Integrated assessment of farm level adaptation to climate change in agriculture

An application to Flevoland, the Netherlands

Maryia Mandryk

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An application to Flevoland, The Netherlands

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Thesis

submitted in fulfillment of the requirements for the degree of doctor
at Wageningen University
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to be defended in public
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at 4 p.m. in the Aula.

Propositions

1. Climate change impact and adaptation assessments of the Intergovernmental Panel on Climate Change (IPCC) underestimate adaptation opportunities in agriculture, because they largely ignore the options at farm level.
(this thesis)

2. Although farmers in Flevoland do have more objectives, in tactical decision-making they focus on economic result maximization, while for strategic decision-making they also prioritize soil organic matter.
(this thesis)

3. Modern food supply chains have become more vulnerable to disturbances due to high performance pressure.

4. An integrated assessment is needed to judge the potential role of insects in global food and feed production.

5. According to modern Dutch farmers' wisdom, the best alternative farm plan includes a partner with an off-farm job.

6. When looked at from the outer space, the Earth seems too small to accommodate all human activity.

Propositions belonging to the thesis entitled:

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Maryia Mandryk
Wageningen, 29 March 2016

Maryia Mandryk

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Chapter 1

General Introduction

1.1 Background

1.1.1 Climate change impacts and adaptation at different levels

Climate change has become an issue of concern during the last decades. In many regions of the world one can observe effects of changes in climatic conditions or climate variability on crop productivity, farmers' income and land use (Audsley et al. 2006; Berry et al. 2006; Bindi and Olesen 2010; Bradshaw et al. 2004; Olesen and Bindi 2002; Porter et al. 2014; Reidsma et al. 2009). Especially severe climate change effects are expected in tropical regions (e.g. Sub-Saharan Africa) (Porter et al. 2014). Also for the future of agriculture in a temperate zone such as the Netherlands, the potential importance of climate change cannot be ignored, especially regarding effects of weather extremes (Bresser 2005; Eitzinger et al. 2013; Peltonen-Sainio et al. 2010; Schaap et al. 2011; Tebaldi et al. 2006; van Dorland 2008).

To withstand the negative impacts and to take advantage of the opportunities arising from climate change, the agricultural sector will need to implement adaptation measures (Olesen et al. 2011; Schaap et al. 2013). Adaptation measures to climate change in agriculture refer to practices that might be adopted to alleviate expected adverse impacts or to take advantage of positive impacts (Smit and Skinner 2002). A body of literature that has been published in the last decade provides a number of theoretical frameworks for adaptation research (Acosta et al. 2013; Berry et al. 2006; Meinke et al. 2009; Tol 2005; Yohe and Tol 2002). In parallel, there is an increasing number of empirical studies that propose adaptation measures at crop, farm and regional/sectoral levels. Considerable attention is given to the development of new adaptation measures, but it is also important to assess whether these measures are feasible in terms of implementation (Easterling et al. 2007; Smit and Skinner 2002).

The recent report of the Intergovernmental Panel on Climate Change (IPCC) is generally more negative regarding impacts of climate change on agriculture compared to the previous report, also for temperate regions (Porter et al. 2014). Such conclusions have been drawn with a focus mostly on crop level impacts and adaptation, whereas actual impacts feature at higher aggregation levels. Adaptation occurs across scales, but actual decisions are made at a management unit, i.e. farm level (Adger et al. 2005; Rodriguez et al. 2014; Rounsevell et al. 2003). Impacts and adaptation should thus be assessed at farm level, and farm variability should be considered. Impacts of future climate change are usually projected on current farms and cropping systems (Porter et al. 2014). Since the impacts of climate change will be relatively minor in the short term, assessments must be performed for a long time horizon, when climate change will likely be more manifest. For such a time horizon, effects of other drivers of change must also be considered. The farms in the future are not the same as the current ones: they will evolve through structural changes.

Assessments of impacts on and adaptation to climate change in agriculture have focused primarily on food production (Porter et al. 2014). At the same time, farming systems in Europe are diverse in terms of their characteristics, objectives and performance, which largely influenced adaptation of farms to past climate change and variability (Reidsma et al. 2010). One of the factors contributing to increasing farm diversity recently is a shift towards multifunctional agriculture associated with a broader role of agriculture in a modern society (van der Ploeg et al. 2009; Renting et al. 2009; Meerburg et al. 2009). Next to primarily economic objectives, farmers are assumed to have other objectives (e.g. social, environmental) influencing their management practices. Farm specific adaptation measures to climate change should therefore account for the differences in farm objectives.

Adaptation of agricultural systems to climate change is embedded in a broader context. In the latest IPCC report (Klein et al. 2014a), it was concluded that effective governance and institutions for facilitating adaptation planning and implementation across multiple sectors within regions is by far the dominant adaptation opportunity and constraint. An assessment of the institutional context is therefore needed to assess the feasibility of implementation of adaptation measures to climate change from an institutional perspective.

In the following sections we introduce main issues relevant to improve climate impact and adaptation assessments in agriculture: farm structural change, farmers multiple objectives, adaptation at different organizational levels and the institutional context.

1.1.2 Farm structural change

Changes in agricultural policy setting, market responses and technological development were shown to be at least equally important drivers of change for agriculture as climate change (Hermans et al. 2010; O'Brien and Leichenko 2000). Due to the impact of these drivers, farms in The Netherlands have been changing considerably since World War II (Meerburg et al. 2009). Those changes affected not only the numbers of farms, but also accounted for new farm types through structural changes. Structural changes fall into the category of strategic (medium to long-term) investment decisions to fundamentally change farm size, specialization or production intensity (Zimmermann et al. 2009).

The most common quantitative methods to study farm structural change are econometric models, as shown in the review by Zimmermann et al. (2009), or agent-based models as applied by Piorr et al. (2009). However, nearly all of the past studies had short time horizons. Econometric models have been used to assess farm structural change due to climate change on the long term (e.g. Seo et al. 2010). Those models have still been using the assumption that all farmers are profit maximizers, which has been disputed for instance by Rufino et al. (2011). In agent-based models the decisions are also often based on profit maximization (Piorr et al. 2009). Furthermore, a long time horizon brings many uncertainties as to how future farm development will unfold in the context of multiple drivers of change acting at different levels. A scenario approach is therefore needed that can deal with both qualitative and quantitative information.

Hierarchical scenario development to arrive at scenarios at regional level has been performed in many studies (Abildtrup et al. 2006; Audsley et al. 2006; Dockerty et al. 2006; Rounsevell et al. 2003; Vandermeulen et al. 2009). These studies, however, focused on modeling spatial distribution of agricultural land use at regional and EU scale under global environmental (climate) change and policy drivers and did not consider farm structural changes induced by these drivers. Reidsma et al. (2006) made an attempt to project changes in intensity of farm types in order to assess changes in agricultural biodiversity, but this study lacked other farm structural characteristics besides intensity. Development of hierarchically consistent scenarios of farm structural change at farm and regional level defined by plausible directions of change in climate and socio-economic developments has not been performed previously. We need these scenarios to put climate change impacts into context of other drivers of change and to assess the impacts of more specific crop and farm level adaptation strategies to climate change in the long term.

1.1.3 Farmers multiple objectives

In many studies on assessment of adaptation to climate change using economic modelling, farmer's multiple objectives are neglected and farmers are seen as ultimate profit maximizers (Audsley et al. 2006; Seo 2010). Profit maximization is an appropriate assumption when exploring optimal farm plans (Janssen and van Ittersum 2007; Van Ittersum et al. 1998), but cannot always be used to project actual choices made by farmers (see also Rufino et al. (2011)). In reality farmers often choose for managerial options considering also other objectives, and they select options that are not necessarily the most optimal from an economic point of view.

Studies that do consider multiple and conflicting objectives generally focus on trade-offs between these objectives (Dogliotti et al. 2005; Groot and Rossing 2011; Tittonell et al. 2007). However, most of these studies did not pay attention to the importance of these objectives for the farmers and/or methods to derive this importance. As argued by Jones (2011), the methodology of weight elicitation and reporting of objectives is currently somewhat random and ad hoc in nature. The weights attached to different objectives are usually recovered through the existing cropping patterns, hence the actual behaviour of farmers is explained through assessment of a compromise between different objectives by modelling farm current performance (Berkhout et al. 2011; Gómez-Limón et al. 2003; Romero and Rehman 2003; Sumpsi et al. 1997). In other studies farmers were asked about their objectives in interviews. Different methods may, however, result in different outcomes, and comparing methods may shed light on differences between what farmers say, do and want.

1.1.4 Levels of adaptation: crop and farm level

There has been much more research on crop response to climate change than on human response to climate change (van Oort et al. 2012). The 5th IPCC Working Group II report (Porter et al. 2014) has focused mainly on crop level impacts and adaptation – based on the results of crop models and statistical analyses – with little emphasis on farm level adaptation. Empirical studies have compared climate change impacts in Europe with and without adaptation (Moore and Lobell 2014; Reidsma et al. 2010) and found that adaptation can largely reduce the impacts of climate change and climate variability on European agriculture.

Climate change impact assessment in agriculture needs to be based on integrated assessment and farming systems analysis, and account for adaptation at *different* levels and not just the crop level (Reidsma et al. 2015). The use of bio-economic models linking crop growth models with economic decision models has been suggested in various studies as a way forward towards integrated assessments of adaptation to climate change (Challinor et al. 2009; Finger and Calanca 2011; Lehmann et al. 2013; Olesen et al. 2011; Reidsma et al. 2010; Reidsma et al. 2015). Most studies with bio-economic models applied optimization techniques to identify adaptation strategies (Kanellopoulos et al. 2014; Lehmann et al. 2013; Schütze and Schmitz 2010). However, those studies solely addressed impacts of climate change and management on economic yield without considering the multifunctional role of agriculture. Multiple objectives have been considered, but not at farm level (Holzkämper et al. 2015; Klein et al. 2014b). I argue that in adaptation research it is important to consider farmers' multiple objectives when further assessing farm and crop level adaptation.

1.1.5 Institutional context

Institutions are the rules of the game in a society or, in other words, institutions are the constraints devised by humans that shape human interaction (North 1991). Under North's framework, institutions consist of both informal (customs, tradition, codes of conduct) and formal (laws, property rights) sets of rules, compliance procedures and moral and ethical behavioral norms designed to constrain individuals in their interaction within society (North, 1991). Although North's definition is probably the most cited one, it has also been criticized. In particular, other scholars have emphasized the potentially enabling properties of institutions for self-organization, besides constraining ones (Arts et al. 2006; Giddens 1981). From these definitions, the functions of institutions can be summarized as giving structure, building expectations, and setting both constraints and incentives for human interactions.

An enabling institutional environment is an important precondition for the implementation of adaptation measures (Adger et al. 2005; Nelson et al. 2007; Challinor 2008). Initially, the IPCC named economic resources, technology, information and skills, infrastructure, institutions and equity as the main determinants of the adaptive capacity of a society to climate change (Smit 2000). Later, the integral roles of institutions, governance arrangements and management practices were further emphasized (Brooks et al. 2005; Gupta et al. 2010; Yohe and Tol 2002; Engle 2011). As stated by the IPCC (2007), when institutions are supporting the social actors to anticipate and proactively respond to changes, other determinants of adaptive capacity improve and consequently adaptive capacity as a whole improves (Parry et al. 2007). Considering that climate change brings unpredictable changes, it calls for institutions that enhance the adaptive capacity of a society. In the latest IPCC report (Klein et al. 2014a), it was concluded that effective governance and institutions for facilitating adaptation planning and implementation across multiple sectors within regions is by far the dominant adaptation opportunity and constraint.

Many studies have focused on the adaptive capacity of institutions to cope with climate change. Recent literature on adaptation reveals different terms used to describe factors that may hinder implementation of adaptation from an institutional perspective (see review by Biesbroek et al. (2013)). Termeer et al. (2012) use the term institutional weaknesses. De Bruin et al. (2009) assess institutional complexities, while Moser and Ekstrom (2010) and Biesbroek et al. (2011) speak about barriers to climate change adaptation. However, none of those studies specifically focus on the agricultural sector.

While farmers can make decisions regarding crop and farm level adaptation measures directly, they are influenced by the institutional context. Assessing this context allows for a broader picture regarding adaptation to climate change for agriculture.

1.2 Objective and research questions

This thesis investigates adaptation measures to climate change for arable farming systems at multiple levels of organization (crop, farm and regional levels) using integrated assessment and a focus on farming systems. The integrated assessment approach includes scenario analysis on the drivers for future changes in agricultural systems; modelling the trade-offs between important farmers' objectives derived through a participatory process; assessment of adaptation measures in terms of improvement of farming systems performance on the important objectives; and an institutional analysis of the adaptive capacity to climate change.

The overall objective of this thesis is to improve climate change impact and adaptation assessment of agricultural systems by focussing on farm level adaptation and the broader context it is embedded in. This thesis is an interdisciplinary study that assesses not only adaptation to climate change for agricultural systems, but also the context within which climate change adaptation takes place.

The following research questions are linked to the different aspects of integrated assessment of adaptation to climate change and investigated in the thesis:

Farm structural change

- How to assess future structural change of farms in a region, under different plausible future scenarios?
- What will the farms of the future look like?

Farmers' multiple objectives

- What are the important farmers' objectives based on what farmers say, do and want?
- How do farmers' objectives relate to farmers' currently implemented practices and to preferred adaptation options?

Crop versus farm level adaptation

- What will be the impact of gradual climate change on farm performance?
- What will be the impact of the changes in future frequency of extreme events on farm performance?
- How important is crop level adaptation compared to farm level adaptation in improving farm performance on important objectives in climate change scenarios?
- How do different farmers' objectives influence preferences for different adaptation measures to climate change?

Institutional context

- How to assess the feasibility of implementing adaptation measures from an institutional perspective?
- What are institutional constraints for adaptive capacity to respond to climate change challenges?

Finally, in the general discussion of the thesis, I address the following questions:

- What future images of agriculture in Flevoland are to be identified, given the findings of this thesis?
- What methodological contribution does this thesis provide to climate change impact and adaptation assessment of agricultural systems?

1.3. Case study

The methods developed in this thesis are meant to be generic and not case study specific. I chose to work with the most productive agricultural region in the Netherlands, province Flevoland, with large scale, intensive arable farming as the main type of agricultural activity. Since the agricultural sector is important for the economy of the province, assessment of impacts of and adaptation to climate change in agriculture has a high relevance for this region. Flevoland had already been a hotspot for the research project Klimaat en Landbouw Noord Nederland (Climate and Agriculture in the North of the Netherlands), thus a participatory process was already ongoing and data availability was relatively good. Besides, Flevoland is considered somewhat representative for other productive agricultural regions, especially in Northern Europe.

Flevoland is the youngest province of the Netherlands, and was formed as a result of reclamation of the former Zuiderzee, later known as IJsselmeer. The first farmers settled in the Northern part of the current province (Noordoostpolder) during WWII. The province was originally designed to serve as an area for optimal agricultural production. High quality soils, good infrastructure, allotment of land (large, rectangular parcels convenient for management) and water availability made it possible to start up large specialized farms. Hence, Flevoland is an area having favourable conditions for agricultural production (Rienks 2009).

Agriculture in Flevoland plays a key role for development and spatial planning. About 75% of the area in the province (89086 ha) is used for agriculture (CBS 2012). Agriculture provides 5.5% of the Gross Regional Product and 6% of employment in Flevoland (in 2012 for the Netherlands these indicators were 1.6% and 2.4%, respectively). The dominating farm type is arable farming which comprises 78% of the total farm population and occupies 70% of utilized agricultural area (CBS 2012). In the past decades the agricultural area has decreased due to urbanization, expansion of infrastructure and natural areas.

Farms in Flevoland have been changing considerably during the last 30 years due to the changing economic and social environment in which they are embedded. A decline in number of farms and increase in farm size has been observed over the past decades. In the period 1980-2010 the number of arable farms decreased by 30%, whereas the average farm area increased by 20% (CBS 2012).

1.4 Thesis outline

This thesis is composed of six chapters, including this General Introduction (Chapter 1) and a Synthesis (Chapter 6). Following the aim of the research, the thesis chapters are focussed on the assessment of adaptation to climate change at different levels of organisation (Chapter 4) and on the assessment of the context of adaptation (Chapters 2, 3 and 5) (Figure 1.1).

Chapter 2 defines the context of adaptation to future climate change for arable farming systems by assessing the contribution of different drivers to farm structural change. In the first step current farm types and their distribution were identified using a farm typology. Next, a historical analysis was performed to assess the impact of important drivers (technology, policy, market and climate change) on the farm structure. The outcome of this step was the relative contribution of each driver to the changes in each of the farm structural dimensions (orientation, size, intensity, specialization). In the next step, socio-economic and climate scenarios were downscaled to the regional level to explore effects of changes in the drivers and subsequent changes in farm dimensions and characteristics towards 2050. First, the results on changes in farm dimensions were obtained at regional level. Subsequently, these were downscaled to the farm level using transition rules, resulting in scenarios of farm structural change.

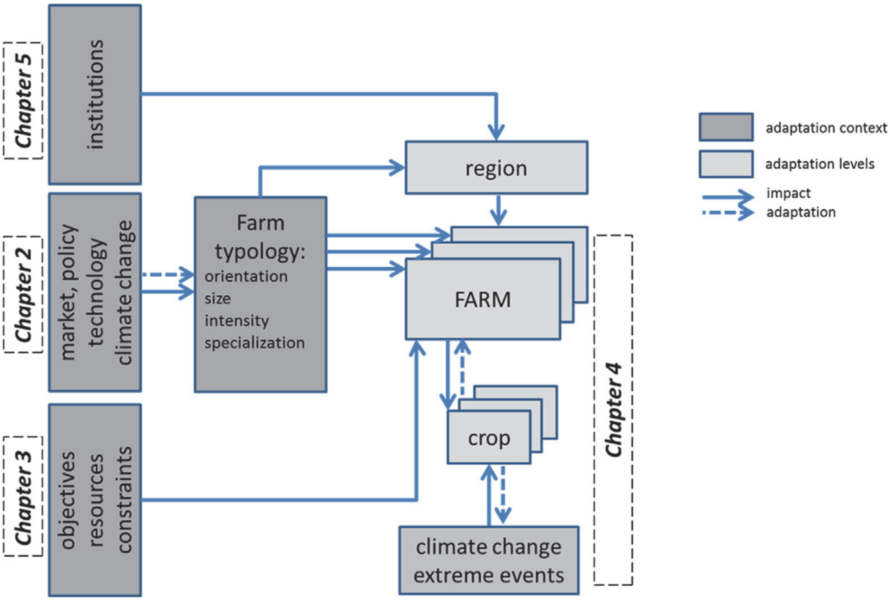

Figure 1.1 – Schematic outline of the thesis.

Chapter 3 further defines the context of adaptation to climate change and is focussed on assessment of important objectives of farmers. The procedure to derive importance weights for multiple objectives built upon different methods: interviews with farmers, assessment of current farm performance and preferred adaptation options. This chapter assessed how a farmer's stated objectives relate to his currently implemented practices and to preferred adaptation options.

Chapter 4 builds on the findings of Chapter 3 and focusses on assessment of adaptation measures at crop and farm level, considering farmer's multiple objectives. First, the impacts of gradual climate change and extreme events on farm performance were assessed in terms of the most important farmers' objectives (identified in Chapter 3). Next, the importance of crop and farm level adaptation measures for the improvement of farm performance was assessed considering the objectives. Chapter 4 further analysed whether different prioritizing in terms of objectives could influence preference for different adaptation measures to climate change.

Chapter 5 describes the development of a framework for the assessment of crucial institutional preconditions that facilitate the implementation of adaptation measures to climate change. The Procedure for Institutional Compatibility Assessment (PICA) was adopted and modified. Institutions in the framework are characterized by a set of crucial institutional preconditions (CIPs) and indicators linked to each CIP. CIPs refer to both institutional incentives and constraints for implementation of adaptation measures (here to climate change). Based on information from workshops, interviews and a literature review, a combination of ranking and scoring techniques was applied to assess institutional incentives and constraints for adaptation measures, together indicating the institutional feasibility of implementation of adaptation measures.

Chapter 6 synthesizes the preceding chapters by presenting images of the future of agriculture in Flevoland under contrasting socio-economic and climate scenarios with the focus on climate change adaptation. The contribution of the thesis to the current research on impacts and adaptation to climate change in agriculture is discussed, and conclusions are drawn.

Chapter 2

Scenarios of long term farm structural change for application in climate change impact assessment

Abstract

Towards 2050, climate change is one of the possible drivers that will change the farming landscape, but market, policy and technological development may be at least equally important. In the last decade, many studies assessed impacts of climate change and specific adaptation strategies. However, adaptation to climate change must be considered in the context of other driving forces that will cause farms of the future to look differently from today's farms. In this Chapter we use a historical analysis of the influence of different drivers on farm structure, complemented with literature and stakeholder consultations, to assess future structural change of farms in a region under different plausible futures. As climate change is one of the drivers considered, this Chapter thus puts climate change impact and adaptation into the context of other drivers. The province of Flevoland in the North of the Netherlands was used as case study, with arable farming as the main activity.

To account for the heterogeneity of farms and to indicate possible directions of farm structural change, a farm typology was developed. Trends in past developments in farm types were analyzed with data from the Dutch agricultural census. The historical analysis allowed to detect the relative importance of driving forces that contributed to farm structural changes. Simultaneously, scenario assumptions about changes in these driving forces elaborated at global and European levels, were downscaled for Flevoland, to regional and farm type level in order to project impacts of drivers on farm structural change towards 2050. Input from stakeholders was also used to detail the downscaled scenarios and to derive historical and future relationships between drivers and farm structural change. These downscaled scenarios and future driver-farm structural change relationships were used to derive quantitative estimations of farm structural change at regional and farm type level in Flevoland. In addition, stakeholder input was used to also derive images of future farms in Flevoland. The estimated farm structural changes differed substantially between the two scenarios. Our estimations of farm structural change provide a proper context for assessing impacts of and adaptation to climate change in 2050 at crop and farm level.

Keywords: Agriculture, adaptation, climate change, farm structural change, Flevoland

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2.1 Introduction

Globally, climate change became an important issue during the last decades. In many regions in the world one can observe effects of the changes in climatic conditions or climate variability on crop productivity, farmers' income and land use (Berry et al. 2006; Bindi and Olesen 2010; Bradshaw et al. 2004; Olesen and Bindi 2002; Reidsma et al. 2009). Also for the future of agriculture in a temperate zone such as The Netherlands the potential importance of climate change cannot be ignored, especially regarding effects of weather extremes (Bresser 2005; Peltonen-Sainio et al. 2010; Schaap et al. 2011; van Dorland 2008). However, changes in agricultural policy setting, market responses and technological development were shown to be at least equally important drivers of change for agriculture (Hermans et al. 2010). Due to the impact of these drivers, farms in The Netherlands have been changing considerably since World War II (Meerburg et al. 2009). Those changes affected not only the numbers of farms, but also accounted for new farm types through structural changes. Structural changes fall into the category of strategic (medium to long-term) investment decisions to fundamentally change farm size, specialization or production intensity (Zimmermann et al. 2009).

Impacts of future climate change are usually projected on current farms and cropping systems (Porter et al. 2014). Since the impacts of climate change will be relatively minor in the short term, assessments must be performed for a long time horizon (2050 in present study), when climate change will likely be more manifest. For such time horizon effects of other drivers must be considered. At the same time, assessments of impacts and adaptation strategies have focused primarily on food production (Porter et al. 2014), while in The Netherlands and Europe as a whole, multifunctionality has become more important. Effective adaptation strategies thus need to consider additional economic, social and environmental objectives, associated with the multifunctionality of agriculture. Therefore, one has to take into account that the farms in the future are not the same as the current ones: they will evolve through structural changes.

The most common quantitative method to study farm structural change is using econometric models, as shown in the review by Zimmermann et al. (2009), or agent-based models as applied by Piorr et al. (2009). However, nearly all of the past studies had short time horizons. Econometric models have been used to assess farm structural change due to climate change on the long term (e.g. Seo et al. 2010), but using the assumption that farmers are profit maximizers, has been disputed by Rufino et al. (2011). Furthermore, a long time horizon brings many uncertainties as to how future farm development will unfold in the context of multiple drivers of change acting at different levels. Agent-based models may provide a more realistic approach, but also in these models decisions are often based on profit maximization (Piorr et al. 2009). Valbuena et al. (2010) developed rules reflecting current farmers' behavior, but their study focused on specific decisions. Generally, when dealing with a long time horizon, these models cannot be used. A scenario approach is needed that can deal with both qualitative and quantitative information.

Hierarchical scenario development to arrive at scenarios at regional level has been performed in many studies (Abildtrup et al. 2006; Audsley et al. 2006; Dockerty et al. 2006; Rounsevell et al. 2003; Vandermeulen et al. 2009). These studies, however, focused on modeling spatial distribution of agricultural land use at regional and EU scale under global environmental (climate) change and policy drivers and did not consider farm structural changes induced by these drivers. Reidsma et al. (2006) made an attempt to project changes in intensity of farm types in order to assess changes in agricultural biodiversity, but this study lacked other farm structural characteristics besides intensity. Development of hierarchically consistent scenarios of farm structural change at farm and regional level defined by plausible directions of change in climate and socio-economic developments has not been performed previously. We need these scenarios to put climate change impacts into context of other drivers of change and to assess the impacts of more specific crop and farm level adaptation strategies to climate change in the long term. The aim of this paper is therefore to assess future structural change of farms in a region, under different plausible future scenarios.

The province of Flevoland in the Netherlands with large scale, intensive arable farming as the main type of agricultural activity has been chosen as a case study for the scenario development of farm structural change towards 2050.

2.2 Materials and Methods

2.2.1 Case study

Flevoland is the youngest province of the Netherlands, and was formed as a result of reclamation of the former Zuiderzee later known as IJsselmeer. The first farmers settled in the Northern part of the current province (Noordoostpolder) during WWII. The province was originally designed to serve as an area for optimal agricultural production. High quality soils, good infrastructure, allotment of land (large, rectangular parcels convenient for management) and water availability made it possible for starting up large specialized farms. Hence, Flevoland is an area having favourable conditions for agricultural production (Rienks 2009).

Agriculture in Flevoland plays a key role for development and spatial planning. About 75% of the area in the province (90820 ha) is used for agriculture (CBS 2009). Agriculture provides 5.5% of the Gross Regional Product and 6% of employment in Flevoland (in 2007 for the Netherlands these indicators were 1.8% and 3%, respectively). The dominating farm type is arable farming which comprises 70% of the total farm population and occupies 65% of utilized agricultural area (CBS 2009). In the past decades the agricultural area has decreased due to urbanization, expansion of infrastructure and natural areas.

Farms in Flevoland have been changing considerably during the last 30 years due to the changing economic and social environment in which they are embedded. We observe a decline in number of farms and increase in farm size over the past decades (Figure 2.1). In the period 1980-2010 the number of arable farms decreased by 30%, whereas the average farm area increased by 20% (CBS 2009).

2.2.2 General procedure

The procedure to assess structural change of farms for 2050 includes several steps (Figure 2.2). In the first step we identified current farm types and their distribution using a farm typology. In the second step, a historical analysis was performed to assess the impact of important drivers (technology, policy, market and climate change) on the farm structure. The outcome of this step is the relative contribution of each driver to the changes in each of the farm structural dimensions (orientation, size, intensity, specialization). In the next step, socio-economic and climate scenarios were downscaled to the regional level to explore effects of changes in the drivers and subsequent changes in farm dimensions and characteristics towards 2050. We first obtained the results on changes in farm dimensions at regional level. Subsequently, we downscaled these to the farm level using transition rules, resulting in scenarios of farm structural change.

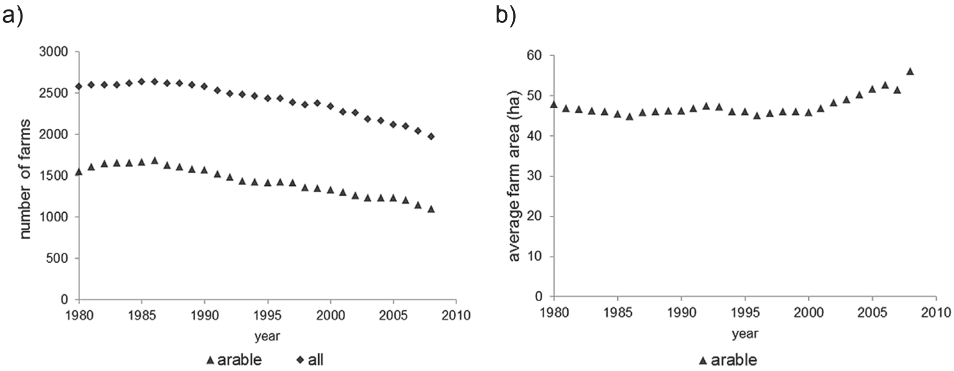

Figure 2.1 – Dynamics in a) farm population in Flevoland in 1980-2008; b) average area of arable farms in Flevoland in 1980-2008. Source: CBS.

2.2.3 Stakeholder input

To develop images on future farms in Flevoland, besides data and literature, we additionally used information from stakeholders (farmers, representatives of water boards, local policy makers). The stakeholder workshop was organized in the study area on the 1st of March 2010. The participants of the workshop contributed to the assessment of historical relationships between drivers and farm structural dimensions and to projections on future impacts of drivers on farm structural change in the scenarios. Their input was also used to derive images of future farms for the two scenarios.

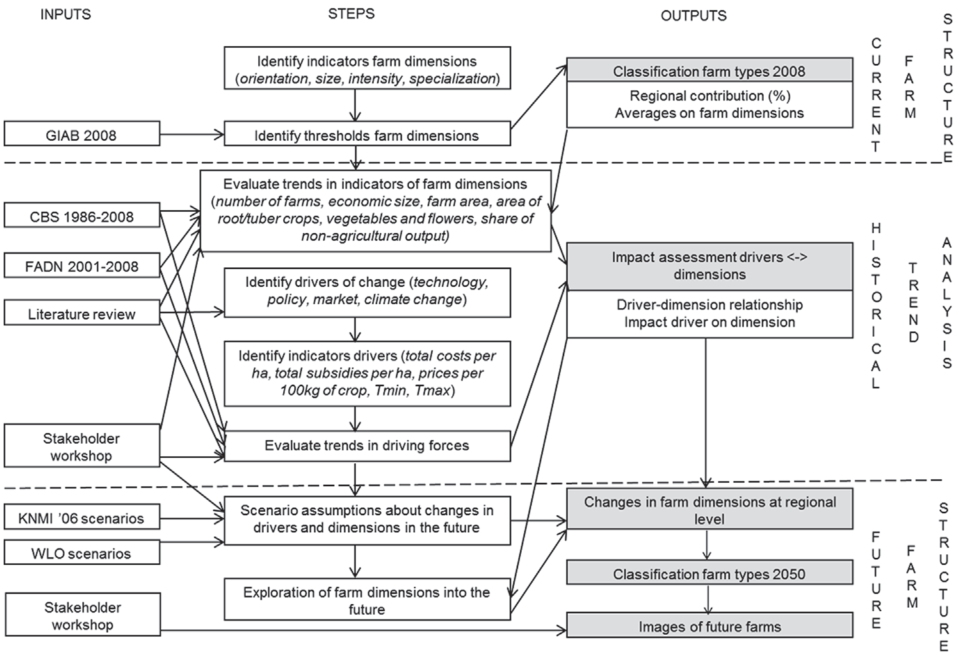

Figure 2.2 – Overview of the methodological approach to assess farm structural change. Abbreviations are explained in the text.

2.2.4 Classification farm types in 2008

To capture the variability in arable farming systems in Flevoland and their structural change in the future, the farm typology for farms in the European Union proposed by Andersen et al. (2007) was further specified for the region. The typology is based on the combination of four dimensions of which size, intensity, and specialization are similar to Andersen et al. Orientation (see below) was added as an extra dimension as it influences decision making of farmers and the landscape. An overview of the typology including thresholds for the dimensions is provided in Table 1.1.

The units of the dimensions of size, intensity and specialization and their thresholds are taken from the Dutch agricultural census. Farm size refers to the economic size of an agricultural holding and is measured in NGE. In 2008 1 NGE equaled to € 1420. It is a Dutch version of the European Size Unit (ESU), used to measure farm size across the EU and record it in FADN (Farm Accountancy Data Network). Intensity is measured in NGE per ha and thus refers to output intensity. Specialization is defined by the crops with the highest share in the standard gross margin (SGM) grown on a farm. Orientation was identified through the share of output from non-agricultural activities. We hypothesize that farms having different orientations adopt different adaptation measures when confronted with external changes, since orientation can point at farmers' objectives, or farming styles as defined by van der Ploeg et al. (2009). We distinguish three farm types based on their major objectives, or orientations: production-oriented, entrepreneur-oriented and nature conservation-oriented. These farm categories are recognized by Dutch policy makers (Dokter and Oppewal 2009; Jongeneel et al. 2008; Venema et al. 2009). To account for other functions agriculture can provide to a society, an entrepreneur-oriented type of farmers was included into the typology. These farmers diversify their income with alternative societal functions of agriculture: sustainable energy production, housing goods or animals (garaging), processing of agricultural products, recreation, education and care farming. Nature conservation farmers represent a separate orientation due to the significant role nature conservation plays in Dutch agriculture (Daniel and Perraud 2009). For assigning all individual farms to the farm typology the Geographical Information System for Agricultural Businesses (GIAB) was used, containing all 1114 arable farms in Flevoland for the year 2008.

Table 2.1 – Farm typology (dimensions and thresholds) used in the research. Each farm type is defined by a size, intensity, specialization and orientation dimension.

Dimension	Division/Class	Thresholds/Description
Size (NGE[1])	Small	<20
	Medium	20-70
	Large	70-150
	Extra large	>150
Intensity (NGE/ha)	Low	<1.3
	Medium	1.4-2.0
	High	>2.1
Specialization	Specialized root crops	sugar beets and potato > 2/3 SGM[2]
	Specialized flower bulbs	flower bulb > 2/3 SGM
	Specialized vegetables	vegetables > 2/3 SGM
	Diverse mainly root crops	1/3 < sugar beets and potato< = 2/3 SGM and cereals, maize, peas, rapeseed, sunflower, natural area AND vegetables > 2/3 SGM
	Diverse arable	all arable > 2/3 SGM
Orientation	Production	no multifunctional activities or <= 10% output from 1 multifunctional activity
	Entrepreneur	> 10-50% output from multifunctional activities OR <10% + minimum 2 different activities
	Nature conservation	farmer participates in nature conservation

[1] NGE is a national size unit, representing gross income from cultivation of a certain crop or from keeping a certain animal (CBS 2008), equaling 1420 € in 2008.

[2] SGM is a standard gross margin of a crop.

2.2.5 Historical trend analysis

In our research we considered four major drivers for farm structural change in the future. Literature and historical data analysis showed that farm structural change is mainly influenced by technological progress, policy intervention and market developments (Koomen et al. 2005; Meerburg et al. 2009; van Bruchem and Silvis 2008). As the aim of this paper is to put climate change impacts into context, for further investigation we chose as drivers technology, policy, market, and climate change.

We first performed historical trend analyses for all typology dimensions (orientation, economic size, intensity, and specialization) to observe the dynamics in structural change. Secondly, historical trend analyses were performed for the drivers, and lastly the relationships between dimensions and drivers were analysed. The major data source for the historical analysis was the Dutch agricultural census accessed through Statistics Netherlands (CBS). These data provide the following information for agricultural development in Flevoland and the Netherlands over the period 1986-2008: total number of farms per year and average values for economic size and area of arable farms, area of most important crops, and dynamics in yields and prices. The data on multifunctional activities (number of farms implementing the activities, types of activities and percentage of total economic output from these activities) were available since 2003. However, these data were not complete and consistent. This is mostly attributed to the procedure the data have been collected: there are different data sources and different definitions of multifunctional activities (Roest et al. 2010). Additional data at farm level were obtained through a sample of individual farms (on average, 25 observations for Flevoland and 165 for the Netherlands per year) from the Dutch FADN for the period 2001-2008. The information in the dataset included farm management (e.g. costs of fertilizer), farm structural (e.g. farm size) and additional characteristics (e.g. total subsidies).

Changes in values of each of the dimensions over time were assessed through selected indicators. For size and intensity these were the same as used for the farm typology (Table 1.1), but for the categorical dimensions, numerical variables needed to be selected. For specialization we selected area of root crops, flower bulbs, and vegetables (% in total arable and non-greenhouse horticultural land); and for orientation: the share of non-agricultural output (% from total economic output). For farm size additionally we considered the farm size in ha.

Indicators were also assigned to drivers, to study the impact of each driver on farm structural change. The indicators were selected on the basis of similar studies that were investigating impacts of certain drivers on farm level responses (e.g. Reidsma et al. 2010). For technology we used variable input costs for cultivating 1 ha of ware potato (€/ha) and winter wheat (€/ha); for policy: total subsidies (€/ha); for market: prices for ware potato (€/100 kg) and winter wheat (€/100kg); for climate: minimum and maximum annual temperature (°C).

The relation between each driver and dimension was investigated based on i) correlation and regression analysis using regional level data from 1986-2008 (CBS); ii) correlation and regression analysis using farm level data from 2008 (FADN); iii) literature review on the contribution of each driver to the change in each dimension (Smit 2004; van Bruchem and Silvis 2008); iv) stakeholder workshop. The four methods mentioned above give qualitative (literature review and stakeholder workshop) and quantitative (statistical analyses) results on the contribution of each driver to the change in each dimension. Consequently, all four methods are considered to assess the relation between the driver and dimension: i) no significant impact on structural change; ii) impact on structural change; iii) strong impact on structural change.

2.2.6 Assessing future farm structural change

Scenarios

We used two plausible contrasting scenarios regarding future climate and socio-economic change to assess future farm structural change. For assessing impacts of climate change towards 2050 we used scenarios from the Royal Dutch Meteorology Institute (KNMI) (van den Hurk et al. 2006). The G climate scenario assumes a moderate temperature increase of 1°C by 2050, whereas the W scenario assumes a significant temperature increase of 2°C by 2050. To account for possible future trends in socio-economic developments, we used scenarios A1 Global Economy and B2 Regional Communities from the commonly used Dutch WLO scenarios (van Drunen and Berkhout, 2008). These scenarios are adapted from Westhoek et al. (2006) for the situation in the Netherlands, and are similar to the IPCC SRES scenarios (Nakicenovic and Swart 2000). Following suggestions of Henseler et al. (2009) we assume that the more economically and globally oriented A1 scenario goes with a significant temperature increase of 2°C by 2050, i.e. the W scenario. The more environmentally and regionally oriented B2 scenario is assumed to match with a moderate temperature increase of 1°C by 2050 represented by the G scenario. These combined scenarios were used by Riedijk et al. (2007) to assess future land use in Flevoland for the year 2040. We extrapolated their results on total arable land towards 2050 and used these in our study.

Drivers at regional level

Per scenario, we analyzed possible developments in drivers impacting structural change. We used the same indicators for drivers as in the historical trend analysis. Applying scenario assumptions on changes in technology, policy, market and climate (Table 2.2) we projected the impact of two scenarios on the indicators for these drivers.

Table 2.2 – Assumptions on development of drivers and dimensions per scenario.

Driver	Indicators	A1	B2	Source
Technology	Total costs	Continuation of historical trend	25% of continuation of historical trend	Own assumption based on Ewert et al. (2005),[1]
Policy	Subsidies	No crop subsidies and price support	Subsidies for environmental and social services	European Commission (2010)
Market	Price wheat Price potato	+68 % increase +15% increase	-11% decrease +5% increase	Ewert et al. (2011)
Climate change	Temperature	+2 °C increase	+1 °C increase	KNMI scenarios (van der Hurk et al. 2007)
Dimension				
Size	NGE & ha	Continuation of historical trend	25% of continuation of historical trend	Own assumption based on Abildtrup et al. (2006) and Janssen et al. (2006)
Intensity	NGE/ha	Depends on changes in size and specialization	No increase possible	Own assumption based on Janssen et al. (2006)
Specialization	Crop areas	Continuation of historical trend	25% of continuation of historical trend	Own assumption based on Janssen et al. (2006)
Orientation[2]	Nature Enterpreneur	0% 30%	For both: all farms that can increase their income with multifunctional activities	Own assumptions and stakeholder consultations

[1] Estimations in Ewert et al. (2005) referred to technology development represented by yield changes. In B2 yield changes were assumed to remain stable. We assume a slight increase in total costs, considering the development of clean and energy saving technology.
[2] Too few data were available to extrapolate. These general assumptions are further detailed in the downscaling to farm level.

Developments in technology will be of a different nature in the two scenarios. While in A1 technological progress will be related to further increase crop productivity accompanied with necessary intensification of production, in B2 the focus will be on clean and energy saving technology, which does not necessarily lead to higher production intensity. The Common Agricultural Policy (CAP) is assumed to develop differently in A1 and B2. In A1 we assume adoption of option 3 proposed by the European Commission (EC) in November 2010, which implies abolishment of direct payments and introduction of small payments for environmental public goods. In B2 we see the CAP to be similar to option 1 as proposed by the EC: maintaining levels of payments for social and environmental services. Future market developments in these scenarios are assessed through changes in prices for agricultural commodities using the CAPRI model (Britz 2005; Ewert et al. 2011). The simulated price scenarios comprise changes on the supply side (yield changes due to climate change and technological development) as well as on the demand side (population and GDP). While in A1 there will be considerable increase in prices for wheat and ware potato due to large increase in demand, in B2 the prices will slightly increase (potato) or decrease (wheat).

Dimensions at regional level

At regional level, farm structural change is represented by changes in regional average values of each of the typology dimensions. These were estimated using three steps. First, we extrapolated historical trends (see e.g. Figure 2.1) in the farm structural dimensions towards 2050, considering different types of functions (linear, exponential, logarithmic) and time periods. The best fitting and explanatory function and time period were used for extrapolation. Scenario assumptions in A1 (B2) on changes in dimensions were used to adjust these extrapolations (Table 2.2). This method yields first estimations based on historical trends.

Secondly, the outcomes from the historical analysis and the development of drivers per scenario show which drivers are important for changes in farm type dimensions in the future. Consequently, the drivers that will have a strong influence on a dimension in the future are used to derive future regional values for the particular dimension. For this we first obtained a statistical relationship (regression) between each impacting driver and a structural dimension. Then we linearly extrapolated the historical trend of the indicator for the drivers that showed significant trends over time, towards 2050. Next, we used A1 (B2) scenario assumptions on changes in drivers in the future and generated the future value for the indicator for a driver. Finally, we used the projected indicator value and the statistical relationship between the corresponding driver and structural dimension to derive values for a structural dimension in the A1 (B2) projection.

Thirdly, both methods were combined and qualitatively interpreted, based on literature and stakeholder consultations. The first method uses historical information on dimensions itself, but ignores the influence of specific drivers. The second method allows to correct projected changes for changes in the drivers. However, a statistical relationship is not necessarily causal and the regression function may be influenced by other factors. Furthermore, even when literature and stakeholders are supportive of relationships, this may not be represented by the data. In some cases, the influence of drivers therefore had to be interpreted more qualitatively. For each dimension, the used procedure is explained in the results section.

Classification farm types in 2050

The current farm typology together with projections on changes in regional averages of structural dimensions towards 2050 were used to assess farm structural change, resulting in a classification of farm types in 2050. Transition rules were developed for the downscaling of regional to farm type level. The structural dimensions for which projected regional averages had a solid statistical basis, were used as a starting point.

As this differed for the A1 and B2 scenarios, the resulting rules were slightly different. Overall, the rules can be summarized as follows:

1. Based on the historical analysis, make assumptions on changes in size classes (stable, decrease, increase).
2. In each size class (starting with the ones that are projected to decrease in number), farms have several options:

a) increase size, b) increase intensity, c) change specialization, d) change orientation, e) stop, f) remain without changes. For each option, the average % change of all farm types should be similar to the projected regional average. In general, it is assumed that the average farm area (in ha and NGE), intensity (in NGE/ha) and crop areas per farm type remain the same. How these rules were applied exactly will be further detailed in the Results section.

2.3 Results

2.3.1 Classification farm types in 2008

In Figure 2.3 and Appendix 2.A we summarize the distribution of farm types in Flevoland in 2008. The currently dominant farm type is production oriented-large size-medium intensive-diverse: mainly root and tuber crops (19.3% of area). This farm type has an average economic size of 104 NGE and area of 64 ha. At regional level, the vast majority of farms is production-oriented (88.5%). Large and medium intensive farms are prevailing. In terms of specialization, most farms are diverse, with mainly root and tuber crops.

2.3.2 Regional level: historical trends of dimensions

The outcomes of the historical trend analyses over 1986-2008 per farm structural dimension show that there was a slight increase in farm size, which was related to an increase in intensity up to 2001, and to an increase in farm area in the last years (Figure 2.4a, b). With farm area increasing faster than NGE, intensity decreased in the last decade. One of the reasons for an increase in average area is that the number of farms with the size of 50-100 NGE decreased dramatically (Figure 2.4c). There have been clear changes in specialization (Figure 2.4d). Area of root and tuber crops is currently decreasing in Flevoland (mainly sugar beet) after a period of slight increase (potato) and stabilization (sugar beet) in the 1980's and 90's. The areas of vegetables and flower bulbs increased, but the latter remains low in comparison to other crop areas. As to orientation, for the last 10 years (since the data is available) the percentage of farm output from multifunctional activities has varied significantly (Figure 2.4e). This variation is most likely due to a change in the way data are collected. Currently, the most popular multifunctional activities, according to CBS (2009), include work loan, nature conservation, and garaging (keeping goods or animals on the farm).

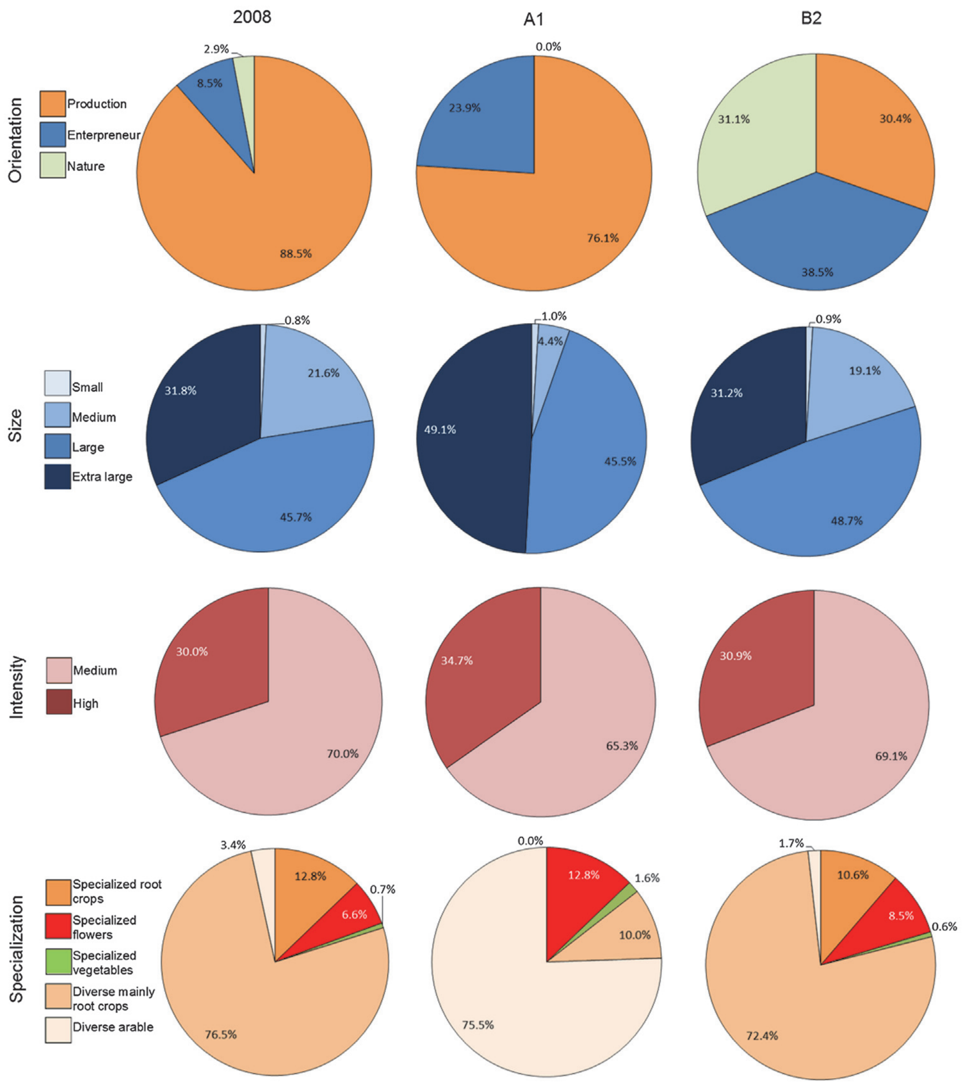

Figure 2.3 – Regional farm type distribution and structural change in % from utilized arable area.

2.3.3 Historical driver – dimension relationship

Changes in farm type dimensions were mainly attributed to technological progress, market development, and policy; climate seemed to have less influence (Table 2.3, Figure 2.5). In some cases the relationship between a driver and dimension was not confirmed by the statistical analyses, whereas literature review and stakeholder interactions had pointed at a relationship.

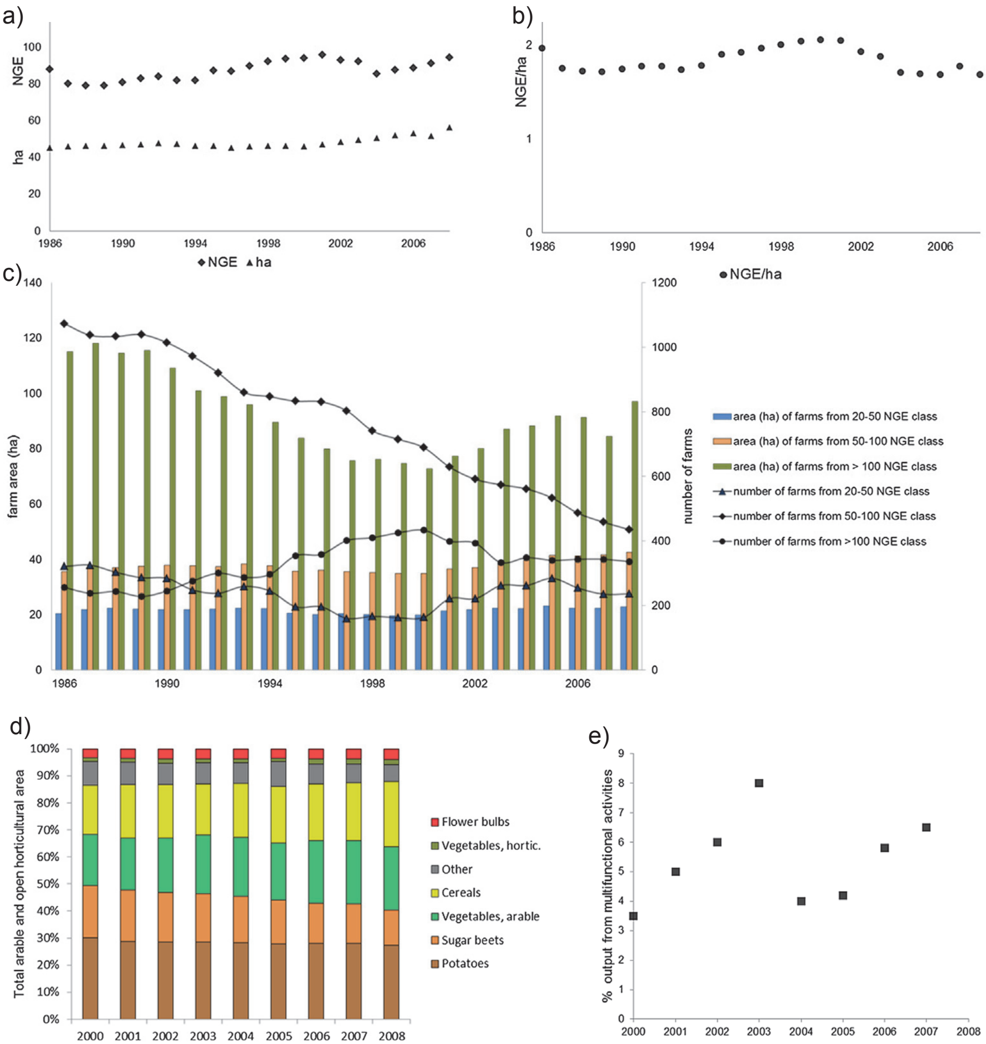

Figure 2.4 – Changes in structural dimensions in time: a) farm size (NGE and ha); b) farm intensity (NGE/ha); c) numbers of farms in different size classes and their average farm area (ha); d) areas (%) of crop types; e) percentage of farm output from multifunctional activities. Source: CBS.
For Figure 4d only data from 2000 onwards are presented, because the way data are collected changed. In the period 1986-2000 the % of sugar beet area in total area was stable, while the areas of potato, vegetables and flower bulbs increased.

Regarding orientation, literature (e.g. Roest et al. 2010) and stakeholders learned us that policy incentives stimulated adoption of non-agricultural activities (Table 2.3). The impact from market was indirect: the farmers looked for alternative sources of income due to a decrease over time in prices for the major crops. Both relationships were not reflected in statistics (Figure 2.5) due to short time series and unreliable data on multifunctional activities.

Table 2.3 – Contribution of drivers to farm structural change based on historical analysis.

dimension (indic.) / driver (indicator)	Orientation (share of non-agricultural output)	Farm size (NGE)	Intensity (NGE/ha)	Specialization (area root crops, flowers, and vegetables)
Technology (input intensity)	0	++	0	++
Policy (subsidies)	++	0	+	+
Market (prices)	+	++	0	++
Climate change (T)	0	0	0	+

0 no significant impact on structural change
+ impact on structural change
++ strong impact on structural change

Farm size was influenced by technology and market (Table 2.3). Increase in crop productivity was mainly caused by technological advances (input intensity, efficient machinery, new crop varieties with higher yields and pest/disease resistance, new management techniques). The output prices define to a large extent farm gross income and therefore they influence farm economic size. While prices for the major crops in Flevoland decreased over time, farmers took some advantage of economy of scales to increase farm size and compensate for low prices. The correlation between farm size and temperature is not considered causal (Figure 2.5), as both gradually increased over past decades.

Intensity was only influenced directly by policies (Table 2.3). Although productivity increased, the NGE unit is adapted over time to reflect developments in technology and markets. Farmers receiving more subsidies, however, have less need to intensify, and subsidies can also be made dependent upon stopping intensification (cross-compliance).

As to specialization, technological developments in crop production (e.g. machinery for large scale vegetable production) and market prices influence crop choice. Crops with high gross margins like root and tuber crops, vegetables and flower bulbs increased their share in a typical rotation in Flevoland. Specific crop subsidies or quotas (e.g. for sugar beets) also influenced crop choice on farms (van Bruchem and Silvis 2008). So far, in Flevoland there is no strong evidence of climate change impact on crop choice or any of the other dimensions of the farm typology. Figure 2.5 shows a correlation between temperature and area of root and tuber crops, but the increase in these crops over time is attributed to other factors (literature, stakeholders) and not related to the simultaneously increasing temperature. Nevertheless, as shown in Olesen and Bindi (2002) and Reidsma et al. (2007) there is spatial variability in yields and crop choice within Europe through impact of climate conditions.

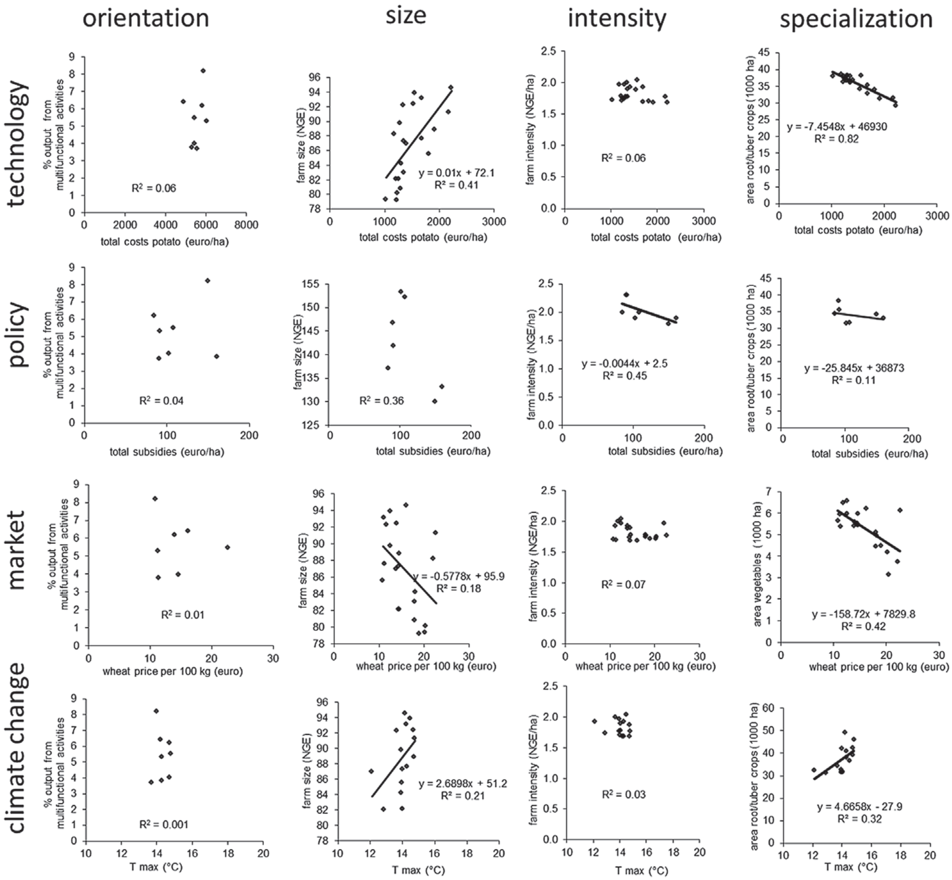

Figure 2.5 – Statistical relationships (correlation) between drivers and structural dimensions. Source: CBS, except for the indicator for driver of policy (total subsidies) and the indicator for dimension of orientation (% output from multifunctional activities) which were taken from FADN. Regression function is shown only in cases when the relationship is significant ($p < 0.05$).

2.3.4 Future driver-dimension relationship

Applying the scenario assumptions on changes in technology, policy, markets, and climate (presented earlier in Table 2.2) we projected the impact of drivers per dimension in two scenarios (Table 2.4). Overall, impacts are similar to Table 2.3, but the size depends on the change in drivers, which is different for the A1 and B2 scenario. Next to size of impact, types of impact can also differ. As mentioned earlier, in B2 the technology changes will be in the direction of energy-saving and environmentally friendly, which will have less influence on farm structure than in A1. For orientation, policy is the major driver that has a different focus per scenario with respect to stimuli for adoption of particular non-agricultural activities on the farm.

Table 2.4 – Impact of drivers on farm structural change in future scenarios.

		dimension (indic.) / driver (indicator)	Orientation (share of non-agricultural output)	Farm size (NGE)	Intensity (NGE/ha)	Specialization (area root crops, flowers, and vegetables)
			A1			
Change in drivers	++	Technology (input intensity)	0	++	0	++
	++	Policy (subsidies)	++	0	+	+
	++	Market (prices)	+	++	0	++
	++	Climate change (T)	0	0	0	+
			B2			
Change in drivers	+	Technology (input intensity)	0	+	0	+
	+	Policy (subsidies)	++	0	+	+
	+	Market (prices)	+	+	0	+
	+	Climate change (T)	0	0	0	+

0 no significant impact on structural change
+ impact on structural change
++ strong impact on structural change
Magnitude in change in drivers (0 no change, + slight change, ++ significant change) is derived from Table 2.3.

2.3.5 Future farm structure

Dimensions at regional level

As different methods were combined to derive regional averages of farm structural dimensions (Table 2.5), we first describe the procedure and present results of intermediate steps. Although our aim was to provide a transparent and consistent methodology, heterogeneity in data availability and ambiguous relationships between dimensions, drivers and time, required also decisions based on expert knowledge and qualitative interpretation.

When linearly extrapolating farm size in NGE for A1, we obtain a value of 118 NGE (25% of this for B2 is 101 NGE; Figure 2.6a). Considering the regressions with technology (Figure 2.6b) and markets (the drivers impacting farm size; see Table 2.4) and scenario assumptions for these drivers (Figure 2.6c), results in slightly lower values (Figure 2.6d). NGE is however a difficult unit; it depends mainly on the type of crops cultivated and the farm area used for this. We had to investigate this before coming to a final value.

Table 2.5 –Regional averages of farm structural dimensions.

Dimensions	Structural characteristics	2008	A1	change	B2	change
	Arable UAA, 10^3 ha	78[1]	68[2]	-13%	72[2]	-8%
	Number of arable farms	1100[1]	716[3]	-35%	962[3]	-13%
	Average farm area, ha	56[1]	75	+34%	59	+6%
Size	Average size, NGE	95[1]	128	+34%	98	+4%
Intensity	Average intensity, NGE/ha	1.7[1]	1.7	0%	1.7	-2%
Specialization	Area root/tuber crops, % arable UAA	40[1]	26	-36%	37	-9%
	Area vegetables, % arable UAA	26[1]	38	+51%	29	+13%
	Area flower bulbs, % arable UAA	4.0[1]	6.4	+60%	4.6	+15%
Orientation	Entrepreneur oriented farms, % of farms	8[4]	30	+275%	30	+275%
	Nature oriented farms, % of farms	2[4]	0	-100%	30	+1400%

[1] CBS
[2] Extrapolated from 2040 values as projected by Riedijk et al. (2007)
[3] Calculated by dividing future arable UAA by projected average farm area. It is assumed that the % arable UAA in arable farm types remains stable, as was the case in the past
[4] GIAB

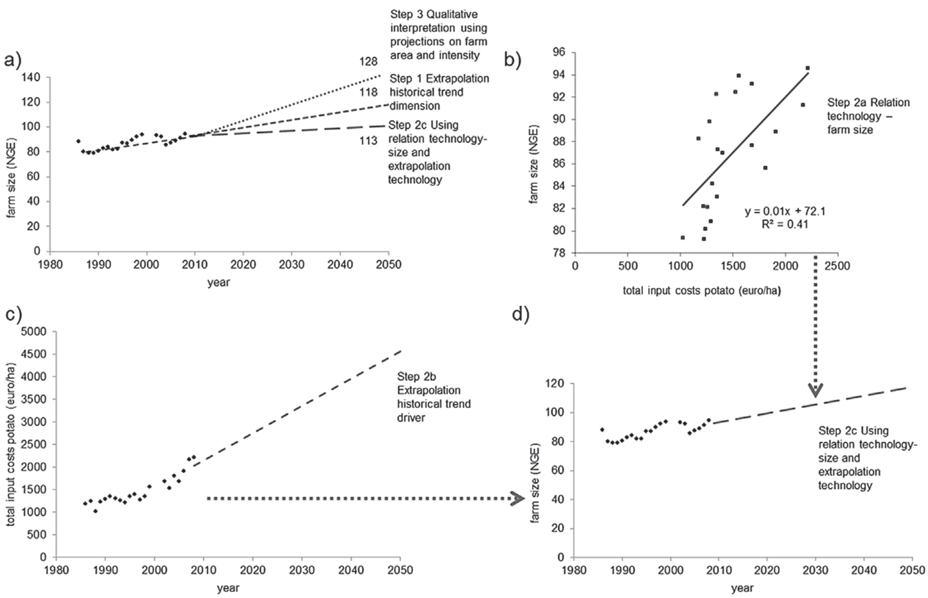

Figure 2.6 – Schematic representation of procedure to derive future farm size in A1 scenario, with a) summary of all steps, b) Step 2a relationship driver-dimension, c) Step 2b extrapolating historical trend driver, d) Step 2c projection dimension based on driver. Source: CBS.

If the increase in farm area since 1995 continues, this results in an average farm area of 84 ha (see Figure 2.4a). Using the relationship with technology (Figure 2.5), we obtain a lower value, and we use the average of both, 75 ha, as the projection for A1 (59 ha in B2) (Table 2.5). As the statistical relationship between farm area and input costs (technology) is much stronger than the relationship with product prices (market) (Figure 2.5), the latter is not used for the projections.

Using values on changes in NGE and in ha as calculated with these two quantitative methods, results in a faster increase in area than NGE, and therefore a decreasing intensity. However, in A1 with increasing areas of vegetables and flower bulbs, it is likely that intensity remains stable. Therefore we calculate the final value for farm size based on the projected value for farm area and a stable intensity (Figure 2.6a; Table 2.5). In B2, intensity can decrease (Table 2.2), and values for farm size and farm area are used to calculate change in intensity.

With regard to specialization, it is clear that potato area is relatively stable (Figure 2.4d), sugar beet area is quickly decreasing, while projecting change in vegetable area depends on the statistical relationship (linear, exponential, logarithmic) and time period taken. It is likely that in A1 sugar beet will disappear (following the trend, further liberalization) and will be replaced by vegetables like onion and carrots (possible due to technological development and high market value). For flower bulbs a linear trend is extrapolated. In the B2 scenario projected changes will be 25% of the historical trend, resulting in similar but smaller changes.

Lastly, orientation will change. In A1 there are no subsidies for nature conservation, so these farms will disappear. Increase in share of entrepreneurial, or multifunctional farming happens, since farmers seek alternative sources of income due to changes in the agricultural policy paradigm (abolishment of payments and little alternative subsidies). It is assumed that 30% of the farmers will be entrepreneur in 2050. In B2, multifunctional activities become profitable when alternative income and subsidies exceed gross margin of crops. It is assumed that also in this scenario 30% will become entrepreneur, and another 30% will become nature oriented. These assumptions are made on the basis of literature review (e.g. Jongeneel et al. 2008, European Commission 2010), and were discussed with stakeholders.

In summary, in A1 large changes are projected for all dimensions, while in B2 the main change is the one in orientation.

Farm level structural change and classification farm types in 2050

At regional level, several changes are very clear in the A1 scenario. Already now, medium sized farms are quickly reducing in number (Figure 2.4c), and it is projected that medium sized production oriented farms cannot remain viable. If all these medium sized farm except for the ones specialized in vegetables and flower bulbs disappear, we come close to the 384 farms that were projected to stop (Table 2.5), and to projected regional averages of size in NGE and ha.

Not all disappearing medium sized farms stop, but some increase farm area (resulting in higher size class), some change specialization and some become entrepreneur. Considering that the resulting average size was similar to projected regional average, we can assume that the number of these medium sized farms moving to large farms is similar to the number of large farms stopping. Only farms specialized in vegetables and flower bulbs move to large size (see Appendix 2.A).

With regard to specialization, in A1 it is projected that all sugar beets are replaced by vegetables. This implies that 'specialized: root crops' become 'diverse: mainly root crops' and the latter become 'diverse: arable'. Farms specializing in vegetables are mainly the horticultural ones, and not much change in area is foreseen here (see Figure 2.4d). Using regional average changes in dimensions as boundaries for changes, we have to conclude that the increase in area of flower bulbs has to come from an increase in the average area of very large farms.

Lastly, it was projected that 30% of the farmers become entrepreneur. Currently, only medium and large sized farms are entrepreneur, and they are all medium intensive. It was assumed that 10% of the medium sized production oriented farms could remain viable by becoming entrepreneur; the other entrepreneurs are large farms. In addition, if these medium sized farms remain instead of stop, this implies that some large farms move to very large, so that the regional projected average is reached.

In the B2 scenario, much less changes occur. As medium sized farms can remain viable, it was assumed that the projected decrease in farm number by 13% occurred in medium, large and very large farms to the same extent. Secondly, the increase in size of 4% needs to come from medium sized farms, as the increase to very large farms is assumed to be restricted. For specialization the same rules are applied as in A1, but as the vegetable area only slightly increases, the contribution to SGM does not cross thresholds, and specialization types remain the same. The main change in B2 is the change in orientation. For the transitions, we assumed that all the medium intensive farms can earn more per ha by moving to other orientation types, resulting in 70% of the farmers compared to the earlier assumed 60%. Currently, 20% of the multifunctional farmers have nature conservation area, but in the B2 scenario we assume this becomes 50%.

The results on classification of farm types in 2050 in two scenarios are given in Appendix 2.A. The most important farm type in A1 is production oriented-very large-medium intensive-diverse: arable (16%), similar to current, but one size class larger and a change from 'diverse: mainly root crops' to 'diverse: arable' due to disappearance of sugar beets. In B2 the largest type is entrepreneur oriented-large-medium intensive-diverse: mainly root crops (15%). The aggregated farm level results are shown in Figure 2.3.

Images of future farms

Images of farms of the future (in 2050) in Flevoland for two scenarios were derived from the farm structural change scenarios, complemented by stakeholder visions.

As presented in the previous section, in the A1 scenario a typical farm is a large scale, capital intensive holding with the average farm size of 130 ha. In the stakeholder workshop, farmers, however, would expect this farm to be larger by 2050, i.e. 150-180 ha. This can be achieved through a considerable share of rented land in the total amount of utilized agricultural area (up to 75%). The farm is operating in a close collaboration with neighbouring farms in terms of management operations and (partial) processing of the products. Technical advances on such farm are the attributes of precision agriculture, which contribute to high labour efficiency and productivity. Production is focused on seed and ware potato. Stakeholders expect Flevoland to guarantee its position in export of seed potato by maintaining the high quality of the product. Sugar beet cultivation disappears due to the high competition on the global sugar market. Besides vegetables, as a substitute for sugar beet in a bio-based economy scenario local stakeholders mentioned energy crops. The quality issue remains important for all groups of products, driven by consumer preferences. Efficient arrangement of processing of products on the farm makes favourable conditions for retail sales. In general, the production-processing-delivering chain is highly technically efficient on this farm. The major "survival" strategy for this farm type is orientation on the world market where it has guaranteed its niche through delivering high quality products (ware and seed potato, vegetables) and innovative technology.

A typical farm in the B2 scenario is multifunctional with a projected farm size of 64 ha (see Appendix 2.A); farmers foresee an average area up to 80-120 ha. According to the stakeholders, this farm type will mostly produce organically. The output intensity is kept to the current level through strict environmental legislation aimed at limiting growth potential of agriculture. The share of rented land varies between 50 and 75 %. Cooperation between neighbours is strongly supported by regional development policy. Technological progress is focused on environmentally friendly production means (environmentally beneficial technology) and development of biological crop varieties. The balance between consumer demand and production supply is regionally based. A farm becomes a part of a local market chain (retail, direct sells from a farm, local supermarkets). Traditional crops dominate in the arable farm specialization: consumption potato, seed potato, winter wheat, and sugar beet.

In general, the projections on future farms based on historical analysis were supported by the vision of stakeholders. The main mismatches between the farmers expectations and quantitative projections are found in estimation of future farm area.

2.4 Discussion and concluding remarks

We presented a method to assess farm structural change at regional and farm level towards 2050, which was not previously performed for such a long time horizon. The analysis shows that historical trends, consistent scenario assumptions and stakeholder input can be used to derive regional and farm level estimations of farm structural change and plausible images of arable farms towards 2050. This information on farm structural change provides a better basis for assessment of impacts of and adaptation to climate change than the current farms.

2.4.1 Limitations and qualifications of the methodology

We experienced that the proposed methodology was not straightforward to implement. A limitation of the method is that it relies on availability of good historical data on farm structure. For some dimensions, such as orientation, this was lacking in our case. Data on multifunctional activities were not complete and consistent. Therefore, we made assumptions based on literature review and consulted stakeholders regarding transition of farms from production oriented towards entrepreneur and nature conservation types. Our assumption was partly confirmed, as the total % of multifunctional farmers as projected based on literature and stakeholder consultations in B2, 60%, was similar to the number of medium intensive farms, i.e. 70%. Those are the farms that may earn more with multifunctional activities than with agricultural activities. The exact percentage and distribution between entrepreneurs and nature oriented farms depends on how budgets for nature conservation and other environmental and social services will be allocated. Stakeholders indicated that most farmers in Flevoland will change their activities if they can earn money with it; on the other hand it is also clear that most of them prefer to select only one additional activity to focus on.

A second limitation is, that our indicator choice is debatable. Ewert et al. (2005) proposed to model technological progress through potential yield and the gap between actual and potential yield. We used variable input costs as a reflection of technological progress. For the quantitative analysis based on statistics we chose to work with one indicator per driver to assess the impact of each driver on farm structural change and to assess the impacts of scenario assumptions on a driver. Yet, scenarios are too complex and cannot be reflected by just one indicator per driver. Therefore we complemented the results based on the drivers with results based on the dimensions itself and with literature review and stakeholders' perspectives.

Transition rules to downscale the regional results to the farm type level could not be developed independent of the scenarios assumptions and results at regional level. The way farm type dimensions and their thresholds are defined differs per dimension, and the same holds for the related scenario projections at regional level. Therefore, it appeared that using the regional level results as boundary conditions for changes at farm level, resulted in more reliable and consistent projections than using general transition rules.

Our results are reflecting the application of a positive rather than a normative approach (see e.g. Waldhardt et al. (2010)), i.e. projections are based on what can be expected, not on what is aimed for or desirable from a normative point of view. Grounded in historical data analysis, the results give predictions on possible developments in drivers and in farm structural characteristics influenced by the drivers. The stakeholders (farmers, representatives of farmers organizations and water board) agreed on the translation of the global change scenarios to the regional application, but often projected more drastic changes (especially in size) than can be expected based on the historical data analysis. This probably originates from the fact that the vision of farmers also reflects how they would like to see their own future; stakeholder views are more normative.

2.4.2 Implications of the estimated farm structural change

The majority of performed studies on impacts of and adaptation to climate change are either focusing on changes in sowing dates and cultivars in the current farming setting (e.g. Easterling 1996; Kaiser et al. 1993), and/or assess economic implications in that current setting (Prato et al. 2010). Our study provides a setting for assessment of adaptation strategies to future climate change in a broader context of other important changes and allows to account for alternative functions of agriculture to society in the future. Specific adaptation strategies, their adoption, and the sensitivity to different drivers can be further explored using bio-economic models (e.g. Kanellopoulos et al. 2010; Kanellopoulos et al. 2011). We note, however, that the detail of the farm structural change assessment should be determined by the exact aim of the follow-up studies. Since the method we propose is laborious and requires consistent historical data, part of our method could be substituted by a stronger role of stakeholder consultations, if images of future farms are sufficient rather than a comprehensive and consistent assessment of farm structural change at regional and farm level.

This paper does not explicitly addresses landscape impacts. However, Figure 2.5 indicates the implications of farm structural change for the landscape in Flevoland towards 2050 in different scenarios. Arable farming occupies a large area of Flevoland and therefore largely influences the landscape. In A1 in Flevoland we can expect large scale farming systems specializing in intensive crops. In B2 there is still place for smaller farms. In general this scenario is characterized by a higher diversity in farming landscape with focus on local crops and markets, more nature conservation and provision of alternative functions to the society. Therefore, the two scenarios will be quite contrasting in terms of implications for nature and other landscape functions in Flevoland.

Appendix 2.A – Farm level results on farm structural change in two scenarios.

					2008	A1	B2			
	Orientation	Size	Intensity	Specialization[1]	% arable UAA[2]			NGE	ha	NGE/ha
1	production	small	medium	diverse: arable/specialized: root crops	0.5	0.6	0.6	11	9	1.1
2				vegetables	0.04	0.1	0.05	13	9	1.4
3		medium	high	diverse: mainly root crop/specialized: root crops	2.4	0	2.0	50	22	2.3
4				flower bulbs	0.06	0	0.05	41	6	7.3
5			medium	diverse: mainly root crops/diverse: arable/specialized: root crops	9.7	0	0	46	29	1.6
6				vegetables	0.4	0	0	41	25	1.7
7		large	high	flower bulbs	0.2	0.5	0.2	111	16	7.0
8				diverse: mainly root crops/specialized: root crops	5.2	6.2	5.4	104	44	2.4
9			medium	vegetables	0	1.0	0	82	50	1.6
10				diverse: mainly root crops	19.3	9.6	0.0	104	64	1.6
11		very large	high	flower bulbs	4	8.1	5.2	589	61[3]	9.7
12				diverse: mainly root crops/specialized: root crops	6.6	8.4	6.2	254	108	2.4
13			medium	diverse: mainly root crops	8.7	16.3	0	224	130	1.7
14	entrepreneur	medium	medium	diverse: mainly root crops	1.4	2.9	6.1	55	36	1.5
15				vegetables	0	0.0	0.2	0	0	0.0
16		large	medium	diverse: mainly root crops	4.1	13.1	14.7	99	61[4]	1.6
17		very large	medium	diverse: mainly root crops	0	0	4.1	224	130	1.7
18	nature	medium	medium	diverse: mainly root crops/diverse: arable/specialized: root crops	0	0	4.0	46	29	1.6
19				vegetables	0	0	0.2	0	0	0.0
20		large	high	diverse: mainly root crops	0.1	0	0.1	97	37	2.6
21			medium	diverse: mainly root crops	0.6	0	11.1	105	61[4]	1.7
22		very large	high	diverse: mainly root crops	0.8	0	0.8	334	132	2.5
23			medium	diverse: mainly root crops	0.4	0	4.0	199	114	1.7

[1] In A1, all ‘specialized: root crops’ become ‘diverse: mainly root crops’, and the latter become ‘diverse: arable’.
[2] The remaining arable area is occupied by arable in mixed farm types.
[3] In A1, the average area of these flower bulbs increases to 108 ha, similar to the other specialization type. In B2, the increase is half of this, i.e. 85 ha.
[4] As in B2 these entrepreneur and nature oriented farms are production oriented farms that moved, the average area is 64 ha.

Chapter 3

The role of farmers' objectives in current farm practices and adaptation preferences

Abstract

The diversity in farmer's objectives and responses is not always considered in integrated assessment studies. In this Chapter we present an approach to assess how a farmer's stated objectives relate to his currently implemented practices and to preferred adaptation options, and we discuss what this implies for integrated assessments of adaptation to climate change.

We based our approach on a combination of Multi-Criteria Decision Making methods. We consistently assessed the importance of a farmer's objectives from what farmers say (based on interviews), from what farmers actually do (by analysing current farm performance) and from what farmers want (through selected alternative farm plan). Our study was performed for six arable farms in Flevoland, a province in the Netherlands. Based on interviews with farmers, we reduced the long list of possible objectives to the most important ones. The objectives we assessed included maximization of economic result and soil organic matter, and minimization of gross margin variance, working hours and nitrogen balance.

In our sample, farmer's stated preferences in objectives were often not reflected in realized farming practices. Adaptation preferences of farmers largely resembled their current performance, but generally involved a move towards stated preferences. Our results suggest that although farmers do have more objectives, in practical decision-making they focus on economic result maximization, while for strategic decision-making they account for soil organic matter which is indirectly related to long term income.

Keywords: multi-criteria decision making; multi-objective optimization; agriculture; arable farm; farmer's objectives

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3.1 Introduction

In the coming decades, climate change will become an important force driving farming systems to adapt (Bindi and Olesen 2010, Hermans et al. 2010, Prato et al. 2010). Besides adaptation to climate change, a farmer also has to adapt his management practices to react to changes in market and policy and to benefit from technological progress. These drivers also influence management and adaptation in the present situation (see Chapter 2). Therefore, in order to assess adaptation preferences of farmers against future challenges, it is relevant to study factors that influence adaptation in the current situation.

Farming systems in Europe are diverse in terms of their characteristics, objectives and performance, which largely influenced adaptation of farms to past climate change and variability (Reidsma et al. 2010). One of the factors contributing to increasing farm diversity recently is a shift towards multifunctional agriculture associated with a broader role of agriculture in a modern society (Meerburg et al. 2009, Renting et al. 2009, van der Ploeg et al. 2009). Next to primarily economic objectives, farmers are assumed to have other objectives (e.g. social, environmental) influencing their management practices. Farm specific adaptation measures to drivers of change will differ depending on farmers' objectives.

In many studies on assessment of adaptation to climate change using economic modelling, farmer's multiple objectives are often neglected and farmers are seen as ultimate profit maximizers (Audsley et al. 2006, Seo 2010). Profit maximization may be used to explore optimal farm plans(Van Ittersum et al. 1998, ten Berge et al. 2000, Janssen and van Ittersum 2007), but not to project actual choices made by farmers (see also Rufino et al. (2011)). In reality farmers often choose for managerial options considering also other objectives, and they select options that are not necessarily the most optimal.

Dogliotti et al. (2005), Tittonell et al. (2007), Groot and Rossing (2011) assessed multiple and conflicting farmer's objectives by emphasizing the values of objectives achieved in certain scenarios. As the result, these studies propose the best alternative farm plan versus current farm performance as to considered objectives. However, elicitation of importance weights and assessment of relations between weights for current and future farm performance in terms of different objectives were not considered in these studies. As argued by Jones (2011), the methodology of weight elicitation and reporting is currently somewhat random and ad hoc in nature. The weights attached to different objectives are usually recovered through the existing cropping patterns, hence the actual behaviour of farmers is explained through assessment of a compromise between different objectives by modelling farm current performance (Sumpsi et al. 1997, Gómez-Limón et al. 2003, Romero and Rehman 2003, Berkhout et al. 2011). Other studies use objectives as stated by farmers in interviews (e.g., van Calker et al. 2005). Different methods may, however, lead to different results, as actions (i.e. performance) are often not the result of conscious goals (i.e. stated objectives) (Dijksterhuis and Aarts 2010).

This paper presents an approach to assess how stated objectives of farmers relate to their currently implemented practices and to preferred adaptation options. Our approach allows to quantify the importance of farmer's multiple objectives and to compare different methods for deriving preferential weights. An important sub-question in the study is to reveal the underlying objectives determining farm adaptation preferences. We hypothesize that different methods to elicit weights of objectives will lead to different results, implying that the chosen method will influence assessments of impacts and adaptation to future changes. We expect profit to be a relatively important objective, as the case study area Flevoland is highly productive.

We first describe the data and the model we used in the study. Next, we describe the procedure to derive importance weights for multiple objectives considered in the study using different methods: interviews with farmers, assessment of current farm performance and preferred adaptation options. Finally, we discuss our findings by comparing different sets of weights for the objectives.

3.2 Materials and Methods

3.2.1 Data collection

In the present study we decided to model individual arable farms rather than to formulate prototypes based on averaging farm characteristics. This provided opportunities to obtain case study specific input for the model, to receive feedback on the modeling results and to perform model validation through multiple iterations with individual farmers (in two rounds of interviews). We surveyed six arable farms from the province of Flevoland, The Netherlands. We assigned each farm to a farm type based on the typology developed in Chapter 2. Variables of the farm typology and data on farm structure and resources are given in Table 3.1.

Table 3.1 – Survey data of the six farms on farm structure and resources. The definition and thresholds for farm orientation, size, intensity and specialization are given in Table 2.1.

Farm code	Structure				% UAA[1] Flevo-land	Resources		
	Orientation	Size	Intensity	Specialization		Area, ha	Labour, hrs/yr	Soil OM[2], %
P1	Production	Large	High	Diverse mainly root crops	5.2	54	3300	2.0
P2	Production	Large	Medium	Diverse mainly root crops	19.3	68	2860	4.3
P3	Production	Large	Medium	Diverse arable	19.3	70	2750	4.5
N1	Nature	Large	Medium	Specialized root crops	0.1	52	4080	2.5
E1	Entrepreneur	Large	Medium	Diverse mainly root crops	4.1	53	5000	2.3
E2	Entrepreneur	Medium	Medium	Diverse mainly root crops	1.4	36	1600	4.2

[1]UAA is utilized agricultural area
[2]OM is organic matter

In the first round of interviews (spring 2011) we obtained individual farm data regarding current farm practices, i.e. crops grown on the farm, crop yields and inputs of nitrogen, phosphorus and potassium (NPK) per crop (Appendix 3.A). In addition, we asked farmers about their preferences regarding alternative crops in their farm plans and about production restrictions for growing certain crops. Some crop level data, i.e. cultivation costs, contract work costs, labour requirement as well as crop prices (the running average of four years) were obtained from the Dutch information handbook for arable farming and horticulture (Anonymous 2009). We also obtained quantitative information of farmer's stated importance of objectives by asking farmers to rank the objectives considered in the study.

In the second round of interviews (summer 2012) we presented the modelling outcomes to farmers in terms of alternative farm plans. Farmers were asked to select the most preferred farm plan from the large set of alternative farm plans generated by the model. The selection procedure was accompanied by a discussion with two authors of this paper, which provided good insights in farmers' reasoning behind the decision-making.

3.2.2 Model description

In the study we used the multi-objective optimization model FarmDESIGN (Groot et al. 2012), developed to support the learning and decision-making process of re-designing farming systems. The model allows to calculate the consequences of farm configuration on a large set of farm performance indicators (e.g. nutrient balances and flows, labour balance, organic matter balance and operating profits), and subsequently to explore trade-offs between farmers' multiple objectives (i.e. selected farm performance indicators), by linking a bio-economic component to a multi-objective Pareto-based Differential Evolution algorithm. The outcomes of the optimization runs are alternative farm configurations based on the original farm plan evaluated in terms of the multiple objectives.

We made some adjustments to the model to make it applicable to our research. We added minimizing of risk as a new objective, defined as a minimization of variance in gross margin. A variance co-variance matrix of gross margins was calculated based on five year data on yields, prices and cultivation costs for main arable crops in Flevoland. Consequently, a quadratic function was obtained and used to calculate variance in gross margin for specific farm production plans, according to Hazell and Norton (1986). For easier communication with farmers, we replaced the original objective of labour balance (defined by a difference between required and available labour on a farm) by labour requirement (i.e. a straightforward reference to the working hours needed for a certain farm plan). A flexible setup of the FarmDESIGN model allows its performance indicators to become either objectives (for minimization or maximization) or constraints (to restrict values to a user-defined range) depending on the user's needs.

A detailed model description is provided by Groot et al. (2012). An overview of rotational, general and nutrient balance constraints, input data for calculating nutrient balances and organic matter balance is presented in Appendices 3.B-3.E.

3.2.3 Methodology

In this study we aimed to analyse how farmers' intentions were related to practical decision-making. Therefore, we investigated whether the stated importance of objectives by farmers was realized in their current performance and reflected in their strategic choice of preferred adaptation options (Figure 3.1).

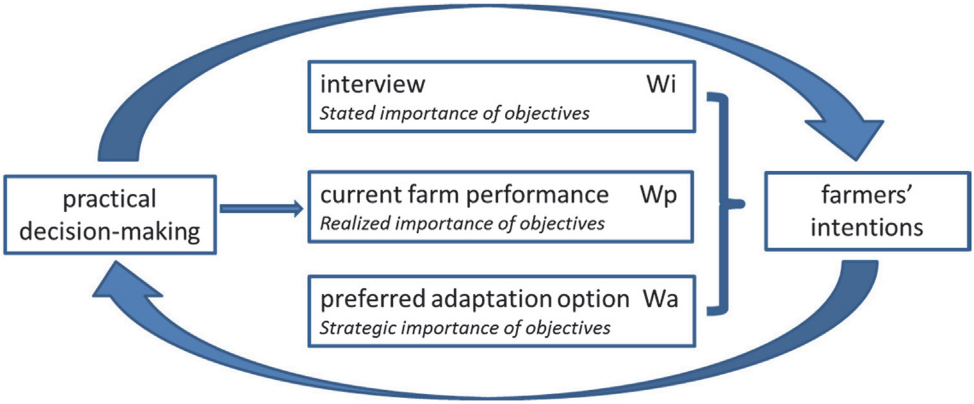

Figure 3.1 – Conceptual framework of the study.

To deal with multiple conflicting objectives, we based our methodological approach on the Multi-Criteria Decision Making (MCDM) techniques as defined by Romero and Rehman (2003). We included the following steps: a) identifying farmers' objectives from a literature review and interviews with farmers and experts; b) ranking the objectives by interviewing farmers and deriving the stated weights for the objectives (w_i interview weights); c) generating alternative farm plans and calculating trade-offs between objectives; d) assessing importance of objectives in farm current performance by comparing current farm plan to all generated alternative plans and deriving the realized weights for objectives (w_p performance weights); e) selecting the most preferred alternative farm plan by farmers and deriving the strategic weights for different objectives from trade-offs (w_a adaptation weights); and f) comparing objective weights w_i, w_p and w_a. In this way we investigated how farmers' stated objectives relate to practical decision-making and whether the objectives influence the choice of most preferred alternative farm plans, or the choice for adaptation. The explanation for each step is given below.

Identification of objectives

The method to identify farmers' objectives was based on literature (Berkhout et al. 2011; Gómez-Limón et al. 2004; van Calker et al. 2005), expert consultations and interviews with farmers. Table 3.2 presents the identified objectives to be used in the research.

Table 3.2 – Overview of objectives and indicators considered in the study.

Objective	Indicator
1. Farm economic result maximization	Gross margin of crops (€/ha)
2. Soil quality maximization	OM balance (kg OM/ha)
3. Working hours minimization	Labour requirement (hrs/ha)
4. Nitrogen balance minimization[1]	N balance (kg N/ha)
5. Gross margin variation minimization	Gross margin variation (€/ha)

[1]Nitrogen balance is calculated as a difference between nitrogen inputs (from fertilizer and atmospheric deposition) and outputs (with crop products) on the farm. A low balance means that there is no large nitrogen surplus in the system

Interviews – stated weights w_i

Each interviewed farmer (n=6) was asked to rank the objectives considered in this study. Assessment of the relative importance of farmers' objectives was based on two ranking methods: interval ranking and ordinal ranking (van Calker et al. 2005). In interval ranking the farmers were asked to rank each objective according to its perceived importance. A Likert scale of 1 to 5 was used, with 1 being not important for management decisions and 5 being very important. In ordinal ranking the respondents were asked to place the objectives in order of importance.

Next, the relative importance weights of the objectives were calculated for each respondent and ranking method. The relative importance weight W_{ijk}, for objective i, respondent j, and ranking method k, is calculated as follows:

$$W_{ijk} = \frac{X_{ijk}}{\bar{X}_{jk}}, \qquad \text{(equation 3.1)}$$

where X_{ijk} is the value of objective i for respondent j and ranking method k, $\bar{X}_{jk}$ is the average ranking of all objectives for respondent j and ranking method k. Next, to be able to compare the weights with weights based on other methods, the standard normalization procedure was used, resulting in the sum of weights for all objectives for each farmer to be 1. By using the relative importance weights of both ranking methods, each respondent was tested for internal consistency with the Spearman Rank Correlation Coefficient. The results of non-consistent respondents are to be omitted from the analysis.

Initially we considered a larger number of objectives (n=10) to be assessed in this study. Besides the objectives presented in Table 3.2, we also considered maximization of alternative income, added value of products and landscape quality, and minimization of costs and work by third parties. After we obtained the results from ranking of objectives by farmers, we selected five objectives that consistently received the highest weights in both ranking methods (interval and ordinal).

Generating alternative farm plans

We used the FarmDESIGN model to generate alternative farm plans for each individual farm. We first included alternative activities for each farm, which included crops currently not grown on the farm, but grown on the other surveyed farms. This means that for each farm there were three to five alternative crops available from a total of nine crops observed on the surveyed farms (Appendix 3.A). Crops from the own rotation on each farm were assumed to maintain the current yields as obtained with current management (NPK application). Yields and NPK management for alternative crops are average values observed among the surveyed farms. Our assumption therefore was that farmers continue growing current crops with current management and only apply alternative management for alternative crops. With this assumption we aim at showing the effect from relatively small changes in the current farm plan, as most of the model options (alternative farm plans) will include one or two new crops. These plans are realistic for a farmer, as they are easy to implement for the farmer within a 1-3 year period. Besides, we did not want to overwhelm the farmer with solutions involving several management options for the same crop.

All crop shares in alternative rotations were within feasible ranges from an agronomical point of view. This requirement was met through rotational constraints that were applied during the generation stage (Appendix 3.B). Machinery was assumed not to be a constraint, as in reality most farmers collaborate with one or more other farmers and have access to different types of machines needed for cultivation of different crops.

After we entered all proposed alternative activities into the model, we ran the model for each farm individually with 10.000 iterations, optimizing the five objectives considered in the study. For each farm the model generated 900 alternative farm plans. The cloud of solutions (consisting of the alternative farm plans) was plotted in a two-dimensional space to represent trade-offs between different objectives.

Current farm performance - realized weights w_p

We compared the values for objectives from the current farm plan with the ideal and anti-ideal values for objectives from the whole set of generated alternative farm plans. The ideal value refers to the best attainable value for an objective, either maximum or minimum (depending on the direction of optimization), within the whole set of generated farm plans. The anti-ideal value is the opposite of ideal, i.e. is the worst value for an objective. To compare the current farm performance according to different objectives and to derive relative importance weights for the objectives w_p, we applied the approach of Nordström et al. (2009):

$$w_j^0 = \frac{O^{r*} - O_j^r}{O^{r*} - O_*^r}, \quad \text{(equation 3.2)}$$

where w_j^0 is the weight for an objective from a generated alternative farm plan, O^{r*} and O_*^r are the ideal and anti-ideal values, respectively, for the *r*th objective within the set of generated alternative farm plans (j); O_j^r is the outcome that corresponds to the *j*th farm plan when it is evaluated according to the *r*th objective (here, it is the value for *r*th objectives from the current farm plan). According to this approach, all the weights are bound between 0 (ideal value) and 1 (anti-ideal value) and represent distances or degrees of discrepancy from the ideal value. We normalized the weights w_j^0 to let the sum of weights for all objectives equal to 1 for each farm plan. In addition, we reversed the ideal and anti-ideal values with 1 becoming an ideal value instead of 0:

$$w_j = \frac{1 - w_j^0}{\sum_j (1 - w_j^0)}, \quad \text{(equation 3.3)}$$

where w_j is the normalized weight for an objective from a generated alternative farm plan. The objectives with the weights, that are closer to the ideal value 1, are considered more important.

Preferred adaptation option – strategic weights w_a

In the second round of interviews each farmer was asked to indicate the most preferred alternative farm plan generated by the model. The selection of the most preferred alternative represented farmer's strategic decision as to the choice of adaptation options. The procedure to present the model results to the farmer included the following steps. Firstly, the model FarmDESIGN was presented and briefly explained (model components, inputs, outputs). Secondly, the farmer was shown clouds formed by all alternative options (n=900) generated by the model for their own farm. The clouds represent trade-offs between different objectives. Current performance of the farm was indicated in the graphs. Thirdly, the farmer was shown a list of 25-30 alternative solutions that were pre-selected from the full set of alternatives. This list included a cropping pattern and values for all 5 objectives associated to each of the alternative activities. For each objective we also provided the relative change compared to the current farm plan (improvement or worsening of objective values). The pre-selection of activities was based on: a) analyses of trade-offs between objectives that can still be improved and other important objectives for the farmer (based on ranking of objectives and farm current performance); b) farmer's crop preferences stated in the first interview; c) production restrictions for certain crops stated in the first interview. The farmer was asked to indicate the most attractive alternative farm plan, considering its contribution to the improvement of farm's current performance and trade-offs between objectives. In case the farmer identified the most preferred alternative activity in terms of objectives, but he was not satisfied with the cropping plan corresponding to these objectives, we went back to the file with all 900 alternatives and tried to find the best compromise.

Next, we derived weights for different objectives by comparing the values for objectives from the preferred alternative farm plan with the ideal and anti-ideal values for objectives from the whole set of generated alternative farm plans.

Comparison of weights w_i, w_p and w_a

We compared weights for different objectives obtained from different methods in the study. We used the percentage of absolute deviation (PAD) to estimate the absolute deviation between different sets of weights (Hazell and Norton 1986):

$$PAD(\%) = 100 * \frac{(\sum_i |x_i - x_i^0|)}{(\sum_i x_i^0)}, \quad \text{(equation 3.4)}$$

where x_i and x_i^0 are the weights of objectives obtained from different methods that are being compared. By using PAD we could determine how close different sets of objectives relate to each other. In addition, we used the Pearson correlation coefficient (r). Whereas the PAD reflects much of the level of the weights, the correlation rather reflects the ranking.

3.3 Results

3.3.1 Interviews – stated weights w_i

Table 3.3 includes the derived stated weights w_i for the objectives based on interval ranking. All respondents (n=6) were internally consistent (there was an association between both interval and ordinal ranking methods at $P < 0.05$).

From the results in Table 3.3 we observe that each farmer demonstrated a unique pattern regarding stated importance of objectives. However, there were certain similarities in ranking of objectives among farmers. In most cases farmers found several objectives equally important. Farm economic result and soil quality (defined as soil organic matter balance) are clearly prioritized. Farms E1 and E2 ranked soil quality higher than farm economic result. The other objectives, especially minimization of working hours, received lower importance weights.

3.3.2. Current farm performance – realized weights w_p

The starting point for generation of alternative farm plans for each farm is given in Figure 3.2. The figure demonstrates how each farm currently performs in terms of different objectives within the sample of farms. The data used to explain current farm performance is given in Appendix 3.A.

Table 3.3 – Normalized weights for objectives, percentage of absolute deviation (PAD) and Pearson correlation (r) between weights obtained from different methods.

		Objectives							
		ER	OM	NB	LR	R		PAD, %	r
	FARM P1								
w_i	interviews	0.25	0.25	0.19	0.06	0.25	Wi-Wp	92	0.29
w_p	performance	0.59	0.04	0.31	0.04	0.02	Wp-Wa	56	0.96
w_a	preferred alternative	0.37	0.18	0.25	0.12	0.08	Wi-Wa	48	0.32
	FARM P2								
w_i	interviews	0.23	0.23	0.18	0.18	0.18	Wi-Wp	40	0.25
w_p	performance	0.35	0.11	0.22	0.23	0.10	Wp-Wa	16	0.94
w_a	preferred alternative	0.32	0.17	0.18	0.22	0.12	Wi-Wa	25	0.52
	FARM P3								
w_i	interviews	0.22	0.22	0.11	0.22	0.22	Wi-Wp	28	-0.12
w_p	performance	0.22	0.15	0.21	0.26	0.16	Wp-Wa	14	0.86
w_a	preferred alternative	0.28	0.12	0.22	0.24	0.14	Wi-Wa	37	-0.16
	FARM N1								
w_i	interviews	0.21	0.21	0.21	0.21	0.17	Wi-Wp	32	0.64
w_p	performance	0.28	0.22	0.29	0.12	0.10	Wp-Wa	0	1.00
w_a	preferred alternative	0.28	0.22	0.29	0.12	0.10	Wi-Wa	32	0.64
	FARM E1								
w_i	interviews	0.19	0.24	0.24	0.09	0.24	Wi-Wp	62	0.19
w_p	performance	0.32	0.10	0.40	0.11	0.07	Wp-Wa	8	0.99
w_a	preferred alternative	0.34	0.11	0.36	0.11	0.08	Wi-Wa	59	0.18
	FARM E2								
w_i	interviews	0.16	0.34	0.16	0.16	0.16	Wi-Wp	37	-0.53
w_p	performance	0.21	0.17	0.17	0.25	0.21	Wp-Wa	36	-0.35
w_a	preferred alternative	0.23	0.14	0.32	0.17	0.14	Wi-Wa	47	-0.44
	AVERAGE								
w_i	interviews	0.21	0.25	0.18	0.15	0.20	Wi-Wp	49	-0.15
w_p	performance	0.33	0.13	0.27	0.17	0.11	Wp-Wa	22	0.98
w_a	preferred alternative	0.30	0.16	0.27	0.16	0.11	Wi-Wa	41	-0.03

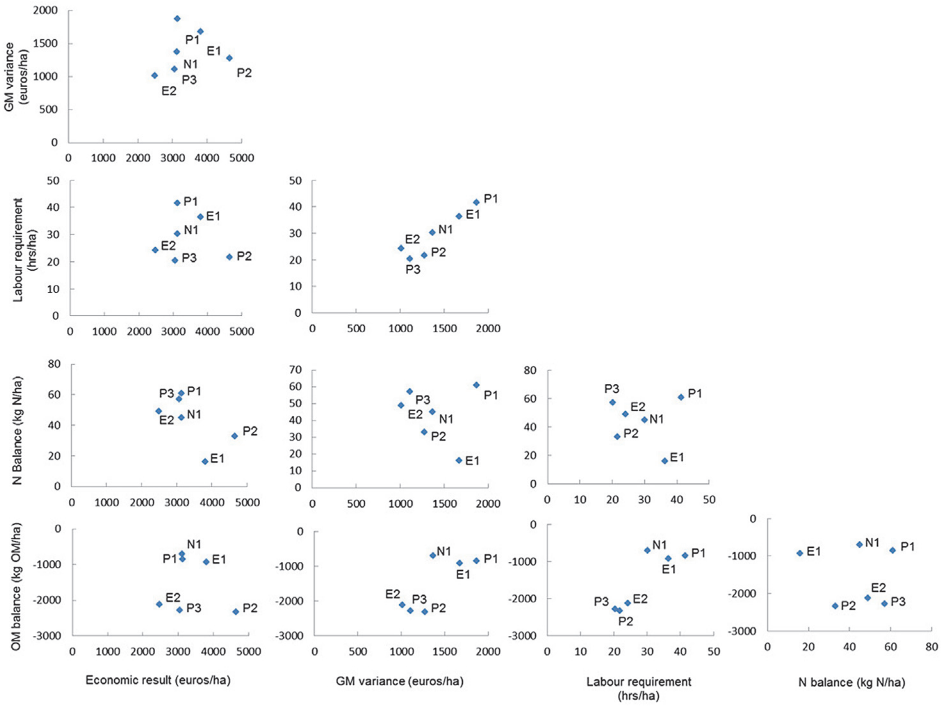

Figure 3.2 – Performance of current farm plans within the sample.

Farms P2 and E1 showed the best performance in terms of economic result. These farms grow seed onion and winter carrot, the crops with the highest gross margin (higher than 7600€/ha). Farms N1, P1 and E1 performed best within the sample on the soil organic matter balance. These farms either applied a lot of organic fertilizer (farms P1 and E1) or had a large share of crops that added a large amount of effective organic matter to the soil (for farm N1 the share of wheat in the rotation is 0.33). The best performance in terms of nitrogen balance was observed for farm E1. This farm has green peas in its rotation, which does not require mineral nitrogen supply. The application of nitrogen for seed potato, which has a 0.3 share in the farm's rotation, did not exceed the average of 116 kg N/ha for Flevoland, as it is often the case on other farms. Farms P3, P2 and E2 demonstrated the best performance for labour requirement. These farms grow a large share of crops with lowest labour requirements (wheat, sugar beet and green peas have joint shares in the farm plans within the range of 0.5-0.6). In terms of gross margin variance, or risk, the best performing farm within the sample was E2. Farm E2 avoided the combination of seed onion and consumption (or seed) potato in the rotation, in contrast to most of the other farms. Seed onion and potato are the crops with high co-variances of gross margins, which means that the simultaneous appearance of these crops in a farm plan makes it more risky due to both yield and price variations for these crops.

The FarmDESIGN model generated clouds of alternative farm plans for each farm. For each alternative farm plan the model calculated the values of performance indicators that were selected as objectives. By plotting all alternative farm plans in two-dimensional spaces we assessed the relations between different objectives. We found that not all pairs of objectives represented trade-offs given the dataset we used. For example, there was a trade-off between the objectives economic result and organic matter balance, but no trade-off between economic result and nitrogen balance within the solution space we considered, i.e. economic result improved with a lower nitrogen balance (Figure 3.3). The no-trade-off situation between economic result and nitrogen balance is explained by policy regulations of nitrogen application in the Netherlands (see also section 3.4 Discussion).

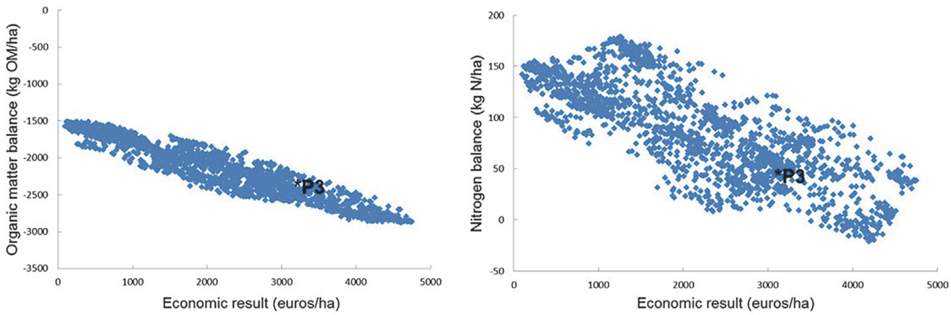

Figure 3.3 – Performance of generated alternative farm plans in terms of economic result and organic matter balance and economic result and nitrogen balance (farm P3).

Table 3.4 presents the results on realized weights of objectives derived from current farm performance relative to the solution space defined by the performance of available alternatives. From the obtained weights for different objectives we observed that all surveyed farms (except for E2) performed well as to the economic result (especially farms P1and P2 are close to the maximum achievable economic result with their current production pattern). Performance in terms of labour requirement and nitrogen balance varied significantly among farms. However, in general farms performed relatively better as to the latter objectives compared to their performance in terms of organic matter balance and risk. None of the farms demonstrated an optimal performance for these two objectives.

Table 3.4 – Importance weights of objectives derived from current performance (w_p) and from preferred alternative farm plan (w_a).

Farm		ER	OM	NB	LR	R
		€/ha	Kg OM/ha	kg N/ha	hrs/ha	€/ha
P1	current[1]	3144	-661	61	42	1869
	alternative[2]	2898	-384	47	36	1629
	ideal[3]	3543	416	-19	13	209
	anti-ideal[3]	71	-936	132	44	1927
	w_p[4]	0.59	0.04	0.31	0.04	0.02
	w_a[4]	0.37	0.18	0.25	0.12	0.08
P2	current	4660	-2332	33	22	1273
	alternative	4387	-2127	51	22	1195
	ideal	4891	-1463	-42	13	229
	anti-ideal	189	-2703	139	37	1658
	w_p	0.35	0.11	0.22	0.23	0.10
	w_a	0.32	0.17	0.18	0.22	0.12
P3	current	3069	-2283	57	20	1108
	alternative	3477	-2475	64	24	1243
	ideal	4752	-1515	-21	13	223
	anti-ideal	101	-2884	179	41	1843
	w_p	0.22	0.15	0.21	0.26	0.16
	w_a	0.28	0.12	0.22	0.24	0.14
N1	current	3134	-702	45	30	1368
	alternative	3134	-702	45	30	1368
	ideal	4931	-22	-45	13	227
	anti-ideal	145	-1344	199	36	1664
	w_p	0.28	0.22	0.29	0.12	0.10
	w_a	0.28	0.22	0.29	0.12	0.10
E1	current	3809	-928	16	36	1673
	alternative	4015	-878	30	36	1643
	ideal	5019	87	3	19	504
	anti-ideal	408	-1206	174	42	1888
	w_p	0.32	0.10	0.40	0.11	0.07
	w_a	0.34	0.11	0.36	0.11	0.08
E2	current	2491	-2127	49	24	1011
	alternative	2655	-2199	-6	29	1283
	ideal	4760	-1358	-39	13	233
	anti-ideal	118	-2633	108	40	1793
	w_p	0.21	0.17	0.17	0.25	0.21
	w_a	0.23	0.14	0.32	0.17	0.14

[1]current - values for objectives from current farm performance
[2]alternative – values for objectives from preferred alternative farm plan
[3]ideal and anti-ideal – best and worst values for objectives, respectively (depending on the direction of optimization: maximization or minimization) from the cloud of generated alternative farm plans
[4]w_p – weights for objectives from current farm performance; w_a – weights for objectives from preferred alternative farm plan; both w_p and w_a are within the range of 0.00 (anti-ideal value) to 1.00 (ideal value)

3.3.3 Preferred adaptation option – strategic weights w_a

For the farm plan that farmers preferred most out of all generated alternatives, we obtained the values for different objectives and derived importance weights for the objectives (see Table 3.4). Due to the existing trade-off between economic result and organic matter balance, for most of the farms it was not possible to choose an alternative farm plan with a better performance for both objectives simultaneously. Farms P3 and E2 preferred to have improved economic result, while farms P1 and P2 preferred an improved organic matter balance (Table 3.5). For farm E1 there were still options for improving both objectives simultaneously. However, the elicited weights indicated a higher ranking for the objective of economic result compared to the organic matter balance on all farms. Weights for objectives from preferred farm plans depend on the distance of the objective's value to the ideal and anti-ideal values for that objective within the whole cloud of alternative farm plans. For example, when farmer P1 chooses an alternative farm plan which improves soil organic matter by 55%, a sacrifice 8% of economic result would be required (Table 3.5). But because among all generated options the value of economic result of the preferred farm plan was closer to the achievable maximum than the value of organic matter, economic result received a higher importance weight compared to organic matter (Table 3.4).

The objectives nitrogen balance, labour requirement and risk were considered as secondary by farmers, after they found the best compromise in terms of economic result and soil organic matter balance. The ranking of these objectives from the preferred alternative farm plan depended on existing trade-offs with economic result and organic matter balance.

In terms of cropping pattern, most farmers preferred to have small changes to their farm plan by introducing only one new crop (Table 3.5). Farmers P3 and E2 were not concerned about an increased complexity of the farm plan and allowed 2-3 new crops to enter the alternative farm plan. Farmer N1 was satisfied with his current performance and cropping pattern and responded that he still prefers his own plan above all the generated alternatives.

Table 3.5 – Comparison between current and selected alternative farm plans in terms of changes in objectives' values and crop areas.

Farm plans	Objectives					Crop areas, ha								
	ER	OM	NB	LR	R	WW	SB	GP	WC	SP	SO	CH	GR	CP
	€/ha	kg OM/ha	kg N/ha	hrs/ha	€/ha									
P1 Current	3144	-661	61	42	1869	0	9	0	0	18	9	9	9	0
P1 Altern	2898 (-8%)	**-384 (+55%)**	**47 (-33%)**	**36 (-15%)**	**1629 (-13%)**	10	9	0	0	18	9	0	8	0
P2 Current	4660	-2332	33	22	1273	17	12	0	11	0	12	0	0	17
P2 Altern	4387 (-6%)	**-2137 (+9%)**	51 (+54%)	22	**1195 (-6%)**	29	0	0	11	0	12	0	0	17
P3 Current	3069	-2283	57	20	1544	21	14	7	0	0	14	0	0	14
P3 Altern	**3477 (+13%)**	-2475 (-8%)	64 (+12%)	24 (+20%)	**1243 (-20%)**	14	7	8	4	4	14	0	5	15
N1Current	3134	-702	45	30	1368	17	10	0	0	11	6	0	0	6
N1 Altern*	3134	-702	45	30	1368	17	10	0	0	11	6	0	0	6
E1 Current	3809	-928	16	36	1673	7	10	4	5	18	9	0	0	0
E1 Altern	**4015 (+5%)**	**-878 (+5%)**	30 (+88%)	36	**1643 (-2%)**	10	7	3	6	16	8	0	0	0
E2 Current	2491	-2127	49	24	1011	9	9	0	0	0	0	9	0	9
E2 Altern	**2655 (+7%)**	-2199 (-3%)	**-6 (-88%)**	29 (+21%)	1283 (+27%)	9	8	0	0	3	5	9	0	1

WW-winter wheat; SB-sugar beet; GP-green peas; WC-winter carrot; SP-seed potato; SO-seed onion; CH-chicory; GR-grass; CP-consumption potato.
ER-farm economic result; OM-organic matter balance; NB-N balance; LR-labour requirement; R- risk (gross margin variance).
In bold are values for objectives that improved, underlined are values for objectives that worsened. Percentage of change in values for objectives for alternative activities is given in parenthesis.
*Farmer N1 selected his own plan.

3.3.4. Comparison of weights w_i, w_p and w_a

The normalized weights for all objectives obtained from the different methods are presented in Table 3.3. Economic result and nitrogen balance are the only objectives that receive more importance for all farms when it comes to what farmers currently do (i.e. farm current performance) and what they want (i.e. preferred alternative) compared to what they say (i.e. interviews). This finding implies that farmers' practical decisions are mostly driven by economic profit at the expense of other objectives, although most farmers declare those other objectives at least equally important as economic result. Farmers' good performance as to the nitrogen balance is due to the fact that there is no trade-off with economic result in the dataset we considered. Besides, farmers have to follow strict regulations regarding nitrogen supply to the soil. In the interviews, the farmers ranked organic matter balance as one of the most important objectives. However, their concern for soil organic matter was not that well reflected in their current performance. Also, in preferred alternative farm plans organic matter balance obtained quite moderate importance weight. Several farmers want to improve their organic matter balance, but due to the trade-off with economic result, this improvement is very small in the selected alternatives. The objective of gross margin variance (risk) received clearly less importance when it comes to current performance and preferred alternative, compared to farmers' interviews (except for farm E2). Labour requirement was generally perceived not very important by farmers (except for farms P3 and N1). In terms of current performance there was large diversity in labour requirement among farms. P1 is the only farm that would like to improve its current performance in terms of labour requirement with an alternative farm plan (see also Table 3.5).

Comparing different sets of objectives shows that a high correlation (0.98) and a small average PAD (22 %) was found between realized weights for objectives derived from current performance and strategic weights derived from the preferred alternative farm plan. This implies that farmers choose for an alternative plan close to their existing farm configuration in terms of weighting objectives. The correlations with stated weights were, however, negative (-0.15 and -0.03 with w_p and w_a, respectively) and PADs higher, implying that farmers' stated objectives do not match well with their current performance or preferred alternatives.

3.4 Discussion

3.4.1 Method and novelty

We presented a method to assess how farmers' intentions and stated objectives are related to practical decision-making. The novelty of our approach is in the consideration of interrelated aspects of decision-making, as we assessed what farmers say (by deriving stated preferences in objectives from the ranking), what farmers actually do (by assessing farm current performance) and what farmers want (through selected alternative farm plan).

Our approach is based on a combination of Multi-Criteria Decision Making methods. We assume that weights elicited from direct ranking of objectives (from interviews), if normalized, can be compared with weights recovered from current and future farm performance. Sumpsi et al. (1997) argued that the elicitation of weights of objectives through farmer's actual behaviour (here: performance) is a more straightforward and sound method than through interviews, but that both methods are valid. Our analysis shows that both methods give very different results, and farmers do not do what they intend. Similar discrepancies between optimal and actual resource-use behaviour have been found in consumer studies (Jager et al. 2000, Janssen and Jager 2001).

In the present study we used the FarmDESIGN model (Groot et al. 2012), that performed optimization based on a heuristic approach. The heuristic algorithms of evolutionary computation have proven to be a reliable and practical approach to simulate real-world systems (Mayer et al. 2008, Dury et al. 2012). The FarmDESIGN model allows simultaneous optimization of multiple objectives to approach the trade-off frontier, and thereby produces a cloud of alternative activities which are not necessarily the optimal solutions (Groot and Rossing 2011). We used the outcomes of the model to elicit weights from current performance and from the most preferred alternative farm plan. The ideal and anti-ideal values from the generated solution space determined importance weights for different objectives. Hence, the elicited weights might be sensitive to the calculated solution space, which does not necessarily reach the Pareto surface (i.e. when the values for conflicting objectives did not reach the optimum in the optimization).

Because of intensive data collection, we only assessed six farms. These farms are, however, representative for six farm types, which comprise 30% of the arable land in Flevoland. They include farms with different orientations, size, intensity and specialization, of which the more dominant ones (see Chapter 2) are represented. The specialization 'diverse arable' is currently small, but could largely increase towards 2050 under certain scenarios (see Chapter 2). We acknowledge that in terms of size, 'very large' farms are missing, while this is a large group and is projected to increase. We are nevertheless confident that the solution space largely covers the possibilities in the region.

3.4.2 Interpretation of results

In terms of objectives considered in the research, economic result appeared to be the most important objective for farms' current performance. These results, however, cannot be generalized to other production circumstances. For example, Berkhout et al. (2010) found that for West African smallholders staple food production, sustainability and risk aversion appear to be more important objectives than gross margin. Some objectives considered in our study received low weights in interviews, while they seemed to be considered in practical decision-making. This applies first to nitrogen balance. Although farmers were not concerned about their nitrogen application, they needed to remain within the regulated norms. Besides, in our dataset a low nitrogen balance was achieved with high economic result. Certain objectives did not seem to be very important for current farm plans, but receive more attention when searching for alternatives, e.g. soil organic matter balance.

The selected alternative farm plan determined the strategic weights for objectives for the future situation. The reasoning behind the choice of an alternative farm plan for most of the farmers was simple: to have a more extensive farm plan (e.g. by increasing share of wheat in the rotation) to maintain the soil organic matter balance, but also to maintain income at a level similar to the current situation. Farmers were concerned about their production level in the long term, and therefore almost all alternative farm plans (or adaptation options) increase the soil organic matter balance in first place. Also, the selected plans were close to their current farm plan (to prevent large investments necessary to switch to alternative crops; see also Sterk et al. 2006). Besides, the current level of soil organic matter and soil structure hinder growing certain crops (e.g. carrots or seed potato). Regarding working hours, farmers can tolerate a higher labour input, if the result in terms of gross margin will be high. Since risk is calculated as a variance in gross margins, farmers assumed that losses in one year could be compensated by extra income in another year. Therefore, risk received smaller importance weights in the selected alternative farm plans.

In our study we observe differences in performance in terms of important objective weights between farms from different farm types (orientations). For example, production-oriented farms P1 and P2 have the largest realized weights for economic result derived from the current performance of their farm plans. In the selected alternative farm plans for these farms the priority in strategic weights goes again to economic result. Farms with entrepreneurial orientation (E1 and E2) have also other sources of income next to primary production, and therefore the economic result receives smaller importance weights for these farms.

3.4.3 Use of objective weights in adaptation research and modelling

Janssen and van Ittersum (2007) stressed the need to better reflect actual farmer decision-making in bio-economic models. Potential heterogeneity in decision-making structure between different farm types can have impact on the choice of adaptation measures. In previous integrated assessments for arable farms in Flevoland it was assumed that farms have a single objective function (Kanellopoulos et al. 2010, Kanellopoulos et al. 2014). In Kanellopoulos et al. (2010), the objective was maximizing gross margin corrected for risk, but as positive mathematical programming was used, other objectives were partly implicitly considered in the quadratic cost functions. Kanellopoulos et al. (2014) suggested that 41% of the farmers in Flevoland could be considered as profit maximizers, but other objectives were not investigated. Here, we made those other objectives explicit. We therefore will be able to assign importance weights to a multi-attribute utility function to assess farm type specific adaptation measures using a bio-economic model.

As a result of this study we obtained three sets of weights for multiple objectives. However, not all weights will be finally used in follow-up impact assessment studies. Weights recovered from the interviews will correspond to the farm plans that will not provide enough income to the farmers to be competitive, as in practice the real threshold, or anti-ideal value, for farm economic result is higher than calculated by the model (the model calculated alternative farm plans with economic result starting from 71€/ha, while for most of the farms the acceptable economic result lies within the range 2500-3500€/ha, see Table 3.4). Weights recovered from current farm performance reflected the actual farmers' decision-making and therefore might appear more suitable. However, these weights are related to the current conditions, which might change in the future (e.g. soil organic matter balance), and thus the performance weights for the objectives might change. Comparing the outcomes of bio-economic modelling studies using different sets of weights will be interesting to understand the importance of different weights of objectives for adaptation.

In terms of importance of particular objectives, economic result and soil organic matter balance seem to be the most crucial ones for strategic decisions (and the selection of adaptation options) of the farmers investigated in this study.

3.5 Conclusions

The presented approach provides insight in farmers' decision-making. We consistently assessed the importance of their objectives from what farmers say (by deriving stated preferences of objectives from the ranking), from what farmers actually do (by analysing current farm performance) and from what farmers want (through selected alternative farm plan).

The stated importance of objectives (from the interview) was not always realized in their practical decision-making (i.e. current performance). However, the strategic weights of farmers' objectives appeared to be relatively close to the realized importance of objectives, as farmers tended to select an alternative farm plan (i.e. adaptation option) that would not differ largely from their current farm plan in terms of objective prioritizing. At the same time, adaptation preferences of farmers moved in the direction of their stated preferences.

In terms of objectives considered in the research, economic result appeared to be the most important objective for farms' current performance. Towards the future, farmers were searching for more sustainable management options and were more concerned about soil organic matter. Nitrogen balance does not receive a lot of additional attention from farmers' side, as nitrogen application is strictly regulated in the Netherlands.

The different sets of weights for multiple objectives from the different methods can be further used in bio-economic modelling, to assess adaptation measures to climatic and socio-economic change.

Appendix 3.A – Characteristics of current farm plans.

	share	price, €/kg	yield, 1000kg/ha	cultivation costs, €/ha	Revenues, €/ha	GM, €/ha	Lab.requir, hrs/ha	Eff.OM, kg/ha	Artificial fertilizer, kg/ha N	P	K	organic fertilizer 1000kg/ha
P1												
seed potato	0.33	0.26	44	7633	11440	3807	70	900	30	0	0	20
sugar beet	0.17	0.04	90	1635	3600	1965	14	1400	54	0	0	20
seed onion	0.17	0.13	90	2727	11700	8973	37	150	0	0	0	20
grass	0.17	0.04	7	805	280	-525	14	2000	54	0	0	20
chicory	0.17	0.13	35	2255	4550	2295	44	650	0	0	0	20
P2												
winter wheat	0.25	0.14	11	786	1540	754	13	2650	81	0	0	30
sugar beet	0.17	0.04	100	1635	4000	2365	14	1400	120	0	0	0
consumption potato	0.25	0.14	63	2610	8820	6210	26	900	54	0	180	40
seed onion	0.2	0.13	70	2727	9100	6373	37	150	125	48	93	0
winter carrot	0.13	0.14	85	2992	11900	8908	21	150	54	0	112	0
P3												
winter wheat	0.3	0.14	10	786	1400	614	13	2650	81	0	0	50
sugar beet	0.2	0.04	100	1635	4000	2365	14	1400	108	0	0	0
consumption potato	0.2	0.14	55	2960	7700	4740	26	900	214	51	96	9
seed onion	0.2	0.13	70	2727	9100	6373	37	150	152	46	0	13.5
green peas	0.1	0.17	8	170	1360	1190	11	500	27	69	0	0
N1												
winter wheat	0.33	0.14	11	786	1540	754	13	2650	199	0	0	0
sugar beet	0.17	0.04	100	1635	4000	2365	14	1400	122	0	90	0
consumption potato	0.07	0.14	63	2960	8820	5860	26	900	265	35	150	0
seed onion	0.17	0.13	70	2727	9100	6373	37	150	140	18	155	0
seed potato	0.26	0.26	45	7633	11700	4067	70	900	72	42	96	0

Appendix 3.A (continued) – Characteristics of current farm plans.

	share	price, €/kg	yield, 1000 kg/ha	cultivation costs, €/ha	Revenues, €/ha	GM, €/ha	Lab.requir, hrs/ha	Eff.OM, kg/ha	Artificial fertilizer, kg/ha N	P	K	organic fertilizer 1000 kg/ha
E1												
sugar beet	0.2	0.04	80	1635	3200	1565	14	1400	128	0	0	0
green peas	0.09	0.17	7	170	1190	1020	11	500	27	0	0	25
winter carrot	0.09	0.14	85	2992	11900	8908	21	150	115	0	240	25
seed potato	0.32	0.26	45	7633	11700	4067	70	900	114	136	240	0
seed onion	0.17	0.13	80	2727	10400	7673	37	150	133	49	240	0
E2												
winter wheat	0.25	0.14	10	786	1400	614	13	2650	213	42	0	0
sugar beet	0.25	0.04	90	1635	3600	1965	14	1400	122	0	90	0
consumption potato	0.25	0.14	55	2610	7700	5090	26	900	359	135	366	0
chicory	0.25	0.13	35	2255	4550	2295	44	650	24	38	173	0

Appendix 3.B – Rotational constraints included in FarmDESIGN

Rotational constraints	Included in FarmDESIGN	Remarks
• *Timing*		
1. Sowing and harvesting dates	-	
2. Minimum inter-crop period	-	
• *Sequence and frequency*		
3. Restriction on crop successions	-	
4. Maximum frequency of each crop in rotation[1]:		
Sugar beet	0.20	Sb quota
Winter wheat	0.5	
Green peas	0.17	
Winter carrot	0.17	
Seed potato	0.25	
Seed onion	0.17	
Chicory	0.25	
5. Maximum frequency of groups of crops in rotation:		
Root and tuber crops		
Potatoes	0.7	
6. Minimum period before repeating a crop	0.33	
• *Farm specific feasibility and applicability*	-	
7. Maximum lengths of rotation in years		
8. Maximum number of different crops in rotation	-	
9. Maximum number of main and secondary crops:	-	
Main crops (sugar beet, seed potato, seed onion, winter wheat,	-	
chicory)	-	
Secondary crops (winter carrot, green peas)		
	-	

[1]Dogliotti et al. (2004)

Appendix 3.C – General and nutrient balances constraints included in FarmDESIGN

Constraints	Min	Max	Original farm plan (P1)
General & profit constraints			
GM crops (euro)	0	1000000	169758
GM variance (euro)	0	1000000	100933
Farm area (ha)	52	54	54
Nutrient constraints			
Balance N (unit)	-100	300	61
Balance P (unit)	0	100	57
Balance K (unit)	-100	100	-48

Appendix 3.D – Organic matter balance at farm P1 (kg/ha)

Inputs	
Crop residues	651
Green manure	0
Own manure	0
Added manure	859
Outputs	
Manure degradation	787
SOM degradation	1572
Erosion losses	0
Balance	-850

Appendix 3.E – Nutrient balances at farm P1(kg/ha/year)

	N	P	K
Inputs			
Crop products to soil	0	0	0
Fixation	0	0	0
Atmospheric deposition	24[1]	1	3
Non-symbiotic fixation	12[2]	0	0
Import fertilizer & manure	169	91	115
Outputs			
Export crop products	145	35	166
Export animal products	0	0	0
Export with manure	0	0	0
Balance			
Inputs	205	92	118
Outputs	145	35	166
Balance	61	57	-48

[1]Janssen (1999)
[2]Calculations by Janssen, depends on the organic matter content

Chapter 4

Crop and farm level adaptation under future climate challenges

Abstract

Climate change is expressed in both a shift of mean climatic conditions and an increase in the frequency and severity of weather extremes. The weather extremes are often projected to have a larger impact on agricultural production than gradual increase in temperature or gradual change in precipitation. To cope with the impacts of future climate change, farmers will have to apply adaptation measures at crop and farm level. The choice of the adaptation measures is assumed to be determined by farm resources, current layout and performance of the farm and farmer's objectives.

Here we present a method to assess the importance of crop and farm level measures to adapt to climate change and extreme events considering farmers' different objectives. We used a multi-objective optimization model to generate alternative farm plans and assess the impacts of previously identified farm and crop level adaptation measures in terms of farm performance on the objectives of maximizing farm economic result and soil organic matter balance.

Our results for selected arable farms in the province of Flevoland (the Netherlands) suggest that gradual climate change improves farm performance in terms of farm economic result. The degree of improvement varies per scenario and per farm, depending on the cropping pattern. At the same time, extreme events neutralize positive impacts of gradual climate change. A combination of crop and farm level adaptation is needed for the surveyed farms in terms of improving both farm economic result and organic matter balance.

Keywords: climate change, extreme events, agriculture, adaptation measures, multi-objective optimization

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Mandryk M, Reidsma P, van Ittersum MK. Crop and farm level adaptation under future climate challenges: an exploratory study considering multiple objectives for Flevoland, the Netherlands.

4.1 Introduction

Climate change is expressed in both a shift of mean climatic conditions (e.g. temperature and precipitation), and an increase in the frequency and severity of weather extremes (Eitzinger et al. 2013; Porter et al. 2014; Tebaldi et al. 2006). The weather extremes are often projected to have a larger impact on agricultural production than gradual increase in temperature or gradual change in precipitation (Moriondo et al. 2011; Schaap et al. 2013; Van Oort et al. 2012a). More frequent droughts and extreme weather events during the cropping season are likely to increase the number of unfavourable years, which may cause enhanced yield instability and make current agricultural areas less suitable for traditional crops (Olesen and Bindi 2002), with climate change impacts varying across crops and regions (Klein et al. 2014; Supit et al. 2012).

The impacts of climate change that induced changes in extreme weather events have only been assessed at crop level (Eitzinger et al. 2013; White et al. 2011). To cope with the impacts of future climate change farmers will also have to apply adaptation measures at other levels than the crop. Adaptation measures to climate change in agriculture include a large variety of activities directly related to reducing vulnerability to climate change, such as technological developments or changes in farm production practices (Smit and Skinner 2002). The latter also include farm level adjustments in crop rotations by shifting from currently grown to alternative crops and changes in land use (Klein et al. 2013). Cropping plan decisions are crucial steps in crop production processes and have considerable effects on the annual and long-term productivity and profitability of farms (Dury et al. 2012). Only few studies examined changes in crop rotations as adaptation option to climate change (Klein et al. 2014).

There has been much more research on plant response to climate change than on human response to climate change (van Oort et al. 2012b). The chapter on “Food security and food production systems” in the 5th IPCC WG2 report (Porter et al. 2014) has focused mainly on crop level impacts and adaptation – based on the results of crop models and statistical analyses – with little emphasis on farm level adaptation. Several empirical studies have compared climate change impacts in Europe with and without adaptation (Moore and Lobell 2014; Reidsma et al. 2010) and found that adaptation can largely reduce the impacts of climate change and climate variability on European agriculture. Details on the measures, their costs and adoption rates have not been studied, however.

Climate change impact assessment in agriculture needs to be based on integrated assessment and farming systems analysis, and account for adaptation at different levels (Reidsma et al. 2015). The use of bio-economic models linking crop growth models with economic decision models has been suggested in various studies as a way forward towards integrated assessment of adaptation to climate change (Challinor et al. 2009; Finger and Calanca 2011; Lehmann et al. 2013; Olesen et al. 2011; Reidsma et al. 2010; Reidsma et al. 2015). The use of an optimization technique to identify adaptation strategies was only conducted in few studies (Kanellopoulos et al. 2014;

Lehmann et al. 2013; Schütze and Schmitz 2010). However, those studies solely addressed impacts of climate change and management on economic yield without considering the multifunctional role of agriculture. Multiple objectives have been considered, but not at farm level (Holzkämper et al. 2015; Klein et al. 2014). Farm level responses towards climate change considering a farmer's multiple objectives have not yet been assessed.

In Chapter 3 we assessed the role of farmer's objectives in terms of current farm practices and adaptation preferences. We showed that prioritizing in farmer's objectives can change when focusing on future adaptation options compared to the current farm performance. Economic result and maintaining the organic matter balance appeared to be the most important farmers' objectives in strategic decision making involving adaptation in the Dutch province Flevoland (Chapter 3). Weights given to different objectives can however change in the future. Farm structural change will take place and current farms will likely look different around 2050 in terms of economic size, specialization, intensity and farmer's objectives (Chapter 2).

The present study assesses the role of crop and farm level measures to adapt to climate change considering farmers' different objectives. More specifically we are aiming at answering the following research questions. 1) What will be the impact of gradual climate change on farm performance? 2) What will be the impact of the changes in future frequency of extreme events on farm performance? 3) How important is crop level adaptation compared to farm level adaptation in improving farm performance on important objectives (i.e. economic result and soil quality maximization) in climate change scenarios with extreme events? 4) How will different farmers' objectives influence preferences for different adaptation measures to climate change?

4.2 Methods

4.2.1 Farms, farmer's objectives and farm plans

We surveyed six arable farms from the province of Flevoland, The Netherlands (Table 4.1). We assigned each farm to farm types based on the typology developed in Chapter 2.

We previously assessed that objectives of maximizing farm economic result (i.e. gross margin of crops, €/ha) and soil quality (i.e. organic matter balance, kg OM/ha) were most important for the surveyed farmers (Chapter 3). Each of the farms performed differently in terms of the most important objectives, which is attributed mainly to the cropping pattern and the management (Table 4.2).

We also previously asked farmers to indicate the "desired", or preferred alternative farm plans. Preferred alternative farm plans were initially meant to improve farm performance on the important objectives in the current climate (see Chapter 3).

Table 4.1– Survey data of the six farms on farm structure and resources. The definition and thresholds for farm orientation, size, intensity and specialization are provided in Chapter 2.

Farm code	Structure				% UAA[1] Flevo-land	Resources		
	Orientation	Size	Intensity	Specialization		Area, ha	Labour, hrs/yr	Soil OM[2], %
P1	Production	Large	High	Diverse mainly root crops	5.2	54	3300	2.0
P2	Production	Large	Medium	Diverse mainly root crops	19.3	68	2860	4.3
P3	Production	Large	Medium	Diverse arable	19.3	70	2750	4.5
N1	Nature	Large	Medium	Specialized root crops	0.1	52	4080	2.5
E1	Entrepreneur	Large	Medium	Diverse mainly root crops	4.1	53	5000	2.3
E2	Entrepreneur	Medium	Medium	Diverse mainly root crops	1.4	36	1600	4.2

[1]UAA is utilized agricultural area
[2]OM is organic matter

Table 4.2 –Current farm plans in terms of objectives' values and crop areas.

Farm	Objectives		Crop areas (ha)								
	Economi c result (k€/ha)	Organic matter balance (t OM/ha)	WW	SB	GP	WC	SP	SO	CH	GR	CP
P1	3.14	-0.66	0	9	0	0	18	9	9	9	0
P2	4.66	-2.33	17	12	0	11	0	12	0	0	17
P3	3.07	-2.28	21	14	7	0	0	14	0	0	14
N1	3.13	-0.70	17	10	0	0	11	6	0	0	6
E1	3.81	-0.93	7	10	4	5	18	9	0	0	0
E2	2.50	-2.13	9	9	0	0	0	0	9	0	9

WW-winter wheat; SB-sugar beet; GP-green peas; WC-winter carrot; SP-seed potato; SO-seed onion; CH-chicory; GR-grass; CP-consumption potato

4.2.2 Climate change, extreme events

Climate change scenarios

The effects of climate change towards 2050 on crop yields of the surveyed farms were assessed based on the available results on simulated potential yields in Flevoland with the WOFOST model (Van Diepen et al. 1989) for two future climate change scenarios G and W+; without any adaptation, e. g. for cultivar and sowing dates (Reidsma et al. 2015; Wolf et al. 2011; see Appendix 4.A). The climate scenarios have been developed by the Royal Dutch Meteorology Institute (KNMI) (van den Hurk et al. 2006). The G climate scenario assumes a moderate global temperature increase of 1°C by 2050 with no change in atmospheric circulation, whereas the W+ scenario assumes a significant global temperature increase of 2°C by 2050 accompanied by a change in atmospheric circulation, resulting in dryer summers. CO_2 concentrations were assumed 478 μmol CO_2 mol^{-1} for the G scenario and 567 μmol CO_2 mol^{-1} for the W+ scenario.

Effects of extreme events on crop yields

The most relevant climate related risks of extreme events on crop production for the sample farms were identified based on Schaap et al. (2011). In the present study we focus on high value crops in Flevoland, which are the most heavily impacted crops by climate change and have high economic importance (Schaap et al. 2013). Besides, climate change impacts on high value crops determine farm level impacts and therefore influence the choice for adaptation. High value crops for arable farming in Flevoland are seed and consumption potato and seed onion, which comprise a large share in typical crop rotations in the region (from 0.25 to 0.50 on 6 surveyed farms). Although winter carrot also has a high gross margin, the share of this crop in rotations in Flevoland is much smaller and therefore in this thesis we refer to potatoes and onion as high value crops. We assessed five effects from extreme events with damage more than 1000 €/ha (de Wit et al. 2009; Schaap et al. 2013). For seed and consumption potato these are heat wave and warm winter; for seed onion, warm and wet conditions.

We calculated the yield reduction caused by extreme events based on change of frequency of extreme events in the future and average damage of the effects:

$$Y_{\Delta} = D * (F_f - F_c), \qquad \text{(equation 4.1)}$$

where Y_{Δ} is a relative yield reduction (fraction); D is the average relative yield damage (fraction); F_f is future frequency of an extreme event and F_c is the current frequency. The results are presented in Table 4.3.

Table 4.3 – Effects of weather extremes on major arable crops in the North of the Netherlands.

Extreme event	Yield damage **D**		Absolute occurrence (nr/30 years)			Frequency (occurrence/year)			Yield reduction $\mathbf{Y_{\Delta}}$		
	min	max	1990	G	W+	1990 $\mathbf{F_c}$	G $\mathbf{F_f}$	W+ $\mathbf{F_f}$	1990	G	W+
Seed onion											
Warm + wet	0.50	0.60	1	10	21	0.03	0.33	0.70	0	0.17	0.37
Seed/consumption potato											
Heat wave	0.25	0.75	8	14	40	0.27	0.47	1.33	0	0.10	0.52
Warm winter	0.25	0.75	3	7	21	0.10	0.23	0.70	0	0.07	0.32

We further estimated the reduction factors for yield in a year when both extreme events would happen sequentially, i.e. heat wave is followed by a warm winter (the case of seed and consumption potato). Yield reduction from a warm winter should be multiplied with the yield reduction by the heat wave:

$$Y_D = Y * (1 - Y_{\Delta 1}) * (1 - Y_{\Delta 2}), \qquad \text{(equation 4.2)}$$

where Y_D is a yield after a total damage from both extreme events (t/ha); Y is the original yield (t/ha); $Y_{\Delta 1}$ is a damage from the first extreme event (fraction); $Y_{\Delta 2}$ is a damage from the succeeding effect (fraction).

4.2.3 Adaptation measures

Crop level adaptation

Adaptation measures against risk of future climate-related extreme events for high value crops in Flevoland have been identified in Schaap et al. (2013). From the list of adaptation measures per crop and per main climate risk we selected measures proposed for the impact of a climatic factor of more than 1000 €/ha/year on average (de Wit et al. 2009) that appeared to be most cost-effective based on Schaap et al. (2013) (Table 4.4).

Table 4.4 – Selected adaptation measures at crop level (source: Schaap et al. 2013).

Climate risks and adaptation measures	Impact (weight of economic loss)	Effectiveness **E** (to reduce crop losses due to climatic factor)	Annual costs (k€/ha)	Investment costs (k€/ha)
Seed and consumption potato				
Heat wave – second growth	0.25-0.75			
1. Plant in wider ridges		0.75	-	> 50
2. Drip irrigation		0.9	1	-
3. Optimise crop cover		0.5	0-0.5	-
Warm winter – early sprouting	0.25-0.75			
4. Air conditioning		0.9	0.1-0.2	-
Seed onion				
Warm and wet – fungi infection	0.50-0.60			
1. Chemical protection		0.9	0.5-1	10-100
2. UV-light protection		0.9	0.5-1	30

We assumed here that if a farmer implements a combination of adaptation measures against different climate risks associated with extreme events in his farm plan, this might further reduce the crop losses. Practically it means combining the measure against warm winter (i.e. air conditioning) with one of the three measures against heat wave (i.e. plant in wide ridges; drip irrigation; and optimize crop cover). It is unlikely that a farmer would choose a combination of more than two adaptation measures per risk, considering the cost-effectiveness of measures and overlap in effects to reduce the impacts of extreme events. We also assumed that a farmer would always apply the adaptation measure in advance of a growing season, not knowing whether the event will occur, so he would also always have costs of the measures.

We calculated the final yield (i.e. yield with (combinations of) adaptation measures against extreme events applied) in a sequence of calculation steps (see also Table 4.5):

$$Y_A = Y * (1 - \prod_{a_i=1}^{n}(Y_{\Delta a_i})), \qquad \text{(equation 4.3)}$$

where Y_A is a final yield (t/ha); Y is the original yield (no impact of extreme events) (t/ha); and $Y_{\Delta a_i}$ is a yield reduction (fraction) due to application of an adaptation measure *a* against an extreme event *i*, calculated as follows:

$$Y_{\Delta a_i} = (1 - E_a) * Y_{\Delta_i}, \qquad \text{(equation 2.4)}$$

where Y_{Δ_i} is a relative yield reduction caused by extreme event i (see equation 2.1) and E_a is the effectiveness of the adaptation measure *a* (fraction; see Table 4.3).

Using the example of seed potato, we can illustrate how the calculation of final yield (Y_A) has been performed for farm P1 (see also Table 4.5). Due to climate change, yield of seed potato in 2050W+ was estimated to increase by 2.8% (Reidsma et al. 2015; Wolf et al. 2011). For farm P1 seed potato yield (Y) will become 45.2 t/ha. The yield reduction (Y_Δ) caused by extreme effect "heat wave" is 0.52 (see Table 4.3). There are three adaptation measures proposed against heat wave (see also Table 4.4), each of them with different effectiveness *E*. Measure 1 (plant in wider ridges), for example, if applied alone, will secure a yield (Y_A) of 39.3 t/ha due to its effectiveness E to reduce the damage by a heat wave by 0.75. However, the yield will still be affected by "warm winter" (with the yield reduction (Y_Δ) of 0.32). Therefore, the yield (Y_A) with impacts of both extreme events and adaptation against heat wave by planting in wider ridges will be 26.9 t/ha.

Table 4.5– Selected (cost-)effective crop level adaptation measures. Yield reduction and impact of extreme events are presented for W+ scenario for farm P1.

adaptation measures				yield 2050 (t/ha)		
	yield reduction $Y_{\Delta 1}$	yield reduction $Y_{\Delta 2}$	yield reduction $Y_{\Delta ai}$	no impact of extreme events **Y**	impact of extreme events and adapt Y_A	cost of adaptation measure (k€/ha)
Seed potato				45.2		
No adaptation					14.8	n/a
Heat wave						
1 plant in wider ridges		0.32	0.13		26.7	-
2 drip irrigation		0.32	0.05		29.2	1.0
3 optimize crop cover		0.32	0.26		22.7	0.25
Warm winter						
4 air conditioning	0.52		0.03		21.0	0.15
Heat wave and warm winter						
5 plant in wide ridges and air conditioning			0.0039		45.0	0.15
6 drip irrigation and air conditioning			0.0015		45.1	1.15
7 optimize crop cover and air conditioning			0.0078		44.8	0.4
Seed onion				102.8		
No adaptation					64.8	n/a
Warm and wet						
1 chemical protection			0.04		98.7	0.5-1.0
2 UV-light protection			0.04		98.7	0.5-1.0

Farm level adaptation

Changes in crop rotations (i.e. shift to alternative crops) are included as adaptation measures at farm level in our study. Adaptation measures aimed at improvement of organic matter balance at farm level include increased share of wheat (up till 50%) and grass in rotation. When farms aim to improve the farm economic result in the first place, they shift to alternative – mostly high value – crops or increase the share of currently grown high value crops in their rotation. In general, in this study preferred alternative farm plans in the current situation represent farm level adaptation in the current situation (i.e. improvement of farm performance on indicators linked to different objectives – see also Chapter 3). We assess whether these preferred alternative farm plans can also be considered as farm level adaptation in future scenarios. In addition, we investigate impacts of climate change on economic result and organic matter balance per crop, to propose improved farm level adaptation, depending on the objectives of the farmers.

4.2.4 Input and output assumptions

Under future climate change one could also anticipate changes in important inputs for crop growth. Additional fertilizer inputs required for the yield increases due to climate change in the W+ and G scenarios have been calculated, using the same approach as described by Kanellopoulos et al. (2014) and Wolf et al. (2011). For higher yield levels we assumed a fixed recovery fraction of the N applied to calculate fertilizer N requirement, while the nitrogen required for 20 % of actual yield is supplied by the soil. The resulting changes in fertilizer nutrient application per crop in the future are provided in Appendices 4.A and 4.B. We focus here on the nitrogen applications (kg N/ha) and assume that the future changes in fertilizer costs are linearly related to those of N fertilizers.

We assumed a neutral impact of future climate change on soil organic matter balance on the surveyed farms, because the effect of climate change on soil organic matter contents is largely uncertain. In our study the organic matter balance is calculated as an average per ha at farm level, and is defined as the sum of organic matter addition from crop residues and manure minus organic matter decomposition (of indigenous plus added soil organic matter). Erosion can be ignored on the flat polders of the Netherlands with clayey soils. Following yield increase under gradual climate change, crop residues to soil might also increase in the future. However, the effects of yield increases on soil organic matter through residues are largely uncertain (Wiesmeier et al. 2014), since especially the link between relatively short-term plant responses to CO2 enrichment and any longer term consequences for organic matter accumulation are very difficult to measure (Norby 1994). The (future) climatic factors influencing the soil organic matter decomposition process (i.e. temperature, precipitation and CO2 concentration) are often shown to cancel out each other, meaning the overall impact of climate change on the soil organic matter balance is not as large as concluded from the results of single factor studies (Gärdenäs et al. 2011). Hence, the effects of climate change on changing inputs of organic matter and its decomposition for given farm plans in Flevoland are assumed to balance each other across the time frame of our study. Changes in organic matter balance in the future will be determined much more by changes in crop types and rotation sequences, as one of the main management practices influencing soil organic matter sequestration on farms at given intensity levels (Ogle et al. 2010).

Assumptions on current and changing labour requirement due to implementation of certain adaptation measures were based on the Dutch information handbook for arable farming and horticulture (Anonymous 2009), depending on a fixed amount of hours for a certain management operation (i.e. a part of the adaptation measure). For example, the adaptation measure “optimize crop cover” will include tillage operation, which implies three hours/ha extra in terms of labour requirement for seed potato cultivation. Since total labour requirement for seed potato cultivation (without adaptation measures) is 70 hours/ha, the total labour requirement with adaptation measure “optimize crop cover” becomes 73 hours/ ha (see Appendices 4.C-4.E).

Crop prices in the future scenarios were assumed to be at the level of 2010 (see also Appendix 4.F).

4.2.5 Model description

In this study we used the multi-objective optimization model FarmDESIGN (Groot et al. 2012), developed to support the learning and decision-making process of re-designing farming systems. The model allows to calculate the consequences of a farm configuration for a large set of farm performance indicators (e.g. nutrient balances and flows, labour balance, organic matter balance and operating profits), and subsequently to explore trade-offs between farmers’ multiple objectives, by linking a bio-economic component to a multi-objective Pareto-based Differential Evolution algorithm. The outcomes of the optimization runs are alternative farm configurations (i.e. cropping patterns) based on the original farm plan evaluated in terms of the multiple objectives. The objectives included in the optimization process of the model include maximization of economic result, soil quality, minimization of labour balance, risk and nitrogen balance (see Chapter 3).

A detailed model description is provided by Groot et al. (2012). The adjustments – referring to risk and labour – we made to the model to make it applicable for our research are described in Chapter 3 and Appendix 4.F. An overview of rotational constraints, general and nutrient balances constraints, input data for calculating nutrient balances and organic matter balance is also presented in Chapter 3.

4.2.6 Model simulations required to answer the research questions

Each simulation with the FarmDESIGN model aimed to answer a specific research question of the paper and show the impacts of future climate scenarios (with and without adaptation against extreme events) for both current and preferred alternative farm plans for each surveyed farm. The short description of the simulations is provided below.

Simulation 1 addresses the research question *What will be the impact of gradual climate change on farm performance?* The aim of the simulation was to show the effects of gradual climate change on farm performance in W+ and G climate scenarios, without the option of implementing adaptation measures specific for climate change. Farm performance may differ per farm and objective. For this simulation we used future yields and fertilizer N application for all crops from Appendices 4.A and 4.B. The results of the simulation are compared to the situation with current climate.

Simulation 2 addresses the research question *Will the changes in future frequency of extreme events impact farm performance to a larger extent than a gradual climate change?* This simulation investigates the damage of future extreme events on yields of high value crops and the impacts on the gross margin of crops for the surveyed farms. Here we applied yield reduction for high value crops caused by extreme events (equations 4.1 and 4.2). Fertilizer input and yields for other crops remained unchanged from simulation 1 (gradual climate change only). The outcomes of the simulation are compared to simulation 1.

Simulation 3 addresses the research question How *important is crop level adaptation compared to farm level in improving farm performance on important objectives (i.e. economic result and soil quality) in climate change scenarios with extreme events?* Here we investigate what gives more benefits: crop or farm level adaptation. We assess whether it is interesting for farmers to invest in crop level adaptation to cope with extreme events affecting potato and onion yields, or whether switching to other crops is a better adaptation option. For this simulation we added adaptation measures for high value crops and the corresponding yield per adaptation measure (Table 4.5) to the FarmDESIGN model. Labour requirement and costs of the adaptation measures are provided in Appendix 4. E. Fertilizer input and yields for other crops were the same as in simulations 1 and 2. We compared the results of the simulation to the results of simulation 1 (gradual climate change and no effects of extreme events).

The research question *Will different farmers' objectives lead to different preferences for different adaptation measures to climate change?* does not require a separate model simulation and can be addressed by analysing the results of simulation 3.

4.2.7 Farm performance in the current situation

We first summarize the performance of the current farm plans in the current climate situation and describe the choice for preferred alternative farm plans, focusing on the objectives of economic result and organic matter balance. These results were presented in detail in Chapter 3.

Farms P2 and E1 showed the best performance in terms of economic result in the situation with current climate (Figure 4.1). These farms grow seed onion and winter carrot, the crops with the highest gross margin (more than 7600€/ha). Farms N1, P1 and E1 performed best within the sample as to the soil organic matter balance. These farms either applied a lot of organic fertilizer (farms P1 and E1) or had a large share of crops that added a large amount of effective organic matter to the soil (for farm N1 the share of wheat in the rotation was 0.33).

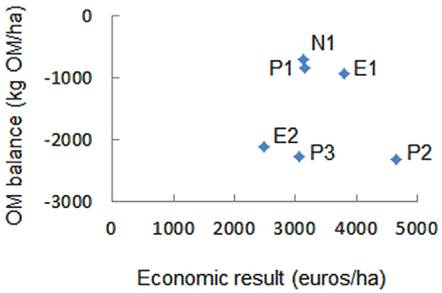

Figure 4.1 – Performance of sampled farms in terms of economic result and organic matter balance.

Regarding adaptation preferences in the current climate, the surveyed farms demonstrated quite a large diversity in terms of preferred alternative farm plans, depending on their current cropping pattern, current performance as to the important objectives and the priorities they gave to different objectives (Chapter 3). Farmers P1, P2 and E1 focused on improvement of organic matter balance and therefore chose to grow more winter wheat. The share of high value crops in these farm plans remained unchanged. Farmers P3 and E2 were more interested in economic result maximization and therefore their preferred alternative farm plans had increased share of high value crops. Farmer P3 decided to grow seed potato next to consumption potato and seed onion, while Farmer E2 preferred to switch from consumption potato to seed potato and seed onion. Farmer N1 was satisfied with his current performance and cropping pattern and preferred to keep it unchanged, including the share of high value crops.

4.3 Results

Table 4.6 provides the simulation results in terms of organic matter balance and gross margin of crops for the current and preferred alternative farm plans. Each simulation corresponds to the specific research question.

4.3.1 *What will be the impact of gradual climate change on farm performance?*

The results of the simulation for selected farms show that in both climate change scenarios farms will achieve a better economic result with the current farm plan (up to 40%), while we assume organic matter balance remains unchanged. Since yield increases in W+ and G climate scenarios vary across crops (see Appendix 4.A), farms with different farm plans will profit differently from climate change. All farms are simulated to have a higher increase in gross margin of crops in the G scenario, due to higher yields – especially for seed potato and onion – compared to the W+ scenario.

The gross margins of crops for the preferred alternative farm plans for farms P1 and P2 profit less from climate change compared to the current plan. For farms E2 and P3 the situation is the opposite, partly because the farms selected more profitable and more intensive crops.

From the simulation results we can conclude that gradual climate change improves farm performance in terms of farm economic result. The degree of improvement varies per scenario and per farm, depending on the cropping pattern. Farms growing seed onion and seed potato profit more from the yield increase and thus also gross margin increase in the G scenario.

4.3.2 *What will be the impact of the changes in future frequency of extreme events on farm performance?*

Our simulation results show that the impacts of extreme events on farm economic result for the current farm plans differ considerably between the G and W+ scenarios (Table 4.6). In the W+ scenario with extreme events, all farms are simulated to have a huge negative impact from the extreme events on gross margin of crops for the current farm plan compared to the gradual climate change scenario, since all farms have high value crops in the current farm plan. In the G scenario with extreme events, the values for the gross margin of crops remain around the current level for all farms.

For the preferred alternative farm plans, there is more diversity in impacts of extreme events on farm plans. In the W+ scenario, there is also a severe negative impact of the extreme events on the gross margin of crops, similarly to the situation with the current farm plans. In the G scenario, farms E1, E2 and P3 can still increase their gross margin of crops compared to the current situation, benefiting from relatively small impacts of the extreme events on high value crops counterbalanced by general productivity increase for other crops. Preferred alternative farm plans for farms E1, E2 and P3 are therefore less vulnerable to climate change.

From the explanations of the simulation results mentioned above we can conclude that the changes in future frequency of extreme events impact farm performance very negatively in terms of gross margin of crops in the W+ scenario (from -24 to -93%) and in the G scenario the impacts differ per farm (i.e. per specific cropping pattern) (from -9 to +22%).

Table 4.6 – Gross margin of crops and organic matter balance for the six farms in different scenarios for the current and preferred alternative farm plans[1].

Scenario	Adaptation level	Farm plan	P1 Organic matter balance (t OM/ha)	P1 % change	P1 Gross margin of crops (k€/ha)	P1 % change	P2 Organic matter balance (t OM/ha)	P2 % change	P2 Gross margin of crops (k€/ha)	P2 % change	P3 Organic matter balance (t OM/ha)	P3 % change	P3 Gross margin of crops (k€/ha)	P3 % change
What will be the impact of gradual climate change on farm performance?														
Current climate		Current	-0.66		3.14		-2.33		4.66		-2.28		3.07	
		Pref.alternative	**-0.38**	**+42**	**2.90**	**-8**	**-2.14**	**+9**	**4.39**	**-6**	**-2.48**	**-8**	**3.48**	**+13**
W+ CC only[2]		Current	-0.66	0	4.00	+27	-2.33	0	5.41	+16	-2.28	0	3.61	+18
		Pref.alternative	**-0.38**	**+42**	**3.66**	**+17**	**-2.14**	**+9**	**4.94**	**+6**	**-2.48**	**-8**	**4.05**	**+32**
G CC only[2]		Current	-0.66	0	4.39	+40	-2.33	0	5.72	+23	-2.28	0	3.79	+23
		Pref.alternative	**-0.38**	**+42**	**4.01**	**+28**	**-2.14**	**+9**	**5.34**	**+15**	**-2.48**	**-8**	**4.35**	**+42**
What will be the impact of the changes in future frequency of extreme events on farm performance?														
W+ CC+EE[3]		Current	-0.66	0	0.55	-82	-2.33	0	3.24	-30	-2.28	0	1.79	-42
	Farm	**Pref.alternative**	**-0.38**	**+42**	**0.21**	**-93**	**-2.14**	**+9**	**2.77**	**-41**	**-2.48**	**-8**	**1.72**	**-44**
G CC+EE[3]		Current	-0.66	0	3.22	+3	-2.33	0	4.97	+7	-2.28	0	3.11	+1
	Farm	**Pref.alternative**	**-0.38**	**+42**	**2.86**	**-9**	**-2.14**	**+9**	**4.58**	**-2**	**-2.48**	**-8**	**3.52**	**+15**
How important is crop level adaptation compared to farm level adaptation in improving farm performance on important objectives (i.e. economic result and soil quality maximization) in climate change scenarios with extreme events?														
W+ CC+EE full adoption of most profitable adaptation measures	Crop	Current	-0.66	0	3.72	+18	-2.33	0	5.16	+11	-2.28	0	3.32	+8
	Farm +crop	**Pref.alternative**	**-0.38**	**+42**	**3.37**	**+7**	**-2.14**	**+9**	**4.69**	**+1**	**-2.48**	**-8**	**3.30**	**+8**
G CC+EE full adoption of most profitable adaptation measures	Crop	Current	-0.66	0	4.16	+32	-2.33	0	5.48	+18	-2.28	0	3.49	+14
	Farm +crop	**Pref.alternative**	**-0.38**	**+42**	**3.80**	**+21**	**-2.14**	**+9**	**5.09**	**+9**	**-2.48**	**-8**	**3.92**	**+28**

[1]Current farm plans and preferred alternative farm plans in different scenarios are compared to the current farm plan in the current climate. The values for preferred alternative farm plans are given in bold.

[2]Gradual climate change scenarios

[3]Climate change scenarios with extreme events

Table 4.6 (continued) – Gross margin of crops and organic matter balance for the six farms in different scenarios for the current and preferred alternative farm plans.

			N1[1]				E1				E2			
Scenario	Adaptation level	Farm plan	Organic matter balance (t OM/ha)	% change	Gross margin of crops (k€/ha)	% change	Organic matter balance (t OM/ha)	% change	Gross margin of crops (k€/ha)	% change	Organic matter balance (t OM/ha)	% change	Gross margin of crops (k€/ha)	% change
What will be the impact of gradual climate change on farm performance?														
Current climate		Current	-0.70		3.13		-0.93		3.81		-2.13		2.50	
		Pref.alternative	**-0.70**	**0**	**3.13**	**0**	**-0.88**	**+5**	**4.02**	**+5**	**-2.22**	**-4**	**2.66**	**+6**
W+ CC only		Current	-0.70	0	3.62	+16	-0.93	0	4.66	+22	-2.13	0	2.96	+18
		Pref.alternative	**-0.70**	**0**	**3.62**	**+16**	**-0.88**	**+5**	**4.65**	**+22**	**-2.22**	**-4**	**3.38**	**+35**
G CC only		Current	-0.70	0	3.92	+25	-0.93	0	5.09	+34	-2.13	0	3.10	+24
		Pref.alternative	**-0.70**	**0**	**3.92**	**+25**	**-0.88**	**+5**	**5.10**	**+34**	**-2.22**	**-4**	**3.58**	**+43**
What will be the impact of the changes in future frequency of extreme events on farm performance?														
W+ CC+EE	Farm	Current	-0.70	0	0.66	-79	-0.93	0	1.17	-69	-2.13	0	1.31	-48
		Pref.alternative	**-0.70**	**0**	**0.66**	**-79**	**-0.88**	**+5**	**1.36**	**-64**	**-2.22**	**-4**	**1.90**	**-24**
G CC+EE	Farm	Current	-0.70	0	2.97	-5	-0.93	0	3.93	+3	-2.13	0	2.72	+9
		Pref.alternative	**-0.70**	**0**	**2.97**	**-5**	**-0.88**	**+5**	**4.01**	**+5**	**-2.22**	**-4**	**3.04**	**+22**
How important is crop level adaptation compared to farm level adaptation in improving farm performance on important objectives (i.e. economic result and soil quality maximization) in climate change scenarios with extreme events?														
W+ CC+EE full adoption of most profitable adaptation measures	Crop	Current	-0.70	0	3.42	+9	-0.93	0	4.38	+15	-2.13	0	2.86	+14
	Farm +crop	**Pref.alternative**	**-0.70**	**0**	**3.42**	**+9**	**-0.88**	**+5**	**4.39**	**+15**	**-2.22**	**-4**	**2.08**	**-17**
G CC+EE full adoption of most profitable adaptation measures	Crop	Current	-0.70	0	3.75	+20	-0.93	0	4.87	+28	-2.13	0	3.06	+22
	Farm +crop	**Pref.alternative**	**-0.70**	**0**	**3.75**	**+20**	**-0.88**	**+5**	**4.89**	**+28**	**-2.22**	**-4**	**3.32**	**+33**

[1]For farm N1 there was no farm level adaptation, since the farmer preferred to keep the current farm plan unchanged

4.3.3 *How important is crop level adaptation compared to farm level adaptation in improving farm performance on important objectives (i.e. economic result and soil quality) in climate change scenarios with extreme events?*

Crop level adaptation

Since we did not ask farmers which adaptation measures against extreme events for high value crops they would eventually choose for their current and preferred alternative farm plans, we assessed the impacts on farm performance in case of a full adoption of the most profitable adaptation measures from Table 4.7 (on 100% of the crop area). For seed and consumption potato adaptation measure 5, which is a combination of plant in wider ridges (measure 1) and air conditioning (measure 4), appeared to have the highest gross margin per ha (Table 4.7). For seed onion measures 1 and 2 (chemical protection and UV-light protection) were equally profitable.

Full adoption of most profitable adaptation measures for high value crops for current farm plans would result in an overall increase in gross margins of crops on all farms, relative to the current climate, with higher gross margins in the G scenario compared to the W+ scenario (Table 4.6). This implies that the negative effects of extreme events for the current farm plans could be almost neutralized (i.e. gross margins are slightly lower than in climate change only scenarios) by adopting crop level measures including plant in wider ridges and air conditioning for potatoes and chemical protection and UV-light protection for onions.

Farm level adaptation

Farm level adaptation in terms of switching to the alternative farm plan, is not effective for all surveyed farms with regard to increase of gross margin of crops in the W+ scenario, since extreme events negatively impact the yields of high value crops in preferred alternative farm plans. In the G scenario, farm level adaptation improved farm gross margin of crops for farms P3, E1 and E2 with the improvement for E2 farm being the most significant (+22%). For farm P2 the impact could be regarded neutral, while for P1 there is a slight negative impact (-9%). At the same time, farm level adaptation – shift to (more) winter wheat – improved organic matter balance on farms P1, P2 and slightly on E1.

In Table 4.7 it can be observed that adaptation towards winter carrot would be most beneficial regarding gross margin for all farms, however soil restrictions often stop farmers from growing this intensive crop. Even without crop level adaptation, the gross margins of seed onion are higher than for other crops, and therefore switching to other crops from seed onion is not interesting from a gross margin point of view. For seed and consumption potato, crop level adaptation ensures higher gross margins than when switching to other crops (except winter carrot), and therefore crop level adaptation is more profitable than farm level adaptation. Shifting to sugar beet and chicory does become relatively more profitable compared to the current situation.

Table 4.7 – Gross margin (k€/ha) of different crops and crop level adaptation measures for the six farms and two climate change scenarios, assuming average damage of extreme events. For numbers of adaptation measures see Table 4.5.

		Farm / climate change scenario											
Crops	Adaptation measures	P1/W+	P1/G	P2/W+	P2/G	P3/W+	P3/G	N1/W+	N1/G	E1/W+	E1/G	E2/W+	E2/G
Seed potato	None	-3.76	2.69	-3.66	2.90	-3.71	2.90	-3.71	2.90	-3.71	2.90	-3.66	2.90
	1	-0.64	3.73	-0.54	4.04	-0.54	4.04	-0.48	3.99	-0.48	3.99	-0.54	4.04
	2	-0.99	2.96	-0.89	3.22	-0.89	3.22	-0.83	3.22	-0.83	3.22	-0.89	3.22
	3	-1.93	3.12	-1.85	3.48	-1.85	3.48	-1.80	3.38	-1.80	3.38	-1.85	3.48
	4	-2.30	3.42	-2.19	3.71	-2.19	3.71	-2.19	3.68	-2.19	3.68	-2.19	3.71
	5	3.92	4.80	4.18	5.09	4.18	5.09	4.18	5.09	4.18	5.09	4.18	5.09
	6	2.94	3.80	3.20	4.09	3.20	4.09	3.20	4.09	3.20	4.09	3.20	4.09
	7	3.62	4.55	3.88	4.84	3.88	4.84	3.88	4.84	3.88	4.84	3.88	4.84
Consumption potato	None	0.15	4.74	0.33	5.22	-0.03	4.22	0.33	5.22	0.15	4.74	-0.03	4.22
	1	2.42	5.51	2.75	6.03	2.08	4.94	2.75	6.03	2.42	5.51	2.08	4.94
	2	1.88	4.65	2.26	5.21	1.50	4.09	2.26	5.21	1.88	4.65	1.50	4.09
	3	1.41	5.05	1.70	5.51	1.13	4.45	1.70	5.51	1.41	5.05	1.13	4.45
	4	1.17	5.25	1.44	5.77	0.91	4.69	1.44	5.77	1.17	5.25	0.91	4.69
	5	5.65	6.20	6.21	6.82	5.08	5.60	6.21	6.82	5.65	6.20	5.08	5.60
	6	4.67	5.20	5.24	5.82	4.09	4.60	5.24	5.82	4.67	5.20	4.09	4.60
	7	5.36	5.95	5.94	6.57	4.80	5.35	5.94	6.57	5.36	5.95	4.80	5.35
Seed onion	None	5.83	9.08	3.96	6.48	3.96	6.48	3.96	6.48	4.90	7.78	4.61	7.39
	1 and 2	9.49	10.44	6.63	7.16	6.63	7.16	6.63	7.38	8.06	8.92	7.63	8.45
WW		0.86	0.98	0.96	1.09	0.82	0.93	0.96	1.09	0.67	0.78	0.82	0.93
WC		11.66	12.37	11.66	12.37	11.66	12.37	11.66	12.37	11.66	12.37	11.66	12.37
SB		3.48	3.14	3.99	3.62	3.99	3.62	3.99	3.62	2.96	2.67	3.48	3.14
CH		3.90	4.17	3.90	4.17	3.90	4.17	3.90	4.17	3.90	4.17	3.90	4.17
GP		1.22	1.24	1.22	1.24	1.31	1.34	1.22	1.24	1.02	1.14	1.22	1.24

WW-winter wheat, WC-winter carrot, SB-sugar beet, CH-chicory, GP-green peas

Crop and farm level adaptation

The combination of crop and farm level adaptation – when applying a full adoption of most profitable measures against extreme events for high value crops in preferred alternative farm plans – neutralizes severe negative impacts of extreme events on gross margin of crops in the future scenarios. The largest neutralizing effect occurs in the W+ scenario, where for farm P1, for example, there is a change in gross margin of crops from -93% to +7%, compared to the current situation (Table 4.6). The most positive effects for gross margin of crops from the combination of crop and farm level adaptation are evident for the G scenario: a maximum of 33% increase in gross margin compared to the current situation can be achieved, as opposite to a maximum of 15% in the W+ scenario (Table 4.6). Additional benefits can be achieved from further farm level adaptation, as mentioned in the previous section.

In general, crop level adaptation was simulated to be most effective in increase of gross margin of crops for farms P1 and P2 in both scenarios, and for farms P3 and E2 in the W+ scenario. Farm level adaptation was simulated to be the most effective for farm E2 in the G scenario. A combination of farm and crop level adaptation was simulated to be the most effective for farm E1 in both scenarios and for farms E2 and P3 in the G scenario. In the W+ scenario farms cannot avoid negative impacts of extreme events on gross margin of crops with farm level adaptation. One needs to apply crop level measures against extreme events either on the current farm plan or in combination with farm level adaptation. In the G scenario, farm level adaptation can be profitable (examples of farms E2 and P3), when increasing the share of seed potato.

4.3.4 *How do different farmers' objectives influence preferences for different adaptation measures to climate change?*

In Chapter 3 we found that among the surveyed farms, P1 and P2 focused on improvement of organic matter balance, when selecting the preferred alternative farm plan in the current situation, while for P3 and E2 farms the priority in terms of objectives was to increase the farm economic result in the current situation. For farm E1 there were still options for improving both objectives simultaneously, and the farm chose to do so. Farm N1 was satisfied with the current performance as to the important objectives.

Using the example of farm P1 we can show how different objectives could lead to different preferences for adaptation measures to climate change. Table 4.6 shows that with the preferred alternative farm plan of farm P1 the gross margin increase will be lower compared to the current farm plan (+7% compared to + 18% in W+ CC+EE full adoption of most profitable adaptation measures), while organic matter balance will be less negative (-0.38 compared to -0.66 t OM/ha). There are additional options generated by the FarmDESIGN model that can increase gross margin of crops and maintain organic matter balance at the level of the preferred alternative farm plan. Crop level adaptation will always be positive for gross margin, and is assumed to have no impact on organic matter. Main differences therefore depend on farm level adaptation in terms of switching crops. Switching from grass to winter wheat would be beneficial regarding both objectives. If the farm would opt for further increase in organic matter balance, there are only few options that do not cause a simultaneous decrease in gross margin of crops. Those options include a switch to winter wheat from grass and partially from chicory and seed potato (see also Appendix 4. G).

If the main objective of the farmer is improvement of gross margin of crops, cultivating high value crops remains the best option, although adaptation measures need to be adopted, which will slightly reduce gross margin. If farms aim to prioritize gross margin of crops and organic matter simultaneously, shifting to winter wheat is a good option, as it improves organic matter balance on the farm and has a relatively small negative effect from climate change on its gross margin.

4.4 Discussion

4.4.1 Impact of climate change, including extreme events, on farm performance

The beneficial effect of gradual climate change on the yield of most of the temperate arable crops in the Netherlands (Angulo et al. 2013; Reidsma et al. 2015; Wolf et al. 2011) was confirmed in our study in terms of economic result at farm level (i.e. gross margin of crops). Similar findings on positive effects on climate change on farm income were reported by Kanellopoulos et al. (2014) and Reidsma et al. (2015), where arable farms in Flevoland were simulated to have an average increase of 7.3% of farm income in the W+ scenario. Our results showed a range from 16 to 27% increase in gross margin of crops on the surveyed farms in the W+ scenario (see Table 4.6).

The assessment of effects of extreme events at farm level is new in adaptation literature. Reidsma et al. (2015) showed that an increased future frequency of extreme events poses large risks on crop yields and therefore affects farm economic results. This was clearly confirmed in our study: positive effects of gradual climate change were offset on all farms in the W+ scenario (Table 4.6).

4.4.2 Adaptation at crop and farm level

One of the important outcomes of this study is the fact that adaptation measures for high value crops help prevent large damage for the gross margin of crops from extreme events on all farm types. At the same time, for some farms climate change will have less impact when farmers apply farm level adaptation and switch to other crops (i.e. reduce the share of high value crops and increase the share of winter wheat). The shift to (more) winter wheat also helps to improve the soil organic matter balance on a farm. The combination of crop and farm level adaptation appeared to be the most effective strategy in improving organic matter balance and maintaining farm economic result under climate change and extreme events.

Crop level adaptation of existing cropping systems (e.g. changes in varieties, planting times, irrigation and residue management) has been widely assessed and acknowledged to be effective against future climate challenges (Challinor et al. 2014). The benefits of this type of adaptation vary with crops and across regions and temperature changes; however, on average, they provide approximately 15 to 18% yield benefit when compared with no adaptation (Porter at al. 2014). Yield benefits in Flevoland were in the same range (Wolf et al. 2011; Reidsma et al. 2015). When considering also the impacts of extreme events as in our study, yield benefits from adaptation measures compared to no adaptation are much higher: up to 67 % if a combination of adaptation measures against different extreme events is used (see also Table 4.5).

Farm level adaptation generally received much less attention in adaptation literature. The studies addressing farm level adaptation to climate change (e.g. Leclère et al. 2013; Klein et al. 2013; Troost and Berger 2014) usually aggregate the results to a regional level. For example, Leclère et al. (2013) assessed farm level autonomous adaptation to climate change for EU-15 member states and showed that largest gains in crop gross margins were found when adopting crop management practices, rather than shifts in cropping patterns, which is also the case in the present study. In general the studies on farm level adaptation show that the adaptation allows farmers to largely benefit from the new possibilities offered by climate change, depending on the various crop responses to climate change.

4.4.3 Influence of farmers' objectives

The importance of different objectives in relation to adaptation preferences to future climate change has been hardly assessed. Klein et al. (2014), for example, assessed the trade-offs between agricultural production and other ecosystem functions (i.e. soil conservation and water provision) under future climate change. Overall they found that the combination of practices that can sustain high productivity in the future was the same as under current climate. Trade-offs between agricultural productivity, soil erosion and N-leaching were found likely to aggravate with climate change. The effects of the extreme events were, however, not included in the analysis.

Chapter 3 concluded that preferences in objectives shift when moving from the current farm practices towards adaptation options in the current climate. Here we show what are the implications from the different preferences in objectives when adapting to future climate change, including extreme events. From the sample of six arable farms in Flevoland we learned that if the main objective of the farmer is improvement of gross margin of crops, cultivating high value crops remains the best option, although under the condition of applying crop level adaptation measures against extreme events. If a farmer aims to prioritize gross margin of crops and organic matter simultaneously, a shift at farm level to (more) winter wheat is a good option, as it improves organic matter balance on the farm and keeps the negative impacts of climate change on gross margin of crops limited, at least under the price ratios we assumed.

4.4.4 Influence of assumptions and methodological limitations

The outcomes of our study involving effects of extreme events are largely dependent on the many, and often simplified assumptions we made regarding future damage of the extreme events on crop yields and on the effects of climate change on soil organic matter. Impacts of extreme events on future crop yields are uncertain, with especially the estimated yield damage having a very wide range (see Table 4.3). We assumed an average impact of extreme events on high value crops, which could have implications for calculated cost-efficiency of certain adaptation measures. For example, drip irrigation was not the most cost-efficient adaptation measure in the present study, as it was in Schaap et al. (2013), when high impact of extreme events on crops yields was assumed. With an average instead of high damage, the high annual costs of drip irrigation cause this measure to be less attractive than other proposed measures with the same efficiency against the negative effects on potato yields from the heat wave. Note that also a switch to another cultivar may be a good adaptation measure. This measure was not included in the present study, as it is rather a sector level measure. However, today already different cultivars are available with variable resistance against heat.

The focus of our study was on high value crops and the most severe climate risks (extreme events). There are several possible approaches of calculating the effects of extreme events on crop yield. In the present study we did not account for current impact of extreme events on current yields, whereas Paas (2013) included the current impacts. Diogo et al. (2014) also did it differently: they showed both impacts of extreme events in the current and in the future situation, and did not focus on the change. There is also much uncertainty regarding incorporation of effects of extreme events in crop models. The recent review article of Barlow et al. (2015) investigates how contemporary processed based crop models do not adequately account for the impact of climate extremes (especially heat stress) on crop yield. In this study we assumed that the effects of climate extremes were not adequately included in the crop model WOFOST, and therefore considered these separately.

We did not perform an uncertainty analysis in the present study, but the information on gross margins of crops with and without adaptation measures in Table 4.7 allows to understand some of the uncertainty related to the effects of extreme events on crop yields. Prices of potatoes, but also of other crops may vary largely over time, influencing their relative profitability. In all scenarios and on all farms, gross margins of seed and consumption potato with adaptation are less than half of those of winter carrot. Prices thus need to change a lot to change this relative difference. Adaptation towards winter carrot would be most beneficial regarding gross margin for all farms, however, we did not assess the impacts of the extreme events on winter carrot. Even without crop level adaptation, the gross margins of seed onion are higher than for other crops, and therefore switching to other crops from seed onion is not interesting from a gross margin point of view. However, in the W+ scenario the gross margin of sugar beet and chicory do come closer to those of seed onion and potatoes for several farms, thus becoming better alternative options of adaptation at farm level.

We assumed that changes in soil organic matter balance on farms will occur with farm level adaptation (i.e. shift to alternative crops), while soil organic matter content for given farm plans will not change due to climate change. In the literature we found very different estimates of the possible effect of climate change on soil organic matter in the temperate zone (especially in Europe), with some showing loss of soil organic matter, and others showing no loss and sometimes a slight accumulation of soil organic matter. According to Smith et al. (2008), small scale laboratory and field experiments and modelling studies suggest that climate change is likely to induce soil carbon loss from northern ecosystems, but little evidence comes from large scale observation. Smith et al. (2005), using the RothC model, showed that increases in plant productivity in Europe would likely counterbalance increased decomposition due to global warming towards 2080. The recent research based on space-for-time substitution technique (Barraclough et al. 2015) also showed that organo-mineral and mineral soils under temperate conditions could exhibit very different responses to changes in climate. Many modelling studies used the IPCC climate scenarios to estimate the effects of climate change on soil organic matter. In most cases, large uncertainties are evident for the different scenarios in terms of future values for soil organic matter (Luo et al. 2015; Smith et al. 2005; Zhong and Xu 2014).

In general, an increase in productivity having a positive impact on soil organic matter balance counterbalances the increase in decomposition under climate change. In our analysis, crop productivity decreases due to climate change and extreme events, so it is likely that soil organic matter will be negatively affected by climate change. The net effect is uncertain, but is projected to be smaller than the effects of crop changes (see also Smith et al. 2005). The large role of crop rotations and land use history in maintaining soil organic matter is also found in Ogle et al. (2010) and Reijneveld et al. (2009). Land use change in their perception is however much broader than the crop change as we simulated.

Maintaining soil organic matter balance appeared to be one of the important objectives for farmers in the region. Therefore one can expect that the farmers would try to prevent soil organic matter decrease over time by applying extra adaptation measures, e.g. keeping more crop residues on the field, applying green manures. There is already much attention for soil conservation measures in the EU Common Agricultural Policy, and also in the Netherlands farmers obtain agro-environmental payments when they take measures that increase soil organic matter contents.

4.4.5 Concluding remarks

Based on bio-economic modelling using individual farm data on farms endowments, structure and objectives, we assessed possible impacts of gradual climate change, extreme events and adaptation measures at crop and farm levels. Our results for selected arable farms in Flevoland suggest that gradual climate change improves farm performance in terms of farm economic result. The degree of improvement varies per climate change scenario and per farm, depending on the cropping pattern. At the same time, extreme events neutralize positive impacts of gradual climate change. A combination of crop and farm level adaptation appeared to be the best option for the surveyed farms in terms of improving both farm economic result and soil organic matter balance.

So far, farm level responses and adaptation strategies to climate change have not received sufficient attention in adaptation literature in our view. While White et al. (2011) and Porter et al. (2014) strive for more accurate simulation of impacts of climate change on crop production, we argue that farming systems analysis and integrated assessment of impact and adaptation options to climate change are similarly important. The present research contributes to a better representation of farm level adaptation in climate change research.

Appendix 4.A – Yield changes in future climate scenarios (%).

Crop	W+	G
Winter wheat	2.7	10.5
Sugar beet	28.6	19.3
Green peas	9.1	10.6
Winter carrot	14.2	20.3
Seed potato	2.8	10.0
Seed onion	14.2	20.3
Consumption potato	2.2	8.4
Chicory	14.2	20.3

Appendix 4.B – Inputs of N fertilizer in future climate scenarios, average among surveyed farms (kg N/ha).

Crop	2010	W+	G
Winter wheat	229	236	259
Sugar beet	128	174	159
Green peas	117	130	133
Winter carrot	195	230	244
Seed potato	116	119	130
Seed onion	151	179	189
Consumption potato	312	322	347
Chicory	78	92	98

Appendix 4.C – Labour hours per crop operation per ha (Anonymous 2009).

Operation	Consumption potato	Seed potato	Seed onion
Land preparation	3	3	3
Planting/sowing	1	3	0
Crop protection	10	13	9
Hand weeding	0	0	15
Harvest and processing	12	51	10
Total	26	70	37

Appendix 4.D– Assumptions regarding changes in labour requirements and costs of adaptation measures (from Schaap et al. 2013).

Adaptation measures	Operation	Extra hours (hrs/ha)	Costs (k€/ha)
Plant in wider ridges	Land preparation	-1	0
Drip irrigation	Extra/irrigation	0	1
Optimize crop cover	Land preparation	3	0.25
Air conditioning	Extra/postharvest	0	0.15
Chemical protection	Crop protection	1	0.75
Uv-light protection	Crop protection	6	0.75

Appendix 4.E – Labour requirements and costs of adaptation measures, included in FarmDESIGN.

Crops	Adaptation measures	Labour requirement (hours/ha)	Costs (€/ha)
Seed potato	1 plant in wider ridges	69	7633
	2 drip irrigation	70	8633
	3 optimize crop cover	73	7883
	4 air conditioning	70	7783
	5 plant in wide ridges and air conditioning	69	7783
	6 drip irrigation and air conditioning	70	8783
	7 optimize crop cover and air conditioning	73	8033
Consumption potato	1 plant in wider ridges	25	2610
	2 drip irrigation	26	3610
	3 optimize crop cover	29	2860
	4 air conditioning	26	2760
	5 plant in wide ridges and air conditioning	25	2760
	6 drip irrigation and air conditioning	26	3760
	7 optimize crop cover and air conditioning	29	3010
Seed onion	1 chemical protection	38	3477
	2 UV-light protection	43	3477
	3 chemical protection and UV-light protection	44	4227

Appendix 4.F – Risk and extreme events.

The change in frequency of future climate related extreme events will influence the crop yields and hence will result in variation of gross margin of crops, which is included as one of the five objectives in a multiple objective optimization modelling with the FarmDESIGN model. A variance co-variance matrix of gross margins was calculated based on five year data on input/output quantities and prices (Hazell and Norton 1986). A quadratic function was obtained and used to calculate variation in gross margin for specific farm production plans.
We calculated co-variance matrices for a five year period (around 2050) with the following assumptions. We used fixed prices and costs for the period 2006-2010 to calculate variation in gross margin for the period 2046-2050 due to yield variation. We assumed that yield change for seed, consumption potato and seed onion will be affected by extreme events and adaptation measures. The future frequencies of extreme events (per scenario) were calculated for the period 2046-2050. In the W+ scenario, for example, a heat wave will occur every year (and one or two years twice per year) in the period 2046-2050. Warm winter and warm and wet conditions will occur three times in five years. The current year 2009 is assumed to be the year without extreme events “warm winter” and “warm and wet conditions” (based on observed highest yields in the period 2006-2010; we assumed that in the future the year 2049 will also be without extreme events). The future yield without adaptation will depend on the damage of the extreme events (see equation 4.1). Yield with adaptation measures will depend on effectiveness of different (combinations of) adaptation measures.
As a result, we obtained a variance-co-variance matrix per scenario. The matrix was used as an input to the bio-economic model FarmDESIGN to calculate the risk for every generated farm plan.

Appendix 4.G – Examples of alternative farm plans generated by FarmDESIGN for farm P1 in the W+ scenario that improve organic matter balance and/or economic result.

Farm plan	Objectives		Crop areas (ha)								
	Economic result (k€/ha)	Organic matter balance (t OM/ha)	WW	SB	GP	WC	SP[1]	SO[1]	CH	GR	CP
Current	3.14	-0.66	0	9	0	0	18	9	9	9	0
Alt 1	3.98	-0.66	7	10	6	0	13	12	2	0	0
Alt 2	4.18	-0.64	7	10	0	0	12	12	9	0	0
Alt 3	3.37	-0.38	18	10	0	0	6	12	4	0	0
Alt 4	1.98	0.04	27	10	6	0	0	4	0	3	0

WW-winter wheat; SB-sugar beet; GP-green peas; WC-winter carrot; SP-seed potato; SO-seed onion; CH-chicory; GR-grass; CP-consumption potato

[1]including most profitable crop level adaptation measures against extreme events

Chapter 5

Institutional constraints for adaptive capacity to climate change in agriculture

Abstract

Institutional feasibility defined as the ability of institutions to support adaptive capacity, is an important aspect of climate adaptation, through its influence on the implementation of adaptation measures to climate change. The objective of this Chapter is to create a framework for assessing institutional preconditions that enable or constrain climate change adaptation measures in agriculture and to apply the framework to a case study in agriculture.

We adopted and modified the Procedure for Institutional Compatibility Assessment (PICA). Institutions in our framework are characterized by a set of crucial institutional preconditions (CIPs) and indicators linked to each CIP. CIPs refer to both institutional incentives and constraints for implementation of adaptation measures (here to climate change). We applied a combination of ranking and scoring techniques based on information from workshops, interviews and a literature review to assess institutional incentives and constraints for adaptation measures, together indicating the institutional feasibility of implementation of adaptation measures. We selected and assessed three adaptation measures relevant to agriculture in Flevoland, a province in the Netherlands: 1) improvement of water management and irrigation facilities; 2) relocation of farms; and 3) development of new crop varieties.

The two main constraining CIPs for the implementation of the measures were found to be (1) heterogeneity of actors' interests and (2) availability of resources. Based on the institutional feasibility analysis, the implementation of water management and improvement of irrigation facilities will potentially face fewer institutional constraints compared to the other two measures. We conclude that our approach proves applicable for institutional analyses of adaptation measures for current and future (climate) challenges at different levels of implementation, but that more applications are needed to test its validity and robustness.

Keywords: institutions; climate change; adaptation; agriculture

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5.1 Institutions and adaptive capacity to respond to climate change

Climate change is very likely to threaten agricultural production in the future and temperate regions like the Netherlands are no exception (Audsley et al., 2006; Bindi and Olesen, 2010; Reidsma et al., 2009; Schaap et al., 2011). To withstand the negative impacts and to take advantage of the opportunities arising from climate change, the agricultural sector will need to implement adaptation measures (Olesen et al., 2011; Schaap et al., 2013). Adaptation measures to climate change in agriculture refer to practices that might be adopted to alleviate expected adverse impacts or to take advantage of positive impacts (Smit and Skinner, 2002).

A body of literature that has been published in the last decade provides a number of theoretical frameworks for adaptation research (Acosta et al., 2013; Berry et al., 2006; Meinke et al., 2009; Tol, 2005; Yohe and Tol, 2002). In parallel, there is an increasing number of studies that propose adaptation measures at crop, farm and regional/sectoral levels. Considerable attention is given to the development of new adaptation measures, but it is also important to assess whether these measures are feasible in terms of implementation (Easterling et al., 2007; Smit and Skinner, 2002). Yet, relatively few assessments on the likely adoption rates of these potential adaptation measures are available (Howden et al., 2007; Reidsma et al., 2010; Reidsma et al., 2007).

An enabling institutional environment is an important precondition for the implementation of adaptation measures (Adger et al., 2005; Challinor, 2008; Nelson et al., 2007). Initially, the Intergovernmental Panel on Climate Change (IPCC) named economic resources, technology, information and skills, infrastructure, institutions and equity as the main determinants of the adaptive capacity of a society to climate change (Smit, 2000). Later, the integral roles of institutions, governance arrangements and management practices were further emphasized (Brooks et al., 2005; Engle, 2011; Gupta et al., 2010; Yohe and Tol, 2002). As stated by the IPCC (2007), when institutions are supporting the social actors to anticipate and proactively respond to changes, other determinants of adaptive capacity improve, and consequently adaptive capacity as a whole improves (Parry et al., 2007). Considering that climate change brings unpredictable changes, it calls for institutions that enhance the adaptive capacity of a society. In the latest IPCC report (Klein et al., 2014), it was concluded that effective governance and institutions for facilitating adaptation planning and implementation across multiple sectors within regions is by far the dominant adaptation opportunity and constraint.

This study aims to develop a framework for the assessment of crucial institutional preconditions that facilitate the implementation of adaptation measures to climate change. More specifically, our article focuses on the following two research questions: 1) how to identify institutional constraints for adaptive capacity to respond to climate change challenges; and 2) how to assess the feasibility of implementing adaptation measures from an institutional perspective. We applied our framework to the agricultural sector in Flevoland. Flevoland is the most productive agricultural region in the Netherlands, and the agricultural sector is important for the economy of the province. Earlier we explored adaptation options for this province at farm and management level (Chapter 4) and now we investigate its institutional feasibility.

5.2 Frameworks to assess institutional factors influencing adaptation

Institutions are the rules of the game in a society or, in other words, institutions are the humanly devised constraints that shape human interaction (North, 1991). Under North's framework, institutions consist of both informal (customs, tradition, codes of conduct) and formal (laws, property rights) sets of rules, compliance procedures and moral and ethical behavioral norms designed to constrain individuals in the interest of maximizing the wealth or utility of the principals (North, 1991). Although North's definition is probably the most cited one, it has also been criticized. In particular, other scholars have emphasized the potentially enabling properties of institutions for self-organization, besides constraining agents for principals (Arts et al., 2006; Giddens, 1981). From these definitions, the functions of institutions can be summarized as giving structure, building expectations, and setting both constraints and incentives for human interactions.

Many studies have focused on the adaptive capacity of institutions to cope with climate change. Recent literature on adaptation reveals different terms used to describe factors that may hinder implementation of adaptation from an institutional perspective (see review paper of Biesbroek et al. 2013). Termeer et al. (2012) use the term institutional weaknesses. De Bruin et al. (2009) assess institutional complexities, while Moser and Ekstrom (2010) and Biesbroek et al. (2011) speak about barriers to climate change adaptation. Gupta et al. (2010) focus on assessment of adaptive capacity of institutions and propose an assessment framework called the adaptation wheel. According to Gupta et al. (2010), institutional adaptive capacity includes characteristics of institutions that enable society to cope with climate change and the degree to which institutions allow and encourage actors to change these institutions to cope with climate change. Qualities of institutions that are crucial to enable climate change adaptation are: variety, learning capacity, room for autonomous change, leadership, resources and fair governance (Gupta et al., 2010). The first three were later labelled core qualities, while the last three were called supporting qualities by Termeer et al. (2012). The failures of institutions on any of the above-mentioned qualities are perceived as institutional weaknesses (Termeer et al., 2012). It seems that this institutional literature on climate adaptation exhibits a normative bias: the more institutions and the better they function, the higher the adaptive capacity. We acknowledge that less institutions can be beneficial as well, for example when they create barriers for innovation. Therefore we adhere to an analytical approach below that is agnostic to more or less institutions for climate adaptation ex ante.

For assessments of institutional preconditions in relation to climate change adaptation in agriculture, the definition and analysis of institutions by Theesfeld et al.

(2010) is – in our view – more analytical, specific and relevant. Institutions include mechanisms – such as rules on distribution of (financial) resources – that facilitate or hamper decision-making aiming at sustainable development by political actors. Further, institutional arrangements affect (positively or negatively) the implementation of rules by the authorities and the behaviour of farmers and other actors, while following the rules. Theesfeld et al. (2010) introduced an approach for ex-ante institutional analysis. They aimed to assess the institutional compatibility of specific policy options. This concept refers to the compatibility between policy options on the one hand and the respective institutional environment on the other. Based on this as an entry point, Theesfeld et al. (2010) developed the so-called Procedure for Institutional Compatibility Assessment (PICA) framework to assess the feasibility of policy options from an institutional perspective. The various institutional properties that potentially influence the implementation of policy options are called Crucial Institutional Aspects (CIAs). A detailed list of CIAs can be found in the report of Schleyer et al. (2007). An example of a constraining CIA is "contradictory policy instruments and rules" referring to a list of regulations and tools that are currently applied in the area and that could be contradictory to future policy options in question.

Here we prefer to use the term Crucial Institutional Precondition (CIP), since we want to stress that we selected and adapted CIAs from PICA in such a way that they are formulated as preconditions, both constraints and incentives, and can be rated and scored accordingly. CIPs include constraints and incentives in facilitating the implementation of respective adaptation measures. In this paper we use the term 'institutional feasibility' in the general assessment and when we focus on the institutional constraints specifically. Institutional feasibility is determined by institutional constraints and incentives. We define institutional constraints to climate change adaptation as conditions that emerge from an institutional setting and which reduce the likelihood of successful implementation of particular adaptation measures. The opposite holds for institutional incentives: these increase the chances of successful implementation.

While Gupta et al. (2010) refer to an abstract set of qualities of adaptive capacity of institutions, other authors are more specific about the institutional preconditions for adaptation options and therefore their frameworks could be used to link with and amend the PICA framework. De Bruin et al. (2009) used the term institutional complexity to assess the institutional environment for the implementation of various adaptation options to climate change. Elements of institutional complexity are: clashes between institutional rules (corresponding to the CIP of contradicting policy instruments and rules); the organizational consequences of the option; the cooperative relations or associations which are necessary for implementation (corresponding to the CIP of heterogeneity/fragmentation of actors' interests); and the degree of renewal of the option in relation to existing arrangements (captured by the CIP of experiences with developing and introducing the measure). Information on institutional complexity can be used in combination with the ranking of an option, to develop an adaptation strategy that both deals with the priority options and solves the institutional barriers that may emerge during implementation. However, the institutional complexity was not integrated in the Multi-Criteria Analysis by de Bruin et al. (2009) and was meant to be used in combination with other complexities (technical and social) to indicate their relative importance for the implementation of particular adaptation measures.

Among the barriers to adaptation occurring at different stages in the adaptation process (i.e. understanding, planning and managing) defined by Moser and Ekstrom (2010) we find barriers (e.g. sufficient resources, availability of information and experience with measures) that directly correspond to the CIPs inspired by the CIAs of Theesfeld et al. (2010). Based on this descriptive wealth of institutional preconditions for adaptation we decided to use CIPs that correspond with the existing literature on institutional feasibility for climate change adaptation.

There is added value in using an amended version of PICA to assess institutional constraints and incentives for implementation of adaptation measures of climate change. PICA captures a variety of aspects essential for the assessment of the institutional preconditions for adaptation to climate change, while some modification allows for a semi-quantitative assessment. A semi-quantitative assessment does not rely on quantitative data which are not available for specific measures in specific regions, while qualitative information from experts and stakeholders can be included. Quantifying this information afterwards allows a comparison of measures. The use of PICA in this study is depicted in Figure 5.1. Adjustments made to PICA are described in the following section.

5.3. Operationalization of PICA

5.3.1 Inventory of climate change risks, impacts and adaptation measures

We started by making an inventory of main risks and impacts of climate change on arable farming in Flevoland and of the relevant adaptation measures. The inventory was mainly obtained from de Wit et al. (2009); Wolf et al. (2010) and Schaap et al. (2013), which are related studies within the AgriAdapt project of which this study was also part. In AgriAdapt quantitative studies and participatory methods were combined to assess climate change impact and adaptation (Wolf et al., 2012). However, other studies that assessed climate risks and adaptation for the Netherlands, i.e. Groot et al. (2006) and Bruin et al. (2009), have also been consulted. As to the crops, the focus was on seed potato, which is the main agricultural commodity, from an economic point of view, in Flevoland.

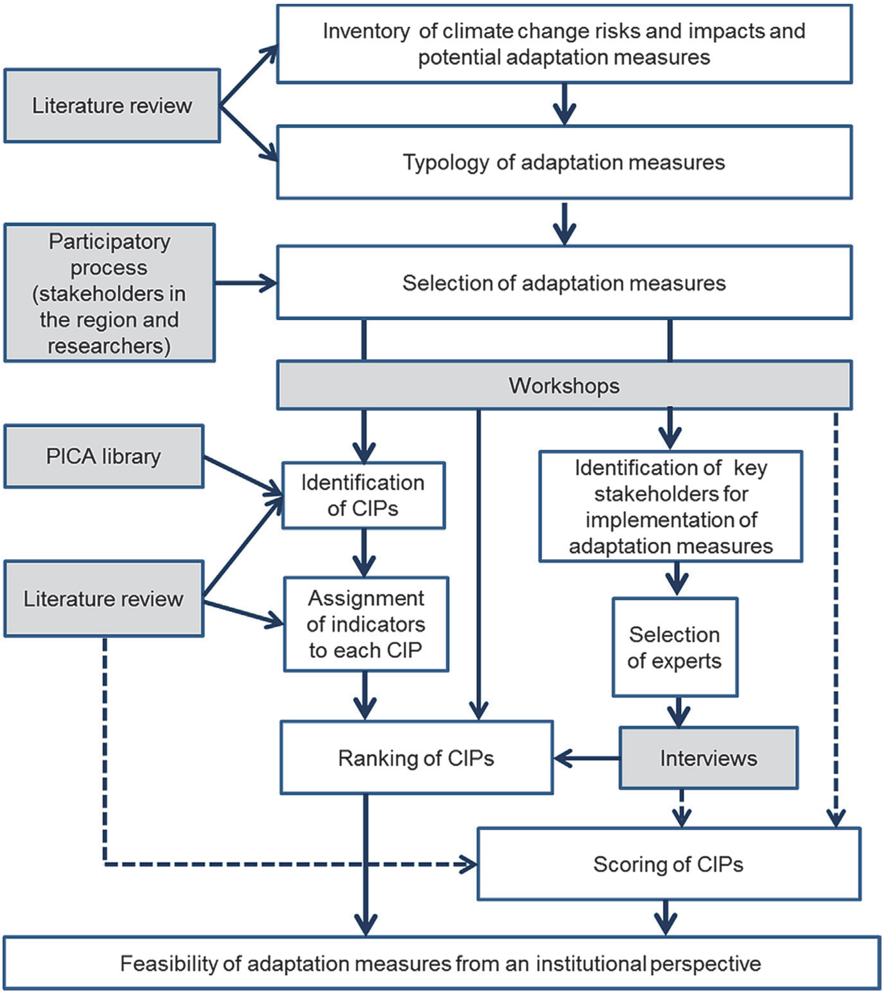

Figure 5.1 – Research framework based on adjustments to PICA. All steps were performed by the research team, except for ranking of CIPs, which was performed by experts. Arrows between plain boxes refer to the sequence of steps. Grey boxes refer to data sources. Arrows from grey boxes refer to direct input. Dashed arrows refer to supportive information.

5.3.2 Typology and selection of adaptation measures

Following the inventory, we made a typology of adaptation measures. Besides the classification of adaptation measures based on the type of risks and impacts, the inventory included adaptation measures for implementation at different levels: crop, farm and regional/sectoral level. Adaptation measures at the crop level are specifically related to options for maintaining yields and quality of production of a specific crop. Farm level measures operate across the entire farm and take into account how changes in production may impact the income of farmers. Measures at regional/sectoral level have a broader context. They address general problems in the region as well as the national policy agenda on climate change adaptation.

We also identified the degree of institutional relevance for each adaptation measure by the number of actors at different levels (i.e. crop, farm, region) involved in the implementation of the measure. The lower the level of implementation of the measure, the fewer actors with different viewpoints and institutional aspects are potentially involved. The measures at crop and farm level mainly involve farmers as the dominant actors. Implementation of adaptation measures at the regional/sectoral level involves a number of actors and therefore more institutional incentives and constraints can potentially arise. The degree of interaction between actors is also higher at the regional/sectoral level compared to the farm and crop level.

For illustration of our framework we selected adaptation measures with relatively high institutional relevance.

5.3.3 Identification of CIPs

We modified PICA with respect to the selection of CIPs which potentially influence implementation of adaptation measures. First, we assigned relevant CIAs from the original PICA library (Schleyer et al., 2007) to the selected set of adaptation measures. We modified and added new CIPs to the PICA library of CIAs based on a literature review (e.g. Gupta et al., 2010; Bergsma et al., 2012; Biesbroek et al. 2011; Termeer et al., 2012). Next, the selected CIPs (from the PICA list and the literature) were checked for their relevance with key stakeholders during workshops. As a result of these steps, we obtained a final list of CIPs to be used to assess the institutional feasibility of adaptation measures. During the process of modifying the PICA list of CIAs, we also assigned two types of indicators to each CIP: quantitative and qualitative (Table 5.1). The aim of the indicators was to explain the meaning of each CIP to the experts we interviewed and to allow for a semi-quantitative assessment of the feasibility of implementation of adaptation measures from an institutional perspective.

5.3.4 Data collection and analysis

We used workshops and interviews as primary sources of information for our research. In total we organized three workshops (held between November 2011 – January 2012) with a total number of 48 participants. We organized one workshop in the study area, where we invited stakeholders from the region (n=9), and two at Wageningen University, which were attended by experts in policy analysis (Forest and Nature Conservation Policy group, n=12) and agricultural systems (Plant Production Systems group, n=27). The workshop participants provided us with quantitative information on the relative importance of the CIPs for each adaptation measure (see Section 5.3.5). Discussions during workshops yielded extra insights into the nature of institutional incentives and constraints to adaptation to climate change in Flevoland.

To obtain a better understanding of institutional preconditions for adaptation measures to climate change in agriculture in Flevoland, we had several follow-up discussions with workshop participants. Additionally, we conducted semi-structured interviews with experts in fields closely related to the adaptation measures we assessed. Interviews with experts (n=9) also provided us with quantitative information on the relative importance of the CIPs for each adaptation measure. During the interviews and workshops experts also provided detailed qualitative information on the CIPs and indicators for each adaptation measure. This supported scoring of the CIPs in terms of the extent to which they are currently constraining each adaptation measure (see Section 5.3.6).

We verified the information from the workshops and interviews with findings from the institutional literature on climate change adaptation in the Netherlands (e.g. Bergsma et al., 2012; Biesbroek et al., 2011; Groot et al., 2006; Gupta et al., 2010; Termeer at al., 2012). Finally, we discussed the results and the draft of this manuscript with a secretary of the provincial board of farmers' organizations and a policy maker on spatial planning and water management from the Dutch Ministry of Infrastructure and Environment. These two experts provided their comments and judgment on the method used and the scores assigned to the CIPs.

5.3.5 Ranking CIPs

The importance of CIPs per adaptation measure was based on ranking using direct ranks R_1 (i.e. *whether* a CIP is important for the implementation of an adaptation measure) and percentage of relative importance R_2 (i.e. *how* important is the CIP). During the workshops and interviews we asked the participants to rank each CIP in the range from the most important (R_1 = 1) to the least important (R_1 = 7) for each adaptation measure. In order to check the consistency of the answers, the participants were also asked to assign a percentage indicating to what extent a certain CIP is important relative to the others.

We summarized the results on ranks (R_1) and percentage of relative importance (R_2) from the workshops and interviews by calculating the average of R_1 and R_2 per CIP from the respondents' answers. We also calculated the frequency of each CIP being ranked the highest (i.e.,1) to check if the result of the three highest ranked CIPs was consistent with the result from the procedure using the average of R_1 and R_2 for each CIP.

Based on the ranking information, we identified which CIPs are considered to be the three most important for each adaptation measure. The most important CIPs (lowest value of R_1) are not necessarily constraining the implementation of particular adaptation measures in the current institutional setting in Flevoland.

5.3.6 Scoring CIPs

To assess to what extent a certain CIP is currently constraining the implementation of the respective adaptation measures; we analyzed qualitative information from workshops and interviews, and checked our findings with literature. Similar to the semi-quantitative analysis in Yohe and Tol (2002), we assigned scores to each CIP through the interpretation of the qualitative information from workshops and interviews. These scores were checked by the secretary of the provincial board of farmers' organizations and a policy-maker on spatial planning and water management from the Dutch Ministry of Infrastructure and Environment. Consequently, we finalized the scores. The scores of CIPs (S) are subjective values ranging from 0 (Low) to 5 (High) according to the perceived degree to which CIPs constrain the implementation of a specific adaptation measure.

5.3.7 Institutional feasibility

An assessment of the institutional feasibility of each adaptation measure was performed in three steps.

We first assessed the Constraint-Ability of each of the seven CIPs as to the implementation of each adaptation measure. Let the average of the percentage of relative importance of ranks be denoted by $R_2(j)$ and Scores of CIPs be denoted by $S(j)$, and $j = 1, \ldots, 7$ referring to the CIPs. The Constraint-Ability $CA(j)$ is the multiplication of $R_2(j)$ and $S(j)$ (Equation 5.1). We normalized the outcome values by multiplying ranks and scores by 0.01. The Constraint-Ability of a CIP is high, if the value is low:

$$CA(j) = R2(j)*S(j)*0.01 \qquad \text{(equation 5.1)}$$

Next, we assumed that a CIP with the maximum value for Constraint-Ability is the most constraining one for the implementation of a particular adaptation measure, i.e. this CIP is an Institutional Constraint (IC), with the value:

IC = max [CA(1), CA(2), … CA(7)] (equation 5.2)

Finally, we identified the overall Institutional Feasibility (IF) of the adaptation measure as the sum of all CAs for this adaptation measure:

$IF = \sum_{j=1}^{7} CA$ (equation 5.3)

The value of IF suggests to what extent the implementation of the adaptation measure is feasible from an institutional perspective. A low value for IF (minimum 0) indicates minor institutional constraints, a high value for IF (maximum 5) indicates significant institutional constraints for the implementation of the adaptation measure.

The procedure was followed for each adaptation measure considered.

5.4. Application of the framework

5.4.1 Case study

Flevoland - now one of the twelve provinces in the Netherlands - was formerly an inland sea called Zuiderzee. After a catastrophic flood in 1916, the region was reclaimed and enclosed to the main land after the Second World War. The chief purpose of the reclamation and development of this new area was for agricultural expansion. The area has become the most productive agricultural region in the Netherlands; currently actual crop yields are close to the potential levels (Wolf et al., 2010).

The Netherlands' 5th National Communication submitted to the UNFCCC reported that under a changing climate it is very likely that the occurrence of high water levels and flooding will increase in Flevoland, there will be more frequent and longer soil water deficits during summer, and the area with brackish water will increase. These are considered as threats to the agricultural production in the Netherlands and the government has developed a set of policies and adaptation measures in response.

5.4.2 Selection of adaptation measures

We classified the adaptation measures relevant for agriculture in Flevoland based on the climate risks and impacts, and the level of implementation (Table 5.1; see also Appendix 5.A). We selected three regional/sectoral-level measures for application of our framework. The measures were identified as important by the stakeholders and the degree of relevance of institutions for implementation of these measures is high. The measures are: (i) improvement of water management and irrigation facilities; (ii) relocation of farms from vulnerable areas; and (iii) development of new crop varieties that can cope with water stress, drought stress, heat waves and sprouting problems during storage (specifically for seed potato stored during warm winters). The only other adaptation measure for which it has been suggested that institutions were very important (Appendix 5.A) was water storage on farmland. We did not assess this measure separately, as it is related to measures (i) and (ii).

Table 5.1 – Risks of climate change on agriculture in Flevoland and relevant adaptation measures.

No	Climate change risk	Adaptation measures
1	Changes in the precipitation	Improvement of water management and irrigation facilities
	a. Changes in the duration and intensity of wet and dry periods	Relocation of farms from the vulnerable areas
	b. High intensity of rainfall in spring and autumn	Adjustment of crop rotation schemes and timing of planting dates and harvesting dates
		Increase ability of surface drainage
		Increase permeability of sub-soil
		Water storage on farmland
		Choice of crop variety and genotype that can cope with increased water stress
		Develop new varieties which can cope with increased water stress
		GPS steering to prevent damage to soil structure
		Automatic inflation correction of the machinery tyres
	c. Reduced rainfall with high evaporation in summer	Soil moisture conservation practices such as conservation tillage
		Water storage on farmland during high rainfall periods
2	Warm and wet conditions during summer	Choice of crop variety and genotype
		Optimise nutrient management
		Develop new varieties which are resistant to the respective pests and diseases
		Chemical protection
		UV-light protection
3	Heat wave	Plant in wider ridges
		Plant and harvest earlier
		Drip irrigation
		Optimise crop cover
		Develop heat resistant varieties
4	Warm winter	Develop new varieties which can cope with the sprouting problem
		Air conditioning
		Sprouting control with chemicals
5	Sea level rise	Relocation of farms from the vulnerable areas
		Develop new crop varieties that can cope with high salinity
		Insurance
6	Gradual climate change	Farm diversification
		Farm size enlargement
		Farm intensification
		Changes in specialization

5.4.3 CIPs and indicators

In Table 5.2 we present the CIPs used in our framework and the quantitative and qualitative indicators required to characterize each of them. Both indicators were used in ranking and scoring the indicator. If quantitative data were available, these were used, but to get a good impression of the constraint-ability of a CIP, qualitative information is needed. The qualitative indicators also helped to explain the meaning of a CIP.

Table 5.2 – Selected CIPs and their indicators.

CIP	Indicators	
	Quantitative	Qualitative
1. Administrative levels involved in the implementation of the measure	Number of administrative levels involved in the implementation of the measure	1. Hypothesis about positive/negative effect of having more/less levels (e.g. nested or multi-level governance) 2. Degree of coordination/communication 3. Clear formal task distribution and/or subsidiarity?
2.Contradictory policy instruments and rules	1. Number of relevant instruments in this field 2. Ratio (%) of contradictory policy instruments and rules to the total number of policy instruments and rules	1. What are the contradictory policy instruments and rules? 2. What is the effect of contradiction? 3. Which instrument has better/stronger political, legal and financial backing?
3.Availability of resources (e.g. financial, personnel, etc)	Share of budget for implementation of the measure (absolute and relative) - should be enough to implement the measure and be coming from the responsible level	1. How large is the share of budget for the implementation of a particular measure a) compared to the share for other programs? b) relative to the actual cost for implementation of the respective measure? 2. What is the annual change in the share of budget and developments over the past years? 3. Is the target met annually?
4.Political continuity	Number of changes in the board within the last 10 years (at the responsible level: province or water board)	1. Even if the board changes, is the composition of political power/coalitions also changed? 2. Do the changes influence the implementation of strategic plans? 3. Does the change in board/cabinet cause changes in financial policy and budget allocation?
5.Heterogeneity/fragmentation of actors' interests	1. Number of related actors 2. Number of farmers (incl. information about his/her farm size and specialization) 3. Number of private companies (e.g. water company, recreation) 4. Number of nature protection organizations	1. Main concerns of farmers from different groups (differing in farm size, specialization, diversification and intensity) 2. Main concerns of other actors such as water board or industry 3. Main/prioritized programs of the local government 4. Hypothesis that high heterogeneity can create constraints in implementing the adaptation measure.
6.Experiences with developing and introducing the measure	Inventory of previous/existing programs related to the measure	1. Improvement of water management and irrigation facilities a. What are main programs for improvement in water management and irrigation facilities? b. What are the highlighted discussions from previous programs in water management and irrigation facilities? 2. Relocation of farms a. Has there been any relocation of farms in the last 10 years? b. What were the highlighted concerns during the relocation? c. Any conflicts/issues? 3. Development of new varieties a. What are the main problems in the development of new varieties? b. What are the highlighted issues?
7.Availability of information	1. Number of written agricultural specialized press outlets (distinguish between scientific and outreach/practice oriented journals) 2. Pattern/network of information dissemination 3. How many of the publications (%) are dealing with climate change in a wider sense?	1. How many related publications per month? 2. What is the main information they deliver? 3. Are the monthly/seasonal weather forecast and climate change scenarios of KNMI distributed/accessible to farmers? 4. Do farmers use this information?

5.4.4 Stakeholder analysis and interviewed experts

The experts we interviewed were identified according to their potential roles in the implementation of the adaptation measures (Table 5.3).

For assessment of institutional feasibility of the first measure (improvement of water management and irrigation facilities), we interviewed five experts in the water sector in Flevoland: one from Zuiderzeeland water board; three from farmers' organizations; and one from the division for Sustainability, Environment and Water of the provincial government in Flevoland. Three of these five respondents were also interviewed for the second measure (relocation of farms), because the issue of relocation is closely related to the management of water and facilities for irrigation in the region, and the same stakeholder groups are involved, although in a different order of priority.

Table 5.3 – Overview of the stakeholder groups in Flevoland related to the implementation of the adaptation measures.

Adaptation measures	Related stakeholder groups	Involvement in the implementation of the measure[1]
Improvement of water management and irrigation facilities	Local water board (Zuiderzeeland)	+++
	Farmers and farmers' organizations (LTO)	+++
	Union of water boards	++
	Municipalities	++
	Central and Provincial government	+
	Nature protection organizations	+
	Domestic (household) water users	+
	Companies, industries, other water users	+
Relocation of farms	Farmers and farmers' organizations (LTO)	+++
	Central and Provincial government	+++
	Domestic (household) water users	+++
	Municipalities	++
	Nature protection organizations	+
Development of new crop varieties	Breeding companies	+++
	Farmers and farmers' organizations (LTO)	+++
	University, research centres, other academic/scientific pool	++
	Municipalities	+
	Provincial government	+
	Central government	+

[1] More + indicate higher involvement in the implementation of the measure, as assessed by the researchers

The interviews for the third measure (development of new crop varieties) were conducted with two plant breeding experts in the Plant Sciences Department of

Wageningen University and one farmer in Flevoland who has been collaborating with a breeding company to conduct research on breeding new crop varieties of seed potato. In addition, we also consulted two breeding experts from two potato breeding companies in the Netherlands on the issue of development of new crop varieties.

5.4.5 Ranking of CIPS

We identified which CIPs are considered as the three most important for each adaptation measure (Table 5.4). The most important CIPs for the first two measures (improvement of water management and irrigation facilities and relocation of farms) were similar: heterogeneity of actors' interests, availability of resources, and administration levels involved in the implementation of the measure. For the third measure (development of new varieties), the market was perceived as the main driver, which was not included as a CIP in our framework. Among the institutional aspects listed in the framework, the three most important CIPs were: availability of resources, experience with developing and introducing the measure and availability of information.

5.4.6 Scoring of CIPs and institutional feasibility

Table 5.4 summarizes the results on constraint-ability, institutional constraints and institutional feasibility of each measure. Details on the derivation of scores based on qualitative information from workshops, interviews and findings from a literature review are provided in Appendix 5.B.

The adaptation measure 'improvement of water management and irrigation facilities' appeared to be the most feasible to implement in Flevoland from an institutional perspective. The value of institutional feasibility for this measure pointed at fewer institutional constraints compared to the other two measures. Relocation of farms appeared the most difficult to implement, since its value for institutional feasibility indicated potentially more institutional constraints.

Different CIPs constrained the implementation of each measure. For improvement of water management, no substantial institutional constraints were named by participants of the workshops and interviews or were found in the literature (Table 5.5 and Appendix 5.B). The most constraining CIP for this measure appeared to be heterogeneity of actors' interests (IC=0.75).

Relocation of farms appears to be mostly constrained by heterogeneity of actors' interests (IC=1.38). The issue of relocation was described by experts and in literature as "very problematic", especially due to the large number of potentially-conflicting parties involved, debates around financial compensation and, no official policy on relocation.

Table 5.4 – Ranking of CIPs for adaptation measures to climate change at regional level.

CIAs	Adaptation measures					
	Improvement of water management[1]		Relocation of farms[2]		Development of new varieties[3]	
	Ranking R_1 (1-7)	Relative importance R_2 (%)[4]	Ranking R_1 (1-7)	Relative importance R_2 (%)[4]	Ranking R_1 (1-7)	Relative importance R_2 (%)[4]
1. Administrative levels involved in the implementation of the measure	**2**	15.0	**3**	15.0	7	10.0
2. Contradictory policy instruments and rules	4	18.0	4	2.5	6	11.0
3. Availability of resources	**1**	25.0	**2**	27.5	**1**	22.0
4. Political continuity	5	15.0	5	12.5	4	8.0
5. Heterogeneity/fragmentation of actors' interests	**3**	25.0	**1**	27.5	5	15.0
6. Experiences with developing and introducing the measure	6	2.0	6	12.5	**3**	14.0
7. Availability of information	7	0.0	7	2.5	**2**	20.0

[1] number of interviewees/number of respondents: 25 persons/25 persons
[2] number of interviewees/number of respondents: 5 persons/ 3 persons (few people consider themselves as experts in this issue)
[3] number of interviewees/number of respondents: 27 persons/27 persons
[4] sum equals to 100%

Table 5.5 – Summary of the results interpretation. See Appendix 5.2 for reasons behind the scoring.

CIP	Measure 1 Water management			Measure 2 Relocation of farms			Measure 3 Development of new varieties		
	R_2 (%) Relative importance	S (0 – 5)[1] Scores	CA (Constraint-ability)	R_2 (%) Relative importance	S (0 – 5)[1] Scores	CA (Constraint-ability)	R_2 (%) Relative importance	S (0 – 5)[1] Scores	CA (Constraint-ability)
1. Administrative levels involved in the implementation of the measure	15	3	0.45	15	4	0.60	10	3	0.30
2. Contradictory policy instruments and rules	18	1	0.18	2.5	1	0.03	11	4	0.44
3. Availability of resources	25	2	0.50	27.5	3	0.83	22	3	**0.66**
4. Political continuity	15	0	0.00	12.5	0	0.00	8	1	0.08
5. Heterogeneity/fragmentation of actors' interests	25	3	**0.75**	27.5	5	**1.38**	15	3	0.45
6. Experiences with developing and introducing the measure	2	1	0.02	12.5	2	0.25	14	0	0.00
7. Availability of information	0	1	0.00	2.5	3	0.08	20	3	0.60
Total sum	100			100			100		
IC (Institutional constraint)			**Heterogeneity/ fragmentation of actor's interests (0.75)**			**Heterogeneity/ fragmentation of actor's interests (1.38)**			**Availability of resources (0.66)**
IF (Institutional feasibility) *(Min institutional constraints =0; Max institutional constraints=5)*			**1.90**			**3.15**			**2.53**

[1]0 represents no institutional constraints, 5 represents major institutional constrains

For the development of new varieties, the availability of resources appeared to be the most constraining CIP (IC=0.66). Specifically for potato, breeding is a long and arduous process, and it can take more than 15 years before a new cultivar can be released. Demand for new varieties is determined by the need to produce more productive, more resistant and higher quality crops. Such demand drives the market and amplifies the interests of all stakeholders, particularly the breeders. In the context of constraining policies, experts did not see any possible effects from the contradiction in policy instruments and rules to their activities. For example, in the light of the present discussion about banning genetically modified organisms (GMO) within the EU, the interviewed experts nevertheless anticipate dynamics in international discussions, and hence believe that in the future GMOs may be allowed.

In summary, from an institutional perspective, heterogeneity of actor's interests and availability of resources appeared to be the most constraining CIPs for adaptation measures to be implemented against risks associated with climate change.

5.5. Discussion

5.5.1 Novelty

We presented a method to assess institutional preconditions for adaptive capacity to respond to climate change challenges. We classified adaptation measures based on the type of risks and impacts the measures address or and the level of implementation (crop, farm and at regional/sectoral). This categorization assisted in identifying different institutions and institutional arrangements involved at each level. The methodology is not scale dependent as it is based on stakeholder input and literature. Hence, our framework can be used to assess adaptation measures at other levels of implementation (e.g. crop, farm, nation) and in other socio-economic and bio-physical contexts, than those presented in this paper.

With our broad definition of institutional context/preconditions - using CIPs - we captured the main barriers to adaptation (i.e. institutional, social, financial, and informational). While many studies on institutional analyses provide potentially endless lists of barriers to adaptation (e.g. Biesbroek et al. 2013; Moser and Ekstrom 2010), our study was relatively focused. Firstly, we focused on three adaptation measures which were designed in a participatory manner and therefore are relevant to stakeholders. Second, we limited our analysis to seven crucial institutional preconditions. As a result, we were able to describe the degree of importance for different institutional constraints to implementation of the adaptation measures. The main objective of our institutional assessment was to evaluate the overall coping capacity of a society through assessment of determinants of adaptive capacity. Such an objective and approach is in line with the adaptation wheel of Gupta et al. (2010), however, dimensions and criteria of the adaptation wheel are rather abstract and difficult to explain to the interviewees (Bergsma et al., 2012).

Few attempts have been performed to define the concept of barriers to adaptation to climate change, to develop indicators and to distinguish barriers from non-barriers (see Biesbroek et al., 2013). In our study we identified and prioritized the relevant institutional preconditions for certain adaptation measures, and by doing so we reframed the concept of adaptation. The concept of adaptation was framed as a definable problem (here in terms of implementing a particular adaptation measure to climate change), which according to Biesbroek et al. (2013), is a constructive approach.

Another advantage of our study comes from the use of contextual knowledge. Many existing studies are theoretical and are not often tested in practice. We used stakeholder workshops and expert interviews with people from the case study area. This enhanced the practical value of our study by incorporating local knowledge from key stakeholders.

Institutional barriers, or constraints to adaptation have been perceived for a long time and treated as static concepts. However, Biesbroek et al. (2014) have shown that institutional barriers are in fact flexible mechanisms, or even organisms that evolve through time. Here we provide an assessment of institutional constraints based on importance ranks and the extent of current constraints, both of which could be used separately. For example, deriving scores for CIPs under future scenarios (e.g. up to 2050) would allow us to capture the dynamics of institutional constraints by exploring the future institutional setting.

5.5.2 Limitations and challenges

We experienced some challenges in assigning scores to assess to which degree certain CIPs are constraining implementation of the measures. Unlike the interpretation of quantitative information to obtain the ranks, scores mainly depend on the researchers' judgment of the interviews with stakeholders and experts. Misinterpretation of the information obtained in the interviews may lead to an incorrect score. Similar challenges were recognized by Gupta et al. (2010).

In some cases the ranking of CIPs overlapped with the scoring (i.e. the constraining aspect of the CIP). For example, the two CIPs, availability of resources and availability of information are closely related to the adaptation measures we assessed. Therefore, these CIPs were generally ranked and scored high in terms of currently constraining the adaptation measures. On the other hand, political continuity refers to the institutional setting exclusively, so the score related to this setting, while the rank referred specifically to the adaptation measure. Similar issues have been reported by Bergsma et al. (2012) and Biesbroek et al. (2013). To a certain extent, individual CIPs may be double counted, but this mostly occurs when CIPs are highly constraining. Given that the primary objective of our assessment was to identify the main constraints, this "double counting" is not a deficiency for the approach per se.

All values in this study, especially the values for constraint-ability (CA) and institutional feasibility (IF), remain indicative only: they cannot be associated with any statistical significance. Their purpose is to indicate relative feasibility of implementation of a particular adaptation measure compared to the other measures.

5.5.3 Institutional feasibility

In general, our results on institutional feasibility of adaptation measures yielded similar findings to other studies focusing on barriers to adaptation (Biesbroek et al., 2013). Our findings are also comparable to those from studies of institutional aspects in water management in Spain (Avellá and García-Mollá, 2009) and irrigation management in Haiti (Boyer et al., 2011). Our and others' results suggest that institutional setting is crucial in water management, especially for the coordination of roles and compromises among different stakeholders. Biesbroek et al. (2011) also found that among the most highly ranked barriers to climate change adaptation in the Netherlands - besides short term thinking of the politicians versus long term dynamics of climate change - are conflicting interests (corresponding to our heterogeneity of interests), lack of financial resources, and unclear division of tasks and responsibilities. The results of our study suggested that availability of resources (in particular financial resources) is potentially one of the most constraining CIPs for the implementation of adaptation measures in agriculture. Interestingly, the importance of financial resources as barriers to adaptation has been often contested (Biesbroek et al. 2011; Gupta et al. 2010; Theesfeld, 2010). In fact, several studies claim that the role of financial resources is generally overestimated and that efforts to create more adaptive capacity by generating more resources is most likely insufficient (Biesbroek et al. 2011; Gupta et al. 2010). Authors of these studies often downplay the discussion about resource constraints by claiming that better use of existing resources (not just financial) would reduce the need for more financial resources (Biesbroek et al., 2013; Burch, 2010).

In our case respondents ranked resources as the highest constraint for development of new varieties. This discrepancy in results between our study and previous research can be explained by the fact that we were referring to a specific adaptation measure for agriculture in Flevoland, while authors such as Biesbroek et al. (2011) were referring to climate change adaptation as a general concept.

5.5.4 Relevance for adaptation to climate change

In general, the regional/sectoral adaptation measures assessed in this study are very important for the agricultural sector in Flevoland to overcome future climate challenges. This statement has been confirmed by stakeholders in the region during workshops and interviews. De Bruin et al. (2009) found that water management scored highest among adaptation measures to climate change in the Netherlands, based on importance, urgency and co-benefits. Choice of crop varieties and genotypes also received high scores in de Bruin et al.'s study. The choice of crop variety and genotype was considered the most important adaptation strategy to climate change in the agricultural sector (Verhagen et al., 2002). Issues related to relocation of farms (i.e. abandoning of low-lying areas) received high institutional, social and technical complexity scores (de Bruin et al., 2009). Although this measure was named among important measures to respond to future climate challenges at stakeholder workshops during our research, the actual implementation might be severely constrained.

Adaptation measures that were proposed for farm and crop level (see Appendix 5.A) were not considered in the institutional assessment in this study. However, structural measures such as farm diversification, farm size enlargement, farm intensification and change in specialization can also be upscaled to regional level priorities (see Chapter 2). In that case similar crucial institutional preconditions might constrain the implementation of these measures. In the end, a farmer as a stakeholder and a decision-maker is involved in implementation of measures from crop up to the regional level (see also Appendix 5.B). This type of analysis could be extended to include adaptation measures at farm and crop levels. Such an application is supportive of the assertion of Biesbroek et al. (2013) that multi-level perspectives in research on barriers to adaptation are needed.

5.5.5 Policy implications

Heterogeneity or fragmentation of actors' interests appeared to be the main institutional constraint for implementation of adaptation measures in agricultural Flevoland. This has implications for policy-making in the region and requires certain changes to reduce the impact of this institutional constraint. Although Flevoland (and the Netherlands in general) has extensive experience with the broad engagement of stakeholders through the so called polder model, this model does not always appear to be the most efficient for decision-making.

Relative to other countries where decision-making is predominantly top-down, the Netherlands has always opted for consultation and compromise when making decisions. Multi-level governance and multi-stakeholder platforms are not new concepts within Dutch policy-making, especially in water management and agriculture. Having its roots in water management, the polder model historically opted for engagement of different and contrasting groups of stakeholders, each with their own interests. Consequently, when proposing to introduce a controversial measure to improve water management (e.g. increasing the ground water level by 0.15 meter), there would be strong opposition. The discussion about decentralization of water management from the water board to the farmer has been around for a few decades already. The parties involved still have not reached consensus, as the model of decision-making has led to an endless sequence of meetings and still no final decision has been made. Frustration and lack of action predominate. Suggesting that a balance is needed between accounting for the heterogeneity of actors' interests and making decisions in a timely manner, one has to strive for the balance between legitimacy and efficiency.

5.6. Conclusions

We proposed a framework for assessment of institutional preconditions for adaptation measures to climate change, based on a modified PICA (Theesfeld et al., 2010). Adjustments were made to most of the steps within PICA. Changes related to the classification of adaptation measures, selection of CIPs, assignment of indicators to each CIP, the ranking and scoring procedure and results' interpretation. We applied our framework to adaptation measures at the regional/sectoral level for agriculture in Flevoland. The adaptation measures assessed were: (i) improvement of water management and irrigation facilities; (ii) relocation of farms from vulnerable areas; and (iii) development of new crop varieties that can cope with water stress, drought stress, heat waves and sprouting problems during storage.

Based on the ranking analysis, heterogeneity of actors' interests and availability of resources were considered the two most important CIPs for the adaptation measures. These two CIPs were also found to be most constraining for implementation of the measures. Heterogeneity of actors' interests is especially constraining for the relocation of farms, as this measure involves a large number of stakeholders with conflicting interests and there is no official policy support. This CIP is also potentially hindering implementation of water management and improvement of irrigation facilities. For development of new varieties the most constraining CIP was found to be the availability of resources.

Based on the institutional feasibility analysis, the implementation of water management and improvement of irrigation facilities will potentially face fewer institutional constraints compared to the other two measures. Our overall recommendation to the policy-makers in the region is to strive for a balance between the legitimacy and efficiency of decision making processes.

In general, the PICA approach – with some adjustments – is applicable for the institutional analysis of adaptation measures. The framework was only applied to one sector in one region. It is therefore recommended to conduct similar assessments in another institutional setting, in other regions or in other sectors to further test the method.

Appendix 5.A – Risks and impacts of climate change on agriculture in Flevoland and relevant adaptation measures[1].

No	Risks	Impacts	Adaptation measures	Level of Implementation	Institutional relevance [2]
1	Changes in the precipitation				
	a. Changes in the duration and intensity of wet and dry periods	Peak water discharges of the river flows	Improvement of water management and irrigation facilities	Regional/sectoral	+++
		Changes in the ground water stock resulting in water logging and/or water limitations	Relocation of farms from the vulnerable areas	Regional/sectoral	+++
	b. High intensity of rainfall in spring and autumn	Soil may become too wet for soil management operations (sowing, planting, cultivation or fertilization) and harvesting with heavy machinery and equipment will be difficult	Adjustment of crop rotation schemes and timing of planting dates and harvesting dates	Crop	+
			Increase ability of surface drainage	Crop	++
			Increase permeability of sub-soil	Farm	-
		Excess of water (may inundate the plantation)	Water storage on farmland	Farm and regional	+++
		High rainfall increases the risk of rotting of tubers in seed potato	Choice of crop variety and genotype that can cope with increased water stress	Crop	+
			Develop new varieties which can cope with increased water stress	Regional/sectoral	+++
		Soil structure is disturbed and makes diseases more common	GPS steering to prevent damage to soil structure	Farm	++
			Automatic inflation correction of the machinery tyres	Farm	++
	c. Reduced rainfall with high evaporation in summer	Less soil moisture may result in sub-optimal plant growth	Soil moisture conservation practices such as conservation tillage	Crop	+
			Water storage on farmland during high rainfall periods	Farm	++

2	Warm and wet conditions during summer	Increase the risk of outbreaks of bacterial diseases and pests, e.g. Erwinia on seed potato	Choice of crop variety and genotype	Crop	+
			Optimise nutrient management	Crop	++
			Develop new varieties which are resistant to the respective pests and diseases	Regional/sectoral	+++
		Fungal infection in seed onion	Chemical protection	Crop	++
			UV-light protection	Crop	++
			Develop new varieties which are resistant to the respective pests and diseases	Regional/sectoral	+++
3	Heat wave	Second growth	Plant in wider ridges	Crop/farm	-
			Plant and harvest earlier	Crop/farm	+
			Drip irrigation	Crop/farm	+
			Optimise crop cover	Crop	-
			Develop heat resistant varieties	Regional/sectoral	+++
4	Warm winter	Increase the risk to sprouting problems in storage (particularly for seed potato)	Develop new varieties which can cope with the sprouting problem	Regional/sectoral	+++
			Air conditioning	Crop/farm	+
			Sprouting control with chemicals	Crop/farm	++
5	Sea level rise	Increase the risk of inundation and risk of loss of arable land	Relocation of farms from the vulnerable areas	Regional/sectoral	+++
		Crops have to cope with high salinity due to salinization/salt intrusion	Develop new crop varieties that can cope with high salinity	Regional/sectoral	+++
			Insurance	Farm	++
6	Gradual climate change	Change in conditions for primary production	Farm diversification	Farm	++
			Farm size enlargement	Farm	++
			Farm intensification	Farm	++
			Changes in specialization	Farm	++

[1]At crop level, economic risks are much higher for potato compared to crops such as sugar beet and wheat (Schaap et al., 2013), and therefore included measures were limited to these crops.

[2]More (+) indicate higher relevance of institutions in the implementation of the adaptation measure, (-) indicates no relevance of institutions for a particular measure. Both + and – have been assigned by the researchers

Appendix 5.B – Scores per CIP (scores from 0 no constraints to 5 major constraints).

CIP	Measure 1 Water management	Measure 2 Relocation of farms	Measure 3 New crop varieties
1. Administrative levels involved in the implementation of the measure	**Score = 3** Only water board and farmers involved; clear distribution of tasks (*member water board*). The water board aims to have all water management centralized and automatized, whereas many farmers would prefer to have a decentralized system, as they know exactly what is happening in the field (*secretary of the provincial board of farmers' organization*). In NL division of responsibilities between actors in water sector (farmer-municipality-water board) is not always clear (*Bergsma et al., 2012*).	**Score = 4** No evidence, but given the current institutional setting in NL, many layers would be involved in the process (i.e. the national and provincial government, the watershed) , especially if the case goes to court. It is not clear which governmental layer would take the initiative for this interventional measure. Besides, the responsibilities of different parties are not clearly delineated (*Bergsma et al., 2012*).	**Score = 3** Actors include farmers, farmer organizations, product boards, consumers, national government, EU and research (*Groot et al., 2006*). Depending on the size of a company, many layers will be involved, but it's not hindering the process (*breeding expert at a research institute of the university*). Different groups can exercise pressure on the breeders; Dutch consumer is especially very critical (*secretary of the provincial board of farmers' organization*).
2. Contradictory policy instruments and rules	**Score = 1** There are no actual contradictory policies (*member farmers' organization LTO*). The regional government adopted rules and regulations at higher levels (EU, national and provincial), so no conflict. Examples of EU legislation are Water Framework Directive, the Birds and Habitats Directive and CAP. National legislation: the Dutch national Water Plan and the Dutch Spatial Planning Act. Contradiction may arise around specific (also location specific) water management decision (*workshop FNP*).	**Score = 1** No official policy on relocation, in NL there is no formal legislation that obliges actors to include adaptation to their activities (*Biesbroek et al., 2011*).	**Score = 4** GMO policies may seem constraining now, but in the future consumer preferences might change (*breeding expert at a research institute of the university*). Institutional aspects include national agricultural laws, EU CAP, cross-compliance measures, publicity and the capability of the agricultural sector to adjust to the changes (*Groot et al., 2006*).
3. Availability of resources	**Score = 2** Budget is available, but additional activities require additional budget (*member water board*). At the national level, funding for measures comes from the general revenue (tax payers) and for big measures from the delta fund. At the regional level, the water	**Score = 3** Relocation is not included in budget calculations of the province or water board, the actual compensation will have to come from the state (*farmer*).	**Score = 3** Budget is sufficiently available, but money is never enough (*breeding expert at a research institute of the university*).

	boards can collect their own taxes, so if the board agrees on their involvement and the necessity of a measure, it is possible to get funding through their own taxing power in addition to national funding (*policy-maker Ministry of Infrastructure and Environment*).		
4. Political continuity	**Score = 0** Neither changes in the cabinet nor in the water board have affected budget for water management. Budget allocation is driven by practical reasons or needs (*member farmers' organization LTO*).	**Score = 0** So far no evidence (*Provincial administration, member water board*)	**Score = 1** No influence so far observed (*breeding expert at a research institute of the university*). But any moment some instructions could be sent from above (*secretary of the provincial board of farmers' organization*).
5.Heterogeneity/fragmentation of actors' interests	**Score = 3** Small possibility of conflict with other sectors (*member farmers' organization LTO*), different users decide together on the water management issues (*farmer, member water board*).	**Score = 5** Very problematic issue due to different interests of parties involved (*Provincial administration, Groot et al., 2006*).	**Score = 3** Rivalry can come from competing companies, but they pursue their goals – to obtain a better variety (*breeding expert at a research institute of the university*).
6. Experiences with developing and introducing the measure	**Score = 1** NL has a profound record as to achievements in water management (*Delta Commission*). In general indeed, but nowadays there are many new techniques, e.g. water level driven drainage of climate-adaptive drainage, which people here are less familiar with (*secretary of the provincial board of farmers' organization*).	**Score = 2** There is some experience in the past, but it always remains a unique case (*Provincial administration*)	**Score = 0** NL has an excellent record in breeding (*Plant research International PRI of Wageningen university*)
7. Availability of information	**Score = 1** Information on the state of water resources for rural farm communities is accessible (*Bergsma et al. , 2012*). Some particular information on adaptation to climate change might be lacking (*field observations*)	**Score = 3** Little information on relocation is available *(Groot et al., 2006*). Might be that not all farmers have access to certain (online) publications (*field observations*). *Room for the River programme* discusses this issue.	**Score = 3** Info on climate change is sometimes contradictory to reality – projections are too extreme (*breeding expert at a research institute of the university*). Information on local varieties is not always clear (*Groot et al., 2006*).

Chapter 6

Synthesis

6.1 Introduction

The overall objective of this thesis is to improve climate change impact and adaptation assessment of agricultural systems by focussing on farm level adaptation and the broader context it is embedded in. This thesis is an interdisciplinary study that assesses not only the process of adaptation to climate change for agricultural systems, but also the context in which this climate change adaptation takes place.

The research questions formulated in Section 1.2 of the General Introduction (Chapter 1) have been answered in respective Chapters of the thesis. Chapter 2 presented the framework to assess farm structural change in the Dutch province Flevoland under contrasting socio-economic and climate scenarios, and described how farms of the future in Flevoland may look like. Chapter 3 assessed important farmers' objectives and how they relate to farmers' currently implemented practices and to preferred adaptation options. Further, this Chapter discussed how farmers' different objectives influence the choice for farm specific adaptation measures. Chapter 4 focused on crop *and* farm level adaptation to climate change, with assessment of impacts of both gradual climate change and extreme weather events on farm performance. It also revealed how different farmers' objectives would influence preferences for different adaptation measures to climate change. Chapter 5 presented a framework to assess the feasibility of implementing adaptation measures from an institutional perspective. It further provided the empirical evidence on institutional constraints for adaptive capacity to respond to climate change challenges in the case study area.

Assessment of adaptation measures to climate change of agricultural systems was central in this thesis. Table 6.1 shows an inventory of main risks and impacts of climate change on arable farming in Flevoland and of the relevant adaptation measures. Adaptation measures to climate change for Dutch agriculture have been extensively documented in de Wit et al. (2009); Wolf et al. (2010); Schaap et al. (2013), and Reidsma et al. (2015), which are all related studies within the AgriAdapt project, of which this research was also part. In AgriAdapt, quantitative studies and participatory methods were combined to assess climate change impact and adaptation (Wolf et al. 2012). Other studies that assessed climate risks and adaptation for the Netherlands, i.e. de Groot et al. (2006) and de Bruin et al. (2009), have also been exploited. As to the crops, the focus was on seed and consumption potato and seed onion, which are the main agricultural commodities, from an economic point of view, in Flevoland. The main adaptation measures relevant for agriculture in Flevoland were classified based on the climate risks and impacts, and the level of implementation. Different adaptation measures were assessed in different Chapters of this thesis.

Table 6.1 – Risks and impacts of climate change on agriculture in Flevoland and relevant adaptation measures[1]. Source: de Bruin et al. (2009); de Groot et al. (2006); de Wit et al. (2009); Reidsma et al. (2015); Schaap et al. (2013); Wolf et al. (2010) and this thesis.

No	Risks	Impacts	Adaptation measures	Level of implementation	Thesis chapter
1	Gradual climate change	Change in conditions for primary production	Change sowing date	Crop	
			Change cultivar	Crop	
			Irrigation	Crop	
			Farm diversification	Farm	Chapter 2
			Farm size enlargement	Farm	Chapter 2
			Farm intensification	Farm	Chapter 2
			Changes in specialization (crop)	Farm	Chapter 2 and 4
2	Changes in the precipitation				
	a. Changes in the duration and intensity of wet and dry periods	Peak water discharges of the river flows	Improvement of water management and irrigation facilities	Regional/sectoral	Chapter 5
		Changes in the ground water stock resulting in water logging and/or water limitations	Relocation of farms from the vulnerable areas	Regional/sectoral	Chapter 5
	b. High intensity of rainfall in spring and autumn	Soil may become too wet for soil management operations (sowing, planting, cultivation or fertilization) and harvesting with heavy machinery and equipment will be difficult	Adjustment of crop rotation schemes and timing of planting dates and harvesting dates	Crop	
			Increase ability of surface drainage	Crop	
			Increase permeability of sub-soil	Farm	
		Excess of water (may inundate the plantation)	Water storage on farmland	Farm	
		High rainfall increases the risk of rotting of tubers in seed potato	Choice of crop variety and genotype that can cope with increased water stress	Crop	
			Develop new varieties which can cope with increased water stress	Regional/sectoral	Chapter 5
		Soil structure is disturbed and makes diseases more common	GPS steering to prevent damage to soil structure	Farm	
			Automatic inflation correction of the machinery tyres	Farm	
	c. Reduced rainfall with high evaporation in summer	Less soil moisture may result in sub-optimal plant growth	Soil moisture conservation practices such as conservation tillage	Crop	
			Water storage on farmland during high rainfall periods	Farm	

Table 6.1 (continued) – Risks and impacts of climate change on agriculture in Flevoland and relevant adaptation measures[1]. Source: de Bruin et al. (2009); de Groot et al. (2006); de Wit et al. (2009); Reidsma et al. (2015); Schaap et al. (2013); Wolf et al. (2010) and this thesis.

	Risks	Impacts	Adaptation measures	Level of implementation	Thesis chapter
3	Warm and wet conditions during summer	Increase the risk of outbreaks of bacterial diseases and pests, e.g. Erwinia on seed potato	Choice of crop variety and genotype	Crop	
			Optimise nutrient management	Crop	
			Develop new varieties which are resistant to the respective pests and diseases	Regional/sectoral	Chapter 5
		Fungal infection in seed onion	Chemical protection	Crop	Chapter 4
			UV-light protection	Crop	Chapter 4
			Develop new varieties which are resistant to the respective pests and diseases	Regional/sectoral	Chapter 5
4	Heat wave	Second growth	Plant in wider ridges	Crop/farm	Chapter 4
			Plant and harvest earlier	Crop/farm	Chapter 4
			Drip irrigation	Crop/farm	Chapter 4
			Optimise crop cover	Crop	Chapter 4
			Develop heat resistant varieties	Regional/sectoral	Chapter 5
5	Warm winter	Increase the risk to sprouting problems in storage (particularly for seed potato)	Develop new varieties which can cope with the sprouting problem	Regional/sectoral	Chapter 5
			Air conditioning	Crop/farm	Chapter 4
			Sprouting control with chemicals	Crop/farm	Chapter 4
6	Sea level rise	Increase the risk of inundation and risk of loss of arable land	Relocation of farms from the vulnerable areas	Regional/sectoral	Chapter 5
		Crops have to cope with high salinity due to salinization/salt intrusion	Develop new crop varieties that can cope with high salinity	Regional/sectoral	Chapter 5
			Insurance	Farm	

[1]At crop level, economic risks are much higher for potato compared to crops such as sugar beet and wheat (Schaap et al. 2013), and therefore included measures were limited to these crops.

The aims for this final Chapter are twofold. The first aim is to provide visions (or images) of the future of agriculture in Flevoland under contrasting, coupled socio-economic and climate change scenarios. Next, the methodological findings of the thesis will be discussed in the light of its contribution to research on adaptation of agricultural systems to climate change.

6.2 Images of the future of agriculture in Flevoland

6.2.1 General approach

In Chapter 2 we defined the context of adaptation to future climate change for arable farming systems in Flevoland by assessing the contribution of different drivers to farm structural change in 2050. In the first step we identified current farm types and their distribution using a farm typology. Next, a historical analysis was performed to assess the impact of important drivers (technology, policy, market and climate change) on the farm structure. Input from stakeholders and literature review were also used to derive historical relationships between drivers and farm structural change. The outcome of this step was the relative contribution of each driver to the changes in each of the farm structural dimensions (orientation, size, intensity, specialization). In the next step, socio-economic and climate scenarios were downscaled to the regional level to explore effects of changes in the drivers and subsequent changes in farm dimensions and characteristics towards 2050. We first obtained the results on changes in farm dimensions at regional level. Subsequently, we downscaled these to the farm level using transition rules, resulting in scenarios of farm structural change. In addition, stakeholder input was used to detail the scenarios and envision the images of future farms in Flevoland (Section 2.2.3).

Contrary to a normative approach that explores the ability to achieve plausible, desired and relevant regional futures expressed by stakeholders (see e.g. Van Ittersum et al. (1998); Rounsevell and Metzger (2010); Waldhardt et al. (2010); Soliva et al. (2008)), the results of this thesis are reflecting the application of a positive approach. The projections are based on what can be expected, not on what is desired based on defined objectives. Grounded in historical data analysis, the results of Chapter 2 give projections on possible developments in drivers and in farm structural characteristics influenced by the drivers.

This analysis has been performed from the perspective of current knowledge and technology, which influenced the outcomes. Due to a long time horizon and the complex dynamics of different drivers of change, the future of agriculture around 2050 remains very uncertain. The findings of this thesis therefore reveal plausible future developments in terms of farm structural change in Flevoland. These may be similar to other regions in Northern Europe.

6.2.2 Scenarios of farm structural change

We used two plausible contrasting scenarios regarding future climate and socio-economic change to assess future farm structural change. For assessing impacts of climate change towards 2050 we used scenarios from the Royal Dutch Meteorology Institute (KNMI) (van den Hurk et al. 2006). The G climate scenario assumes a moderate global temperature increase of 1°C by 2050, whereas the W scenario assumes a significant global temperature increase of 2°C by 2050. The climate change scenarios also differ in terms of atmospheric circulation. In Chapter 2 we did not consider the magnitude in change of atmospheric circulation in the W scenario. In Chapter 4 we used the W+ scenario, including change in atmospheric circulation resulting in drier summers and more extreme weather events. CO_2 concentrations were assumed 478 μmol CO_2 mol^{-1} for the G scenario and 567 μmol CO_2 mol^{-1} for the W+ scenario in Chapter 4.

To account for possible future trends in socio-economic developments, we used scenarios A1 Global Economy and B2 Regional Communities from the commonly used Dutch WLO scenarios (van Drunen and Berkhout 2008). These scenarios are adapted from Westhoek et al. (2006) for the situation in the Netherlands, and are similar to the IPCC SRES scenarios (Nakicenovic and Swart 2000). Following suggestions of Henseler et al. (2009) we assume that the more economically and globally oriented A1 scenario goes with a significant temperature increase of 2°C by 2050, i.e. the W scenario. The more environmentally and regionally oriented B2 scenario is assumed to match with a moderate temperature increase of 1°C by 2050, represented by the G scenario.

Around 2050, different pathways of socio-economic development could lead to different futures for agriculture in Flevoland (Figure 6.1). In the A1 Global Economy scenario, agricultural area in Flevoland is expected to decrease, while the number of arable farms is projected to drop by one third (Table 6.2). Crop production on remaining arable farms will be impacted by climate change. While gradual climate change will have mostly positive effect on crop yields through both gradual temperature increase and an elevated CO_2 level, an increase in frequency and severity of extreme weather events will have negative impacts on crop yields. Especially heat waves in summer and warm winters may cause large damage for production of high value crops (i.e. seed and consumption potatoes and seed onions), reducing the yields by 32-52% if no adaptation takes place (see Table 4.3).

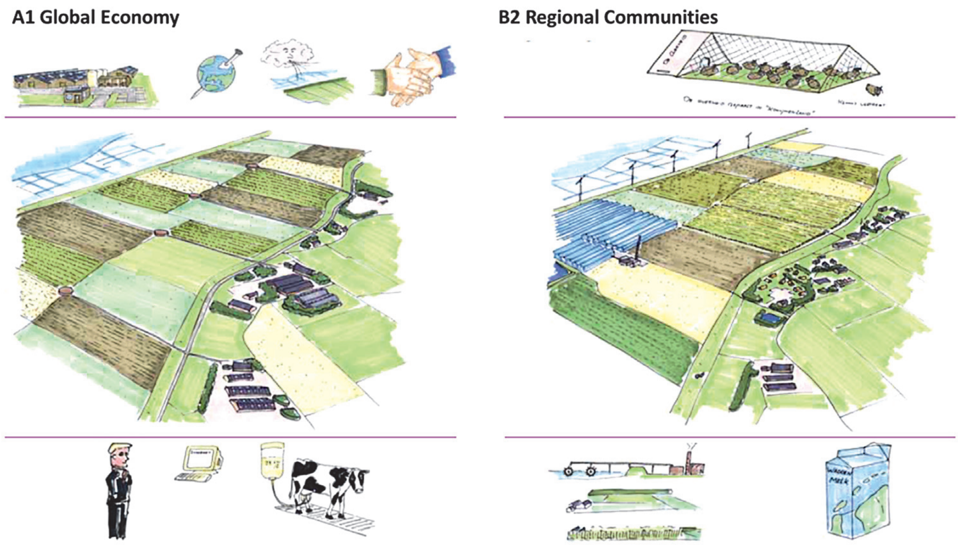

Figure 6.1 – Images of future agriculture in two scenarios, A1 Global Economy and B2 Regional Communities (van der Kolk et al. 2007).

Table 6.2 – Projected changes in the main features of agriculture in Flevoland in the two scenarios (based on Table 2.5).

Main features	A1 Global Economy	B2 Regional Communities
Arable land	Decrease (-13%)	Less decrease compared to A1 (-8%)
Number of farm	Large decrease (-35%)	Less decrease compared to A1 (-13%)
Average farm area, ha	Large increase (+34%)	Decrease (-13%)
Area root/tuber crops, % UAA[1]	Large decrease (-36%)	Decrease (-9%)
Area vegetables	Large increase (+51%)	Increase (+13%)
Area flower bulbs	Large increase (+60%)	Increase (+15%)
Entrepreneur oriented farms	Large increase	Large increase
Nature oriented farms	Disappear	Large increase

[1]UAA is utilized agricultural area

The main farm type in Flevoland in this scenario is projected to be "production oriented – very large – medium intensive – diverse: other arable", occupying 16% of utilized agricultural area in the province. Such a farm is a large scale, capital intensive holding with a farm size of 130 ha, as projected in Chapter 2. According to the stakeholders, the farm is expected to have a considerable share of rented land in the total utilized agricultural area (up to 75%). The farm is operating in close collaboration with neighbouring farms in terms of management operations and (partial) processing of the products. Technical advances on the farm are the attributes of precision agriculture, which contribute to high labour efficiency and productivity. Seed and ware potato remain important crops, but other high value crops such as tulips and vegetables increase in importance. The area of flower bulbs was projected to increase considerably in Chapter 2 (+60%; see Table 6.2). An increase of flower bulb area in Flevoland was a likewise outcome for cropping patterns adaptation simulations in the A1/W+ scenario in Reidsma et al. (2015). At the same time, consultations with stakeholders yielded an interesting remark on cultivation of sugar beet, which could disappear due to the high competition on the global sugar market and could be replaced by vegetables such as onions and carrots. However, sugar beet is expected to profit from both gradual warming and elevated CO_2 concentrations (Angulo et al. 2013; Jones et al. 2003; Maracchi et al. 2005; Olesen and Bindi 2002; Wolf et al. 2012). Using a bio-economic farm model, Kanellopoulos et al. (2014) found that under the abolishment of the sugar beet quota, a substantial increase in production of sugar beet can be expected in the A1W scenario in Flevoland. What will finally happen, will largely depend on changes in prices, and these remain uncertain (Nelson et al. 2014).

The projected changes in quantitative features of agricultural systems under B2 Regional Communities scenario in 2050 are less drastic than in the A1 Global Economy scenario (Table 2), while at the same time many new developments are expected to take place in Flevoland. In general this scenario is characterized by a higher diversity in the farming landscape with a focus on local crops and markets, more nature conservation and provision of alternative functions to the society. Due to a moderate increase in temperature, the impacts of climate change (and especially of extreme weather events) on crop yields in the G scenario will be less damaging compared to the W+ scenario.

A typical farm in the B2 scenario is projected to be multifunctional with a projected farm size of 64 ha (Chapter 2). According to the stakeholders, this farm type will mostly produce organically. The output intensity is kept to the current level through strict environmental legislation aimed at limiting growth potential of agriculture. The share of rented land on the farm could vary between 50 and 75 %. Cooperation between neighbours is strongly supported by regional development policy. Technological progress is focused on environmentally friendly production means (environmentally beneficial technology) and development of biological crop varieties. The balance between consumer demand and production supply is regionally based. A farm becomes part of a local market chain (retail, direct sells from a farm, local supermarkets). Traditional crops dominate in the arable farm specialization: consumption potato, seed potato, winter wheat, and sugar beet, under the assumption that local (national) market supports sugar beet production in the Netherlands (and particularly in Flevoland).

6.2.3 Crop and farm level adaptation

Farmers in Flevoland were found to have different objectives (Chapter 3), which could determine preferences for certain adaptation measures against future extreme events in different scenarios (Chapter 4). If the main objective of a farmer is improvement of gross margin of crops, cultivating high value crops in the W+ scenario remains the best option, although adaptation measures need to be adopted, which will slightly reduce gross margin compared to the gradual climate change scenarios and slightly increase gross margin compared to the current situation. A combination of planting in wider ridges (to reduce the impact of heat waves) and air conditioning (to reduce the impact of warm winters) for seed potato and chemical protection or UV-light protection (to reduce the impact of warm and wet conditions during summer) for seed onion were found to be the most profitable measures (see Table 4.6). In the G scenario the impacts of extreme events on crop yields are less severe, so the importance of crop level adaptation is less compared to the W+ scenario. If a farmer aims to improve gross margin of crops and organic matter simultaneously, switching from grass to winter wheat would be beneficial regarding both objectives.

Crop level adaptation of existing cropping systems (e.g. changes in varieties, planting times, irrigation and residue management) has been widely assessed and acknowledged to be effective against future climate challenges (Challinor et al. 2014). Wolf et al. (2012) assessed future climate change impacts for a number of arable crops in Flevoland with and without adaptation measures (change in sowing date and cultivar); see also Reidsma et al. (2015). They found that in the A1W scenario for consumption potato climate change resulted in 11% increase without adaptation, whereas with adaptation a 20% increase in yield was projected. For onion these figures were +26% and +42%, respectively. These yield benefits with adaptation are similar to the average across crops and regions according to Porter et al. (2014). However, these studies did not consider the impacts of and adaptation to extreme events. This thesis assessed the impacts of extreme events and showed that adaptation becomes more important when the impacts of extreme events are also considered (i.e. up to 67 % yield benefits from adaptation measures compared to no adaptation can be achieved if a combination of adaptation measures against different extreme events is used; see Table 4.5).

It should be noted that crop and farm level adaptation measures were assessed in this thesis keeping technology, prices and policy constant. When considering possible changes in prices or technological development, other options may become interesting. Prices of potatoes and of other crops may vary largely over time, influencing the relative profitability. In all scenarios and on all farms, gross margins of seed and consumption potato with adaptation were less than half of those of winter carrot (see Table 5.7). Prices thus need to change a lot to change this relative difference. Adaptation towards winter carrot would be most beneficial regarding gross margin for all farms, however, we did not assess the impacts of the extreme events on winter carrot. Even without crop level adaptation, the gross margins of seed onion are higher than for other crops (apart from winter carrots), and therefore switching from seed onion to other crops is not interesting from a gross margin point of view. However, in the W+ scenario the gross margin of sugar beet and chicory do come closer to those of seed onion and potatoes for several farms, thus becoming better alternative options of adaptation at farm level.

The potential for crop substitution under climate change conditions has received much less attention than research on the effect of climate and its variability on a given crop (Eyshi Rezaei et al. 2015). Elsgaard et al. (2012) analysed the effect of temperature and precipitation on crop fractions of oats, wheat and maize for Europe, and assumed that the climatic factors explaining present spatial cropping patterns might also explain changes due to climate change until 2040. Based on this assumption they calculated that the proportion of oats will decline and that the proportion of maize will increase across Europe, while the fraction of wheat will increase in northern Europe. The results of this thesis also suggest that winter wheat will remain an important crop on arable farms in Flevoland, especially if farms would aim to improve organic matter on the farm.

In Chapter 2 we showed that adaptation to future climate change will take place in the context of other important drivers, most notably technology, policy and market development. Additionally, farm structural change will determine the future composition of different farm types in the region, with most likely different adaptation preferences. In this thesis we did not assess crop and farm level adaptation measures to climate change considering the influence of important non-climatic drivers, but such analysis was performed for Flevoland in Kanellopoulos et al. (2014) and Reidsma et al. (2015). Reidsma et al. (2015) also estimated average regional impacts of climate change and other important drivers based on future farm structural change from Chapter 2. For the A1 scenario it was assessed that the abolishment of sugar beet quota and changes of future prices of agricultural inputs and outputs caused a decrease in gross margins of smaller farms (in terms of economic size), while gross margin of larger farms increased. For the B2 scenario the future price ratios between inputs and outputs were shown to be the key factors for the viability of arable farms (Kanellopoulos et al. 2014; Reidsma et al. 2015). When farms do not have sufficient income from crop production, they might diversify and search for alternative sources of income. In Chapter 2 we projected an increase in entrepreneur oriented farm types and nature oriented farm types in the B2 scenario and the studies of Kanellopoulos et al. (2014) and Reidsma et al. (2015) confirm that this will be needed.

6.2.4 Regional level adaptation

At the regional level, we performed an institutional analysis for the implementation of the following important measures for the agricultural sector in Flevoland to overcome future climate challenges: improvement of water management and irrigation facilities; relocation of farms and development of new crop varieties (Chapter 5). The adaptation measure ‘improvement of water management and irrigation facilities’ appeared to be the most feasible to implement in Flevoland from an institutional perspective. The value of institutional feasibility for this measure, indicating to what extent the implementation of the adaptation measure is feasible from an institutional perspective, pointed at fewer institutional constraints compared to the other two measures. Relocation of farms was found to be the most difficult to implement, since its value for institutional feasibility potentially indicated more constraints. The relatively high institutional feasibility of improvement of water management and irrigation facilities was implicitly assumed in Chapter 4, by using potential instead of water limited yields when assessing impacts of gradual climate change.

The importance of the regional/sectoral adaptation measures to climate change assessed in this thesis has been confirmed by stakeholders in the region during workshops and interviews and by literature review. De Bruin et al. (2009) found that water management scored highest among adaptation measures to climate change in the Netherlands, based on importance, urgency and co-benefits. Choice of crop varieties and genotypes also received high scores in the study of de Bruin et al. (2009). The choice of crop variety and genotype was considered the most important adaptation strategy to climate change in the agricultural sector (Verhagen et al. 2002). Issues related to relocation of farms (i.e. abandoning of lowland areas) received high institutional, social and technical complexity scores (de Bruin et al., 2009). Although this measure was mentioned among important ones to respond to future climate challenges at stakeholder workshops during our research, the actual implementation might be severely constrained.

Heterogeneity or fragmentation of actors' interests and availability of resources appeared to be the main institutional constraints for implementation of adaptation measures in agricultural Flevoland (Chapter 5). This finding can have implications for policy making in the region and requires certain changes to reduce the impact of these institutional constraints. We did not assess the future institutional context and thus we can only provide an indication of what could be expected in Flevoland given different socio-economic and climate scenario logic. When climate becomes more extreme in the W+ scenario, for example, we can expect more conflicts on the issue of farm relocation from the most vulnerable areas, but also more heated debates between the water board and farmers about water management.

6.2.5 Policy implications

There is a need for better information to support adaptation planning over the next few decades since this is an appropriate time horizon for considering and implementing practical and policy options to deal with climate change. The results of this thesis indicate which areas of development in Flevoland can be (better) targeted by policies or regional and national action plans:

- Chapter 2 projects an increase in entrepreneur and nature oriented farms in Flevoland. Subsidies for landscape management and multifunctional agriculture remain necessary to support the entrepreneur and nature oriented farms, which next to primary production will also provide additional services to society.

- In Chapter 3, soil quality was found to be one of the important objectives for farmers in Flevoland. Improvement of soil structure should receive enough support in policies and regulations. Currently it is not very popular due to high (investment) costs and a long time horizon for the expected effects. Increase of organic matter in soils could lead to more carbon sequestration, which is also a very important climate change mitigation measure.
- Chapter 4 argues that next to applying crop level adaptation measures against extreme events, farmers may also shift to alternative crops. The province should facilitate "innovation labs" for new crops (and new varieties); and adapt water management to the new crops. Locally produced food should also fit the needs of local markets.
- Chapter 5 mentions an ongoing debate between farmers and water board regarding flexibility of water management on farms. The province should stimulate farm oriented water management, following the examples of already existing initiatives, such as water level driven drainage and household level water management. The available water should be used most effectively according to the farmers' particular needs.

6.3 Methodological contribution to assessment of adaptation of agricultural systems to climate change

Overall, this thesis performed a prospective (using scenarios), multi-scale (taking into account the crop, farm and regional level), integrated (notably multi objective) and participatory assessment, abbreviated PIAAS (Participatory Integrated Assessment of Agricultural Systems, as used in Delmotte et al. (2013)). The assessment in this thesis particularly focused on adaptation of agricultural systems to climate change. The overview of different elements of PIAAS in the thesis is given in Table 6.3.

Below we address each of the aspects of PIAAS from the thesis, with the emphasis on climate change adaptation.

Table 6.3 – Elements of PIAAS (Participatory Integrated Assessment of Agricultural Systems) in different Chapters of the thesis.

Chapter	Research focus	Prospective	Integrated	Multi-scale	Participatory
Chapter 2	Farm structural change	Scenarios 2050	Farm typology accounting for different farmers objectives (dimension of orientation)	Farm, region	Development of future visions of arable farming with farmers, representatives of water board and local policy makers
Chapter 3	Farmers multiple objectives	Preferable adaptation options in current situation	Multiple objectives	Farm	Elicitation of weights for different objectives based on farmers' input to assess farmers' decision-making
Chapter 4	Crop and farm level adaptation	Scenarios 2050	Multiple objectives	Crop, farm	Builds on the findings of Chapter 3
Chapter 5	Institutional context	Current institutional setting	Multiple barriers to adaptation (i.e. institutional, social, financial, and informational)	Region	Assessment of institutional context through ranking of crucial institutional preconditions performed by representatives of water board, provincial government, farmers' organizations and plant breeding experts

6.3.1 Prospective: development of scenarios

In Chapter 2 we presented a method to assess farm structural change at regional and farm level towards 2050, under contrasting climate and socio-economic scenarios, which was not previously performed for such a long time horizon. The analysis shows that historical trends, consistent scenario assumptions and stakeholder input can be used to derive regional and farm level estimations of farm structural change and plausible images of arable farms towards 2050. The analysis of farm structural change developed in this thesis provides a better basis for assessment of impacts of and adaptation to climate change than the current farms. When climate change impacts will be strongly manifested, the adaptation measures should be proposed to the future farms that have evolved through structural changes.

We used coupled socio-economic and climate scenarios to place climate change in the context of other important drivers, similarly to other studies on the impacts of climate change on agricultural land use ((Audsley et al. 2006; Lehtonen et al. 2006; Rounsevell et al. 2003). These coupled scenarios have been criticized by Audsley et al. (2015), with the main argument being the impossibility to compare the impact of specific factors within these scenario sets. They further explain that whether the effects observed are due to the change in rainfall, temperature, population, oil price, crop breeding or any of the other parameters of the scenario, is a matter of speculation and the what-if questions by the reader cannot be answered. In this thesis we did assess the contribution of different single drivers (i.e. technology, market, policy and climate change) to changes in dimensions of a farm typology (i.e. orientation, size, intensity and specialization), reflecting future farm structural change. For the quantitative analysis based on statistics we chose to work with one indicator per driver to assess the impact of each driver on farm structural change and to assess the impacts of scenario assumptions on a driver. Yet, scenarios are too complex and cannot be reflected by just one indicator per driver. Besides, in some cases the relationship between a driver and dimension was not confirmed by the statistical analyses, whereas literature review and stakeholder interactions suggested a relationship. Therefore we complemented the results based on the drivers with results based on the dimensions themselves and with literature review and stakeholders' perspectives.

The approach used in this thesis (i.e. to assess climate change impacts and adaptation under coupled socio-economic and climate scenarios) is also followed in the most recent scenarios specifically developed for integrated impact assessments (van Vuuren and Carter 2014; van Vuuren et al. 2014). Also Wiebe et al. (2015) suggest that insight in sensitivity of climate change impacts to differences in socio-economic and emissions pathways allows assessing most efficient adaptation measures to climate change in respective combined scenarios.

At the same time, the approach that was applied in Chapter 2 in terms of socio-economic and climate scenario coupling has not been consistently applied throughout this thesis. When developing the scenarios for the assessment of future impacts of and adaptation to climate change at crop and farm levels considering extreme weather events (Chapter 4), I focused on climate change scenarios only. The assumptions regarding development of other important drivers (i.e. technology, market and policy) were left out of the study. This could have had implications for certain adaptation measures (i.e. future price changes may affect attractiveness for farmers to implement measures). Follow-up studies could perform assessment of crop and farm level adaptation measures to climate change in the future scenarios considering also non-climatic drives of change, which has partly been performed by Kanellopoulos et al. (2014) and Reidsma et al. (2015).

I did not apply scenarios to assess the future institutional context in Chapter 5, although a basis for future assessments through the analysis of the current institutional setting was provided. The framework for the assessment of institutional feasibility of adaptation measures to climate change, developed in Chapter 5, is rather flexible since it is based on importance ranks and scores for institutional constraints, both of which could be derived separately, also under future scenarios.

When discussing future dynamics of institutions, Lane and Montgomery (2014) refer to Williamson's hierarchy (Williamson 2000), which suggests path dependency of institutions. Current institutions affect the relative power of interest groups, they determine the extent of networks, and they induce actors to invest in specialized capital. In effect, the presence of a given structure of institutions at one point in time will constrain the adoption of future institutions, policies, or technologies. Therefore, the assessment of current institutions is crucial for understanding the future institutional context for adaptation to climate change.

6.3.2 Integrated: considering multiple objectives

Chapter 3 presented a method to assess how farmers' intentions and stated objectives are related to practical decision-making. The novelty of the approach developed in this thesis is in consideration of interrelated aspects of decision-making, as we assessed what farmers say (by deriving stated preferences in objectives from the ranking), what farmers actually do (by assessing farm current performance) and what farmers want (through selected alternative farm plans).

Janssen and van Ittersum (2007) stressed the need to better reflect actual farmer decision-making in bio-economic models. Potential heterogeneity in decision-making structure between different farms and farm types can have impact on the choice of adaptation options (Jakoby et al.2014). In previous integrated assessments for arable farms in Flevoland it was assumed that an average farm of a farm type has a single objective function (i.e. maximizing gross margin), thus no distinction has been made between objective functions of different farm types (Kanellopoulos et al. 2010; Reidsma et al. 2015). In positive mathematical programming other objectives are partly implicitly considered in the quadratic cost functions (Louhichi et al. 2010). In this thesis those other objectives were made explicit.

This thesis obtained three sets of weights for multiple objectives. However, not all weights were finally used in the follow-up study in Chapter 4. Weights recovered from the interviews would correspond to the farm plans that do not provide enough income to the farmers to be competitive. Due to a stated high priority for soil organic matter balance, such weights would correspond to farm plans with relatively high share of wheat and grass and a smaller share of high value crops, which would lead to low farm economic result. Weights recovered from current farm performance reflected the actual farmers' decision-making and therefore appeared more suitable. However, these weights were related to the current conditions, which might change in the future (e.g. soil organic matter balance), and thus the performance weights for the objectives might change. Weights based on adaptation preferences seemed to be the best option when assessing future adaptation options to climate change.

Chapter 4 considered trade-offs between the most important objectives according to the weights derived from adaptation preferences of farmers in Chapter 3 (i.e. farm economic result and soil organic matter balance). Farm plans generated by the FarmDESIGN model were assessed accounting for possible improvement of farm performance on the most important objectives (i.e. farm economic result and soil organic matter balance). Different adaptation options (i.e. alternative farm plans including crop level adaptation measures) became interesting, depending on what objective a farmer prioritized most. Comparing the outcomes of bio-economic modelling studies using different sets of weights in extended utility functions will be useful to understand the importance of objectives for adaptation and is therefore a recommendation for a follow-up study. Recently Kanellopoulos et al. (2015) developed an alternative method for multi-objective calibration, to use weights in future scenarios. They stated that such methods are also applicable without interactions with the decision maker (farmer). Although this will be a step forward compared to the often assumed objective of profit maximization in larger scale studies, it remains good to be aware that farmers perceive their objectives differently.

6.3.3 Multiscale: Adaptation at different levels

This thesis considered adaptation measures at different levels of implementation - region, farm and crop - which enabled to assess cross-level interactions between the measures: farm and regional level (Chapter 2) and crop and farm level (Chapter 4).

Farm level adaptation generally received little attention in adaptation literature. The studies addressing farm level adaptation to climate change (e.g. Leclère et al. (2013); Klein et al. (2013); Troost and Berger (2014)) usually aggregate the results at a regional level and do not make impacts at farm level explicit. For example, Leclère et al. (2013) assessed farm level autonomous adaptation to climate change for EU-15 member states and showed that largest gains in crop gross margins were found when adopting crop management practices, rather than shifts in cropping patterns, which is also the case in the present study. In general the studies on farm level adaptation show that the adaptation allows farmers to largely benefit from the new possibilities offered by climate change, depending on the various crop responses to climate change.

Studies using bio-economic farm modelling (Janssen and van Ittersum, 2007) showed that an optimization technique can be used to evaluate different adaptation options at farm type and individual farm level and to assess the impacts of climatic, market, technological and policy changes (see e.g. Kanellopoulos et al. 2014). However, bio-economic models often use economic criteria to simulate farmers' behaviour. Besides, often availability of capital is not taken into account as a constraint in assessments with bio-economic models, as well as farm specific variability in soil quality (Kanellopoulos et al. 2014).

In this thesis a model FarmDESIGN (Groot et al. 2012) was used, which has been developed to overcome the abovementioned limitations by coupling a bio-economic farm model that evaluates the productive, economic and environmental farm performance, to a multi-objective optimization algorithm that generates a large set of Pareto-optimal alternative farm configurations. The optimization aimed to maximize the operating profit and organic matter balance, and to minimize the labour requirement, risk and soil nitrogen losses. The model outcomes showed that trade-offs existed among various objectives, and at the same time identified a collection of alternative farm configurations that performed better for all four objectives when compared to the original farm plan. To improve climate change impact and adaptation research, farm level adaptation is needed to be better represented, as this is the level where management and decision making takes place. Both farming systems analysis and integrated assessment are needed for analysis of farm level adaptation.

Regional level adaptation was considered in the institutional analysis in Chapter 5. A method was developed to assess crucial institutional preconditions for adaptive capacity to respond to climate change challenges. The methodology is not scale dependent as it is based on stakeholder input and literature. Hence, the framework can be used to assess adaptation measures at other levels of implementation (e.g. crop, farm, nation) and in other socio-economic and bio-physical contexts, than those presented in this thesis.

6.3.4 Participatory: involvement of stakeholders

The methodological framework of this thesis facilitated participatory research by creating space to discuss assumptions, methods developed for the assessment and results with the stakeholders. This thesis therefore widely used contextual knowledge (i.e. stakeholder workshops and interviews with farmers from the case study area; see also Table 6.3), which enhanced the practical value of the results.

The engagement of relevant stakeholders in any research activity on climate change adaptation is seen as a key element for generating solutions that are feasible, sustainable, legitimate and acceptable to those who have to implement and live with them (Rounsevell and Metzger 2010). In the context of adaptation to climate change and climate variability, assessments of agricultural systems require that researchers take farmers' skills and knowledge seriously (Crane et al. (2011). According to Feola et al. (2015), while farmer behaviour is a key determinant of agricultural systems' adaptability, too often research relies on theories and methods that do not capture the complexity of farmer behaviour. Finally, the role of decision-making by individual farmers is often studied in individual cases to determine its environmental, economic, and social effects. There have been few efforts to link across studies in a way that provides opportunities to better understand empirical farmer behaviour, design effective adaptation and sustainable agriculture policies, and be able to aggregate from case studies to a broader level. The research networks AgMIP and MACSUR have recently committed to address these challenges (see Bindi et al. 2015).

At the same time, in climate change adaptation research, highly complex computer models are often developed and used, which increases the challenge of translation of qualitative statements to quantitative model input and hinders the communication of results to the stakeholders (see Gramberger et al. 2015; Kok et al. 2015). In this thesis I deliberately chose to use a model (FarmDESIGN; Groot et al., 2012) developed to facilitate presentation and discussion of the simulation results with farmers. The model demonstrated the usefulness of multi-objective optimization in the design of mixed farming systems in several cases (Groot et al. 2012). Due to possibility of rapid inspection of the farm configurations (crops areas, animal numbers, manure application, etc.) associated with different performance levels, the model can support the learning and decision-making processes of farmers and advisers.

6.4 Conclusions

The present thesis assessed adaptation measures to climate change of arable agricultural systems at different levels of implementation, with a focus on the farm level. Besides empirical findings on the plausible future of agriculture in Flevoland under climate change scenarios and possible adaptation measures, this thesis also contributed methodologically to the portfolio of climate change impact and adaptation assessment. The main conclusions of the thesis are summarized below.

- Integrated assessment of important drives of change towards 2050 shows that next to climate change, other important drivers (i.e. technology, market, policy) form the context of adaptation of agricultural systems to climate change at regional and farm levels.
- Historical trends, consistent scenario assumptions and stakeholder input can be used to derive regional and farm level estimations of farm structural change and plausible images of arable farms towards 2050. When climate change impacts will be strongly manifested, the adaptation measures should be proposed to future farms that have evolved through structural changes. Our estimation of farm structural change provides a proper context for assessing impacts of and adaptation to climate change in 2050 at crop and farm level.
- Farmer's stated preferences in objectives (i.e. what farmers say) were often not reflected in actual farming practices (i.e. what farmers do). Adaptation preferences of farmers (i.e. what farmers want) largely resembled their current performance (i.e. what they do), but generally involved a move towards stated preferences (i.e. what they say).
- Although farmers in Flevoland do have more objectives (i.e. maximization of farm economic result and soil organic matter, and minimization of gross margin variance, working hours and nitrogen balance), in practical decision-making they focus on economic result maximization, while for strategic decision-making they account for soil organic matter, which is indirectly related to long term economic results.
- Gradual climate change improves farm performance in terms of farm economic result in Flevoland by 2050. The degree of improvement varies per climate change scenario and per farm, depending on the cropping pattern. At the same time, extreme events cause a considerable damage to farm economic result unless adaptation measures against extreme events are adopted.
- A combination of crop and farm level adaptation appeared to be the best option in terms of improving both farm economic result and soil organic matter balance.
- From an institutional perspective, heterogeneity of actor's interests and lack of resources appeared to be the most constraining crucial institutional preconditions (CIPs) for adaptation measures against climate change.

- The results of this thesis enrich the choice of adaptation measures by farmers, the design of public adaptation policies, regional action plans and extension activities.

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Summary

Climate change has become an issue of concern during the last decades. In many regions of the world one can observe effects of changes in climatic conditions or climate variability on crop productivity, farmers' income and land use. Also for the future of agriculture in the Netherlands climate change must be considered. To prevent the negative impacts and to take advantage of the opportunities arising from climate change, the agricultural sector needs to work on adaptation measures. In the literature, the vast majority of studies focused on field and crop level adaptation. Adaptation may, however, occur across different scales, and actual decisions in agriculture are made at the farm level. Impacts and adaptation should therefore certainly be assessed at farm level, and farm variability must be considered. Adaptation to climate change is embedded in a broader societal context, hence many factors can influence adaptation.

Against this background, the overall objective of this thesis was to improve climate change impact and adaptation assessment of agricultural systems by focussing on farm level adaptation and the broader context it is embedded in. This thesis is an interdisciplinary study that assesses not only adaptation to climate change for agricultural systems, but also the context in which this climate change adaptation takes place. The methods developed in this thesis are meant to be generic and not case study specific, but they were illustrated and applied for the Dutch province Flevoland, with large scale, intensive arable farming as the main type of agricultural activity.

In future, other important drivers (i.e. markets, technological change and policy) will be impacting farming systems next to climate change. Due to these drivers current farms will evolve in time through structural changes. Chapter 2 therefore analysed the context of adaptation to future climate change for arable farming systems by assessing the contribution of different drivers to farm structural change. Scenario assumptions about changes in drivers - elaborated at global and European levels - were downscaled for Flevoland, to regional and farm type level to project impacts of drivers on farm structural change towards 2050. The estimated farm structural changes differed substantially between the two scenarios considered: A1 Global Economy and B2 Regional Communities. Around 2050 in the A1 scenario in Flevoland we may expect large scale farming systems specializing in intensive crops. In the B2 scenario there is still place for smaller farms. In general this scenario is characterized by a higher diversity in the farming landscape with focus on local crops and markets, more nature conservation and provision of alternative functions to the society. The analysis of farm structural change provides a proper context for assessing impacts of and adaptation to climate change in 2050 at crop and farm level in Flevoland.

Next to primarily economic objectives, farmers have other objectives (e.g. social, environmental) influencing their management practices. Farm specific adaptation measures to climate change should therefore account for the differences in farm objectives. Chapter 3 consistently assessed the importance of farmers' objectives from what farmers say (based on interviews), from what farmers actually do (by analysing current farm performance) and from what farmers want (through selected alternative farm plans). The objectives assessed included maximization of economic result and soil organic matter, and minimization of gross margin variation, working hours and nitrogen balance surplus. Among six arable farms surveyed, farmers' stated preferences in objectives were often not reflected in realized farming practices. Adaptation preferences of farmers largely resembled their current performance, but generally involved a move towards stated preferences. The results of Chapter 3 suggest that although farmers in Flevoland do have more objectives, in practical decision-making they focus on economic result maximization, while for strategic decision-making they wish to account for soil organic matter which is indirectly related to long term income.

Chapter 4 built on the findings of Chapter 3 and focussed on assessment of adaptation measures against future gradual climate change and an increased frequency of extreme events, considering farmers' multiple objectives. First, the impacts of gradual climate change and extreme events on farm performance were assessed in terms of two important objectives identified in Chapter 3: maximization of economic result and of soil organic matter. The impacts of extreme events were investigated for high value crops in Flevoland, which are seed and consumption potato and seed onion. The results for selected arable farms in Flevoland suggest that gradual climate change by 2050 improves farm performance in terms of farm economic result. The degree of improvement varies per scenario and per farm, depending on the cropping pattern. At the same time, extreme events (such as heat wave in summers and warm winters) offset positive impacts of gradual climate change and - in a most severe scenario - they cause a considerable damage to farm economic result through associated yield losses. A neutral impact of future climate change on soil organic matter balance at the crop level was assumed, but soil organic matter balances could be affected by changes in the cropping patterns on a farm. Next, the importance of crop and farm level adaptation measures for the improvement of farm performance was assessed, considering farmers' important objectives. Different prioritization in terms of objectives can influence preference for different adaptation measures at crop and farm level. If the main objective of the farmer is improvement of economic result, cultivating high value crops remains the best option, although adaptation measures to extreme events need to be adopted. Crop level adaptation measures can largely neutralize negative impacts of these extreme events, but some loss of gross margin of crops will still occur. If farms aim to prioritize economic result and soil organic matter simultaneously, shifting from grass and chicory to winter wheat is a good option, as it improves organic matter balance on the farm and as winter wheat has a relatively small negative effect from climate change on its gross margin. A combination of crop and farm level adaptation is needed for the surveyed farms in terms of improving both farm economic result and organic matter balance.

Besides at crop and farm level, adaptation for agricultural systems to climate change should also be considered at the regional level. At regional level, an enabling institutional environment is an important precondition for the implementation of adaptation measures. Chapter 5 developed a framework for the assessment of crucial institutional preconditions that facilitate the implementation of adaptation measures to climate change. The Procedure for Institutional Compatibility Assessment (PICA) was adopted and modified. In the framework, institutions are characterized by a set of crucial institutional preconditions (CIPs) and indicators linked to each CIP. CIPs refer to both institutional incentives and constraints for implementation of adaptation measures to climate change. Based on information from workshops, interviews and a literature review, a combination of ranking and scoring techniques was applied to assess institutional incentives and constraints for adaptation measures, together indicating the institutional feasibility of implementation of adaptation measures. From an institutional perspective, heterogeneity of actor's interests and availability of resources appeared to be the most constraining crucial institutional preconditions (CIPs) for adaptation measures to be implemented against risks associated with climate change in Flevoland. Based on the institutional feasibility analysis, the implementation of water management and improvement of irrigation facilities was found to potentially face fewer institutional constraints compared to the other adaptation measures assessed in Chapter 5. The presented approach proved applicable for institutional analyses of adaptation measures for current and future climate challenges at different levels of implementation, but more applications are needed to test its validity and robustness.

Overall, this thesis performed a prospective (using scenarios), multi-scale (taking into account crop, farm and regional level), integrated (notably multi-objective) and participatory assessment. The findings of the thesis allowed assessing plausible futures of agriculture in Flevoland around 2050 with insights in effective adaptation to climate change at different levels. Besides empirical findings, this thesis contributed methodologically to the portfolio of climate change impact and adaptation assessment. The following features have been elaborated in this thesis to better assess the context of farm level impact and adaptation: analysis of long term farm structural change, assessment of farmers' multiple objectives, assessment of contribution of crop and farm level adaptation measures to improvement of farm performance on important objectives, and an analysis on institutional feasibility of implementation of adaptation measures.

Samenvatting

Klimaatverandering is de afgelopen decennia een belangrijk maatschappelijk thema geworden. Wereldwijd zijn effecten van klimaatverandering op de productiviteit van gewassen, het inkomen van boeren en het landgebruik reeds zichtbaar geworden. Ook voor de toekomst van de landbouw in Nederland moet men rekening houden met deze problematiek. Om de negatieve effecten te voorkomen en om te profiteren van de mogelijkheden die klimaatverandering biedt, moet de agrarische sector aan adaptatiemaatregelen werken. Literatuuronderzoek laat zien dat de meeste recente studies gericht zijn op aanpassingen op veld- en gewasniveau. Adaptatie kan echter op verschillende schalen gebeuren, en feitelijke beslissingen in de landbouw worden uiteindelijk op bedrijfsniveau genomen. Effecten en adaptatie moeten daarom ook op bedrijfsniveau worden beoordeeld, en de variatie aan bedrijfstypen moet daarbij een rol spelen. Bovendien is adaptatie aan klimaatverandering ingebed in een bredere maatschappelijke context, en daarom wordt het door vele factoren beïnvloed.

Tegen deze achtergrond was de algemene doelstelling van dit proefschrift om de toetsing van de effecten van klimaatverandering op landbouwsystemen en adaptatie aan klimaatverandering van landbouwsystemen te verbeteren, door te focussen op het niveau van bedrijven en hun context. Dit proefschrift is een interdisciplinair onderzoek dat niet alleen adaptatie van landbouwsystemen aan klimaatverandering bestudeert, maar ook de context (markt, technologie, beleid, institutionele omgeving) waarin deze adaptatie plaatsvindt. De methoden die ontworpen zijn in dit proefschrift beogen generiek en niet case specifiek te zijn. De methoden werden geïllustreerd en toegepast voor de Nederlandse provincie Flevoland, met grootschalige en intensieve akkerbouw als de belangrijkste landbouwactiviteit.

In de toekomst zullen naast klimaatverandering andere belangrijke factoren (d.w.z. markt, technologie en beleid) de landbouwsystemen beïnvloeden. Gestuurd door deze factoren, zullen huidige landbouwbedrijven in de tijd evolueren door structurele aanpassingen. In dit verband werd in hoofdstuk 2 de context van adaptatie aan toekomstige klimaatverandering voor de akkerbouwsystemen geanalyseerd. Dit werd gedaan door het beoordelen van de bijdrage van de verschillende factoren (markt, technologie, beleid en klimaat) aan bedrijfsstructurele aanpassingen. Scenarioveronderstellingen over veranderingen in deze factoren - uitgewerkt op mondiaal en Europees niveau - werden vertaald naar Flevoland, op regionaal en bedrijfstype niveau. Hierdoor konden de effecten van de factoren op bedrijfsstructurele aanpassingen naar 2050 geprojecteerd worden. De geschatte aanpassingen verschillen aanzienlijk tussen de twee scenario's: Mondiale Markt (A1) en Zorgzame Regio (B2). In het A1 scenario kan men in Flevoland rond 2050 grootschalige landbouwbedrijven verwachten die gespecialiseerd zijn in intensieve teelten. In het B2 scenario is er nog plaats voor kleinere bedrijven. In het algemeen wordt dit laatste scenario gekenmerkt door een hogere diversiteit binnen het agrarisch

landschap, met een focus op lokale gewassen en markten. Ook zal er meer ruimte zijn voor natuurbescherming en het bieden van alternatieve functies voor de samenleving. De analyse van de bedrijfsstructurele aanpassingen zorgt voor een juiste context voor het beoordelen van de effecten van en adaptatie aan klimaatverandering in Flevoland rond 2050 op gewas- en bedrijfsniveau.

Naast voornamelijk economische doelstellingen, hebben boeren ook andere doelstellingen die hun bedrijfsvoering beïnvloeden (bijvoorbeeld op gebied van sociale en milieuaspecten). Bedrijfsspecifieke adaptatiemaatregelen aan klimaatverandering moeten daarom rekening houden met verschillende doelstellingen van boerenbedrijven. In hoofdstuk 3 werd het belang van boerenbedrijfsdoelstellingen onderzocht op basis van i) wat boeren zeggen (via interviews), ii) wat boeren werkelijk doen (door het analyseren van de huidige bedrijfsprestatie) en iii) wat boeren willen (door middel van geselecteerde alternatieve bedrijfsplannen). De volgende doelstellingen werden in het onderzoek opgenomen: maximalisering van economische resultaat en van het gehalte aan organische stof in de bodem, en minimalisering van de variatie van economisch resultaat, werktijden en stikstofoverschot. Onder de zes bestudeerde akkerbouwbedrijven werden de door de boeren aangegeven voorkeuren in doelstellingen (wat boeren zeggen) vaak niet in de praktijk gerealiseerd (wat boeren doen). Adaptatievoorkeuren van de boeren (wat boeren willen) leken grotendeels op hun huidige bedrijfsprestaties (wat boeren doen), maar tegelijkertijd betroffen de adaptatievoorkeuren een stap in de richting van de aangegeven voorkeuren (wat boeren zeggen). De resultaten van hoofdstuk 3 suggereren bovendien dat boeren in de praktijk beslissingen nemen gericht op het maximaliseren van economisch resultaat, ofschoon ze in de regel meerdere doelstellingen hebben. Dit terwijl ze ook vinden dat het organische stofgehalte een belangrijke overweging in de strategische besluitvorming is, hetgeen gerelateerd kan worden aan een inkomen op lange termijn.

Hoofdstuk 4 bouwt verder op de bevindingen van hoofdstuk 3 voort en is gericht op de beoordeling van adaptatiemaatregelen tegen geleidelijke klimaatverandering en tegen een verhoogde frequentie van weerextremen in de toekomst, rekening houdend met meerdere doelstellingen van boeren. Eerst werden de effecten van de geleidelijke klimaatverandering en weerextremen op de bedrijfsprestaties beoordeeld in termen van de twee belangrijke doelstellingen uit hoofdstuk 3: maximalisatie van het economische resultaat en van de organische stof in de bodem. De effecten van weerextremen werden onderzocht voor hoogwaardige gewassen, namelijk poot- en consumptieaardappelen en zaaiuien. De resultaten voor de geselecteerde akkerbouwbedrijven in Flevoland suggereren dat geleidelijke klimaatverandering in 2050 de bedrijfsprestaties *verbetert* in termen van economisch resultaat. De mate van verbetering varieert per scenario en per bedrijf, afhankelijk van het gewaspatroon. Tegelijkertijd *compenseren* weerextremen (zoals een hittegolf in de zomer en warme winters) deze positieve effecten van een geleidelijke klimaatverandering weer en zorgen ze - in het meest extreme scenario – voor aanzienlijke opbrengstverliezen. Er werd aangenomen dat de balans van de organische stof in de bodem onder toekomstige klimaatverandering op gewasniveau onveranderd blijft, terwijl het op bedrijfsniveau zou kunnen worden beïnvloed door veranderingen in het gewaspatroon. Vervolgens werd het belang van adaptatiemaatregelen voor verbetering van de bedrijfsprestaties op beide niveaus geëvalueerd. Daarbij werden de verschillende doelstellingen van de boeren meegewogen, omdat prioritering van doelstellingen de voorkeur voor verschillende adaptatiemaatregelen op gewas- en bedrijfsniveau kunnen beïnvloeden. Als de belangrijkste doelstelling van de boer een verbetering van het economisch resultaat is, blijft de teelt van hoogwaardige gewassen de beste optie, hoewel adaptatiemaatregelen voor weerextremen moeten worden genomen. Adaptatiemaatregelen op gewasniveau kunnen de negatieve effecten van deze weerextremen grotendeels neutraliseren, maar verlies van een deel van de bruto winstmarge van de gewassen zal nog steeds optreden. Als de bedrijven naast het verbeteren van het economisch resultaat ook de organische stof in de bodem willen maximaliseren, is een verschuiving van gras en witlof naar wintertarwe een goede optie. Dit verbetert de balans van organische stof op het bedrijf, ofschoon er dan bij wintertarwe sprake is van een klein negatief effect op de bruto winstmarge. Een combinatie van aanpassingen op gewas- en bedrijfsniveau is dus nodig voor een verbetering van het bedrijfseconomisch resultaat en de organische stof balans.

Behalve op gewas- en bedrijfsniveau, moet aanpassing van landbouwsystemen aan klimaatverandering ook op regionaal niveau geanalyseerd worden. Op regionaal niveau is een gunstige institutionele omgeving (wet- en regelgeving, beleid, sociale netwerken) een belangrijke voorwaarde voor de uitvoering van adaptatiemaatregelen. In hoofdstuk 5 wordt een kader geschetst voor de beoordeling van institutionele randvoorwaarden die de uitvoering van adaptatiemaatregelen aan klimaatverandering vergemakkelijken. De ‘Procedure for Institutional Compatibility Assessment’ (PICA) werd aangepast ten behoeve van dit onderzoek. In deze benadering worden instituties gekarakteriseerd door een aantal ‘crucial institutional preconditions’ (CIPs) met daaraan gekoppelde indicatoren. CIPs verwijzen naar een aantal institutionele prikkels en belemmeringen voor de toepassing van adaptatiemaatregelen. Informatie uit workshops, interviews en literatuuronderzoek werd gebruikt om relevante institutionele prikkels en belemmeringen te toetsten op basis van een combinatie van scoren en rangschikken van de CIPs. Deze methode geeft een indicatie van de institutionele haalbaarheid van de implementatie van adaptatiemaatregelen. Vanuit dit perspectief blijken ‘de heterogeniteit van de belangen van betrokken actoren’ en ‘de beperkte beschikbaarheid van hulpbronnen’ de meest belemmerende CIPs. Op basis van deze analyse werd vastgesteld dat waterbeheer en verbetering van irrigatie op minder institutionele weerstand stuit dan andere adaptatiemaatregelen (relocatie van boerenbedrijven en ontwikkeling van nieuwe gewasrassen). PICA blijkt inderdaad goed toepasbaar voor institutionele analyse van adaptatiemaatregelen voor huidige en toekomstige klimaatrisico’s op verschillende niveaus. De methode zou echter in meer onderzoek toegepast moeten worden om deze nader te kunnen valideren en de robuustheid ervan aan te tonen.

Dit proefschrift beschrijft een toetsing van klimaatonderzoek voor landbouwsystemen die toekomstgericht is (op basis van scenario's), niveau-overstijgend (van gewas tot bedrijf tot regio), geïntegreerd (rekening houdend met meerdere bedrijfsdoelstellingen) en participatief (focusgroepen en workshops met boeren). De bevindingen in dit proefschrift maken het mogelijk om aannemelijke toekomstperspectieven voor de landbouw in Flevoland rond 2050 te schetsen, rekening houdend met klimaatverandering. Naast empirische bevindingen, levert dit proefschrift een bijdrage aan de ontwikkeling van methoden voor onderzoek naar effecten van en adaptatie aan klimaatverandering. De volgende methoden zijn uitgewerkt met als doel om de context van het landbouwbedrijf en de opties voor klimaatadaptatie beter te evalueren: (i) analyse van bedrijfsstructurele aanpassingen op de lange termijn, (ii) inachtneming van de verschillende doelstellingen van boeren, (iii) beoordeling van de bijdrage van adaptatiemaatregelen op gewas- en bedrijfsniveau aan de verbetering van de bedrijfsprestaties, en (iv) analyse van de institutionele haalbaarheid van adaptatiemaatregelen.

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About the author

Maryia Mandryk received academic training in geography at Belarusian State University, Minsk (2000-2005) and subsequently worked at Belarusian National Institute for Soil Science and Agrochemistry of the National Academy of Sciences. In 2008 she obtained her MSc degree in Environmental Sciences (Environmental Systems Analysis) at Wageningen university. After her internship at Alterra (WUR) with Centre Landscape Maryia worked for UNISCAPE – the European Network of Universities for the implementation of the European Landscape Convention. Maryia performed her PhD research on integrated assessment of adaptation to climate change in agriculture at Plant Production Systems group (Wageningen university) as a part of 'Scaling and Governance' strategic program and the AgriADAPT research project within the Dutch 'Climate changes Spatial Planning' program. Since 2013 Maryia has been working as researcher global environmental issues at PBL the Netherlands Environmental Assessment Agency. Maryia has been involved in the research projects Global Biodiversity Outlook-4, FOODSECURE and OpenNESS which focussed on the contribution of sectors to sustainable use and conservation of biodiversity, global food and nutrition security, and on operationalisation of natural capital and ecosystem services.

List of publications

Mandryk, M., Reidsma, P., Ittersum, M.K. van (2012) Scenarios of long-term farm structural change for application in climate change impact assessment
Landscape Ecology 27 (4). - p. 509 - 527.

Mandryk, M., Reidsma, P., Kanellopoulos, A., Groot, J.C.J., Ittersum, M.K. van (2014) The role of farmers' objectives in current farm practices and adaptation preferences: a case study in Flevoland, the Netherlands
Regional Environmental Change 14 (4). - p. 1463 - 1478.

Mandryk, M., Reidsma, P., Kartikasari, K., Ittersum, M.K. van, Arts, B.J.M. (2015) Institutional constraints for adaptive capacity to climate change in Flevoland's agriculture
Environmental Science & Policy 48 . - p. 147 - 162.

Reidsma, P., Wolf, J., Kanellopoulos, A., Schaap, B.F., **Mandryk, M.**, Verhagen, J., Ittersum, M.K. van (2015) Climate change impact and adaptation research requires integrated assessment and farming systems analysis: a case study in the Netherlands
Environmental Research Letters 10 (4).

PE&RC Training and Education Statement

With the training and education activities listed below the PhD candidate has complied with the requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities)

Review of literature (5.6 ECTS)

- Adaptation of arable farming systems to climate change and other future challenges; Scaling and Governance regular scientific meeting

Writing of project proposal (4 ECTS)

- Integrated assessment of adaptation of agricultural systems to climate change in the North of the Netherlands

Post-graduate courses (6.6 ECTS)

- Scaling and governance; WUR (2009)
- Introduction to bio-economic modelling: advanced bio-economic modelling; Mansholt Graduate School (2009)
- Agriculture and natural resources management: a multi-criteria approach; Mansholt Graduate School (2010)
- Introduction to R for statistical analysis; PE&RC (2010)

Deficiency, refresh, brush-up courses (3 ECTS)

- Quantitative analysis of land use systems; Qualus, WUR (2009)

Competence strengthening / skills courses (1.7 ECTS)

- PhD Competence assessment; WGS, WUR (2009)
- Scientific writing skills; CENTA, WUR (2012)

PE&RC Annual meetings, seminars and the PE&RC weekend (2.1 ECTS)

- PE&RC Weekend (2009)
- PE&RC Day (2010)
- PE&RC Weekend last years (2012)
- SENSE Day (2015)

Discussion groups / local seminars / other scientific meetings (5 ECTS)

- Maths and Stats discussion group (2009)
- Regular scientific meetings of Scaling and Governance project (2009-2010)
- Scaling and Governance discussion group (2010)
- WaCASA Meetings (2012-2013)
- Contested agronomy seminar (2013)

International symposia, workshops and conferences (6.6 ECTS)

- Integrated Assessment of Agriculture and Sustainable Development: setting the agenda for science and policy; Egmond aan Zee, the Netherlands (2009)
- Scaling and Governance conference; Wageningen, the Netherlands (2010)
- Final conference: climate changes special planning programme; Amersfoort, the Netherlands (2011)
- 12th Congress of the European Society of Agronomy; Helsinki, Finland (2012)

Supervision of MSc students

- A framework for assessment of institutional feasibility of climate adaptation: a case study on agriculture in Flevoland
- Assessment of differentiated farm performances of arable farms in Flevoland and in the Netherlands

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