global (national and international) levels. In engineering, insurance, and financial applications, equations of type (6) are known as chance (or probabilistic) constraints (Prekopa 1988), safety or reliability constraints (Marti, 2008), or Value-at-Risk (VaR) constraints (Rockafellar and Uryasev 2000). The optimal value $F(x^*)$ is a Conditional Value-at-Risk or CVaR risk measure (Rockafellar and Uryasev 2000).

Annex A3: An example of effects from policy measures on production: the EU protein crop deficit

(http://www.europarl.europa.eu/sides/getDoc.do?type=REPORT&reference=A7-2011-0026&language=EN)

A recent study published by the European Commission* on the protein crop sector reveals a remarkable decrease in protein crop production in the European Union in the past ten years. The main dried pulses excluding soybeans decreased by 30%, and soybean production by 12%. This trend increases an already existing alarming dependence of the Union on the imports of protein crops, which are mainly used for animal feed and carries major risks especially for the EU livestock sector, as price volatility on international markets has substantially increased. *(LMC international report).

Overall EU protein crop production currently only occupies 3% of the Union's arable land (excluding fruit and vegetables). In spite of public support for the sector since 1978, production of dried pulses, which temporarily increased during the 1980s, has again decreased to roughly one million ha in 2008. More than 40 million tonnes of crop proteins, mainly soy beans and corn gluten feed are imported annually, **representing 80% of the EU's crop protein consumption**. In terms of land use abroad for crop protein imports into the EU, this represents ten per cent of the EU's arable land, or 20 million ha.

Historical reasons for the deficit and its consequences

The deficit in protein crop production goes back to previously established international trade agreements (the General Tariff and Trade Agreement (GATT) and the Blair House Agreement), which allowed the EU to protect its cereal production and in return allowed duty-free imports of oilseed and protein crops into the EU. Protein crop production was therefore at a severe competitive disadvantage and fell sharply accordingly. Farmers and local processing business therefore lost interest in protein crops and also lost practical knowledge of cultivating and adding value to them. Breeders stopped developing disease resistant and highly performing varieties. European research in this field has also substantially declined reflecting the low demand in seeds and technical support. The EU is phasing out support for protein crops and drying facilities for lucerne/alfalfa and other leguminous fodders. The most worrying fact is that throughout Europe, practical experience in protein crop production as part of extended crop rotation is being lost, including on-farm selection, storage, processing and on-farm use as animal feed. Finally, also traders in oil and protein crops are now fully focussed on protein crop imports and show little interest in domestic production.

Reducing the EU's protein deficit - an important element of CAP reform

The European Commission and member states have pointed at advantages of a more balanced supply and consumption of domestic protein crops as part of an integrated strategy responding to new challenges like climate change, agricultural biodiversity loss, depletion of soils, and pollution of groundwater and price volatility for agricultural products on the world market. The extended use of protein crops in crop rotation offers major agro-environmental and climate mitigation advantages. Regarding climate change, leguminous varieties such as field peas, broad and field beans, lupins, lentils, chicken peas, but also lucerne/alfalfa and clover can substantially reduce greenhouse gas emissions through assimilation and fixation of nitrogen in the soil and thus reduce of the use of nitrogen fertiliser by up to 100kg N per ha and month. With a higher percentage of protein crops in crop rotation, soil fertility and structure, nutrient storage as well as health of following crops is improved. Permanent grass-clover mixtures for animal feed, mixtures of cereals and proteins cover soils better and so reduce nutrient run-off into groundwater and rivers, as well as offering better conditions for bees and other pollinating insects. Extended crop rotation reduces the need for crop protection intervention and can contribute to the conservation of diversity in wild and cultivated species and varieties.

Protein crops and enlarged crop rotation - reduced production costs and increased environmental advantages

The extended use of leguminous crops in crop rotation substantially reduces the need to apply nitrogen fertiliser which contributes not only to reduce greenhouse gas emissions in its production but also overall production costs for farmers. With a global trend towards rising crude oil prices, costs for agricultural inputs including fuels are also increasing continuously. Crop rotation including protein crops can reduce fuel consumption in soil treatment, as the content of humus and soil moisture is better preserved and requires less tilling. A recent study published by the European Parliament (PE 438.591) and a study of the French Commission on sustainable development of the French Government (Dec 2009 no 15) estimates a reduction of costs for fertiliser use in France of up to 100 Mio € per annum. In short, the following advantages of protein crop production within extended crop rotation have been identified in the mentioned studies:

Increase of nitrogen fixation, creation of a balanced C/N ratio in the soil and improvement of humus content, reduction of pesticides treatments and use of herbicides as a consequence of reduced plant disease and herb invasion; improved soil structure.

Quality of protein crop production and compound feeding stuff

The efficiency of using protein crops in animal feed production strongly depends on the content of essential amino acids in the various crops and the composition of compound feedstuffs. Soybeans are currently considered to deliver the highest integrated content of these acids with a very good balance of nutrients especially for pork and poultry production. Therefore today the soy content of compound feedstuffs is around 50% for egg and poultry production is based on soy beans. In the production of pork meat and beef the soy content of compound feeds fluctuates around 28% and 21% respectively.

Possibilities for substituting imported soybeans and other non-domestically produced animal feed products strongly depend upon new incentives for farmers to grow these crops and on adequate infrastructure for processing into animal feed. The European Commission should therefore look into possibilities to overcome the current low level of research, seed selection and marketing, knowledge of production, storage and use of these crops for on-farm feed production.

Specific support, research, extension services and training

In order to offer farmers new incentives to grow and use protein crops along with cereals and oil seeds and their by-products, the reform of the CAP should include horizontal measures which do not offer a specific crop premium but which encourage farming practices responding to the new challenges and at the same time overcoming the protein deficit of the Union. Article 68 of Regulation (EC) No 73/2009 has been used by a number of Member States for specific support for protein crop production as a contribution to agro-environmental practices. This option should become EU-wide practice to respond to the new challenges. The Commission should consider a top-up payment with compulsory rotation of at least four different crops including at least one protein crop, as well as increased support for non-arable permanent grassland areas including specific grass-leguminous fodder mixtures. These measures would not only reduce greenhouse gas emissions, but also contribute to a higher level of plant and animal health. The Commission should also consider specific support of investments in regional, local or on-farm facilities for storage, cleaning, and on-farm processing of protein crops as part of rural development programmes. It is also important to carry out a study on current deficits in research and seed production, including the needs of improved extension services and to consider a decentralised approach to research programmes which takes into account farmers' local knowledge and sustainable farming systems. The Commission might also consider to re-establish an agricultural research unit in the General Directorate for agriculture and rural development.

Towards a better balance between and animal protein and crop protein production

A very high percentage of protein crops is currently produced for animal feed, while the human consumption of grain legumes has continuously decreased in the EU. Regarding the commitments of the EU to actively contribute to global food security and to actively combat climate change, future agriculture and rural development policy should work towards not only a more balanced animal protein and crop protein production so as to reduce greenhouse gases and run-off of nutrients into watersheds, but should also motivate consumers, public procurement authorities and catering services to choose a more balanced, environmentally friendly and diverse choice of food in their diet.

At the same time the Commission should take legislative initiatives to reduce food waste throughout the food chain, including slaughter offal and swill the use or disposal of which is still not adequately regulated. The Commission should firmly apply the precautionary principle in this field, but should also take legislative initiatives to reduce food waste and to improve the overall balance of animal and crop production in view of the new challenges.