

climate changes spatial planning

Adaptation

Assessing the adaptive capacity of agriculture in the Netherlands to the impacts of climate change under different market and policy scenarios (AgriAdapt project)

J. Wolf | P. Reidsma | B. Schaap | M. Mandryk
A. Kanellopoulos | F. Ewert | P. van Oort
C. Angulo | C. Rumbaur | R. Lock | A. Enders
M. Adenauer | T. Heckelei | R. Rötter | S. Fronzek
T.R. Carter | A. Verhagen | M.K. van Ittersum

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Authors

J. Wolf [2], P. Reidsma [2], B. Schaap [1], M. Mandryk [2], A. Kanellopoulos [2], F. Ewert [4], P. van Oort [3], C. Angulo [4], C. Rumbaur [4], R. Lock [4], A. Enders [4], M. Adenauer [5], T. Heckelei [5], R. Rötter [6], S. Fronzek [7] and T.R. Carter [7], A. Verhagen [1], M.K. van Ittersum [2]

1 Plant Research International, Wageningen UR, Wageningen, the Netherlands
2 PPS, Wageningen UR, Wageningen, the Netherlands
3 CSA, Wageningen UR, Wageningen, the Netherlands
4 INRES, University of Bonn, Bonn, Germany
5 ILR, University of Bonn, Bonn, Germany
6 MTT, Mikkeli, Finland
7 Finnish Environment Institute (SYKE), Helsinki, Finland

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Contents

Summary

Summary in Dutch

Het AgriAdapt project heeft methodieken ontwikkeld die het mogelijk maken om (a) de effecten, risico's en veerkracht te bepalen van landbouwsystemen die bloot staan aan veranderingen in klimaatsomstandigheden en ook aan veranderingen in andere factoren (bijv. markten, technologie en beleid) en (b) adaptatie-strategieën op bedrijfs- en regionaal niveau te evalueren. De methodieken zijn toegepast op akkerbouwsystemen over Europa en in een meer geïntegreerde manier, op akkerbouwbedrijven in Flevoland, Nederland. De toegepaste technieken op Europees niveau zijn (a) Gewasgroeimodellering, en b) Marktmodellering. De toegepaste methodieken op regionaal niveau zijn de volgende: (a) Geïntegreerde duurzaamheidsanalyse, (b) Ontwikkeling van scenario's van bedrijfsstructuur-verandering voor scenario's voor 2050, (c) Berekening van gewasopbrengsten voor verschillende scenario's voor 2050 inclusief agro-klimaat kalenders, en (d) Gedeeltelijk en volledig geïntegreerde analyse van diverse akkerbouwbedrijfstypen in Flevoland in 2050, inclusief opschaling naar de provincie als geheel. Resultaten van de toepassingen van de verschillende methodieken worden hier getoond. Bijvoorbeeld, het analyseren van toekomstige bedrijfssystemen laat zien dat de meest belangrijke sturende factoren voor het A1-W scenario met een sterke globalisatie van de economie in 2050, zijn (a) de opbrengsttoename vanwege klimaatsverandering, (b) de te verwachten prijsveranderingen van landbouwproducten, en (c) de mate van innovatie t.b.v. gewasproductiviteit. De gevolgen van klimaatsveranderingen zullen volgens onze analyses een positief economisch effect hebben op de akkerbouw in Flevoland.

Summary

The AgriAdapt project has developed methodologies that enable (a) the assessment of impacts, risks and resiliencies for agriculture under changes in climatic conditions but also under changes of other drivers (market, technology, policy, etc.) and (b) the evaluation of adaptation strategies at farm type and regional scale. The methodologies are applied to arable farming over Europe and in a more integrated way, to that in Flevoland, the Netherlands as the key case. The methodologies at European level include (a) Crop modelling and (b) Market modelling. The methodologies at regional level cover the following main areas: (a) Integrated sustainability assessment, (b) Development of scenarios of farm structural change towards 2050, (c) Calculation of crop yields for different scenarios in 2050 inclusive agro-climate calendars, and (d) Partial and fully integrated analysis of farming systems in 2050, inclusive the aggregation to the regional level. Results from the application of the different methodologies are presented here. For example, exploring future farming systems shows that the most important driving factors towards 2050 within the A1-W scenario with a globalized economy, are (a) the yield increase due to climate change, (b) the expected product price change and (c) the degree of innovation in crop productivity. The effects of climate change are projected to have a positive economic effect on arable farming.

Extended summary

The AgriAdapt project aimed at developing methodologies and assessing the impacts of climate change on agriculture towards the year 2050. The project integrates climate change with other drivers of change, notably markets and technology development, in the assessment. In addition to earlier studies AgriAdapt addresses the farm and regional level impacts and adaptation measures in the context of changes at EU level.

Starting from EU and regional level scenarios, the impacts of climate change on agriculture in Flevoland were assessed. For this regional level, adaptation measures were identified and discussed with local stakeholders (see Figure 1).

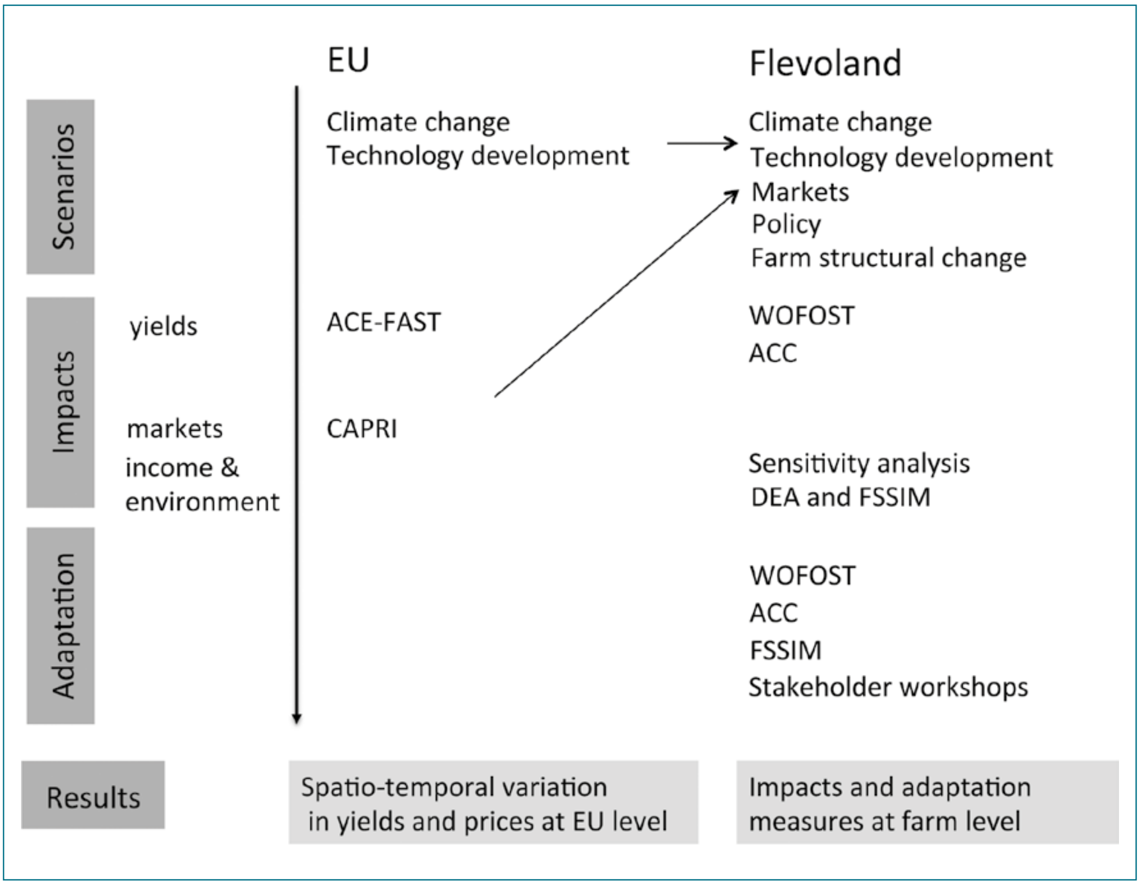

Figure 1.
The different steps and tools used in the AgriAdapt study. The link between the two scales is indicated by an arrow. Vertically, links are mainly top-down. Abbreviations are explained in the text.

Using the outline of Figure 1 we first present the main results and conclusions at the EU level followed by the results and conclusions at the regional level. Market changes can only be assessed at the larger scale (such as the EU level) and form the context, within which the regional scale analysis can next be done. Information about the methods and calculations can be found in this synthesis report and more details and background information in the project reports (see the abstracts of these reports in Section 7.1 up to and including Section 7.4).

The EU level

For the EU27 we assessed the relative importance of climate change impacts on crop yields and prices of agricultural commodities, using a range of scenarios. The impacts of climate change and technology development on crop yields were assessed using the crop model ACE-FAST. The results of this model confirmed earlier findings that the impact of climate change and CO_2 concentration is outweighed by assumptions about the degree of technology development. Compared to an earlier study by Ewert *et al.* (2005), who applied a statistical approach to project changes in crop yields, the relative importance of climate change is higher, but the effect of climate change is still less than that of technology change. The main improvement compared to earlier crop modelling studies was that regional differences of model parameters related to crop growth in addition to crop phenology were used. This considerably improved yield simulations at the regional scale.

The clear importance of technology development in estimating 2050 yield levels indicates the need to further investigate this driver and to define and quantify it in a generic way to allow for inclusion in crop modelling. In our study, technology development was determined via a statistical data analysis, using a historical trend and scenario assumptions. To improve projections, the factors contributing to technology development (e.g. breeding, crop management) and their possible further improvement should be investigated more explicitly.

The study was successful in capturing spatio-temporal variation of current and future agricultural production in relation to climate, crop management and technology (see Figure 2 for wheat). In many regions and for several crops yield increases of 30% or more were simulated. For grain maize the spatial variability is highest, ranging between -30% and over +30%.

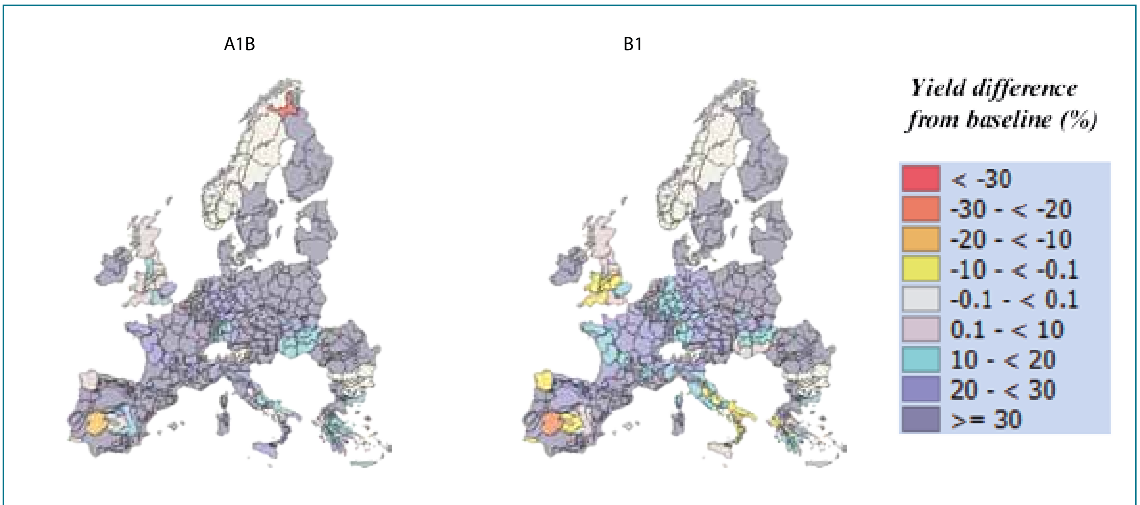

Figure 2.
Differences between simulated yields (% of base year) for the climate change scenarios A1B and B1 for winter wheat over 24 years in Europe (EU25). The base year and future time series are centred around 1990 and 2050, respectively.

Changes in production systems clearly not only depend on yield levels but also to a large extent on price levels. Predictability of prices and price changes up to 2050 is however difficult if not impossible. In this study the influence of climate and technology driven production levels in 2050 was incorporated in the agricultural market equilibrium model CAPRI to project effects on price levels. It was shown that introducing yield changes as simulated by the crop model in an agricultural market model leads to significant price impacts. The impacts of changes on the demand side (such as the changes in GDP and population) however appear to be much stronger. Price changes are an important catalyst for changes in investments, management and policies. The interactions between yield levels, prices and decision making is still poorly studied. Developing linkages between crop and market models is a first step.

Flevoland

Food production is one of the reasons Flevoland was created, and although the economy of the region has diversified, over the years agriculture remained the dominant economic activity. To assess the relative impacts of climate change and define feasible adaptation strategies, AgriAdapt developed regional scenarios and assessed the impacts of climate change, technology development, markets and policy on regional farm structural change, farm types and a range of crops. Two scenarios were considered based on WLO/SRES and KNMI'06 scenarios: the A1-W scenario, i.e. a Global Economy with severe climate change, and the B2-G scenario, i.e. Regional Communities with moderate climate change. They are of interest, as contrasting with respect to the rate of economic growth, global warming, and the degree of globalization, and for that reason, both scenarios have often been used in related studies (Ewert *et al*., 2005; Riedijk *et al*., 2007; Van den Hurk *et al*., 2006).

Most studies assessing impacts and adaptation strategies in relation to climate change, only consider current farm types and management. Towards 2050, farm structure and farm characteristics will however change due to changes in technology, markets and policy. This changing context will certainly also influence the impacts and adaptation to climate change. We therefore developed a new method to study farm structural change, using data, literature and stakeholder workshops, to assess historical trends and to develop scenarios for projecting farm structural changes towards 2050.

The farm level decision process focuses on specialization, size, intensity and orientation. These dimensions influence the farming landscape, and were therefore used to develop a farm typology. While currently most farms in Flevoland are production-oriented, in 2050 the number of entrepreneur and nature-oriented farms is expected to be higher. Additionally, size is projected to increase with 7% (B2-G scenario) to 25% (A1-W scenario), and more intensive crops (e.g. tulips, vegetables) will be cultivated, especially in the A1-W scenario.

Underlying the changes in farm structure are socio-economic reasons that are partly related to potential revenues. For arable farming these revenues are linked to yield levels. The calculated future yields of the main crop types in Flevoland are subject to a range of uncertain factors. But similar to the EU level crop modeling results for Flevoland (now using the WOFOST crop model) reveal that assumptions on the increase in genetic yield potential as based on the technology development, are most important. Factors influencing technology development were further investigated, but resulting estimates of technology development remained close to the estimates as used at the EU level. Second, the effects on yields of climate change and increased atmospheric CO_2 are also significant and generally positive (+10% - +30% in the A1-W scenario). With yields in Flevoland already fairly close to the potential production (61-92%), measures to close or stabilise the yield gap appear difficult to find.

Apart from the yield effects from gradual changes in the climate, assessed at EU and Flevoland level using ACE-FAST and WOFOST, respectively, extreme weather events were investigated using the Agro Climate Calendar (ACC). The ACC includes potential yield losses, as well as loss of product quality, and assesses the risks of a variety of climate factors including weather extremes and the emergence and abundance of pests and diseases. By linking expert knowledge and results from crop models with changes in the frequencies of occurrence of critical climate factors, the ACC has proven to be an effective tool to identify main climate risks and relevant adaptation measures, and to share and discuss these with stakeholders.

Adaptation measures that were evaluated, include changes in cropping patterns, increasing soil organic matter, re-sowing, irrigation and techniques of precision agriculture (GPS steering and automatic tire inflation, changing sowing densities) as identified by the ACC. The impacts of climate change in a farm context were firstly analyzed with sensitivity analyses of farmers' income while assuming a fixed cropping pattern. Secondly, a modeling exercise was set up in which Data Envelopment Analysis (DEA) was used to rank current farming systems based on their capacity to convert inputs into outputs, and identify farms that are most efficient in converting inputs into outputs. The practices of these farms identified with DEA were then offered to the bio-economic farm model (FSSIM), which simulates farmer's behavior and calculates optimal farm plans (crop rotations completely specified with input and output coefficients) for different scenarios. Also, the adaptation measures as mentioned above, were offered to FSSIM for their assessment at farm level.

The sensitivity analyses for the main arable farm types in Flevoland show that the differences in gross margin per labour hour in arable farming in 2050 are mainly determined by first, the increases in input and product prices and second, the yield increase (due to climate change, CO_2 and technology development). Currently, farm types with a large area of potatoes have the highest gross margin per labour hour and this will remain so in all future scenarios. However, only in the A1-W scenario including climate change, increased [CO_2] and technology development, gross margins will increase. The reason for decreases in other scenarios is that input prices are projected to increase faster than output prices; only the large increase in crop yields due to technology development as projected for the A1-W scenario, can outweigh this. Tulip production requires a large amount of labour and is only possible if the prices of hired labour are relatively low.

The DEA-FSSIM modeling revealed that changes in the A1-W scenario are driven mostly by expected yield increase and price changes of important outputs and inputs. The effects of the increased occurrence of extreme events are not that important and will not lead to major changes in cropping patterns and adoption of adaptation measures. The effects of climate change are projected to have a positive economic impact on arable farming. However, a substantial increase in the use of biocides, fertilizers, and energy is also expected, to realize the increased yields. Increase in these inputs combined with a shift in production to other arable crops (mainly tulips and vegetables), can lead to an increased environmental pressure per ha. Nevertheless, the environmental pressure per ton of product is projected to decrease. Making new and more productive varieties available appears to compete with promoting the use of existing technologies that focus on improving resource use efficiencies (e.g. increasing soil organic matter and/or precision agriculture techniques). The results of the analysis show that accessibility to capital can increase the adoption rate of the tested adaptation measures (being higher in larger farms).

Throughout the project, stakeholder workshops were organized to present and discuss impacts and adaptation to climate change. The interactive discussions resulted in a range of adaptation foci ranging from technical to socio-economic and governance. Stakeholders recognised the integrative nature of adaptation and at the same time indicated that adaptation is what agriculture is and has been all about: a continuous interaction with nature, markets and policies. Overarching issues are risks related to extreme events and the costs and benefits of adaptation measures.

Stakeholders indicated that at farm level several adaptation measures are already available. Reducing disease pressure via crop rotation and crop selection and improving soil structure via a wider rotation and selection of machinery are only two examples. Major shifts or changes in crops were not foreseen by stakeholders; introduction of new crops will depend mainly on market changes.

Improved information about future climate change impacts is of high value for most farmers. We can conclude that the co-design of adaptation measures to reduce impacts of climate extremes (using the ACC method), leads to relevant adaptation strategies. However, compared to other non-climate factors, the impacts of extremes on crop production seems to be relatively small (as shown with the modelling exercises). As costs are a critical issue in the adoption of adaptation measures, the most competitive and capital intensive larger farmer are the first to invest in on-farm adaptation. In fact this can be seen as part of the ongoing efforts to remain competitive in a changing environment. The discussions made clear that for individual farmers adaptation is not something that they need to do in the short term. They acknowledge that in the future adaptation will be needed. However, for most farmers it is too early to invest in risk management for climate change, if other risks such as variations in market price and changing policies are currently dominant. The discussion about the scenarios for 2050 made clear that the costs of inputs and measures and the product prices in the future will be crucial for the decisions about adaption measures.

1. Introduction

The Netherlands is an important producer and exporter of agricultural products. Changes in climate, markets and policies may have a large impact on the agricultural sector and farmers will need to adapt to these changes. Sector and policy documents have, so far, insufficiently considered the impacts of climate change and increased climate variability on the sector. The Dutch government has recently started an Adaptation Programme for Spatial Planning and Climate (CcSP[1]) to develop a comprehensive agenda for "climate proofing" the Netherlands over all sectors (Kabat *et al.*, 2005). Agricultural land accounts for 68% of the total land area making it the most dominant land use and giving it a high priority in CcSP. There is a clear need for agriculture in the Netherlands to be better prepared to deal with climate change impacts by understanding (i) the risks associated to climate change, (ii) the strength of the agricultural sector to sustain impacts from climate change, and (iii) possible options for adaptation.

Originally, climate impact studies have focussed mainly on bio-physical relationships, explaining the potential impacts of climate change on primary production (Rosenzweig and Parry, 1994; Downing *et al.*, 2000; Reilly *et al.*, 2003). In recent years the importance of socio-economic developments is increasingly recognised and considered in climate impact assessments for agriculture (Parry *et al.,* 2004; Fischer *et al.*, 2005; IPCC, 2007). Also, the importance of management and technology development (Ewert *et al.*, 2005), changes in other land uses (Rounsevell *et al.*, 2005; Rounsevell *et al.,* 2006) and land prices (van Meijl *et al.*, 2006) for agricultural production has recently been stressed. It has further become evident that a significant challenge for agriculture with regard to climate change can be expected from changes in the magnitude and frequency of extreme conditions like droughts, hail, storms and excessive wet periods (Lemmen and Warren, 2004).

1 The CcSP programme (BSIK-KvR) started in 2004 and runs until 2011. The projects within the CcSP programme are complementary and often interconnected with each other. CcSP is the principal employer for this proposal. More info: www.climatechangesspatialplanning.nl

A limitation of climate impact studies for agriculture is that adaptation is often not adequately considered. Farmers, regions and countries are sensitive to exposure to climate change, but will be able to adapt through a variety of strategies. Adaptation can moderate potential damages or create new opportunities. Implementation of adaptation options will result in substantial benefits for certain cropping systems under moderate climate change (Howden *et al.*, 2007; IPCC, 2007).

The capacity to adapt will depend on both biophysical and socio-economic conditions. Recent analyses have shown the importance of farm characteristics and regional socio-economic conditions for the responses of crop yields and farmers income to climate change (Reidsma *et al.*, 2010). However, only few studies have explicitly considered adaptation in impact assessment studies (Metzger *et al.*, 2006), and quantification of adaptation remains difficult (Reidsma *et al.*, 2010).

1.1 Links with other CcSP projects

In a preceding scoping study the competitiveness of Dutch agriculture under climate and market change was addressed. Adaptation in agricultural production was assumed to depend on the economic size of the farms within a sector, with larger farms being less vulnerable than smaller farms (Hermans and Verhagen, 2008; Hermans *et al.*, 2010). The assessed changes were limited to selected crops and did not aim to assess the effects of climate variability and the ability of farmers to adapt through changes in management and farming systems. Scale dependency of adaptation strategies has been reported (Reidsma and Ewert, 2008) but was not addressed in this (Hermans and Verhagen, 2008; Hermans *et al.*, 2010) and other studies. As shown for regions in southern Europe, individual farms may be vulnerable to climate change but the region as a whole may be not, which can be a result of high diversification of farming systems (Reidsma and Ewert, 2008).

At the regional level the impacts of extreme events were assessed for a selected number of crops and presented in a calendar type format (Schaap *et al.,* 2011; Wit *et al.*, 2009). The scoping and the agro-climate calendar approaches were used in a practical and stakeholder-driven assessment on climate impacts and adaptation strategies for the agricultural sector in the Northern provinces of the Netherlands. This work started in 2008 within the CcSP programme, focused on the development of strategies and action plans for agriculture in the Northern part of the Netherlands in response to climate and market changes (Wit *et al.*, 2009).

1.2 Scales and methods

Consideration of multiple factor and scale interactions in assessment studies requires not only conceptual and methodological developments, but also technical solutions to link quantitative models that represent different parts of the system. The integrated assessment framework SEAMLESS-IF (Van Ittersum *et al.,* 2008; Ewert *et al.*, 2009; being further developed within the SEAMLESS Association, see http://www.seamlessassociation.org/) provides such solutions, being designed for integrated assessments of policy impacts and technological innovation on agriculture and using knowledge from different scientific disciplines. The model components of this framework that are applied within this study, consist of the agricultural sector model SeamCAP (Britz *et al.*, 2010), a version of CAPRI (Britz *et al.*, 2007; Britz and Witzke, 2008), the bio-economic farm model FSSIM (Janssen *et al.*, 2010; Louhichi *et al.*, 2010), and its pan-European integrated data base (Janssen *et al.*, 2009). The strong point of this framework is that it allows to assess, ex-ante, agricultural and agri-environmental policies and technologies across a range of scales, from field–farm to region and the European Union, and that it supports the technical linkage of individual model and data components.

Clearly, the role of adaptation in agriculture to moderate impacts of climate change is increasingly recognised. There is an apparent need for a methodology to assess impacts of climate change on agriculture at the regional and farm type level, also considering changes in socio-economic and market conditions. It should conceptually and technically link biophysical models that enable estimation of climate impacts on e.g. crop yields, land use and associated environmental impacts (e.g. nitrogen leaching, change in soil carbon content, and water use), with farming system and market models. Despite the significant progress that has been made in recent years on climate change impact and sustainability assessments, key issues for assessing responses and adaptation at farming system and regional levels using a coherent modelling framework, appeared to remain unresolved. We have developed in this project such a modelling framework, allowing to do integrated climate change impact assessments, as described in the following.

1.3 Objectives

The key objective of the AgriAdapt project is to develop methodologies to assess climate change impacts on agriculture, also including adaptation at regional and farm type levels in combination with market changes. More specifically, the methodologies enable:
(i) the assessment of impacts, risks and resiliencies for agriculture under first, changes in climate conditions and second, other changes (e.g. market, technology, policy, etc.), and
(ii) the evaluation of adaptation strategies at farm type and regional scale levels.

The methodologies have been applied to arable farming. First, the impacts of climate and market changes on arable farming over Europe have been analysed. Market changes cannot be assessed at the regional level and also the impacts of climate change are related to the impacts in other regions. Hence, this high-scale (e.g. EU) level analysis is required as a context, within which a regional level analysis can next be done. In a second step an integrated analysis of the impacts of climate change on arable farming within the context of changes in technology, policy, farm structure and markets, has been done for the province Flevoland, the Netherlands. Flevoland is used as the key case study to demonstrate the integrated approach.

The methodologies provide answers to questions such as:
- What are the risks and opportunities for arable farming in Europe and in more detail in Flevoland under climate and market changes?
- How important are climate change effects on agriculture as compared to market changes?
- Are farming systems able to cope with increased frequencies of extreme climate events?
- Does adaptation to climate change provides opportunities for agriculture?

The different methodologies as applied in the AgriAdapt project and their main outcomes, cover the following issues:
- Assessment of the potential impacts of climate and market changes in 2050 on arable farming (i.e., mainly crop yields and product prices) over Europe (Chapter 2; for more detailed information, see project reports no. 2 & 3),
- Integrated assessment of the impacts of climate and other changes (e.g. technology and markets) on arable farming in Flevoland in 2050 and the possible ways for adaptation to climate change (Chapter 3; for more detailed information, see project reports no. 1, 4 & 5),
- Learning from knowledge exchange during stakeholder workshops and feedback from stakeholders about their perspectives (Chapter 4; for more detailed information, see project report no. 6).

The abstracts of these project reports are given in Chapter 7.

2. Impacts of climatic and market changes on arable farming at EU level

2.1 Introduction

Climate impact studies have, with a few exceptions (e.g. Rötter and van Diepen, 1994), focused on biophysical relationships explaining the potential impacts of climate change on primary production (Rosenzweig and Parry, 1994; Downing *et al.*, 2000; Reilly *et al.*, 2003). In recent years the importance of socio-economic developments is increasingly recognized and considered in climate impact assessments for agriculture (Parry *et al*., 2004; Fischer *et al*., 2005; IPCC, 2007). Also, the importance of management and technology development (Ewert *et al.*, 2005; Hermans *et al.*, 2010) for agricultural production has been stressed.

Another important point is the scale at which impact and adaptation options are assessed. Scale dependency of adaptation strategies has been reported earlier (Reidsma and Ewert, 2008; Reidsma *et al*., 2007, 2009, 2010). For example as shown for regions in southern Europe, individual farms may be vulnerable to climate change but the region as a whole may be not, which can be a result of high diversification of farming systems (Reidsma and Ewert, 2008).

This study for the EU aims to assess potential climate change impacts on agriculture in Europe in combination with market changes. This has been done at different scales, ranging from the field and farm to the EU. We have developed scenarios and provide estimations of the changes in crop productivity and commodity prices for important crops in Europe, as affected by climate change and changes in market drivers such as GDP and population growth. In more detail the objectives of this study for the EU are:

- To develop scenarios with climate change, increased atmospheric CO_2 and technology development for the modeling of future crop productivity,
- To model future crop productivity at EU level as affected by climate change, increased CO_2 and technology development; specific emphasis is put on methods of model calibration to improve estimations of the spatio-temperal variability of crop productivity,
- To develop scenarios for the modeling of future market changes in EU27,
- To model future market changes and changes in the prices of agricultural commodities in the EU27.

For more detailed information about this study at EU level, see the project reports no. 2 & 3 and see their abstract in Section 7.2.

2.2 Impacts of climate change and technology development on crop productivity

2.2.1 Methodology and inputs

The crop modeling activities are based on the crop model LINTUL2 for potential and water-limited conditions (Spitters and Schapendonk, 1990; Farré *et al.*, 2000; van Ittersum *et al.*, 2003), integrated in ACE (Analysing Cropping systems and Environment) which is a further development of the recently developed cropping system modelling framework APES (Van Ittersum *et al.*, 2008; Donatelli *et al.*, 2010; see http://www.apesimulator.org/default.aspx). The crop model was further extended with a calibration algorithm and implemented to allow fast simulations for large numbers of spatial units and years, resulting in ACE-FAST.

ACE-FAST considers effects of climate including limited water supply as described in Spitters and Schapendonk (1990) and Farré *et al.* (2000). Different to other model versions (Ewert *et al.*, 1999; van Oijen and Ewert, 1999; Rodriguez *et al.*, 2001; Wolf and van Oijen, 2002), for the present study a simple representation of the effects of increased atmospheric CO_2 concentration on biomass production was considered, using the relationship between atmospheric CO_2 and radiation use efficiency as proposed by Stockle *et al.*, (1992).

Weather data were obtained from the SEAMLESS database (van Ittersum *et al.*, 2008; Janssen *et al.*, 2009) for 533 climate zones in the EU25 (Janssen *et al.*, 2009; Andersen *et al.*, 2010) for the period 1983-2006. A climate zone is a spatial unit that combines NUTS-2 administrative regions and Environmental Zones (EnZ) (Metzger *et al.*, 2005). Soil characteristics at the level of AgriEnvironmental Zones (AEnZ) (Hazeu *et al.*, 2010), a further refinement of the climate zones, were also available from the Pan European SEAMLESS database (van Ittersum *et al.*, 2008; Andersen *et al.*, 2010). Six different soil types were defined according to topsoil organic carbon levels (Hazeu *et al.*, 2010). However, in this study only the dominant soil type per AEnZ, i.e. the soil type covering the largest area in each AEnZ, was considered and aggregated to the level of NUTS-2 regions, for which yield statistics were also available.

Yearly sowing and harvest dates for grain maize, potatoes, sugar beet, winter barley and winter wheat were obtained from the JRC/MARS Crop Knowledge Base for regions across Europe (JRC, 1998). However, due to missing values in some NUTS-2 regions and years, these dates were averaged to the level of 13 Environmental Zones (EnZ) across Europe (Metzger *et al.*, 2005). Subsequently, the obtained sowing and harvest dates for the 13 EnZs were disaggregated again to the climate zones.

Before applying ACE-FAST for projecting climate change impacts in Europe, we tested the effects of three different calibration methods to identify the most suitable method. The methods tested were;

(1) Region-specific calibration of phenology parameters only,
(2) Region-specific calibration of phenology parameters and a correction factor for yield estimations,
(3) Region-specific calibration of phenology and selected growth parameters instead of a yield correction factor.

Observed and simulated yields have been compared for the three calibration methods. This clearly showed that model calibration considering growth parameters (method 3) provided the best agreement between observed and calibrated yields. Thus, for the simulations of future crop yields in Europe calibration method 3 has been applied. These simulations have been done in three steps, first including climate change (Section 2.2.2), next also with an increase in atmospheric CO_2 (from 369 μmol CO_2/mol in year 2000 to respectively 532 and 478 μmol CO_2/mol for A1-b and B2 scenarios for 2050 (IPCC, 2001), and finally also including technology development.

The importance of considering technology development in climate change impact assessments studies has been stressed by several authors (Ewert *et al.*, 2005; Challinor *et al.*, 2009; Semenov and Halford, 2009; Rötter *et al.*, 2011). Here we use the approach described by Ewert *et al.* (2005) to estimate yield changes due to improved varieties and crop management. In this approach, historic yield trends are used as a basis to extrapolate yields into the future. The extrapolated trends are, however, modified depending on scenario-specific assumptions about progress in breeding to increase potential yields and in crop management to reduce the yield gap (Ewert *et al.*, 2005). In this study we used the same technology parameters to correct the historic yield trends, as described by Ewert *et al.* (2005). Importantly, historic trends were calculated for the period 1983-2006 for each NUTS-2 region and disaggregated to the climate zone. Thus, all climate zones in one NUTS-2 region use the same historic yield trend. Calculated scenario-specific yield changes due to technology development were then used to correct simulated yields under climate change and increased atmospheric CO_2.

2.2.2 Climate change scenarios

The methods used for scenario development are summarized in Fig. 2.1 and are described in more detail in the following sections. Briefly, future crop yields in Europe considering the effects of climate change and technology development, are simulated with ACE-FAST. The projected yield changes are then considered in CAPRI, together with scenario-dependent assumptions about changes in global drivers (e.g. population and GDP) and climate-induced changes in global crop yields, to simulate changes in product prices.

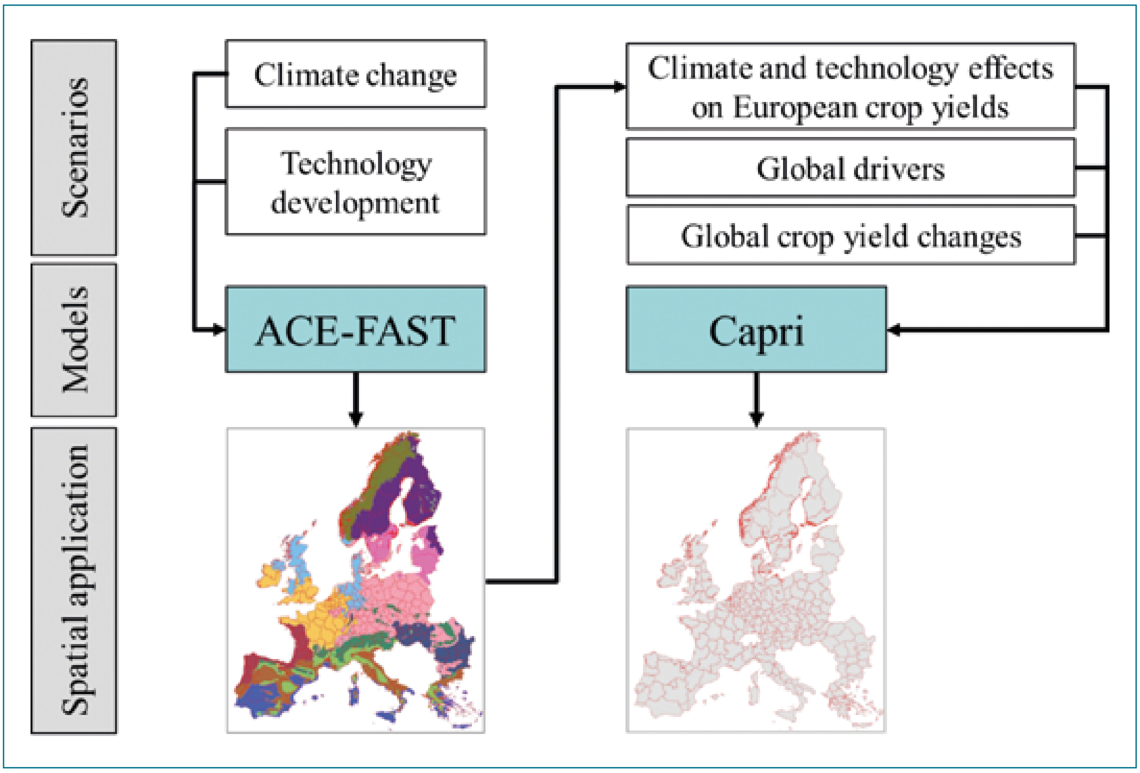

Figure 2.1.
Overview of the scenario approach for the two models used in this study. The two maps show the climate zones (i.e. simulation unit for ACE-FAST) and the NUTS-2 regions (i.e. simulation unit for CAPRI). See text for further explanation.

The climate change scenarios considered projections for the period 2040-2059, assuming alternative emission pathways from 15 different general circulation models (GCM)s, archived as part of the third Coupled Model Inter-comparison Project (CMIP3) at the Intergovernmental Panel on Climate Change (IPCC) Data Distribution Centre (DDC) (DDC IPCC, 2010). The following seven GCM-based scenarios, two ensemble means and five individual GCM simulations, were selected to provide a wide range of changes in temperature and precipitation by the mid-21st century:

- SRES A1B 15-model ensemble mean – this provides a central estimate of changes with respect to all variables provided,
- Pattern-scaled SRES B2 15-model ensemble mean – all changes of the A1B ensemble mean are reduced by a factor 0.90; for more explanation see below,
- BCCR_BCM2_0/SRES B1 – less warming consistent across all European regions and seasons,
- MIROC3.2(hires)/SRES A1B – more warming consistent across all European regions and seasons,
- CCCMA-CGCM3.1/SRES A2 – wet in northern Europe,
- MIROC3.2(hires)/SRES B1 – wet in southern Europe,
- GISS_MODEL_E_H/SRES A1B – dry in most European regions and most seasons.

Changes in temperature simulated by individual GCMs are fairly consistent across Europe; two simulations could therefore be identified that span a large part of the range of temperature changes simulated by all GCMs for all seasons and parts over Europe. As precipitation changes considerably vary across Europe and between seasons, no single simulation provides consistent dry or wet conditions throughout the year and in all parts of Europe. Two GCMs each have been selected for northern and southern European conditions separately to represent dry and wet conditions, although also this selection does not cover the full range of precipitation changes in all seasons.

Simulated climate changes have been calculated relative to the Baseline period 1980-1999 for all variables and all regions. For relative changes, the ensemble averages have been first calculated for the absolute values of the Baseline and scenario periods, before calculating the relative change. Changes have been averaged for the SRES A1B 15-GCM ensemble mean scenario. Simulations for the SRES B2 ensemble mean scenario have not been conducted with the GCMs analysed in this work or were not available from the CMIP3 archive. In order to provide climate projections for the B2 scenarios, we applied a simple version of the pattern-scaling method (Ruosteenoja *et al.*, 2003). Pattern-scaling factors were obtained from the simple climate model MAGICC that emulates GCM-responses to different forcing scenarios and provides estimates of global mean temperature. The spatial pattern of changes for climate variables from one GCM simulation is then linearly scaled to different forcing scenarios. For the other five scenarios above, simulated monthly climate changes between Baseline and future periods from GCM output are added to the observed time series (i.e. weather data from the SEAMLESS data base). These monthly climate changes were interpolated to daily changes using cubic splines. This gives a smooth curve of daily values that avoids "steps" from one month to the next.

2.2.3 Results on changes in crop productivity

The calibrated model ACE-FAST has been used to simulate five annual crops, i.e. winter wheat, winter barley, potato, sugar beet and grain maize for Europe (EU-25) for the Baseline period from 1983 to 2006. Future crop yields were simulated for the 24 years period centred around 2050 (2041-2064) for the 7 climate change scenarios described above. In order to analyze separately the effects of climate, increased atmospheric CO_2 and technology development, each scenario has been run in three steps. First, simulations considered the influence of climate change on yields only. The next step included also the effect of increased CO_2. Finally, in the third step, the influence of technology development was considered in addition to the effects of climate change and increased CO_2. Simulations of the third step were used as inputs into CAPRI.

Impact of climate change

Climate change without considering increasing atmospheric CO_2 and advances in technology, causes a yield decrease for all crops and scenarios compared to the Baseline yields (Fig. 2.2a,d,g,j,m). The largest yield declines due to climate change were simulated for the GISS A1B scenario, a predominantly dry scenario. However, differences between crops were observed. Projected climate change impacts on yields were strongly negative for maize, approximately -1.7 Mg ha^{-1} (Fig. 2.2m) and slightly negative for winter wheat, about -0.4 Mg ha-1 on average over EU25 (Fig. 2.2a). We also realized that the simulated negative responses to climate change were less for winter crops as compared to spring crops. This may be due to the longer vegetative period typical for winter crops, which allows winter crops to recover better from extreme events.

Combined impacts of climate change and increased CO_2

Taking into account elevated CO_2 when simulating climate change impacts, increases simulated yields for all crops and scenarios but with some variation. Yield increases are highest for the winter crops and compensate for the negative yield effect due to climate change (Fig. 2.2b,e). For these crops projected future yields are higher for all scenarios than their Baseline yields. Also for the root crops, sugar beet and potatoes, the simulated yields are higher than the Baseline yields in most scenarios; however, for the scenario with the largest climate change impact, GISS A1B, the positive CO_2 effect cannot compensate for the negative effect of climate change (Fig. 2.2h,k). For grain maize, as C4 plant, there is no significant increase in yields due to CO_2, since only an effect of increased CO_2 on transpiration rate was considered but not on radiation use efficiency (Fig. 2.2n).

Combined impacts of climate change, increased CO_2 and technology development

When both the effect of increased CO_2 and technology development are taken into consideration together with the effect of climate change, simulated yield increases are considerable (Fig. 2.2c,f,i,l), but with some noticeable differences among the crops. While for winter cereals and root crops the yields become higher for all future scenarios than those for the Baseline, the grain maize yields for the scenarios are lower than the Baseline yields (Fig. 2.2o). Apparently, the negative climate change effect on maize yield could not be compensated by the positive effects of increased CO_2 and technology development. For the other crops, the strongest yield increases are simulated for the A1B scenario (Fig. 2.2c,f,i,l), in which atmospheric CO_2 and temperatures reach the highest values. It is important to note that the consideration of technology development results in larger differences between the simulated yields among the scenarios.

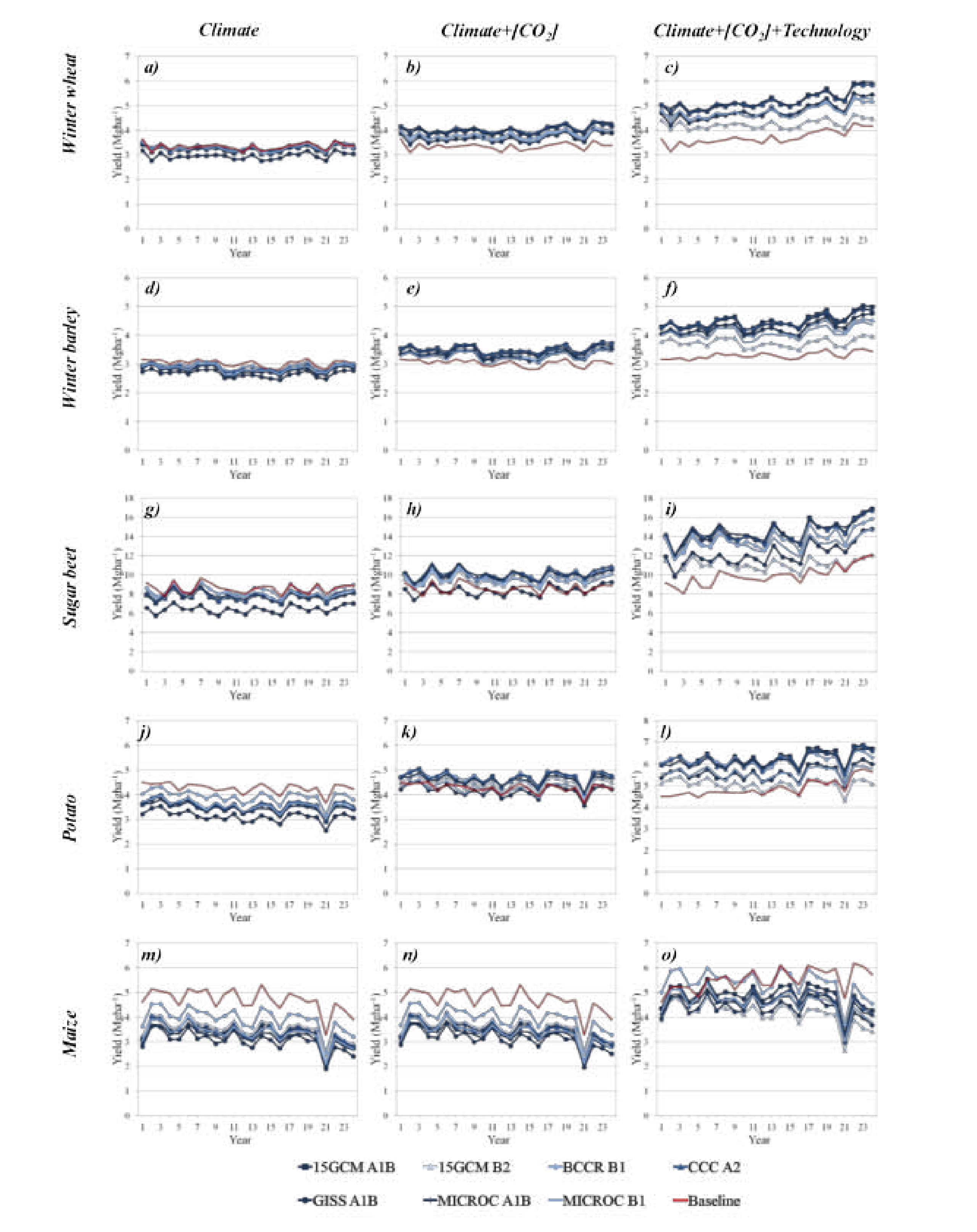

Figure 2.2.

Simulated effects of climate change (a,d,g,j,m), climate change and increased CO_2 (b,e,h,k,n), and climate change, increased CO_2 and technological development (c,f,i,l,o) on yields of five crops for 24 years in Europe (EU25), using different IPCC climate change scenarios (see text); Baseline and future scenarios are centred around 1990 and 2050, respectively; crops considered are winter wheat (a,b,c), winter barley (d,e,f), sugar beet (g,h,i), potato (j,k,l) and maize (m,n,o).

An analysis of the spatial variability of simulated yields under combined changes in climate, CO_2 and technology shows little differences among scenarios. This can been seen from the comparison of yield simulations for the A1B and B1 scenarios, although some differences in the yield changes in the individual regions can be noticed (Fig. 2.3). For the winter cereals yield increases of 30% and more compared to the Baseline are simulated for most regions. There are small areas on the Iberian and Italic peninsulas, where yield decreases are projected compared to the Baseline (upto -10%, Fig. 2.3b,d). These declines are mainly due to the pronounced negative climate change effect, which could not be compensated for by the positive CO_2 and technology effects. The latter is relatively small due to the comparably small yield increases for these regions observed in the past. For potatoes and sugar beet, yield increases are also simulated for most regions in Europe, except for some areas in south Europe (Italy and Spain), and few regions in Poland and Sweden, but the decreases do not surpass 10% in comparison to the Baseline. For grain maize the spatial variability in yield changes ranges between -30% and more to 30% and more (Fig. 2.3i,j). Yield increases are highest in South-western Europe and yield declines are mainly projected for Eastern Europe.

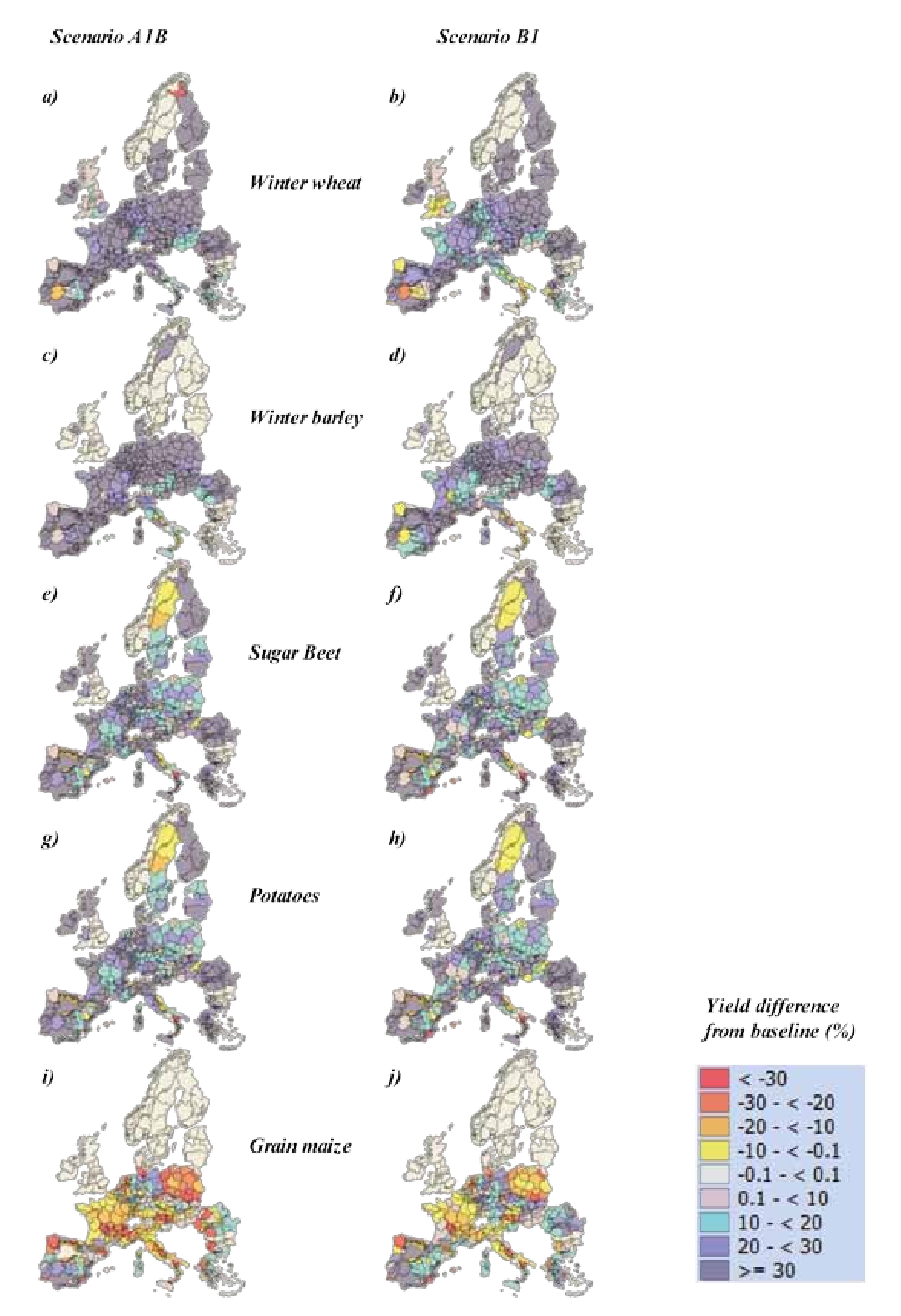

Figure 2.3.
Differences between simulated Baseline yields and yields (% of Baseline)) for the climate change scenarios A1B (a,c,e,g,i) and B1 (b,d,f,h,j) for 5 crops over 24 years in Europe (EU25); Baseline and future time series are centred around 1990 and 2050, respectively; crops considered are winter wheat (a,b), winter barley (c,d), sugar beet (e,f), potato (g,h) and maize (i,j).

2.2.4 Discussion

Simulated climate change impacts for EU25 show that climate change without considering increases in atmospheric CO_2 and advances in technology, resulted in negative effects on crop yields in the range of -15% to -30% depending on the crop and region. Negative climate change effects are less pronounced for winter cereals (barley and wheat) as compared to tuber crops (potatoes and sugar beet) or other spring crops (maize). These yield decreasing effects were compensated and partially superseded, when increase in atmospheric CO_2 and technology development were taken into account. Most substantial positive yield changes were projected to occur due to technology development. This is consistent with earlier results (Ewert *et al.*, 2005), but partly conflicting with analyses on winter wheat yields in Europe by Brisson *et al.* (2010). The latter suggest that increased temperatures and drought stress may level off positive effects by technology development, especially in regions with currently highest potential yields and inputs.

Our results show the importance of considering not only the effects of climate changes, but also of increased atmospheric CO_2 and technology development for future yield estimations. Particularly, consideration of technology development can have substantial impacts on the yield projections. This needs further investigation to reduce the uncertainty in the assumptions about technology development. It is important to note that considering technology development, not only increased the crop yields but also increased the differences between the scenarios. Projected yields were highest for the CCC A2 and 15GCM A1B scenarios and smallest for the 15GCM B2 scenario, following the different assumptions made regarding the technologies associated with these contrasting socio-economic and emission scenarios. In scenario family A (IPCC, 2001) it is assumed that agriculture undergoes the strongest intensification, associated with more advanced technology development (e.g. breeding for higher yields and more efficient resource use) than in scenario family B. And for the latter, in the B2 scenario, least progress in technology is assumed.

We have demonstrated the importance of crop model calibration for the assessment of climate change impacts on crops at the regional scale. We have found that considering regional differences in model parameters related to crop growth in addition to crop phenology, can considerably improve crop growth simulations at the continental scale (EU25). This indicates that projections with crop models can be improved, if their calibrations are done better.

2.3 Impacts of climate, technology and market change on product prices

2.3.1 Methodology and inputs

The CAPRI modelling system (Britz and Witzke, 2008; Heckelei and Britz, 2001) comprises two major modules for respectively supplies and markets. The supply module consists of independent aggregate non-linear programming models, representing activities of all farmers at regional or farm type level captured by the Economic Accounts for Agriculture. These programming models are a kind of hybrid approach, as they combine a Leontief-technology for variable costs covering a low and high yield variant for the different production activities with a non-linear cost function, which captures the effects of labour and capital on farmers' decisions.

The market module consists of two sub-modules. The sub-module for marketable agricultural outputs is a spatial, non-stochastic global multi-commodity model for about 40 primary and processed agricultural products, covering about 40 countries or country blocks in 27 trading blocks. Bi-lateral trade flows and attached prices are modelled based on the Armington assumptions. The behavioural functions for supply, feed, processing and human consumption apply flexible functional forms, where calibration algorithms ensure full compliance with micro-economic theory including curvature. This sub-module delivers prices used in the supply module and allows for market analysis at global, EU and national scale, including a welfare analysis. A second sub-module deals with prices for young animals.

As the supply models are solved independently at fixed prices, the link between the supply and market modules is based on an iterative procedure. After each iteration, during which the supply module works with fixed prices, the constant terms of the behavioural functions for supply and feed demand are calibrated to the results of the regional aggregate programming models aggregated to Member State level. Solving the market modules then delivers new prices.

The databases exploit wherever possible, well-documented, official and harmonised data sources and in particular, data from EUROSTAT, FAOSTAT, OECD and extractions from the Farm Accounting Data Network (FADN). Specific modules ensure that the data used in CAPRI are mutually compatible and complete in time and space. They cover about 50 agricultural primary and processed products for the EU (Britz and Witzke, 2008), from farm type to global scale including input and output coefficients.

2.3.2 Changes in global (macro) economic drivers and crop yields for CAPRI in 2050

The method used for scenario development is summarized in Fig. 2.1 and is described in more detail in the following. There are three types of scenario parameters applied to one CAPRI scenario in this study. The first type of parameters defines the regional crop yields derived from the ACE-FAST simulation. Thereby we could not simply take over the absolute numbers from ACE-FAST, because of differences in yield definition (dry weight versus harvested weight) and some database differences. Crop yields for a certain scenario (like B2) were defined by using the CAPRI Baseline yields and multiplying them with the relation of ACE-FAST yields for the B2 scenario compared to those for the B1.1 scenario (considered as the Baseline). We had to make certain assumption to extrapolate the ACE-FAST results for 5 crops to the complete CAPRI activity list (i.e. all arable crops) and to all the NUTS-2 regions as used in CAPRI.

The second type of parameters allude to the macroeconomic environment, namely population and GDP growth. They were taken from a previously done IMPACT simulation, made available by René Verburg (LEI). Again, these data were mapped to the CAPRI definition of world regions and defined relative to the B1.1 scenario. Since the data were available at country level, no extrapolation procedure was needed. However, preliminary simulation experiments revealed that the effects of changes in GDP dominate model results. Hence, simulations were also done for reduced changes in GDP (0%, 25% and 50% of GDP in IMPACT simulation).

Finally, also assumptions about the climate effects on yields in the rest of the world had to be incorporated. Unfortunately, there are not yet many studies assessing the effects of climate change on crop yields at a global level. We found a background note in the world development report by Müller *et al.* (2010; see http://siteresources.worldbank.org/INTWDR2010/Resources/5287678-1255547194560/WDR2010_BG_Note_Mueller.pdf), in which average climate effects on crop yields for some of the IPCC scenarios (i.e. A1 and B1) have been given. We have used this limited information to derive climate change responses of agriculture for the rest of the world.

The Common Agricultural Policy in the EU in the Base year is implemented, as declared in the so-called 2003 CAP reform. Future simulations consider the changes made in the 2009 Health check (see http://ec.europa.eu/agriculture/healthcheck/index_en.htm). In the A1 scenarios a trade liberalization according to the 2009 Falconer proposal is implemented. A summary of the CAPRI scenario settings is given in Table 2.1.

Table 2.1.
Description of the scenarios for the CAPRI simulations.

<table>
<tr><th></th><th>Base year [2004]</th><th>B1 (Baseline) [2050]</th><th>B2 [2050]</th><th>A1_b1 [2050]</th><th>A1_b2 [2050]</th><th>A1_b3 [2050]</th></tr>
<tr><td rowspan="4">Exogenous assumptions</td><td rowspan="4">Observed data (average 2003 - 2005) taken from EuroStat, FAO, OECD etc.</td><td colspan="5">Inflation rate of 1.9% per year</td></tr>
<tr><td colspan="5">constant exchange rates</td></tr>
<tr><td>Projection of GDP</td><td rowspan="2">Derived from IMPACT scenarios (decreasing demand for agricultural</td><td colspan="3" rowspan="2">Derived from IMPACT scenarios (leading to increasing demand for agricultural products compared to B2)</td></tr>
<tr><td>Projection of population (growth)</td></tr>
<tr><td>Commodity Prices</td><td>Observed prices (average 2003 - 2005)</td><td>Extrapolated from market outlooks (European Commisssion and IFPRI)</td><td colspan="4">Simulation results</td></tr>
<tr><td>Input Prices</td><td>Observed prices (average 2003 - 2005)</td><td colspan="5">Extrapolated from market outlooks (constant in all simulations)</td></tr>
<tr><td>Yield</td><td>Observed yields (average 2003 - 2005)</td><td>Trend projection combined with ACE-FAST simulation (BCCR_BCM2_0/SRES B1 - less warming consistent across all European regions and seasons)</td><td>ACE-FAST simulation (Pattern-scaled SRES B2 15-model ensemble mean)</td><td>ACE-FAST simulation ·(SRES A1B 15-model ensemble mean)</td><td>ACE-FAST simulation (MIROC3.2(hires)/SRES A1B - more warming consistent across all European regions and seasons)</td><td>ACE-FAST simulation (GISS_MODEL_E_H/SRES A1B - dry in MED and NEU)</td></tr>
<tr><td>Set-aside and quota policies</td><td>With obligatory set-aside and quota (milk and sugar)</td><td colspan="5">Abolishing obligatory set-aside, expiry of milk quota, continuation of sugar quota</td></tr>
<tr><td>Premium scheme</td><td>2003 CAP reform (decoupled + partially coupled payment)</td><td colspan="5">2009 Health Check (decoupled payment, increased modulation)</td></tr>
<tr><td>WTO trade policy</td><td>Tariffs and TRQ as in 2004</td><td colspan="2">Tariffs and TRQ as in 2004</td><td colspan="3">Reduction of tariffs and expansion of TRQ (sensitive products) as proposed by Falconer (2010)</td></tr>
</table>

The simulated scenarios comprise changes on the supply site (i.e. the crop production changes) as well on the demand site (population and GDP). World-wide trade liberalization according to probable WTO rules (tiered tariff reduction, expansion of tariff rate quotas, and abolition of export subsidies) is assumed in some scenarios. The yield changes have been derived for the following scenarios:

- A1b_1 (SRES A1B 15-model ensemble mean)
- A1b_2 (MIROC3.2(hires)/SRES A1B - more warming consistent across all European regions and seasons)
- A1b_3 (GISS_MODEL_E_H/SRES A1B - dry in MED and NEU)
- B1 (BCCR_BCM2_0/SRES B1 - less warming consistent across all European regions and seasons)
- B2 (Pattern-scaled SRES B2 15-model ensemble mean)

In order to analyze the effects of changing yields independent from the demand changes, we have carried out the CAPRI simulations by combining the changes in yields with:

- Constant GDP and population,
- GDP and population changes as predicted by GTAP (being different for A1 and B2 scenarios),
- 25% of the GDP and population change from GTAP,
- 50% of the GDP and population change from GTAP.

The A1 scenario assumes tiered tariff reduction, expansion of tariff rate quotas and abolition of export subsidies according to the currently discussed WTO modalities of the Doha Development Round (WTO, 2008). In order to separate impacts, all A1 scenarios are simulated with and without trade liberalization. The B1 scenario comes closest to the CAPRI Baseline projection for 2050. Hence, this scenario is used for comparison and thus as Base line.

2.3.3 Results on product prices

Among many other variables, the CAPRI model output comprises market prices. National prices (so-called producer prices) are derived from the market price. Producer prices for the main agricultural commodities as simulated with CAPRI, have been supplied (not shown here) for the different scenarios for first, the European level and next, the Netherlands.

Fig. 2.4 and 2.5 show the development of the European wheat price under various scenario settings. Compared to the Baseline scenario B1, the prices can increase by up to 200%, whereas the prices can also drop by at most -10% (Fig. 2.4). Yield impacts (ignoring demand changes) cause price effects between -12% and +75%. The macro-economic assumptions in all A1 scenarios strongly influence the price effects. In each A1 scenario the price difference between no and full GDP change is about 100%, which shows that macro-economic assumptions cause more variation in the results than yield effects. It should be noted that the consumption pattern is assumed to remain unchanged. Different assumptions regarding the consumption of meat might also have significant effects on the results (not tested so far).

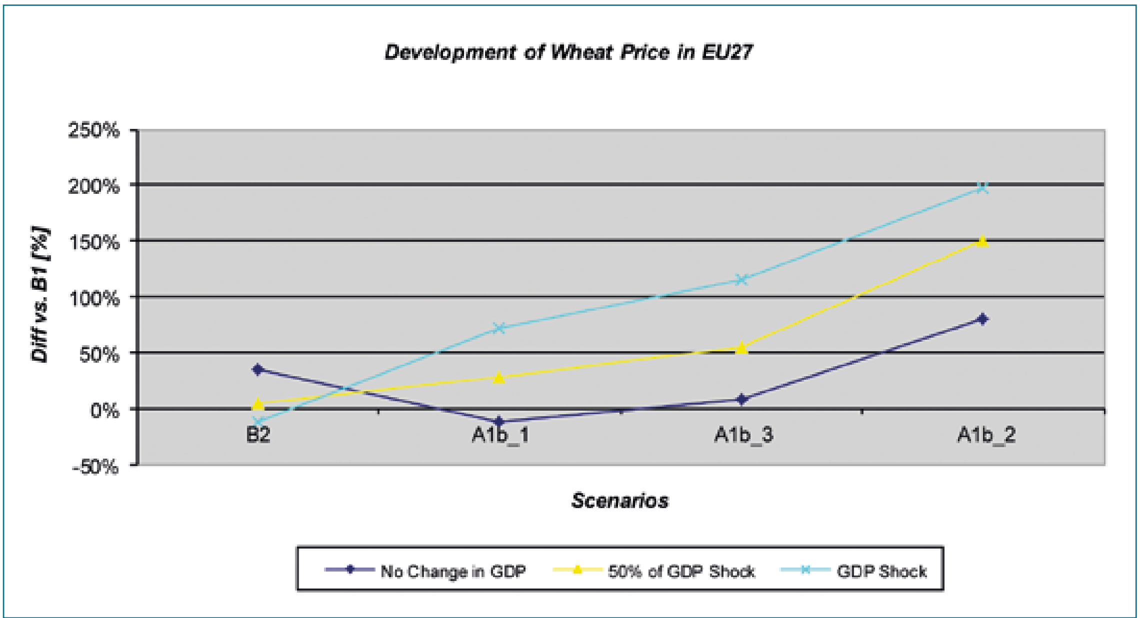

Figure 2.4.
Relative change in wheat price (in % of wheat price for B1 scenario) for different demand changes and scenarios.

Compared to the effects of yield and demand changes, the influence of trade liberalization is simulated to be small, differing at most 10% from the comparable scenario without liberalization (see Fig. 2.5). In general, trade liberalization leads to increasing wheat prices. When agricultural prices go up, exports from the EU will increase and hence, EU farmers will profit from trade liberalization. It has to be noted that the trade liberalisation effects on prices for agricultural goods are not the same across commodities. Those products that experience currently a higher degree of border protection than wheat (for example, meat), will then show price decreases.

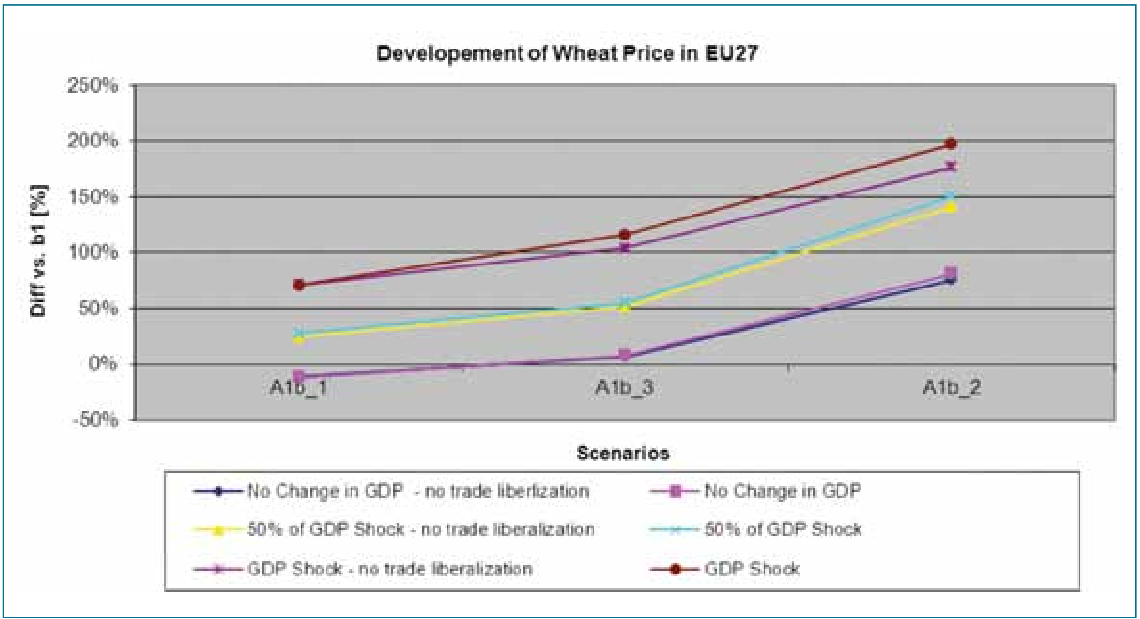

Figure 2.5.
Relative change in wheat price (in % of wheat price for B1 scenario) for different demand changes and scenarios; demand changes are without trade liberalization (left) and with trade liberalization (right).

2.3.4 Discussion

Results show that yield changes due to climate change as well as projections of the macro-economic environment can lead to fundamental changes in agricultural prices. Compared to other simulations (CAP reform, WTO scenarios, milk quota abolition) carried out so far with the CAPRI model, the observed price changes are relatively strong. However, the changes implemented in the model are tremendous as well. Yields (and subsequently supply) of arable field crops are up to 25% lower in the A1b1_2 scenarios, compared to the B1 (Baseline) scenario. Since demand elasticities for agricultural commodities are generally low, the price effects can be significantly stronger. Further, wheat prices were rather volatile during recent years, with the maximum price being more than twice the minimum price. All in all, the modelled changes appear to be drastic, but these can be seen as plausible, given the scenario assumptions.

Some results are discussed here in more detail. For example, the B2 scenario simulates lower yields, combined with a decreasing demand due to a lower population and GDP compared to the B1 scenario. These yield and GDP changes potentially cancel out each other. If the demand would be constant for the B2 scenario with no change in GDP, the prices of arable products would increase by 20% to 45% (not shown). Due to the increasing prices for feed stocks, animal products would become more expensive too (between +14% and +32%). When also the decreasing demand projected for this scenario is taken into account (i.e. GDP change), the prices are generally lower compared to those for the B1 scenario. This indicates that the change on the demand site in the B2 scenario is stronger than the impact of the yield reduction. Prices of arable products are nil to slightly lower (between -12% and + 3%), whereas animal products become significantly cheaper (between -5% and -41%).

The results from the analyses with CAPRI of the commodity price changes due to GDP and yield changes can be summarized as follows:

(1) Price impacts on arable products that result from a changed yield potential due to climate change, are considerable,
(2) Price impacts on arable products that result from the macro-economic assumptions (GDP/population), are very strong and even stronger than those under point 1 (i.e. yield change),
(3) Price impacts on animal products are even more significant than those on arable products, given that feed prices rise as well,
(4) Price impacts of the political environment, as for example the WTO-liberalization, appear to be quite modest.

Of course, these results are subject to a number of model assumptions and simplifications. CAPRI is very detailed at the EU level, but the price reaction is very much dependent on how the rest of the world responds to the applied changes. For example, the supply response of Brazil may be underestimated and consequently, the price effects may be overestimated. Currently, the representation of the rest of the world in CAPRI is changed in an ongoing project, by introducing land use and a land market. See also Table 2.1 for more detailed information about the scenarios used in the CAPRI simulations.

3. Impacts of climate change in the context of other changes on arable farming in Flevoland

3.1 Introduction and Scoping

The study for Flevoland is set up along the steps of integrated sustainability assessment (ISA). ISA is a cyclical, participatory process of scoping, envisioning, experimenting and learning, through which a shared interpretation of sustainability for a specific context is developed and applied in an integrated manner, in order to explore solutions to persistent problems of unsustainable development (Weaver and Rotmans, 2006; Bohunovsky *et al.*, 2010).

Scoping includes a thorough definition of the problem and aims at developing a context-specific interpretation of sustainability. The main problem to be assessed in this study is the impact of climate change on agriculture in Flevoland. The main aim of this research is to explore adaptation strategies that contribute to a viable, sustainable agricultural sector. A sustainable development of the agricultural sector does, however, not only depend on the impacts of climate change, but also on changes in technology, policy and markets. Drivers act at multiple scale with climate change impacting the farm level mainly through the crop level (assuming that sea-level rise can be controlled at higher hierarchical levels), while other drivers (such as markets and policies) act at regional to global level.

This study thus considers multiple drivers, multiple scales and multiple dimensions of sustainable development (economic, environmental, social). The main level of analysis is the farm level, but specific parts of the study have been done at lower and higher levels for an integrated assessment. For more detailed information about this study on arable farming in Flevoland, see first, the project report no. 1 about the applied methodologies and its abstract as given in Section 7.1 and second, see the results from the Integrated assessment of the impacts of climate and other changes on arable farming in Flevoland in 2050 and the possible ways for adaptation to climate change in project reports 4 & 5 and their abstract as given in Section 7.3.

3.2 Envisioning: scenarios and visions

In this study for Flevoland we have opted for two types of analysis of impacts of and adaptations to climate change in 2050:

1. Projecting climate change of 2050 on present arable farming systems in Flevoland, with their present layout, agro-management and productivity, markets and policies – 2050 climate change only analysis ('*2050-CC-only*').
2. Projecting climate change of 2050 on images of future arable farms in Flevoland, with alternative future scenarios (2050) of agro-management and productivity, markets and policy environment; this includes improved crop cultivars and management (i.e. improved Technology à T) and changes in Prices (i.e. P) – 2050 integrated analysis ('*2050-CC-P-T*').

Both were assessed against the Base year. In the 2050 integrated scenario we aimed at assessing climate change in the context of technological, socio-economic (markets) and political changes towards 2050. This is relevant as climate change is only one of the drivers of agricultural systems in 2050; these other factors influence, for instance, the changes in crop yields, prices and farm structure.

3.2.1 Base year analysis

A typology of farms was specified for Flevoland, based on the farm typology developed in the SEAMLESS project, using the dimensions size, intensity, specialization and orientation of farms. For the Base year, potential crop yields (as dependent on climate and CO_2 concentration) are calculated for a time period around year 2000, actual yields (from statistics bureau CBS, see http://statline.cbs.nl/statweb/?LA=en) are for about year 2005, and most input data and costs for arable cropping are from KWIN (2009) and are averages for 2003-2007, all prices include VAT, and total variable costs include costs for contract work, taxes, energy, N, P and K fertilizers, and crop protection.

3.2.2 2050 climate change only analysis

In the 2050-CC-only scenario, climate change has been assessed in the context of two SRES scenarios, i.e. A1FI and B2. They are contrasting with respect to the rate of economic growth, global warming, and the degree of globalization, and for that reason, both scenarios have often been used in related studies (Ewert *et al.*, 2005; Riedijk *et al.*, 2007; Van den Hurk *et al.*, 2006). For the climate change in Flevoland, we used weather data sets for present and 2050 conditions from KNMI for Lelystad, the Netherlands; A1FI was associated with the W and W+ scenarios (+2°C) and B2 with the G and G+ (+1°C) scenarios of KNMI (Van den Hurk *et al.*, 2006; see for more information http://www.knmi.nl/climatescenarios/knmi06/index.php). Future CO_2 concentrations are combined with these KNMI climate scenarios for 2050 and are derived from the SRES emission scenarios in the IPCC assessment report from 2001 (Scientific basis, Appendix II, Table II.2.1 with CO_2 abundances; see the link: http://www.grida.no/publications/other/ipcc_tar/). We have used the CO_2 concentrations from the ISAM model (Jain *et al.*, 1994) for 2050 for first, the high emission scenario A1FI (or called *A1* in the rest of this report) and second, the low emission scenario B2, being respectively 567 and 478 μmol CO_2/

mol, and for the base year, we have used 369 µmol CO_2/mol. We have mainly applied two climate change scenarios, A1-W and B2-G, of which the scenario characteristics are indicated by, for example, 2050-A1-W-only (i.e. climate change only), 2050-A1-W-P-T (i.e. integrated analysis with price and technology effects included too), 2050-B2-G-only, etc.

3.2.3 2050 integrated analysis

For the 2050 integrated analysis we have used a combination of the socio-economic and emission scenarios A1FI and B2 and related climate change scenarios (see above). We have made this operational through three analyses for these two scenarios:

1. An assessment of the relative influence of climate change on markets of agricultural commodities in 2050 (global, EU and national level analysis),
2. Making explicit estimations of technological change towards 2050, i.e. progress in genetic potentials of crops and yield gap closure.
3. Drafting images of future farms in Flevoland for the year 2050 using the typology that was also used for the Base year.

In this way we were able to put climate change in the context of market (and policy) changes, changes in farm structure and technological progress. Here we briefly present the methods and results for each of these three analyses.

Relative influence of climate change on markets in the EU

The effects of climate change on markets and prices of agricultural products have been calculated with the CAPRI model (Britz and Witzke, 2008). A summary of the CAPRI settings is given in Table 2.1 for the scenarios, for which the market and price changes towards 2050 have been established. Note that these price changes have been determined for more scenarios than subsequently used in the farm analyses (i.e. A1_b1 or A1 and B2). More information about this work can be found in Section 2.3.

Assessing technological change for 2050

We have assessed the future possibilities for respectively, the genetic increase in yield potential and the decrease in yield gap due to improved crop management. These two elements determine technological progress by 2050.

The increase in the genetic potential yield level in 2050 is a result of physiological, phenological and morphological characteristics of crops. Yield potential (YP) can be expressed in its simplest form as a function of light intercepted (LI), radiation use efficiency (RUE), and the partitioning of biomass to yield, or harvest index (HI): YP= LI * RUE * HI. LI and HI have been optimized for, in particular, grain crops during the last decades, and future genetic progress in yield of grain (and other main) crops will most likely be achieved by focusing on constraints to RUE, being indirectly influenced by sink strength (Reynolds *et al.*, 2005). Elaborate reviews of the possibilities to raise the yield potential in the coming decades by increasing RUE are given by Reynolds *et al.* (2009) and Long *et al.* (2006).

Based on these reviews, the increases in yield potential during the coming decades by genetic improvement can be derived and are estimated at 1% per year. This estimate corresponds well with the estimate as based on the historical yield trends to the future (Chapter 2; Ewert *et al.*, 2005; Reilly and Fuglie, 1998). Assuming that the genetic improvement will result in a gradually decreasing relative growth rate, which will become about nil in year 2050, we estimate the total increase in yield potential from genetic improvement for the A1-W scenario (with rapid economic growth, global free trade and strong increase in wealth and thus food demand) for year 2050 at 30% of the current yield potential in Flevoland. For the B2-G scenario (because of its more limited economic growth, more trade blocks and environmental taxes, and more limited increase in wealth and thus food demand) we estimate the total increase in yield potential from genetic improvement for 2050 at 10% of the yield potential in Flevoland (assuming less pressure to use improved crop varieties and less investment in research to increase the yield potential due to less increase in food demand, less increase in other drivers such as less globalization, and more environmental restrictions).

In Flevoland the yield gap between the potential yields and the actual yields in 2006-2008 is for the main crops small (maximally 25%), indicating optimal crop management at present. We assume that this yield gap of 10 to 25% for main crops can hardly be reduced further, being related to yield losses in the few years with extreme conditions (e.g. strong rainfall during harvest) and by disease infestations in wet years. Hence, for the A1-W scenarios for 2050 the yield gap is set to 1 minus actual yield/potential yield, but maximally 0.2. For the B2-G scenario we assume that half of the difference between the actual yield gap and a gap of 0.2 can be filled towards 2050.

Images of future farms in Flevoland

Images of future arable farms in Flevoland have been developed using a semi-quantitative method, complemented with iterative feedback from stakeholders during two workshops. These visions have been developed within two contrasting scenarios of development. For this purpose, the two global SRES scenarios were downscaled to the regional level. The A1 scenario reflects a globalized economy, whereas the B2 scenario reflects regional communities (IPCC 2001, Riedijk *et al.*, 2007). The downscaling used trends in socio-economic developments, as applied in detailed scenarios that were developed quite recently for the future of rural Europe (Westhoek *et al.* 2006). We used the outcomes of the work of Riedijk *et al.* (2007) to assess future land use in Flevoland under future socio-economic and climate scenarios. For climate change towards 2050 we used the A1-W and B2-G scenarios, as described above.

Within these scenarios, images of future farms have been developed using a combination of a quantitative analysis and stakeholder input and feedback (Chapter 4). This delivered possible future farms and their distribution for the two alternative scenarios for 2050. The farm typology of current farms (based on size, intensity, specialization and orientations of farms) was used as a basis. Based on a historical trend analysis and the expected changes in climate, technological development, markets and policies, possible changes in farm structure were projected. These changes in farm types and their distribution in the region were discussed with stakeholders. Note that the visions of future farms are of an explorative nature – they cannot be considered as predictions. They give a context for future farm level analysis and an indication of the context, in which adaptation will take place, also including technological development influencing crop production.

In A1-W scenario the average farm size may increase from 95 to 118 NGE (Nederlandse Grootte Eenheid; Dutch Size Unit) due to increase in crop productivity and shift to more profitable crops. Since area is a limited factor in Flevoland, and there have been increases in farm size in NGE, we observe further intensification. In specialization we assess a shift towards crops with high standard gross margin (flower bulbs and vegetables) and energy crops. In terms of orientation there is projected to be a larger share of entrepreneurial farms (around 30% of total farm population). Increase in share of entrepreneurial, or multifunctional, farming happens, since farmers seek alternative sources of income (e.g. recreation, processing and selling own products) due to changes in the agricultural policy paradigm (abolishment of payments and little alternative subsidies).

In the B2-G scenario we assess a larger diversity in farming the landscape. We estimate that average farm size (economic and area) only slightly increases and remains close to the current level. No major changes are expected in the specialization of the farms either. Regarding orientation, a large share of nature conservation farms will be notable for the B2-G scenario (around 30% of the farms will do nature and landscape conservation). This will occur when subsidies exceed gross margin of arable crops and the 'conservation' activity becomes more profitable, as the level of payment for social and environmental services will be increased in the B2-G scenario.

The most important farm type in the A1-W scenario will be production oriented-very large-medium intensive-diverse mainly root crops. In the B2-G scenario it will become entrepreneur oriented-large-medium intensive-diverse mainly root crops and specialized root crops.

3.3 Experimenting at multiple scales and for two types of analysis

In the next phase, the experimenting phase of the project, the scenarios and images of future farms have been explored in terms of climate change assessment. We used different methods for different questions, to assess the impacts of different drivers, and the most effective adaptation strategies. Different methods complement each other, and together they can provide a detailed picture of the various pathways to a climate robust, sustainable arable farming in Flevoland in 2050.

This experimenting has been done at two levels, crop level and farm level, and, as indicated, for two types of analyses (2050 climate change only; 2050 integrated analysis). For the 2050 climate change only, the climate change scenarios for 2050 are projected on the current farming systems, their impacts are assessed and options for adaptation are explored. This is a traditional way of assessing climate change impacts and identifying adaptation measures. In the 2050 integrated analysis, climate change impacts and adaptation measures are assessed in the context of other drivers that affect farming, i.e. markets, policies, technological development and structural change The main research questions are:

– What are the climate change (time horizon 2050) impacts and adaptation strategies projected on the current (2010) arable farming systems in Flevoland? – 2050 climate change only
– What is the relative importance of climate change (time horizon 2050) impacts and the effect of adaptation strategies for future (2050) arable farming systems in Flevoland vis à vis other major driving factors for agricultural development (markets, policies, farm structure, technology)? – 2050 integrated analysis.

3.3.1 Approach for and results of assessment at Crop level

For calculating the yields of the main arable crops in Flevoland for different scenarios for 2050, we have considered the following factors affecting yield changes compared to the actual yields in the 2050 climate change only scenario: 1) increase in atmospheric CO_2, 2) change in climatic conditions; 3) changing effects of extreme conditions during crop cultivation. For the 2050 integrated analysis the following additional factors were considered: 4) genetic improvement of crop varieties, 5) decrease in yield gap due to improved crop management. In Fig. 3.1 the integration of this work is shown.

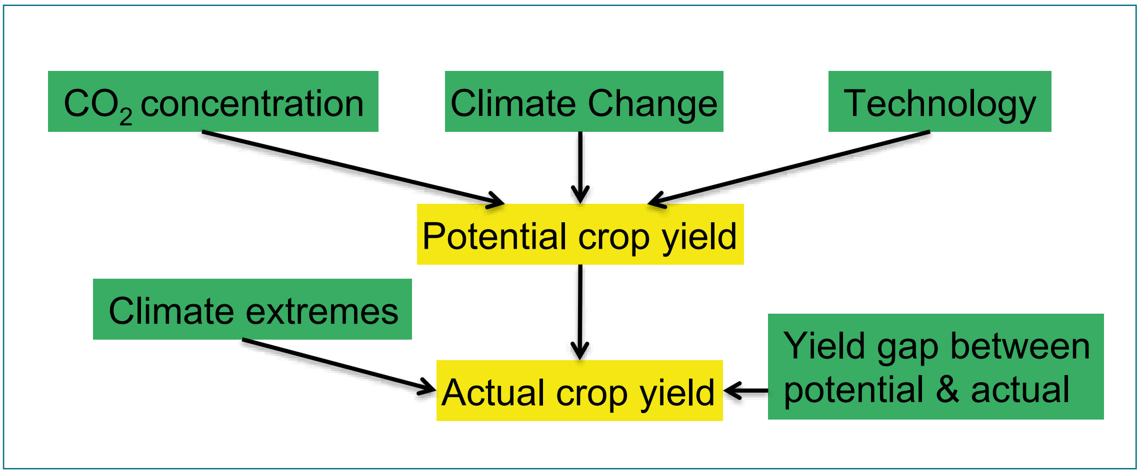

Figure 3.1.
Crop level assessment of the effects of CO_2 concentration, climate change, climate extremes and technology on crop yields.

CO_2 and Climate change

The following initial questions at crop level were addressed by doing crop growth simulations with the WOFOST model:

- What is the impact of climate change (incl. changes in atmospheric CO_2 concentration) on potential and water-limited crop yields?
- What is the difference in impacts among different crop types?
- What is the difference in impacts between different climate change scenarios?
- To what extent can generic adaptation strategies such as 'changing sowing date' and 'changing cultivar' (i.e. cultivars adapted to more southern climates) reduce the impacts or increase the benefits of climate change?

The effectiveness of management adaptation to climate change has been established by repeating the WOFOST simulations for the four KNMI scenarios and changing both the sowing date (i.e. 15 days earlier except for winter wheat and winter rapeseed) and the varieties (assuming more southern varieties with temperature requirements for phenological development that are 10% higher than those of the current varieties).

Summarizing, simulation runs for the thirteen main crop types in Flevoland have been done for:

a) the current climate conditions for Lelystad, the Netherlands (369 µmol CO_2/mol),
b) the four KNMI scenarios for Lelystad with the high emission scenario A1FI (567 µmol CO_2/mol),
c) the four KNMI scenarios for Lelystad and the moderate emission scenario B2 (478 µmol CO_2/mol), and
d) the four KNMI scenarios with the high emission scenario A1FI plus management adaptation to climate change.

The simulation runs have been done for both potential (i.e. irrigated, optimal nutrient supply and management) and water-limited conditions (i.e. rainfed, optimal nutrient supply and management).

Main conclusions are:

- Change in climate and increase in atmospheric CO_2 in year 2050 result in yield increases for all crop types in Flevoland and all climate change scenarios; for the G/G+ scenario the yield increase varied for most crops between +5% and +15%; for sugar beet, rapeseed and onion the increases were up to +20%; in the W/W+ scenario, the effects varied between +2% and +18% for most crops, but for sugarbeet, rapeseed and onion effects yield increases were up to +25-30%;

- The four different climate change scenarios for 2050 from KNMI result in simulated yields for the different crop types that in general differ from highest to lowest yield for the scenarios in the following order: G → G+ → W → W+; this yield order can be explained from: G scenario has the coolest summer and the W+ scenario has the warmest summer, and the other scenarios have in-between changes;
- Increases in yields in 2050 compared to the current yields are mainly caused by the positive effect of the increase in atmospheric CO_2, whereas this effect is partly counteracted by the negative effect of temperature rise. Hence, the yield increases for the A1-W/W+ scenarios with a higher CO_2 concentration appear to be only slightly higher than those for the B2-G/G+ scenarios (Table 3.3 for 2050 without genetic improvement);
- Management adaptation results in slightly to moderately higher (+5% to +10%) yields for the main crop types in Flevoland.

Extreme events

Crop simulation models capture mainly gradual climate changes (i.e. changes in average conditions) and their effects on product quantity; only some adaptation options can be simulated. In practice, climatic extremes may have more impact than a gradual climate change. At the same time, many adaptation strategies to such extremes are available and for farmers these may be more relevant. Therefore, we assessesed the impacts of climate extremes on crop production, the frequencies of these extremes for the current situation and changes towards the future, and based on the major climate risks, adaptation strategies are identified. Main questions include:

- What are possible weather induced limitations for operational farm management?
- What are the main climate factors influencing crop production and what is the expected damage?
- What is the current frequency of climate extremes and what are the projected changes in these frequencies?
- What are the major climatic risks and opportunities related to the change in frequency of climate extremes?
- What are relevant adaptation strategies for the major climate risks, and what are indicative annual and investment costs to implement these strategies?

Results from agro-climate calendar (ACC) analysis

The ACC assesses first the most important risks of extreme climate events and climate driven changes in pests and diseases on crop production and crop quality and next, the adaptation measures that prevent damage from the above risks (Schaap *et al.*, 2011). An important part of this method is the stakeholder interaction (see Chapter 4).

For Flevoland, we identified for the main crop types the crop and crop management specific vulnerable periods and climate factors. These climate factors are critical weather thresholds for crop damage that occur in specific periods in the year. The frequencies of occurrence of climate extremes (exceeding the threshold) have been derived first for the historic climate data records and next, for two climate change scenarios (van den Hurk *et al.* 2006) for Flevoland. Changes in frequency of extreme climate events for the climate change scenarios indicate the changes in growing conditions that may become critical for crop production and quality. As an example of the ACC analysis, results for seed potato are given below.

Current situation for Seed Potato - For the current production of seed potato, wet fields between October and March are problematic for plowing (Tables 3.1 and 3.2). This may lead to lower yields or increased costs if planting starts too late or under unfavorable conditions. A too dry soil between March and April can lead to planting delays. Moreover, the growth of the potato tubers can be reduced, if moisture conditions are sub-optimal for the newly planted potatoes. Heat waves occur more regularly. The frequencies of sustained wet weather are high compared to other climate factors.

Table 3.1.
Frequency of the occurrence of climate factors in Eelde as calculated by KNMI for the period 1976-2005 and indicative values for management costs and investments to cope with these climate factors for seed potato.

	Month												Manag costs (k€/ha) 1)	Investment (k€/ha) 2)
Climate factor	J	F	M	A	M	J	J	A	S	O	N	D		
Wet field	13	5	5	0						5	8	9	nd	nd
High int. rain fall					0	0	0	2	1				0,4 – 0,5	7 - 8
Heat wave							2	6	0				1 - 2	15 - 25
Warm and wet							0	1	0				0,1 - 0,2	1 - 2
Sustained wet					5	8	7	5					5 - 6	80 - 90
Wet field								5	4	5			nd	nd
Warm winter	0	0	3									0	0,4 - 0,5	7 - 8

1) Indication of the maximal annual management costs to cope with the climate factor in Euro x 1.000 per hectare (see Wit et al., 2009, annex 3 for further information).
2) Indication of the maximal one-time investment costs to cope with the climate factor in Euro x 1.000 per hectare (see Wit et al., 2009, annex 3 for further information).
nd: not determined because of insufficient information).

Situation 2040 for Seed Potato - It is expected that in 2040 there will be a notable increase in the frequency of warm winter months. Consequently, farms without adequate cold storage facilities will be negatively affected. As mentioned before, wet field conditions between August and October may become problematic when harvesting is done with heavy machinery.

Table 3.2.
Frequency change in the occurrence of climate factors in Eelde as calculated by KNMI for the period 2026-2055 for respectively the G+ (white column per month) en W+ (grey column per month) scenarios and indicative values for management costs and investments to cope with these climate factors for seed potato.

	Month																								Manag costs (k€/ha)[1]	Investment (k€/ha)[2]
Climate factor	J		F		M		A		M		J		J		A		S		O		N		D			
Wet Field	+1	+4	0	+1	0	0	0	0											0	-1	+1	0	+2	+3	nd	nd
High int. rainfall									0	0	0	0	0	0	0	-1	+1	+1							0,5 - 0,7	10 - 15
Heat wave													+2	+12	+7	+12	+1	+3							3 - 5	60 - 100
Warm and wet													+4	+6	+5	+6	+1	+2							1 - 2	20 - 35
Sustained wet									-2	-2	-2	-4	-2	-5	-4	-3									-	-
Wet field															-3	-3	0	-1	0	-1					nd	nd
Warm winter	0	+2	+1	+3	+3	+8																	+1	+1	1 - 3	20 - 60

1) Indication of the maximal annual management costs to cope with the climate factor in Euro x 1.000 per hectare (see Wit et al., 2009, annex 3 for further information).
2) Indication of the maximal one-time investment costs to cope with the climate factor in Euro x 1.000 per hectare (see Wit et al., 2009, annex 3 for further information).
nd: not determined because of insufficient information.

According to Table 3.2 the frequencies of high intensity rainfall will not increase dramatically, relative to the Base year frequencies presented in Table 3.1. However, it is expected that heat waves will occur more frequently: they range from an extra 1 to 7 events under the G+ scenario from June to August, and from 3 to 12 events under the warmer W+ scenario. Thus, increased occurrence of second-growth can be expected. The environmental conditions for the development of Pectobacterium carotovorum become more favorable in both the G+ and W+ scenarios. This may lead to increased yield losses. Interestingly, it may become easier to combat one of the current major hazards in potato production, late blight (Phytophthora infestans). Both under the G+ and W+ scenarios, the occurrence of sustained periods of humid weather will decrease. However, storage problems may occur because of higher winter temperatures, especially under the W+ scenario. High intensity rainfall (which can lead to rotting of tubers) may increase, but the frequency change is expected to be rather limited. Summarizing, changes in climate factors for seed potato under future scenario conditions appear to be partly positive and partly negative.

For the main crop types in Flevoland the ACC has supplied the risks of the impacts of unfavourable weather conditions on crop growth and yields for both current climate conditions and for different scenario climates for 2050. The resulting information about the frequency and the degree of yield losses due to extreme climate events has been used in the farm modeling with DEA and a bio-economic farm model. Next, the adaptation measures that are able to prevent or limit yield losses due to extreme climate event with their effectiveness and their costs, have been specified and some of these have been used too in this farm modeling (see model run Alter in Table 3.6).

Quantifying the effects of extreme events based on historical data

The previous assessment of extreme events was based on literature, expert knowledge and stakeholder discussions. The main result was an overview of major climatic risks and relevant adaptation strategies, but quantifications were not accurate. Therefore, more data have been collected to investigate the impacts of climatic risks in more detail and more quantitatively.

We have identified the weather extremes that were responsible for the largest negative yield anomalies in ware potato and sugar beet. For ware potato in the province of Flevoland during the last 50 years the two most important weather extremes are the following: 1. a wet start of the season that delays planting which in turn reduces the yield; 2. a wet end of the season that inhibits harvesting operations. Quantitative meteorological definitions of these extremes have been developed. Climate change scenarios indicated either no change or increased frequency of the extremes identified here. However, statements on changes in frequency are uncertain, due to lack of long (> 30 years) historical weather data and due to uncertainty in the climate change projections in terms of rainfall. In climate change scenarios, the uncertainty in rainfall projections appears to be much larger than the uncertainty in temperature projections.

In sugar beet, late sowing seems to be a major cause, though not the only cause, of low yields in specific years. A statistical negative relationship was found between total solar radiation in the 200 to 260 days prior to sowing and the actual sowing date, as well as between rainfall in the period between day 80 and 130 and the actual sowing date. These relationships are not yet completely understood and need further study, but may indicate that an earlier sowing date is possible after a relatively dry winter and spring. Our data suggest that if farmers do not change their rules for selecting their sowing date, a shift towards a 1 to 5 days earlier sowing date can be expected for 2050 compared to the Base year.

The method developed here of identifying relevant weather extremes through a form of reverse engineering, in which we start with yield anomalies, weather data and descriptions of management, and derive quantitative definitions of extremes, is widely applicable, provided that sufficient historical data are available. In our reconstruction of historical data we noted that since 1990, far less experimental data are available than before 1990 (with a notable exception for the data availability from the Dutch sugar beet institute IRS).

What is striking in our highly empirical analysis is that the main extremes are related to rainfall (and in case of sugar beet also probably indirectly to radiation) and not to temperature. In climate change scenarios there is a large uncertainty about the rainfall data. This raises the question whether at this stage, calls for adaptation to these extremes are necessary and possible. The outcomes of our research can help meteorological modellers to focus their research on those extremes that really matter for agriculture.

Yield gap closure and increases in the genetic yield potential

In practice, potential or water-limited yields are not achieved due to other limitations or reducing factors causing a yield gap. Furthermore, climate change is not the only factor that results in changes in crop yields. Therefore, we addressed the following questions for 2050:

- What is the combined impact of climate change, genetic improvement and management change (genetic improvement and management change jointly stand for technological change) on actual crop yields in the different scenarios?
- What is the relative impact of climate change on actual yields?

We estimated the increases in yield potential and the decreases in yield gap towards 2050 for the different scenarios, as described in Section 3.2.3. Based on this information, the actual yields for the main crops in Flevoland for the different scenarios for 2050 have been calculated. These yield calculations have been done for current conditions and for future conditions, both with and without changes in yield gap and in yield level due to genetic improvement (Table 3.3).

Table 3.3.
Actual yields (ton/ha air dry) for crop types in Flevoland as calculated for different scenarios for 2050[a] with and without changes in yield gap and yield potential towards 2050.

Scenario	Current		2050, no genetic impro-vement, actual yield gap				2050, genetic improvement, yield gap for 2050			
Crop	Actual yield	Yield poten-tial	G scen.	G+ scen.	W scen.	W+ scen	G scen.	G+ scen.	W scen.	W+ scen.
Winter wheat	9.19	12.32	10.16	9.76	10.63	9.76	11.58	11.12	14.82	13.60
Potato ware	54.14	70.97	58.71	56.46	64.99	60.01	66.15	63.62	88.60	81.81
Sugar beet	73.39	84.56	87.55	87.67	97.46	97.88	96.30	96.44	126.70	127.25
Onion	62.75	68.13	75.48	71.57	88.85	82.16	83.03	78.73	115.51	106.80

a The potential yield calculations are based on crop modeling with WOFOST for weather conditions and CO_2 concentrations around year 2000 (current) and 2050; the crop management is adapted to climate change for the W and W+ scenarios only.

For example, for the A1-W/W+ scenarios with a strong decrease in yield gap and a strong increase in yield potential, the yields in 2050 for all crop types become higher to much higher than the current yield potential due to mainly the strongly improved varieties and crop management (Table 3.3, columns to the right).

Table 3.4 shows for some crops the relative contributions from climate change, increase in yield potential and decrease in yield gap to the total changes in productivity towards the year 2050. The table shows that assumptions on the increase in genetic yield potential are most important. Second, the effects of climate change and increased atmospheric CO_2 are also rather important. Finally, the effects of both adaptation and closure of the yield gap are smallest. Overall, these results are similar to the EU level assessment as presented in Chapter 2. However, this assessment gives more pronounced differences between scenarios and between crops. Further, while the EU level assessment projected largest changes for winter wheat, this assessment for Flevoland indicates larger increases for sugar beet than for winter wheat.

Table 3.4.
Relative contributions of different factors to yield changes for the A1-W and B2-G scenarios towards 2050.

Crop	Actual yield in 2000-2009 (t fresh/ha)	Effect of climate change (%)	Effect of climate change + adaptation[1] (%)	Effect of increase in genetic potential (%)	Effect of yield gap closure (%)	Overall increase in actual yield 2050 vs. 2000-2009
A1-W scenario						
Winter wheat	9.19	+10.7	+15.7	+30.0	+7.2	+61.2
Potato ware	54.14	+10.9	+20.0	+30.0	+4.8	+63.7
Sugar beet	73.39	+30.8	+32.8	+30.0	0.0	+72.6
Onion	62.75	+26.0	+41.6	+30.0	0.0	+84.1
B2-G scenario						
Winter wheat	9.19	+10.5	-	+10.0	+3.6	+26.0
Potato ware	54.14	+8.4	-	+10.0	+2.4	+22.2
Sugar beet	73.39	+19.3	-	+10.0	0.0	+31.2
Onion	62.75	+20.3	-	+10.0	0.0	+32.3

1 No management adaptation has been applied for the B2-G scenario.

Main conclusions from this analysis are:

- The proposed method for the calculation of actual yields for the different scenarios in 2050 is straightforward;
- Climate change has a positive impact on actual yields. However, in the A1-W scenario the relative influence of technology development is larger for most crops; in the B2-G scenario, the relative influence of climate change is larger;
- Calculated actual yields for scenarios in 2050 are depending on several assumptions (e.g. increase in yield potential towards 2050) and uncertain data (e.g. weather data for 2050) and hence, have a range of uncertainty; however, there appears to be no solid alternative solution;
- A main factor that determines the actual yields in 2050, is the degree that the yield potential of different crop types may increase towards 2050 through genetic improvement; we derived a relationship between this increase in yield potential (+30% and +10%) and respectively, the A1-W and the B2-G scenarios, which relationship is rather uncertain.

3.3.2 Approach for integrated assessment at Farm and regional level

At farm level we have employed two methods:

1. Sensitivity analysis at farm level using fixed cropping patterns to assess the relative importance of different drivers of change towards 2050 at farm and regional level;
2. Data Envelopment Analysis (DEA) combined with bio-economic farm modelling to assess adaptation options for the climate change only and the integrated analyses for a range of farms.

The fixed cropping pattern method is a straightforward sensitivity analysis that estimates the relative influence of climate change, technological development, policy and market changes and farm structural change on farmer's income. It projects these changes on the current farm structure.

In the analysis using Data Envelopment Analysis (DEA) and bio-economic farm modelling, we assess adaptations at the whole farm level. Often bio-economic farm models like FSSIM are applied for average farm types, using average data on inputs and outputs for these farms. For most FSSIM applications, 'simple survey' data based on expert knowledge were used, which have been collected in the SEAMLESS project (Van Ittersum *et al.*, 2008) and were based on expert knowledge for a region, characterizing the inputs-output coefficients of the most common activities. DEA provides an approach that can capture data on inputs and outputs from actual and individual farms. By using these data, it can recover current technical relationships (the current production functions) and rank individual farms based on their capacity to convert inputs into outputs. Farms that are superior with respect of converting inputs into outputs form the production frontier, while other farms are enveloped by this frontier.

Based on the technical relationships and without any behavioural assumption (e.g. profit or utility maximization), DEA can furthermore indicate realistic farm level adaptation strategies to these farms. These are strategies to adapt to current conditions, including climate, markets and policy, to improve farm performance. When the input-output relationships of future agricultural activities are defined, realistic adaptation strategies for 2050 can also be identified for future farms. DEA can be coupled to a bio-economic farm model like FSSIM, in which behavioural assumptions can be made to identify optimal strategies of farmers. DEA is thus a substitute for the 'simple survey' data that are averaged per farm type, and besides, can answer additional questions. The main difference between using FSSIM with expert knowledge from 'simple survey' data and with DEA is that when using expert knowledge more specific agricultural activities and adaptation strategies can be included (rotations linked to management), whereas DEA depends on data available for actual farms. With DEA the most efficient rotations or production methods (in terms of input-output relationships) result from the analysis, and only these are included as input-output relationships in FSSIM.

Sensitivity analysis at farm and regional level

Economic results have been assessed for arable farming in Flevoland. The calculations have been done assuming fixed (but being different per scenario) cropping patterns and not applying any optimization of the cropping pattern. This indicates whether specific cropping patterns remain viable towards 2050. The fixed cropping patterns for the Base year and 2050 are based on the farm typology and farm structural change work (see Section 3.2.3 about Images of future farms). The calculations have been done first for the main arable farm types in Flevoland in the Base year. Second, the calculations have been repeated for the same farm types in Flevoland with the same cropping patterns, farm area, labour use per crop type, product prices, and costs but with yields calculated for the A1-W scenario for 2050 with management adaptation and for the B2-G scenario for 2050 (i.e., climate change only analysis, thus: 2050-A1-W-only and 2050-B2-G-only scenarios).

Third, the calculations have been repeated for the same farm types in Flevoland with the same farm area and labour use per crop type, but with cropping patterns, product Prices, costs and yields for respectively the A1-W and B2-G scenarios for 2050, called 2050-A1-W-P and 2050-B2-G-P. Fourth, the calculations have finally been done for the same farm types in Flevoland with the same farm area and labour use per crop type, but with cropping patterns, product prices, costs, and yields for respectively the A1-W and the B2-G scenarios for 2050, and also with further yield increases due to Technological (i.e. both crop genetic and management) improvements, called 2050-A1-W-P-T and 2050-B2-G-P-T scenarios. The analyses have been done for five main farm types in Flevoland.

The economic results for the different farm types in Flevoland and for the Base year 2005 and the different scenarios are summarized in Table 3.5. Farm types C and D with half of the farm area used for seed potato production, result in the Base year in much higher values for the gross margin per labour hour than those for farm types A and B. This difference between the farm types can be explained from the high economic values of seed potato in combination with the cropping pattern per farm type in the Base year. Flower bulb and vegetable production (farm types A and B) require a large amount of labour and are therefore only possible, if the prices of hired labour are relatively low.

Effects of climate change and increased atmospheric CO_2 on the gross margin per labour hour are clearly positive. The 2050-A1-W-only scenario with some management adaptation gives 30% to 50% higher yields and thus gross production compared to those in the Base year, which results in 50% to 90% higher total gross margin and gross margin per labour hour (Table 3.5). The 2050-B2-G-only scenario gives 15% to 35% higher yields and thus gross production compared to those in the Base year, which results in 25% to 60% higher total gross margin and thus gross margin per labour hour.

Table 3.5.
Summary of the Economic results (i.e. Gross margin per labour hour, in euros of 2005) for farm types in Flevoland and for arable farming in Flevoland as a whole for the Base year and for the different scenarios. Note that compared to the Base year the following changes are applied in the scenarios: a) *Scen. 2050-A1-W-only:* effect of climate change and increased CO_2 on yields, b) *Scen. 2050-A1-W-P:* idem point a plus changes in product prices, costs and cropping patterns for the scenario in 2050 (A1-W or B2-G), and c) *Scen. 2050-A1-W-P-T:* idem point b plus further yield increase from technology (i.e. both crop genetic and management) improvements.

Farm type Scenario	Production oriented., Very large High intensive, Specialized: flower bulb, type A	Production oriented, Medium size Medium intensive Specialized: vegetables, type B	Production oriented, Large size, Medium intensive, Diverse: mainly root crops, type C	Entrepreneur oriented, Large size, Medium intensive, Diverse: mainly root crops, type D	Entrepreneur oriented, Large size; High intensive Diverse: mainly rootcrops/ specialized: root crops, type E	Regional[1]
Gross margin in euro-2005 / labour hour [2]						
Base year 2005	28.2	28.2	61.5	61.4		56.2
Scen. 2050-A1-W-only	54.3	54.3	90.5	90.5		84.7
Scen. 2050-B2-G-only	45.4	45.4	76.3	76.3		71.4
Scen. 2050-A1-W-P	38.1		55.4	55.5	62.2	48.9
Scen. 2050-B2-G-P	18.3	18.3	38.7	38.7		34.2
Scen. 2050-A1-W-P-T	62.8		89.0	89.0	99.2	79.2
Scen. 2050-B2-G-P-T	24.7	24.7	48.8	48.8		43.5

1 Regional average for Flevoland; based on area fractions for the five farm types (see text).
2 Based on cost trend of +45% in total from 2005 to 2050; crop yields for A1-W scenarios assume management adaptation to climate change but those for B2-G scenarios do not (see Table 3.3).

If in addition to the effects of climate change and increased atmospheric CO_2, we also include the changes in product prices, costs and cropping patterns from 2005 towards 2050, the gross margins per labour hour, as expressed in euros of 2005 (Table 3.5), strongly decrease for both scenarios and all farm types (e.g. by minus one third for scenario 2050-A1-W-P compared to scenario 2050-A1-W-only). These strong decreases in gross margin can be explained from the stronger increases in costs over time than the increases in product prices. Finally, if we also assume that further yield increases are possible by way of crop genetic and management improvements, the changes in gross margin per labour hour for the 2050-A1-W-P-T scenario are nil to slightly positive compared to the scenario 2050-A1-W-only (Table 3.5). This shows that only for the 2050-A1-W-P-T scenario with the highest yields and best management in 2050, the gross margins per labour hour, when expressed in euros of 2005, are higher than those in the Base year for all farm types (Table 3.5). For the 2050-B2-G-P-T scenario, however, the gross margins per labour hour are still lower than those in the Base year for all farm types, which is mainly caused by its more limited yield increases. This indicates the need for improved crop cultivars and management to increase the gross margin per labour hour.

For arable farming in Flevoland as a whole, the changes in the economic results for the different scenarios have also been established. These mean values for the gross margin per labour hour in arable farming in Flevoland (Table 3.5) have been derived from the values for the five different farm types, using the area fractions for the different farm types as weighing factors. The differences in gross margin per labour hour between the Base year and the six scenarios for the average arable farm in Flevoland appear to be roughly similar to those for the individual farm types (Table 3.5).

The outcomes for the different scenarios (Table 3.5) show that the differences in gross margin per labour hour are mainly determined by first, the increase in product prices from 2005 to 2050 (and in particular, the degree that these price increases are lower than the cost trend) and second, the yield increase from 2005 to 2050. Fig. 3.2 shows that, for example, the gross margin per labour hour on farm type C in the Base year of 61.5 euro/hour (Table 3.5) can be attained in year 2050, when the yields increase to 140% compared to the Base year and the product prices increase to 120% (in euros of 2050). The 2050-A1-W-P scenario results on farm type C in a gross margin per labour hour of 55.4 euro-2005/hour (Table 3.5), which corresponds with an increase in yield to 130% and in price to 120% (see Fig. 3.2). The 2050-A1-W-P-T scenario results on farm type C in a gross margin per labour hour of 89.0 euro-2005/hour (Table 3.5), which corresponds with an increase in yield to 182% (due to further crop genetic and management improvements) and in price to 120% in Figure 3.2.

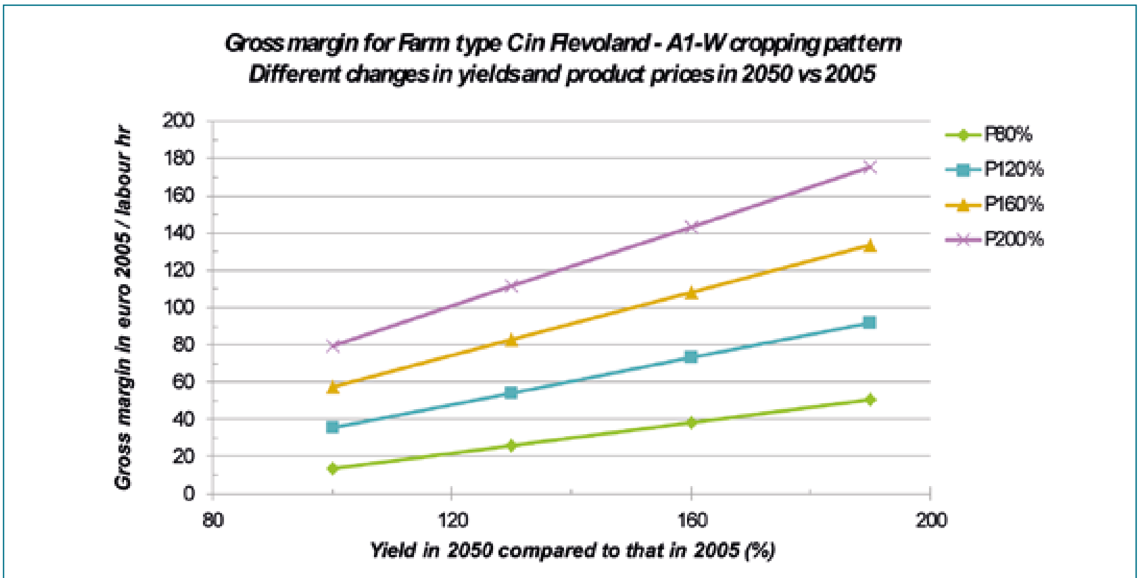

Figure 3.2.
Gross margin per labour hour (expressed in euro for 2005) on farm type C in Flevoland, the Netherlands for different values for respectively, the future product Prices (expressed in euros of 2050) and the relative yields in 2050 (as dependent on the assumed yield increases due to climate change, increased CO_2 and crop genetic and management improvements); cropping pattern of A1-W scenario is applied.

Exploring arable farming systems and adaptation strategies to climate change using Data Envelopment Analysis (DEA) and bio-economic farm modelling

The effects of the A1-W scenario have been evaluated for arable farms in Flevoland. Individual farm data (i.e. inputs, outputs and farm resources) of 85 individual representative farms from FADN were used. The Base year scenario was calculated by averaging FADN data of years 2000-2006. The DEA procedure was used to specify the technical relationships between important inputs and outputs. Inputs used in the DEA procedure were: capital (€), crop protection (€), fertilizer (€), energy use (€), labour (distinguishing between hired and family labour in hours), and other inputs (€). The outputs used were: potatoes, onions, sugar beet, wheat (tons), other arable output (€) total livestock output (€) and other outputs (€). Technical efficient farms (with best farm practices) were identified and formed the DEA frontier, which was assumed to be the current production function. A farm is characterized as having “best” farm practices, when at a certain input level there is no linear combination of the inputs and outputs of the other existing farms, that results in a lower input level without increasing the level of another input or decreasing the level of an output.

Expected yield and input (i.e. fertilizers) changes due to climate change scenario A1-W were calculated for year 2050 without (i.e. 2050-A1-W-only scenario) and with technological change (i.e. 2050-A1-W-T scenario), whereas the price change towards 2050 was applied in some model runs (i.e. *Price* and subsequent runs) for both scenarios. The calculated inputs and outputs of future activities were used to identify the new input-output relationships for the A1-W scenario using DEA.

Ten model runs have been performed for the two scenarios. In the first model run (*Profit*), it is assumed that farmers are gross margin maximizers. The available farm resources are allocated to the best current production possibilities and optimum farm plans are calculated. In the second model run (*Calibr*), FSSIM is calibrated to the observed input and output levels of the Base year. The difference between the gross margins of this model run with the gross margin of the previous one represents the costs that farmers are willing to take, for maintaining their own current production strategy that satisfies their multiple objectives. In the third model run (*B2050*), the expected yield change due to climate change, without accounting for the effect of extreme events, is evaluated using the calibrated FSSIM model. In the fourth model run (*Extreme*), the effect of the increased occurrence of extreme events (i.e. prolonged wet conditions during spring and dry conditions during spring and summer) are taken into account. In the fifth model run (*Alter*), alternative adaptation measures are offered. In the sixth model run (*Price*), the future price changes, simulated with CAPRI, are used. Finally, in model runs 7 to 10 (*Scaling*), it is allowed to increase labour, capital, other inputs, livestock outputs and other outputs. In model run 7, we allow for 20% more hired labour. In model run 8, on top of model run 7, we allow for 20% more capital. In model run 9, on top of model run 8 we allow for 20% more other inputs and in model run 10, on top of model run 9 we allow for 20% more livestock output and other outputs. It is important to notice that specifications of model run 4 to 10 are additive.

Results from all FSSIM model runs for arable farming in Flevoland as a whole are presented in Table 3.6. Detailed results for different farm types in Flevoland have also been produced (but not shown here). The simulated inputs and outputs in the *Calibr* model run represent the current situation, since the PMP based calibration procedure guarantees exact reproduction of historical input-output levels. Comparing the gross margins achieved in the Profit model run with the gross margin that is currently achieved (i.e. *Calibr* model run), it can be concluded that in all farm types, farmers sacrifice a substantial part of their profit for maintaining their current production activity. In the Profit model run, the production of main cash crops like potatoes, onions and other arable output (i.e. mainly tulips and vegetables) increase. This is achieved by increasing their areas but also by intensifying production (i.e. selecting systems with higher yields). The shift of production to cash crops and higher yields causes an increase in inputs, such as fuel (energy), fertilizers and crop protection (Table 3.6).

In the *B2050* model run for the 2050-A1-W-only (without technological change) scenario, the increased expected yields cause a substantial increase in gross margins (compared to the current situation in the *Calibr* model run) (Table 3.6). Compared to the current situation, inputs of fertilizers, energy and crop protection increase. In the *B2050* model run for the 2050-A1-W-T scenario, where technological change is assumed and improved varieties (in terms of yields) were offered to the model, similar but more dramatic changes are observed (Table 3.6). Areas of onions and potatoes decrease compared to those for the 2050-A1-W-only scenario. The consequence is that the inputs of fertilizer substantially increase. Another interesting result is that in the *B2050* model run for the 2050-A1-W-T scenario, the fraction of hired labour increases substantially compared to the fraction of hired labour in the *B2050* model run for the 2050-A1-W-only scenario (Table 3.6). This is related to the large increase in other arable output for the 2050-A1-W-T scenario and the seasonality of labour involved in growing crops like tulips and vegetables.

The effect of the increased occurrence of extreme events (i.e. wet conditions in spring and/or dry conditions in spring and summer) in the *Extr* model run is minor for both scenarios (Table 3.6). The average yields of main crops decrease, which causes a marginal decrease in gross margins. No major adaptation or changes in production orientation (e.g. crop rotation and inputs) occurred. In the *Alter* model run, a number of adaptation options are offered. For the 2050-A1-W-only scenario, the adoption of alternative activities is the highest in the large farms, and only for these farms the gross margin benefits marginally (compared to the *Extr* model run; not shown). The main reason for this is that activities which require investment decisions and involve additional maintenance costs, become profitable only at the larger scales of production. At smaller scales, the beneficial effects of alternative activities level out with additional costs related to maintenance of machinery, energy and labour. Alternative activities with no or low investments are mainly selected. For the 2050-A1-W-T scenario, the adoption of alternative activities is minor and lower than the adoption for the 2050-A1-W-only scenario.

Accounting for the expected price changes as those have been calculated by CAPRI for the *Price* model run, results in a substantial decrease in gross margin in the 2050-A1-W-only scenario (Table 3.6). Areas of potatoes, onions and sugar beet decrease. Production swifts further, from main arable products to other arable outputs (i.e. tulips and vegetables). Given the 2050 prices and without any technological change, it becomes less profitable to grow the current cash crops. For the 2050-A1-W-T scenario the effects of price change are smaller than for 2050-A1-W-only scenario because of the higher yields (due to technological improvement) of the main crops.

In model runs 7 to 10, the consequences of expanding in terms of hired labour, capital, other inputs, other outputs and livestock outputs, have been investigated. In all farms and both scenarios, capital availability appears to be the most important factor for increasing adoption of alternative activities (compared to the *Price* model run) (Table 3.6). Additional capital is invested in adapting or purchasing machinery that allows to increase the sowing density.

Results from the evaluated scenarios (i.e. A1-W scenarios assuming a globalized economy and strong climate change context) show that the most important driving factors towards 2050 are the yield increase due to climate change, the expected price change and the degree of technological innovation that focuses on crop productivity. The effects of climate change (i.e. increase in temperature and atmospheric CO_2 concentration) are projected to have a positive economic effect on arable farming. However, a substantial increase in inputs, such as biocides, fertilizers, and energy, is also expected. Increase in these inputs combined with a swift of production to other arable crops (mainly tulips and vegetables) can lead to additional environmental pressure per ha. Nevertheless, the environmental pressure per ton of product is projected to decrease.

Effective policy decisions that target at promoting production of currently grown crops, should promote research and development projects to make new highly productive varieties available. However, it appears that lack of new more-productive varieties as in the 2050-A1-W-only scenario, results in a higher adoption rate (compared to the 2050-A1-W-T scenario) of alternative activities (being highest at the large farms) with improved management practices (e.g. investing in precision agriculture systems or increasing top soil organic matter content). It appears that making new more-productive varieties available may compete with promoting the use of existing technologies that focus on improved resource use efficiencies. From the results of the analysis, it can be derived that improved accessibility to capital can increase the adoption rate of the tested adaptation strategies.

Table 3.6.
Simulated input-output levels, areas and yields of an average farm in Flevoland for two scenarios for 2050.

	Profit	Calibr	Scenario 2050-A1-W-only without technological change								Scenario 2050-A1-W-T with technological change							
							Scaling								Scaling			
			B2050	Extr	Alter	Price	Mod. run7	Mod. run8	Mod. run9	Mod. run10	B2050	Extr	Alter	Price	Mod. run7	Mod. run8	Mod. run9	Mod. run10
Capital (1000 €)	213	335	270	266	266	222	223	229	230	232	242	242	242	227	227	235	239	243
Crop protect. (1000 €)	21	15	17	16	16	14	14	14	15	15	15	15	15	16	16	16	17	17
Energy (1000 €)	19	13	18	18	18	18	19	19	21	21	21	21	21	22	23	23	23	24
Fertilizers (1000 €)	7	7	10	9	9	7	7	7	8	8	13	12	12	11	11	12	12	12
Family labour (hrs)	2512	2854	2382	2373	2361	2160	2175	2191	2154	2178	2010	1999	1999	1978	1985	2004	1942	1960
Hired labour (hrs)	1285	1776	1423	1416	1475	1489	1602	1672	1650	1653	1608	1611	1611	1605	1733	1778	1871	1875
Area (ha)	46	49	47	46	47	40	40	40	40	40	44	43	43	43	42	43	42	43
Other input (1000 €)	104	149	127	127	126	113	114	115	120	121	134	133	133	130	131	132	144	146
Gross margin (1000 €)	284	146	275	263	267	134	135	138	141	143	333	326	326	346	351	354	367	373
Livestock output (1000 €)	0	29	11	11	11	10	10	10	10	10	11	11	11	4	4	4	4	4
Other output (1000 €)	17	32	21	21	21	20	20	21	20	21	19	19	19	18	18	18	18	19
Onions (tons)	591	412	544	441	468	325	321	325	336	342	550	454	458	453	444	463	475	476
Potatoes (tons)	896	547	648	632	642	523	528	537	545	548	741	721	727	776	780	791	742	753
Sugar beet (tons)	457	467	814	803	811	636	635	653	638	630	849	836	838	888	884	904	850	858
Wheat (tons)	29	49	62	67	66	72	71	72	66	66	85	87	87	109	108	108	99	100
Oth. arable output (1000 €)	79	53	105	109	104	129	134	135	149	149	269	274	272	280	289	289	331	334
Areas																		
Onions (ha)	12	11	11	10	10	7	7	7	8	8	9	8	8	8	8	8	8	8
Potatoes (ha)	16	12	12	12	12	10	10	10	10	10	10	10	10	11	11	11	10	11
Sugar beet (ha)	9	7	9	9	9	7	7	7	7	7	7	7	7	7	7	7	7	7
Wheat (ha)	3	6	7	7	7	8	7	8	7	7	6	7	7	8	8	8	7	7
Other crops (ha)	6	13	9	9	9	8	8	8	8	9	11	11	11	8	8	8	9	9
Yields																		
Onions (tons/ha)	48	37	52	44	46	44	44	45	45	45	63	55	55	55	55	56	57	57
Potatoes (tons/ha)	57	44	55	54	55	51	51	52	52	52	72	70	71	71	71	71	71	71
Sugar beet (tons/ha)	49	70	91	92	92	94	93	94	93	94	119	119	119	122	122	122	122	123
Wheat (tons/ha)	9	8	9	9	9	9	10	10	9	10	13	13	13	14	14	14	14	14

4. Learning from knowledge exchange during stakeholder workshops

4.1 Introduction

The last phase in the project includes learning, evaluation and monitoring. During the experimenting phase, internal evaluation has taken place continuously, as different methods give answers to different questions, and interactions help to improve assessments. Outputs have been evaluated with stakeholders: do the modelling results reflect what will likely happen in reality? This may potentially provide the basis for a next integrated sustainability analysis (ISA) cycle, leading to a reframing of the shared problem perception (e.g., climate change may be more or less important than expected), and reformulation of the experiments and analyses to be conducted.

For more detailed information about the stakeholder workshops and the noted stakeholder perspectives of adaptation to climate change, see the project report no. 6 and its abstract in Section 7.4.

4.2 Stakeholder interactions and perspectives

The aim of the interaction with stakeholders is to inform them and to learn from them. Main questions are:

- Do stakeholders consider identified climate risks as risks on their farm and do they perceive damage?
- Do stakeholders agree that identified adaptation measures are relevant?
- Do stakeholders recognize the classified farm types and their change in structure over time in different scenarios?
- Based on collected knowledge from research experiments and stakeholder workshops, can we design adaptation strategies?

Fig. 4.1 shows the applied process of interactions with the stakeholders over time. The process includes steps related to research as described in Chapter 3 and four stakeholder workshops which have been held for feedback on (a) risks and impacts on crop and field level, (b) possible adaptation measures, (c) farm typology and scenarios on farm structural change, and (d) relevant adaptation measures and design of adaptation strategies. The resulting ideas and perspectives from the stakeholders about arable farming in the future have been used in steps V and VI for the farm modeling (see Section 3.3.2).

Work shop I - Interaction with stakeholders on risks and impacts at crop and field level

We have presented possible risks and impacts from climate change and their impacts at the field and farm level (see Section 3.3) and have collected the feedback from the stakeholders. This is to ensure that the presented risks are actually recognized by the farmers and other sector members (practitioners). Three crop-specific sessions have been held for potato, sugar beet and wheat, as well as a regional Flevoland session. In the crop-specific sessions the risks and impacts have been discussed for the future yield and the quality of the yield (see Tables 3.1 and 3.2), and subsequently, their influence on the future farm income. In the regional session the impacts which are of importance to the region, have also been discussed, such as the increased need for fresh water in case of drought situations.

In the crop specific sessions, farmers and other stakeholders in general agreed about the main climate risks and impacts. Whether extreme climate events had an impact in the current situation differed per farm. For example, hail appears to be a local problem in certain areas in Flevoland. In these regions, some farmers insure themselves. In other areas however, hail rarely occurs and therefore insurance is not required. For certain crops the minimum and maximum possible impacts of extreme events had to be adapted.

In the regional session, impacts and adaption in Flevoland was discussed more general, and important points include:

Climate change impacts

- Because of higher temperatures a possible shift of the growing season, a longer growing season and a higher disease pressure (e.g. nematodes, aphids) are possible.
- Pressure from aphids as herbivore and as a vector of viruses need extra attention, because higher winter temperatures will decrease winter mortality.
- Soil structure is a big problem in Flevoland; waterlogging is a problem in years with high precipitation, and this is expected to become more severe; work on the physical characteristics of the field such as making the field slightly convex ('kilveren'), are becoming more popular in the region.

Adaptations

- Diseases pressure can be lowered by adapting the crop selection.
- Learn from disease pressures elsewhere.
- A possible measure to improve soil structure is to make the switch to organic farming with a wider rotation; however, organic farming is not always an option because of unstable market prices; other measures might be the use of more light machinery and/or 24hr shifts with precision farming techniques; also increase in soil biodiversity and gps steering are important options; market circumstances are key for every decision.
- It is expected that climate change will not lead to an introduction of new crops; the rotation scheme is dominated by the (grain) prices; crops with a high added value could be interesting and may be added sooner to the rotation scheme.
- The local market is getting more appealing; more products come from the region, and the consumer engagement is growing; farmers mention that they should aim for the potential benefits.

Work shop II - Interaction with stake holders on possible adaptation measures

In the second workshop a synthesis of the most relevant climate risks has been presented together with possible adaptation measures from Wit *et al.* (2009). See Table 3.3. for an example for seed potato. The result from Workshop II is a table with adaptation measures that are: a) a response to meaningful risk and impacts, b) specific for the region c) co-developed by farmers, sector representative and policy makers (water board) and d) thought to be adequate responses to the risks and impacts.

Feedback on adaptation measures ranged from:

- In this part of the Netherlands this impact does not exist, so adaptation is not needed.
- The damage caused by the impact can easily be avoided with simple management and/or skill.
- The damage caused by the impact is severe but the crop has too little revenue and therefore, this adaptation measure is not likely to be profitable.
- The adaptation measure is potentially interesting and might be adopted, if other measures are not more effective.
- The adaptation measure is a new opportunity if market conditions are right.

In general, all the adaptation measures that were identified, were judged relevant for the region, but whether they are likely to be adopted, differed per farm type and local conditions.

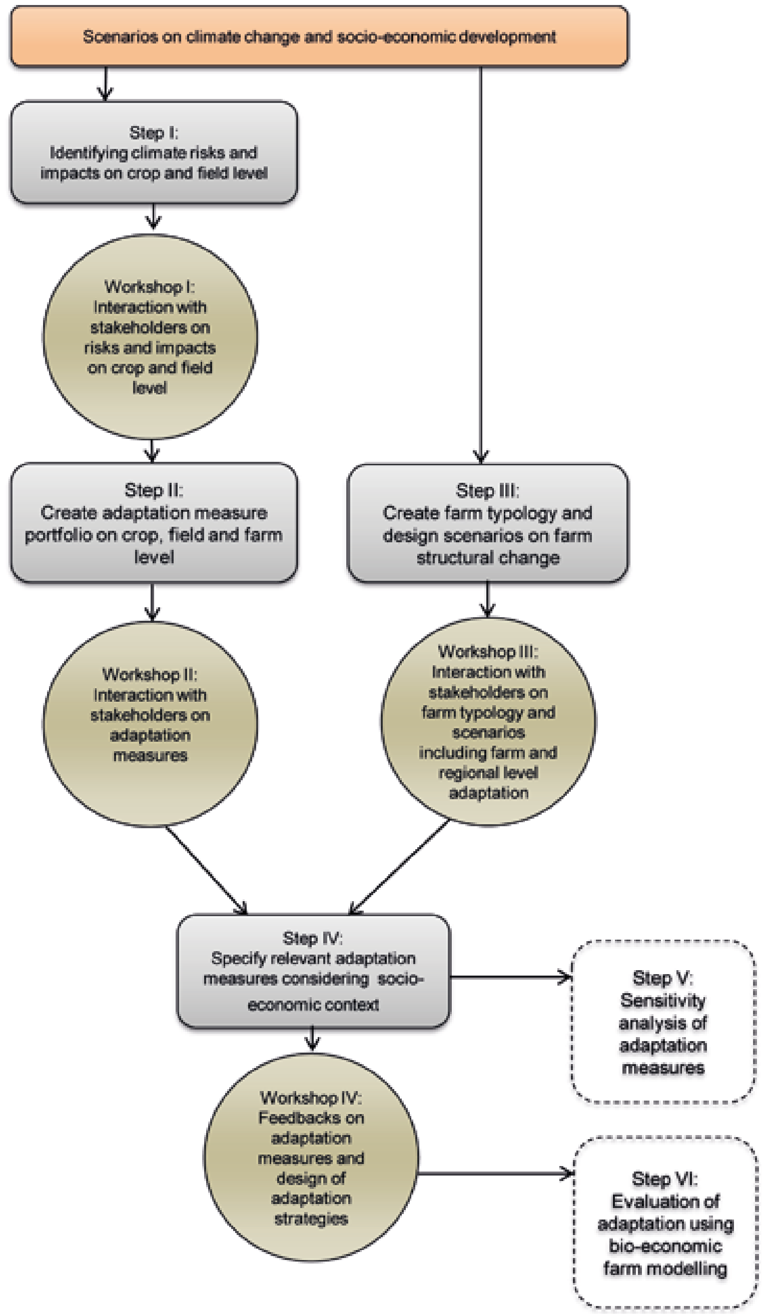

Figure 4.1.
Diagram with the process of interactions with the stakeholders. Central points are the four workshops, in which scientific knowledge and practical implications are shared between researchers and stake-holders. The knowledge and perspectives of the stakeholders about arable farming in the future are used in steps V and VI for the farm modeling, as described in Section 3.3.2.

Work shop III - Interaction with stakeholders on farm typology and scenarios of farm structural change

The 3rd workshop has been designed to receive feedback from farmers on the proposed scenarios of farm structural change that are developed in Step III (Section 3.2.3). This feedback was aimed to give information on the views of stakeholders on a changing future in general and climate change and adaptation in particular. The outcomes of this workshop are also used in step IV to select adaptation measures according to farm orientation and two contrasting future scenarios.

During the interactive session the participants shared their visions on adaptation strategies to climate, market and policy changes for arable farming in Flevoland in the future for the two contrasting socio-economic and climate scenarios. The participants were asked to write down the most important adaptation strategies to market, policy and climate change. Adaptation strategies could be from the categories market opportunities, farm size, technology, crop choice, or additional ones defined by the farmers themselves. Stakeholders were also asked to rank the strategies. The results of the exercise were discussed in a round table closing discussion afterwards. This provided us with quantitative and qualitative farm characteristics in different scenarios.

Each of the stakeholders mentioned the main expected adaptation with regard to size, markets, technology, crops and climate change. Overall, the order of importance was markets > farm size > crops > technology. Climate change was not mentioned much.

With regard to markets, expectations for the A1-W scenario were: more added value, sustainable energy, knowledge, and organic production comes close to conventional production. In the B2-G scenario, sustainable energy and organic production were also seen as important, but instead of value added products more emphasis is put on local products and nature and landscape management. In general, farmers in Flevoland do 'anything to earn money', so they can be considered as profit maximizers. If they have a side activity next to their specialization, this is usually limited to one. Side activities can include processing, nature management and shops.

With regard to size, stakeholders expected farms to double or triple to 150-180 ha in the A1-W scenario, while in the B2-G scenario there is less need for growth and increases will be limited to 75-100 ha. Land increases in the A1-W scenario are possible due to collaboration and more rental land. Small farms can have a niche. In the B2-G scenario increased collaboration with livestock farmers was specifically mentioned.

In the A1-W scenario, crop production in the region will be uniform. In general, more energy will be produced, also from crop residues. High quality seed potatoes remain important. More vegetables are expected due to their high added value, more wheat production for soil structure, and new crops depending on their prices. In the B2-G scenario, there will be less changes in crop types, but throughout the region production will become more diverse including more local crops and varieties. Healthy rotations and nature management will be stimulated.

Technology development is expected in both scenarios, but in the A1-W scenario this will be more focused on minimizing labour use, and in the B2-G scenario on the environment. GPS, robots and further mechanization were mentioned.

Overall, farmers and other stakeholders largely agreed. Researchers gave similar answers but they were less precise in their estimates. Priorities of important aspects were similar, except for the farm size, for which the projections differed. The size increases projected by the stakeholders were larger than the trend based on historical data. The workshop proved that farmers and other stakeholders can think in scenarios. However, as earning money is their main objective, they considered this in both scenarios. Their responses in the two scenarios differed depending on likely prices and subsidies. As currently 80% of the farmers is export-orientated, farmers have a preference for the A1-W scenario; acting globally appears to be easier than focussing on the regional market. Climate change has not been mentioned much. One point mentioned was that farmers in high-rainfall areas are likely to convert to livestock farming.

The expectations expressed by the stakeholders were used to improve the scenarios and their impact on farm structural change as presented in section 3.2.3. The historical data analysis and stakeholder perceptions were translated to visions on farms of the future (in 2050) in Flevoland. These are presented and discussed in Chapter 3 of projects reports 4 & 5 (see Section 7.3).

Workshop IV – Feedback on relevant adaptation measures and design of adaptation strategies

Workshop IV was used to a) update the stakeholders on the scientific process and outcomes, b) receive feedback on the proposed adaptation measures, and c) create adaptation strategies for 2050 for the main climate change threats and associated opportunities.

The adaption measures as discussed in step II were revised and presented in the following categories of extreme climate events: 1) soils too wet for traffic-ability, 2) warm conditions, 3) drought, 4) high intensity rainfall, and 5) sustained wet conditions during growing season. This was done to be able to make a simple overview for an improved discussion.

To discuss adaptation in different scenarios and to discuss different future farm types, combinations were made of the A1-W (Global Economy) scenario versus the B2-G (Regional Communities) scenario and Primary Production- versus Nature-oriented farm types. Stakeholders were divided into two groups that worked on either Nature-oriented – B2-G scenario and Nature-oriented – A1-W scenario or Primary production-oriented – B2-G scenario and Primary production-oriented – A1-W scenario. Stakeholders were asked to mention preferred adaptation measures for the five extreme climate events in the different orientation-scenario combinations. In a plenary closing session the most important adaptation strategies were presented by the stakeholders for arable farming in Flevoland.

Stakeholders put much emphasis on generic and already known adaptation measures in virtually all combinations of farm orientation and scenario type. Especially, improving the soil structure was of high importance, because this measure is believed to be effective against drought, wet field conditions and high-intensity rainfall. For each of the five extreme climate events, within the different orientation-scenario combinations, several relevant adaptation measures were selected to form an adaptation strategy. However, the discussions also showed that adaptation differs per farmer and location, and each farmer has to define his/her own adaptation strategy.

5. Conclusions

Climate change mainly provides opportunities for arable farming in Flevoland. Climate change and increased CO_2 are projected to increase yields with 11-31% in the A1-W scenario, and 8-20% in the B2-G scenario. Also in the rest of Europe, average impacts are mainly positive due to the CO_2 effect, except for maize. Extreme events may, however, have large impacts in specific years, but the relative impact is small, anyway in Flevoland (with its temperate climate and high ground water level, allowing irrigation), and adaptation measures are available to reduce these impacts. From the basic rotation with potato, winter wheat and sugar beet, the potato crop is the most vulnerable to climate change impacts. Heat waves, warm and wet periods, wet fields and warm winters, which can have severe impacts on potato yields are projected to increase in frequency. Projected increases in potato yield due to gradual climate change are relatively small compared to, for example, those in sugar beet. For winter wheat projected increases are also small, but there are also few climate risks.

The integrated assessment shows the importance of not only considering the climate change effects, but also including the effects of increased atmospheric CO_2 and technological development for future yield estimations. Technology development has substantial impacts on yield projections (for Flevoland estimated at +30% in A1-W scenario and at +10% in B2-G scenario). This indicates the need for further investigation to reduce the uncertainty in the assumptions about technology development. The considered ensemble of climate change scenarios at EU level results in a range of yield responses, which becomes more pronounced, when technology development is considered. Such extensions of our work may be further developed in the framework of the global AgMIP Initiative (www.agmip.org), that was launched in October 2010 and aims to establish a modelling framework “to provide more robust estimates of climate impacts on crop yields and agricultural trade, including estimates of associated uncertainties” (Rötter *et al.*, 2011).

For the assessment of climate change impacts on crops at the regional scale, we have demonstrated the importance of crop model calibration. We have found that considering regional differences in model parameters related to crop growth in addition to crop phenology, can considerably improve crop growth simulations at the continental scale (EU25). This indicates that projections with crop models can be improved, if their calibrations are done better.

Impacts on product prices that result from changes in yield due to climate change and technology development, are shown to be considerable, however, the price impacts of the macro-economic assumptions (such as the changes in GDP and population) appear to be much stronger. Compared to these price impacts by yield changes and demand changes, the influence of trade liberalization (i.e. WTO modalities of the Doha Development Round (2008)) is calculated to be small (at most 10%).

At farm level, market changes appear to have a larger influence than climate change, as was earlier shown by Hermans *et al.* (2010). This was first of all reflected in the farm structural change scenarios for Flevoland, which showed that changes in markets, technology, and policy influence farm structure and therefore, the context to adapt to climate change. While currently most farms are production-oriented, in 2050 the number of entrepreneur- and nature-oriented farms may increase. Additionally, size will increase and more intensive crops will be cultivated, especially in the A1-W scenario.

Also the sensitivity analyses for the main arable farm types in Flevoland show that the differences in gross margin per labour hour for arable farming in 2050 are mainly determined by market changes. As input prices are projected to increase faster than product prices from 2005 to 2050, gross margins are projected to decrease, when technology development is not considered. Only for the 2050-A1-W-P-T scenario with the strongest technology development and thus, the highest yields and best management in 2050, the gross margins per labour hour, when expressed in euros of 2005, are higher than those for the Base year.

The third assessment at farm level, using data envelopment analysis combined with bio-economic modelling, also indicates the importance of market changes (i.e. prices), climate change and technology development.. The effects of climate change are projected to have a positive economic effect on arable farming. However, a substantial increase in inputs, such as biocides, fertilizers, and energy is also simulated. Increase in those inputs combined with a shift in production to other arable crops (mainly tulips and vegetables), can lead to additional environmental pressure per ha, but not per ton of product. All farm types appear to be able to cope with the increased frequency of climate extremes in the future, as these have relatively little impact compared to the overall increases in yields. As adaptation measures require capital input, these measures are more often adopted by large farms as compared to small farms.

The methodologies applied provide a good framework for integrated assessment of climate change in the context of other changes. Specific parts of the methodology also provided a good basis for discussions with stakeholders. The Agro-climate calendar (ACC) method to identify climate risks and impacts and to design adaptation measures has proved to be a good tool to inform stakeholders about climate change and to discuss results. Whereas crop modeling implicitly includes the impact of climate factors, with this semi-quantitative ACC method each climate factor can be explicitly addressed and discussed with stakeholders. Stakeholders generally agreed about the most important climate risks and impacts, and the relevant adaptation measures.

Overall, it can be concluded that although there are risks, climate change also provides opportunities for arable farming in Flevoland in the future. The current favorable agro-environmental conditions compared to the rest of Europe and the generally more positive (or less negative) impact of climate change compared to that in other regions, suggest that there is a good future for arable farming in Flevoland. On average, the impact of climate change is smaller than the impact of technology development or market change, but for several crops and scenarios, the impact can still be relatively large.

6. References

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7. Summaries of the project reports

The reports that describe the underlaying studies in the AgriAdapt (A19) project, are listed in the following. Subsequently, the abstracts of these studies are given which cover the main approaches and main results from these studies.

a) J. Wolf, M. Mandryk, A. Kanellopoulos, P. van Oort, B. Schaap, P. Reidsma, J. Verhagen, & M.K. van Ittersum, 2010. Methodologies for analyzing future farming systems and climate change impacts in Flevoland as applied within the AgriAdapt project. AgriAdapt project report no. 1, Wageningen UR
b) F. Ewert, C Angulo, C. Rumbaur, R. Lock, A. Enders, M. Adenauer, T. Heckelei, M. van Ittersum, J. Wolf, & R. Rötter, 2011. Scenario development and assessment of the potential impacts of climate and market changes on crops in Europe. AgriAdapt project reports no. 2 & 3, University of Bonn
c) J. Wolf, M. Mandryk, A. Kanellopoulos, P. van Oort, B. Schaap, P. Reidsma, & M.K. van Ittersum, 2011. Integrated assessment of adaptation to Climate change in Flevoland at the farm and regional level AgriAdapt project reports no. 4 & 5, Wageningen UR
d) B. F. Schaap, P. Reidsma, M. Mandryk, J. Verhagen, M. van der Wal, J. Wolf & M. K. van Ittersum, 2011. Adapting agriculture in 2050 in Flevoland; perspectives from stakeholders. AgriAdapt project report no. 6, Wageningen UR

7.1 Abstract of Project report no. 1

A key objective of the AgriAdapt project is the development of methodologies to assess climatic change impacts on agriculture including adaptation at regional and farm type level in combination with changes in other drivers (e.g. markets). More specifically, the methodologies should enable (a) the assessment of impacts, risks and resiliencies for agriculture under first, changes in climatic conditions including increasing climate variability and second, other changes (e.g. markets, technological development, policies, etc.), and (b) the evaluation of adaptation strategies at farm type and regional scale.

The methodologies are applied to arable farming in Flevoland, the Netherlands as the key case study to demonstrate the approach. The methodologies cover the following main areas, as described in the following: (a) Integrated sustainability assessment, (b) Development of scenarios of farm structural change towards 2050, (c) Calculation of crop yields for different scenarios in 2050 and analysis of the effects of extreme events, (d) Agro-climate calendars, (e) Partial and fully integrated analysis of farming systems with different methods (i.e. bio-economic farm modeling, Fixed cropping pattern method, and Data envelopment analysis) for both 2010 and 2050, and (f) Integration of methodologies at crop and farm level. The report presents the different methodologies and their proposed integration, whereas the actual and consistent application of the proposed methods will be the subject of the second part of the project.

Integrated sustainability assessment shows how the different methodologies, as described in the following, are linked and integrated. We use different methods for different questions, to assess the impacts of different drivers (e.g. climatic change, policies, market, technology), and the most effective adaptation strategies. Different methods complement each other, and together they can provide a detailed picture of pathways to a climate robust agriculture in the future. This is done at two levels, crop level and farm level, and for two time horizons, 2010 and 2050. Two SRES emission scenarios, A1F1 and B2 (IPCC, 2001), and related KNMI climate change scenarios, W (or W+) and G (or G+), for the Netherlands are used. Stakeholders are consulted to define specific questions that will be analysed with the different methods.

Development of scenarios of farm structural change towards 2050 has been done, using a farm typology for arable farms in Flevoland and considering the effects of different drivers on the different dimensions of the farm typology. The drivers have been derived from the A1F1 and B2 SRES emission scenarios. The possible farm structural changes are only indications and provide images of future farms; however, any precision as to structural changes for such a long time horizon cannot be provided.

Potential yields of the main crop types cultivated in Flevoland have been calculated with the WOFOST crop model. These yield calculations have been done for four different climatic change scenarios from KNMI (i.e. G, G+, W, W+) for 2050 and for two related atmospheric CO_2 concentrations, corresponding to the A1F1 and B2 emission scenarios. Changes in climate and increases in atmospheric CO_2 in year 2050 for the four scenarios result in yield increases for all crop types in Flevoland, except sometimes for the most extreme climatic change scenario W+. These simulated potential yields appear to be reliable.

Actual yields for 2050 are calculated as: simulated potential yields times (1 + GI) times (1 - GAP50), with GI being equal to the Genetic Improvement factor (e.g. 0.30; based on yield increase by plant breeding towards 2050) and GAP50 being the yield gap in 2050. GAP50 is equal to the minimum of either GAP50s (i.e. yield gap set for 2050) and GAPc being equal to the current (year 2000) yield gap as dependent on the crop management level. This method is straightforward, however, the calculated actual yields for 2050 depend on a number of assumptions. We can assume that the effects of climatic change and increase in atmospheric CO_2 on the actual yields are represented reasonably well by the simulated potential yields for 2050, but the changes in yield by genetic improvement and by yield gap reduction due to improved management are both uncertain, in particular when the method is applied to many regions over Europe. In Flevoland where the current crop management is almost optimal and hence, the yield gap is almost at its minimum, the uncertainty in the calculated actual yields for 2050 is mainly caused by the estimated yield change due to genetic improvement.

Agro-climate calendars have been applied to determine the climatic change sensitivity of the main cropping systems in the Netherlands. The climate sensitive periods of cropping systems have been determined on the basis of long-term (30 year) weather data, both for current conditions and for a time frame around 2050 (as based on KNMI climatic change scenarios). An example of the approach is given for winter wheat cultivation in the Northern part of the Netherlands. For the occurring management problems, adaptation measures have been proposed. As the climate sensitivity of the main cropping systems in the Netherlands have already been studied, we are mainly interested and will discuss here, how the information from this approach can be combined with and integrated in the modeling results from the other approaches applied within the AgriAdapt project.

Analysis of the effects of extreme events on crop yields from the historical field trials provides some insightful results, which also show limitations as to what can be quantified. It was possible to derive definitions of weather extremes. For example, preliminary results indicate that the largest losses of production in the past 50 years in ware potato were caused by a prolonged wet start of the growing season which delayed planting and by a prolonged end of the growing season which caused harvesting problems. On the other hand, limitations are that weather extremes and changing rainfall patterns in the future are very difficult to predict and that historical data on effects of weather extremes are available for only a few crops and events.

Exploration of farming systems has been done with the bio-economic farm model FSSIM for an average farm in Flevoland, maximizing the gross margin and applying the following constraints: available land and labour, obligatory set-aside constraint, sugar beet quota constraints and possibly also bounds on total N leaching and the change in soil organic matter content. This example study shows the advantage of a bio-economic farm model, being the capacity to generate and assess a large number of alternative activities on the farm in an explicit, transparent and reproducible way. For the optimized farms under different constraints, outcomes are calculated with respect to the financial results, labour demand, N leaching, cropping pattern, etc. A limitation of the procedure when applied to future situations, is that it requires detailed information on the activities (i.e. input-output relationships) and on the prices of inputs and outputs in the future. Another limitation is that many binding constraints need to be identified (e.g. related to main crop rotations) or a calibration procedure should be employed to add non-linearities by recovering the un-observed parameters that are related to e.g. risk aversion, complementarity and substitution. Parameters that are recovered with calibration based on historical data are not always valid for long term forecasts and hence, such a calibration procedure is preferably used for short term predictions. For longer term predictions (e.g. 2050) a normative approach (analysing 'what-if' questions) is to be applied.

Fixed cropping pattern calculations (showing the impacts of climatic change, technological development, policy and market changes on farmer's income and assuming that the cropping pattern is fixed and is not determined by an objective function and constraints as in FSSIM) have been done for arable farming in Flevoland. First, this was done for the four main arable farm types in Flevoland for current conditions (about 2010). Second, the calculations are repeated for these four farm types with the same cropping patterns and farm area but for 2050. Third, the calculations are done again for 2050 and the same farm types but assuming more specialized cropping patterns. Fourth, the calculations are done for 2050 and the same farm types and cropping patterns, but with a tripled farm area. Relative changes in yields, product prices, variable costs and additional labour costs, that have been set (as first estimates) at respectively about 1% (of which 0.3 % from climatic change and increased atmospheric CO_2 and 0.7% from genetic improvement), 1%, 2% and 2% per year, are strongly determining the economic farm results. Effects of climatic change and subsidies appear to be of minor importance compared to the other factors (e.g. farm size and specialization, changes in product prices and variable costs, and yield increases due to genetic improvement of crops) for the economic results in 2050.

Data envelopment analysis (DEA) is a method used in operational research to rank entities that convert multiple inputs into multiple outputs. Such entities are defined as decision making units (DMU), being for example firms and farms. The capacity of each DMU to convert inputs into outputs is evaluated and compared to the capacity of all other existing DMUs to convert inputs into outputs. A multi dimensional frontier is created by the superior decision making units, while all other inferior decision making units are enveloped (enclosed) in this frontier. Inputs can be seen as criteria to be minimized while outputs as criteria to be maximized. In the example we apply the DEA based approach to arable farming systems in Flevoland (the Netherlands) to show its approach and its potential in three steps. First, the basics of DEA for identifying a production frontier are revealed and an approach for including technological innovation and alternative agricultural activities is presented. Second, the proposed DEA based methodology is used to identify the current technology of Flevoland (the Netherlands) and based on this current technology to demonstrate how alternative activities or technological advances can be taken into account. Third, the results of the experiment in Flevoland are presented.

Integration of methodologies at crop level shows that changes in the effects of extreme events on crop yields towards 2050 cannot easily be included in the actual yield calculations for 2050. Part of the effects of extreme events on yields are already included in the yield gap. Changes in these effects towards 2050 might result in changes in the yield gap due to changed yield losses or in the simulated potential yields due to changed planting/sowing dates. However, both changes are difficult to quantify and probably remain within the range of uncertainty in the actual yield calculations. If so, the effects of extreme events should not be included in the actual yield calculations but should be presented separately.
Problematic with crop model results is that they mainly show the effects of gradual climatic changes on crop production and yields, and that they cannot assess all types of adaptation measures. In practice, climate extremes may have more impact than a gradual climatic change. Many adaptation measures for such extremes are available and for farmers these may be highly relevant. Impacts of climate extremes on crop production are determined for both current and future climate conditions, and based on the major climate risks, adaptation measures are identified. Together, these methods provide a good picture of the impacts of climatic change on crop production and the most relevant adaptation measures and their effects.

Integration of methodologies at farm level - The analyses and projections at crop level are used for the farm level analyses. Several complementary methods are used at farm level, as they provide answers to different research questions. Although climatic change is already apparent, impacts are mainly expected in the long term. However, in the long term other drivers such as technological development, markets and policies will change, too. Farm analyses have therefore been done for two time periods, 2010 and 2050.

The farm level assessment for 2010 is performed for current farms and their activities (2010), but assuming climatic conditions for 2050. This is done to explore which most effective adaptation strategies are available for current farms if a change in the climate occurs. Although it is likely that climatic change will occur in a gradual way, extreme years that represent 2050 conditions, can occur already now. Two farm level assessment methods are used for the 2010 assessment: i) DEA + FSSIM and ii) Expert knowledge + FSSIM. DEA + FSSIM uses data on 27 actual farms in Flevoland as a basis for the assessment, whereas Expert knowledge + FSSIM uses data for typical farms using the expert-based 'simple survey' data. Future climate change scenarios from KNMI (as related to the SRES emission scenarios A1 and B2) are used, whereas the other conditions are assumed to be as in 2010. These assessments give answers to questions such as: i) What is the impact of climatic change on cropping patterns and associated economic, environmental and social indicators, considering different farm objectives; ii) Which adaptation strategies are effective and therefore selected on different farm types, considering their objectives. The two methods are to some extent complementary, allowing to address different questions.

The farm-level assessment for 2050 is done for images of future (2050) farms. The main method used is the 'Fixed cropping pattern method', but additional explorations are done using DEA+FSSIM. Towards 2050 many developments will take place simultaneously, and technological development cannot easily be separated from adaptation. It is assumed that the technological development (i.e.

crop genetic and management improvement) includes adoption of the most effective crop level adaptation measures. The A1 and B2 scenarios for 2050 are used to project changes, not only with respect to the climate, but also for e.g. farm structural change and technological development. For estimating future actual yields, estimates on potential yields are combined with estimated improvements in the crop's genetic characteristics and its management. Future prices are estimated by the agricultural market model CAPRI. These assessments give answers to questions such as: i) What is the relative importance of climatic change, technological development, markets and policy changes for the farmer's income on the main farm types in 2050; ii) What is the impact of farm size and specialization on the farmer's income in 2050; iii) What are the most effective farm level adaptation strategies in 2050.

7.2 Abstract of Project reports no. 2 and 3

Impacts of climate change, [CO_2] increase and technology development

Simulated climate change impacts ranged from moderately to severely negative, to moderately positive effects on yields, depending on whether merely climatic factors were taken into account, or climate change was analysed in combination with increasing atmospheric [CO_2] and advances in technology were considered. An important finding of this modelling study is that considering regional differences of model parameters related to crop growth in addition to crop phenology can considerably improve yield simulations at continental scale (EU25).

Our results also suggest that for EU25 climate change without considering increasing atmospheric [CO_2] and advances in technology resulted in negative effects on crop yields in the range of 11.7% and 34.4% depending on the crop and region. Negative climate change effects are less pronounced for winter cereals (barley and wheat) as compared to tuber crops (potatoes and sugar beet) or other spring crops (maize). One possible explanation, still subject of further investigation, is the longer vegetative period for winter crops which may allow the winter crops to better recover from extreme events such as drought spells in spring. Also, changes in growing season length due to temperature increase will be relatively smaller in winter as compared to spring crops.

GISS A1B is the scenario with the strongest negative influence on yields even when taking the [CO_2] fertilization effect (Rötter and van de Geijn, 1999; Tubiello *et al.*, 2007) into account. This is most likely related to the dry conditions projected in this scenario which were more pronounced in this than in other scenarios. The overall range in simulated yield changes among scenarios is large with clear differences among crops. Again, the range was less pronounced for winter-sown as compared to spring-sown crops. For the latter, on average for EU25 the differences among scenarios were larger than the climate change effect within one scenario or the simulated temporal yield variability.

The changes that we simulated are more pronounced than those projected by Ewert et al, (2005) who applied a statistical approach to calculate a climate change effect by 2050 which was on average over 15 EU member countries less than 3%. This points at the tendency of crop simulation models to project higher effects of climate changes than statistical approaches. One explanation for this is that crop-climate models primarily consider the effects of climate factors on crop growth and development. Effects of other factors such as weeds, pests and diseases are mostly not considered in these process-based models but are inherently part of statistical models. More comprehensive experimental data will be required to better evaluate such results (Rötter *et al.*, 2011).

Positive effects of elevated atmospheric [CO_2] enhanced yields mainly for C3 crops to an extent which is consistent with data from FACE experiments (Ainsworth and Long, 2004; Long, 2006;

Manderscheid and Weigel, 2007). Increasing [CO_2] concentration stimulated yields in wheat, barley, sugar beet and potatoes by 14.1%; 11.1%, 14.4% and 7.4% respectively, with small differences between years and regions. This is generally less pronounced than effects simulated in some earlier studies (e.g. Rötter & van Diepen, 1994).

However, most substantial positive yield changes were projected when considering the effect of technology development. This is consistent with earlier results (Ewert *et al.*, 2005) but partly conflicting with analyses on winter wheat yields in Europe by Brisson et al (2010). The latter suggest that increased high temperature and drought stress may level off positive effects by technology development, especially in regions with currently highest potential yields and inputs. It is important to note that considering a technology effect not only increased the crop yields but also increased the differences between the scenarios. Projected yields were highest for the scenarios CCC A2 and 15GCM A1B and smallest for the scenario 15GCM B2, following the different assumptions made regarding technologies associated with these contrasting socio-economic and emission scenarios. In scenario family A (IPCC, 2001) it is assumed that agriculture undergoes highest intensification associated with more advanced technology development (e.g. breeding for higher yields and more efficient resource use) than in scenario family B. And for the latter, in B2, least progress in technology is assumed.

Clearly, considering the effects of climate change, atmospheric [CO_2] elevation and technology development separately had two main implications for our yield projections. On the one hand, the yield decreasing effect of changes in mere climatic factors was compensated and partially superseded when atmospheric [CO_2] elevation and technology development were taken into account. On the other hand, the yield differences between scenarios became greater when considering atmospheric [CO_2] elevation and technology development.

Finally, our results show some changes in variability under climate change (Fig. 11). However, these changes were mainly observed for maize and differed considerably depending on the region from decreasing to increasing variability under climate change. Other studies have reported increased yield variability as an impact of climate change in Europe (Jones *et al.*, 2003; Porter and Semenov, 2005; Iglesias *et al.*, 2010). However, in the present study we have not considered an approach to model the possible effects of extreme temperature stress or drought stress as increasingly referred to (Porter & Gawith, 1999, Porter and Semenov, 2005; Brisson *et al.*, 2010; Asseng *et al.*, 2011; Trnka *et al.*, 2011). Modelling such effects is likely to result in a more pronounced yield variability under climate change as recently shown in a global assessment for four crops (Teixeira *et al.*, this Issues; Rötter *et al.*, in Press).

Impacts on prices

Traditionally, assessments of climate change on food production and supply have been carried out by using process-based crop models, as we have done in the present study. When such crop model based yield estimates are available for larger regions or a continent, they are "usually combined with projections of future populations, trade and commodity prices to help us to estimate the future of the overall system (such as how much food we can grow in a warmer world)" (Rötter *et al.*, 2011, p. 175). The AgriAdapt approach used relative yield changes under climate change to calculate effects on commodity prices. The analysis of price effects resulting from the implemented scenarios can be summarized by the following observations:

(1) Price impacts resulting from a reduced yield potential as a consequence of climate change are considerable strong but the impact of the macro-economic assumption (GDP/population) is even stronger.

(2) Price impacts on animal products are even more significant than those for crops, given that feed prices rise as well.
(3) Given this, the price impacts of the political environment, as simulated with WTO-liberalization assumptions, are quite modest.

Naturally, these results are subject to a number of model assumptions and simplifications. Firstly, the link of yields between the crop model and CAPRI was established in a quite explorative manner. There is plenty of room to improve this link, e.g. by aligning the management assumptions of the two models. Secondly, the scenario set up can be enhanced. For example the GDP in developing countries is based on the agricultural sector to a large extend. Increasing the GDP without assuming gains in the agricultural sector is therefore inconsistent. This is why the 25% and 50% GDP shock scenarios where also analyzed, since it may be more realistic to assume smaller GDP changes. Finally, CAPRI is very detailed on the EU level, but the price reaction is very much dependent on how the rest of the world responds to the applied shocks. Since capacities do not play a role in the currents specification, e.g. the supply response potential of Brazil may be underestimated and consequently the price effects overestimated. Currently the representation of the rest of the world in CAPRI is changing in an ongoing project introducing the land use variable and a land market.

We have demonstrated the importance of crop model calibration for the assessment of climate change impacts on crops at regional scale. We find that considering regional differences of model parameters related to crop growth in addition to crop phenology can considerably improve yield simulations at continental scale (EU25). Calibration also effects simulations of climate change impacts on yields suggesting that projections with crop models can be improved if they are well calibrated.

Our results also show the importance of considering not only the effects of changes in weather variables, but also increased atmospheric [CO_2] and technology development for future yield estimations. Particularly, consideration of technology development can have substantial impacts on yield projections which need further investigation to reduce uncertainty in the assumptions about technology development. The considered crops respond differently to climate change which also poses the need to extent climate change studies to a larger range of crops.

The considered ensemble of climate change scenarios results in a range of yield responses which again is more pronounced when technology development is considered. As some of this technology development refers to yield improvements, future research on improving model calibration for large scale climate change studies will also need to address temporal changes in model parameters.

Such proposed extensions of our work may be further developed in the framework of the global AgMIP Initiative (www.agmip.org) that was launched in October 2010 and aims to establish a modelling framework "to provide more robust estimates of climate impacts on crop yields and agricultural trade, including estimates of associated uncertainties." (Rötter *et al.*, 2011).

Impacts of projected yield changes on prices cannot be neglected when analyzing climate change scenarios. It was shown that introducing yield shocks simulated by the calibrated crop models in an agricultural market model leads to significant price impacts and thus stimulation of management adjustments. The latter is not yet reflected in our analysis, but should be in future research, because a permanent situation of high prices would definitively accelerate technical progress in the agricultural sector und thus reducing the simulated yield loss induced by climate change. An iterative process between crop and market models would be in line with these considerations.

7.3 Abstract of Project reports no. 4 and 5

A key objective of the AgriAdapt project is the assessment of Climate change impacts on agriculture including adaptation at regional and farm type level in combination with changes in other drivers (e.g. markets). Different methodologies have been developed and applied to (a) to assess the impacts, risks and resiliencies for agriculture under first, changes in climatic conditions including increasing climate variability and second, other changes (e.g. markets, technological development, policies, etc.), and (b) evaluate adaptation strategies at farm type and regional scale.

The methodologies have been applied to arable farming in Flevoland, the Netherlands as the key case study to demonstrate the approach. The methodologies cover the following main topics, as described in the following: (a) Integrated sustainability assessment and the linkage and integration of different methodologies, (b) Development of scenarios of farm structural change towards 2050, (c) Calculation of crop yields for different scenarios in 2050 and analysis of the effects of extreme events, (d) Agro-climate calendars, (e) Partial and fully integrated analysis of the main arable farming systems in Flevoland and of arable farming in Flevoland as a whole with different methods (i.e. Sensitivity analysis at farm level, and Data envelopment analysis) for 2050.

Chapters 3-9 of the report present first, briefly the different methodologies and next, the results attained within the AgriAdapt project and an evaluation of these results. For more detailed information about the applied methodologies, see AgriAdapt report no. 1 with the applied methodologies.

Chapter 2 describes the integrated sustainability assessment as applied within AgriAdapt, showing how the different methodologies are linked and integrated. We have used different methods for different questions, to assess the impacts of different drivers (e.g. climate change, policies, market, technology), and the most effective adaptation strategies. Different methods complement each other, and together they provide a detailed picture of pathways to a climate robust agriculture in the future. Next, this report gives a description of the results from the different methodologies (from Chapter 3 onwards). The assessments have been done at two levels, crop level and farm (+ regional) level, and for mainly two levels of integrating the driving factors in 2050, i.e., either climate change effects alone (2050-CC-only) or changes in climate, agro-management, crop productivity, markets and policy environment combined (2050-CC-P-T) . Two SRES emission scenarios, A1FI and B2 (IPCC, 2001), and related KNMI climate change scenarios, W (or W+) and G (or G+), for the Netherlands have been used, resulting in e.g. the A1-W and B2-G scenarios. Stakeholders have been consulted to define specific questions to analyse.

We refer to Chapter 2 covering the integrated sustainability assessment, for a comprehensive overview of the results from the AgriAdapt project. Some of the many results from the project include:

a) A method to assess farm structural change at regional and farm level towards 2050 has been developed and applied. For this we used historical analysis (statistics based) combined with hierarchical scenario analysis to project regional structural changes. We have developed transition rules to downscale the regional results to the farm type level. The analysis shows that historical trends, consistent scenario assumptions and stakeholder involvement can be used to derive plausible images of arable farms towards 2050. These future farm images provide a proper basis for detailed assessment of impacts of and adaptation to climate change. The scenarios we developed and the method to derive them can be re-used in other regions in the Netherlands or elsewhere in Europe.

b) A method for the calculation of yields for the different scenarios in 2050 has been developed and applied. The future yields of the main crop types in Flevoland are calculated in a straightforward way, but are dependent on several assumptions (e.g. increase in yield potential towards 2050) and uncertain data (e.g. weather data for 2050) and hence, are affected by uncertainty.
c) Sensitivity analyses for the main arable farm types in Flevoland and the different scenarios show that the differences in gross margin per labour hour in farming are mainly determined by first, the increase in product and input prices from 2005 to 2050 (and in particular, the degree that the product price increases are lower than the increases in costs) and second, the yield increase from 2005 to 2050. Results show that only for the 2050-A1-W-P-T scenario (i.e. A1-W scenario for 2050 combined with all other changes) with the highest yields and best management in 2050, the gross margins per labour hour, when expressed in euros of 2005, are higher than those in the Base year for all farm types.
d) Results from exploring farming systems in Flevoland and adaptation strategies to climate change using the data envelopment analysis, show that the most important driving factors towards 2050 (within the A1-W scenario with a globalized economy and strong climate change), are the yield increase due to climate change, the expected price change and the degree of technological innovation focused on crop productivity. The effects of climate change are projected to have a positive economic effect on arable farming. However, a substantial increase in inputs for crop protection, fertilizers, and energy is also simulated. Increase of those inputs combined with a shift of production to other arable crops (mainly tulips and vegetables), can lead to additional environmental pressure per ha. Nevertheless, the environmental pressure per ton of product is projected to decrease.

7.4 Abstract of Project report no. 6

Effective adaptation measures for agricultural in Flevoland in 2050

What are the risks and impacts of climate change for agricultural production in Flevoland?

The aim of this study was to assess how agriculture in Flevoland can effectively adapt to climate change in context of other changes. First of all, the risks and impacts of climate change on agriculture production in Flevoland was assessed with the semi-quantitative ACC method and a cropping system model WOFOST. The combination of these methods gives a picture of future climate impact on crop production. The ACC focuses more on the risks related to extreme events and pests and diseases. Although it seems the best possible method to describe future climate risks of extreme event and pests and diseases it has some limitations and shortcomings as described in Schaap *et al.* (2011).

The ACC method is useful to scan the region for possible risks and impacts of extreme events and to show trends of changing frequencies. The method is therefore equipped to identify the most imminent threats to crop production and prioritize adaption measures. However, the ACC method is less suited as a tool to evaluate the total impact of an event on total crop production in the area due to the spatial and temporal variability of growing conditions

Crop simulation with the WOFOST model shows how potential crop production will develop; see Wolf *et al.* (2011) for more detailed results and discussion on the outcomes. The impacts show that in general yields will rise towards 2050, but the ACC highlights some changes of the risks for extreme events that cause crop losses and crop damage in terms of quality. The crop simulations with WOFOST showed that future average climate conditions are also an opportunity to gain higher yields.

From the impact analysis with the ACC, drought is flagged to be a problem for crop production. For Flevoland the fresh water supply does not depend on rainfall and can be kept near optimal with water coming from the Dutch river system. Moreover the soil structure and relative low water tables allow for capillary rise of groundwater to the root zone. This was explicitly mentioned in the stakeholder workshops, and is also shown with the crop simulation modelling. Even if there is a drought effect and yield decrease this is not perceived as a problem. Price mechanisms works as follows in the case of drought: low yields because of drought on National-European scale create scarcity on the markets, Flevoland has a comparative advantage to other regions were drought has a higher impact and prices go up because of this scarcity. The virtually non-existing problem of drought for the main arable crops can be a problem for specific crops such as flower bulbs or crops that are vulnerable in a very specific stage in the growing season (e.g. onion directly after emergence).

Is the changing climate being recognized as a major driver by farmers and other stakeholders?

Farmers recognize climate as a driver of crop production and farm performance, but consider other drivers such as markets, policy and technology development more important. This is consistent with our scientific assessments, showing the relative importance of these different drivers. Results of crop model simulations can be understood, but these are difficult to recognize by the farmers. The ACC method provides a good tool to discuss specific climate risks that are directly observed in the fields by the farmers. Most of the climate risks as identified by the ACC were also occurring on at least some of the farms. Some were not considered as problematic, as adaptation measures are already available and applied. For other climate risks, adaptation strategies need to be developed.

Is adaptation already taking place?

From the results in Workshop II it was clear that a large share of the adaptation is already taking place because farmers indicate that the adaptation measures are current practice. However, this does not mean that the scale and intensity of the adaptation measure has already reached the potential adoption levels. Information from Workshops I and II helped the participants to evaluate the potential for current adaptation practices in a situation with a changed climate.

What are effective adaptation measures for each climate factor?

For each of the climate factors that are identified as climate risks as the potential damage is high and frequencies are expected to increase, adaptation measures have been identified. One of the most important adaptation measures is improving the organic matter content of the soil to improve the soil structure. Furthermore the emphasis of the adaptation regarding wet circumstances (for both wet soils during planting/harvest and high intensity rainfall events) is on better drainage. As a matter of fact farmers are improving the drainage of their fields constantly. They do this to meet the demand for high quality products. A much heard of adaptation measure is a more proactive water management by the water board. This measure seems very practical but it can also be that farmers underestimate the technical problems associated with this measure.

For pests and diseases the proposed adaptation measures are breeding efforts to increase resistance, especially in the A1-W scenario. But in the B2-G scenario also preventive measures are mentioned such as an optimal soil quality to make the healthy plants less susceptible to diseases. Farmers in Flevoland don’t see many opportunities for Functional Agro Biodiversity (FAB) measures because these are costly measure without a guarantee for keeping disease pressures down.

The level where the adaptation measures take place differ. For improving the organic matter content the farmer can choose to do this on a field level. Whereas breeding for higher resistance of crops will require a sector wide approach with possible even the need for knowledge from universities.

Adaptation on the provincial/water board level is also a different level. Water boards are not likely to take an adaptation measure such as a more proactive water management if the costs are high and if the benefits for farmers are largely unknown.

In earlier studies (Easterling *et al.*, 2007), adaptation measures where quantified using crop models. A crop model however, can only assess the impact of improved cultivars and earlier sowing dates, as the simulations with WOFOST showed, these measures have some impact, but not much. Furthermore, in Flevoland, as yields are projected to increase with climate change, these are options that further increase yields, instead of minimizing losses. The ACC method allows to identify the major climate risks, and focus the identification and subsequent quantification of impacts of adaptation measures on the most relevant ones.

What are feasible adaptation strategies given the context of two contrasting 2050 scenarios?

Many of the adaptation measures identified are currently already applied. Whether these will still be adopted in the future, and whether other ones will be adopted, depends on the future scenario. In the A1-W scenario, there will be more focus on production and intensification, and therefore technology options will be more often adopted, like for example genetic modification or the use of more efficient machinery. In the B2-G scenario there is more attention for the environment, so also other measures, like improving the soil structure, receive much attention.

Stakeholder interaction and co-learning

Do stakeholders consider identified climate risks as risks on their farm and do they perceive damage?

Farmers did recognize the future risks of extreme events and pests and diseases as important climate factors. During the stakeholder process farmers shared their knowledge on current impacts from extreme events. However, although the current overview of most important impacts is quite extensive, it can still be argued that the overview is not complete. Although some climate factors were not given high priorities due to low economic impact for example, the information was still valued. Also opportunities were identified. This information was highly valuable to the researchers to refine the list of risks and impacts. In Workshop II the participants acknowledged the fact that the extreme events that were ultimately presented were the most important extreme events for the region of Flevoland.

Do stakeholders agree that identified adaptation measures are relevant?

Results from Workshop II show that there are many adaptation measures to think of. However, not all adaptation measures are effective. And, not for every climate factor suitable adaptation options are present that are also cost efficient. Especially the pests and diseases are problematic climate factors in the Flevoland region.

Results from Workshop IV show a variety of feasible adaptation strategies in two contrasting 2050 scenarios. Those were the ones getting most attention and can be considered as the most relevant for the stakeholders.

Do stakeholders recognize the classified farm types and their change in structure over time in different scenarios?

Farm structural change was discussed with stakeholders, and their ideas were included in images of future farms. In some cases, the expectations from stakeholders diverged from what could be expected based on historical analysis. For example, historical trends do not indicate fast increases in size, and therefore the scenarios on size increases are also limited. Farmers however expect a doubling or tripling, especially in the A1-W scenario. Probably this is also partly due to the type of farmers that were involved in the workshops. Generally, these were innovative farmers, involved in agricultural organizations and water boards.

Based on collected knowledge from research experiments and stakeholder workshops, can we design adaptation strategies?

The stakeholders did their best to design effective adaptation strategies in Workshop IV. However, because the parallel sessions had a lot of information as input, the participants did not always use all the information. In the end they managed to design general adaptation strategies for 1) warm conditions, 2) drought, 3) high intensity rainfall events, 4) wet and warm condition during the growing season and 5) wet field conditions during planting/harvesting. Unfortunately the information about the orientation did not give desired results because the participants in Flevoland found it hard to imagine a scenario in the A1-W world with a nature orientation. Partly because this orientation is already practically non-existent in Flevoland. Nevertheless the participants did follow the task to make adaptation strategies as good as they could. The results can be used as most relevant adaptation strategies were given, but the discussions also showed that adaptation also differs per farmer and location, and each farmer has to define his/her own adaptation strategy.

Concluding remarks

The concept of risk is daily reality for most farmers and the ACC seemed to do well as a method to further discuss the potential risks. In the discussion with farmers on the risks and impacts from extremes the farmers relate the impacts directly to their current situation with site specific characteristics. They do point out the fact that there is spatial variability and that described impacts found on location A can be very different from location B due to differences of the water table, soil structure, and management.

Because farming operations are sensitive to economic incentives such as subsidies and market prices, also the future adaptation options are driven by these incentives. This point is also made by Otto-Banaszak *et al.* (Otto-Banaszak *et al.*, 2011) where the authors point out that collective adaptation is difficult as the economics incentives are dynamic because of fluctuating market prices and even subsidies.

Some of the stakeholders, including scientists, are more focussed on the technical aspect of adaptation. Policy makers, scientists are interested in the quantitative details of the risks and the without considering the markets as an integral part of the balance. Other stakeholders such as policy makers are also interested in the economics of adaptation but then more from a 'cost to society' perspective. "Can we reduce the need for additional fresh water with new technology?"

For individual farmers adaptation is not something they 'need to do', at least not on the short term. Most farmers acknowledge that in the future adaptation is needed but for most it is too early to invest in risk management for climate change if other risks such as market prices are dominant. To make the necessary risk assessment and the cost and benefit equation farmers need improved information on future climate change impacts. Information, especially on not-regrets adaptation measures are already of value to farmers. However, the uncertainty about future developments of markets, policy and technology and climate change impacts is for a large portion of the adaptation measures too high to justify large investments. The scenario approach helped farmers and stakeholders to focus on the "what if" questions and structure the discussion.

Climate changes Spatial Planning

Climate change is one of the major environmental issues of this century. The Netherlands are expected to face climate change impacts on all land- and water related sectors. Therefore water management and spatial planning have to take climate change into account. The research programme 'Climate changes Spatial Planning', that ran from 2004 to 2011, aimed to create applied knowledge to support society to take the right decisions and measures to reduce the adverse impacts of climate change. It focused on enhancing joint learning between scientists and practitioners in the fields of spatial planning, nature, agriculture, and water- and flood risk management. Under the programme five themes were developed: climate scenarios; mitigation; adaptation; integration and communication. Of all scientific research projects synthesis reports were produced. This report is part of the Adaptation series.

Adaptation

Dutch climate research uses a 'climate proofing' approach for adaptation. Climate proofing does not mean reducing climate based risks to zero; that would be an unrealistic goal for any country. The idea is to use a combination of infrastructural, institutional, social and financial adaptation strategies to reduce risk and optimalise opportunities for large scale innovations. Climate changes Spatial Planning realised projects in a multidisciplinary network that jointly assessed impacts and developed adaptation strategies and measures. The following themes were central to the programme: water safety, extreme precipitation, nature and biodiversity, agriculture, urban areas, transport (inland and road transport) and the North Sea ecosystem. In special projects, the so called hotspots, location-specific measures were developed that focused on combining 'blue', 'green' and 'red' functions.

Programme Office Climate changes Spatial Planning

P.O. Box 1072
3430 BB Nieuwegein
The Netherlands
T +31 30 6069 780

c/o Alterra, Wageningen UR
P.O. Box 47
6700 AA Wageningen
The Netherlands
T +31 317 48 6540
info@klimaatvoorruimte.nl

www.climatechangesspatialplanning.nl