Comparing bio-economic farm models: evaluating uncertainty of impacts of climate and socio-economic changes on arable farming in Flevoland (the Netherlands)

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Summary

Bio-economic farm models (BEFMs) can be used to assess the impact of climate change and associated socio-economic scenarios on farming systems and to evaluate different adaptation options. One of the BEFMs, Farm System SIMulator (FSSIM) was initially developed to generalize farm plan modeling and to be re-used for different bio-physical and socio-economic contexts. Two research projects – AgriAdapt and LIAISE – used FSSIM to assess the impact of climate change and associated socio-economic scenarios on arable farming in Flevoland in the Netherlands in 2050. In these two projects, FSSIM was linked to crop and market models and simulated farm plans under certain resource and policy constraints, where profit maximization was incorporated as underlying mechanism. Although AgriAdapt and LIAISE used FSSIM for arable farming in Flevoland for the same research aim, many factors were different: objective function, activities, farm types, data source, and constraints (we shall call these 'modelling frameworks' in this study), climate and socio-economic scenarios, and crop and market models that simulated the yield and price changes respectively. It has not been investigated so far how these differences affected the simulation results between AgriAdapt and LIAISE.

BEFMs are used to support decision making for policy makers or farmers. It is important not only to make projections for the future, but also to better understand uncertainties in simulated results in order to make decisions that are robust under a wide range of possible futures. Recently, much attention has been given to comparing crop and market models, but BEFMs have not been compared and their uncertainties have not been discussed much to date.

The aim of this research is to get insight in the uncertainty of the impact of climate change and associated socio-economic scenarios on arable farming in Flevoland as simulated by FSSIM; whether uncertainties come from modelling frameworks or uncertainties in linked models (crop and market models that provide yield and price changes for FSSIM). To this end, first, we compared the FSSIM input and output between AgriAdapt and LIAISE. Second, the yield and price changes of AgriAdapt were applied to LIAISE and *vice versa*, to assess the influences of uncertainties in yield and price changes and also to assess the influences of modelling frameworks on the farm plans and gross margins. Third, the resource constraints of FSSIM were altered to evaluate the influences of farm resources on FSSIM output.

Our results showed that the modelling framework of LIAISE allowed more changes in farm plans (more potato area) than AgriAdapt. The effects of modelling frameworks on simulated farm plans were larger (varying between +21.4 – +44.7% of Percentage Absolute Deviation; PAD[1]) than the effects of uncertainties in yield and price changes from linked crop and market models (varying between +1.1 – +13.8% of PAD). Regarding gross margins, changes against the base year were always more positive in the LIAISE modelling framework than in AgriAdapt (range between +17.3 – +141%); however, yield and price changes affected the gross margin changes in the opposite way – application of yield and price change of AgriAdapt were always more positive than that of LIAISE (range between +13.4 – +212%). Therefore, the impacts of modelling

[1] The percentage absolute deviation (PAD) is defined as the absolute deviation between original and altered simulation activity levels per unit of original simulation activity level:

$$PAD\ (\%) = \frac{100 \times \left(\sum_i |x_i \ - x_i^0|\right)}{\left(\sum_i x_i^0\right)}$$

framework on gross margins were balanced out by the impact of yield and price changes when original simulations were compared. In the AgriAdapt modelling framework, removing resource constraints had also effects on farm plans (2.3 – 89.4% of PAD) and gross margins (2.5 – 349.1%). In the LIAISE modelling framework, more rented land from dairy farms increased the area of profitable mono-crop, resulting in higher gross margins, although the magnitudes of effects were dependent on yield and price changes.

In general, we can conclude that for farm plans, the impact of modelling framework was larger than the impact of yield and price changes. For gross margin changes, the input of yield and price changes is at least as important.

This study revealed that uncertainties in farm plans in FSSIM are more dependent on modelling frameworks than on uncertainties in linked crop and market models. For further development of FSSIM, it is important to improve evaluation and incorporation of future changes in farm structure, resources, activities and objectives, because this can affect the prediction of the model.

Key words: Bio-economic farm models; Climate change; Decision support; Model uncertainty; Objective function

Abbreviations

AEnZ: AgriEnvironmental Zones

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

DEA: Data Envelopment Analysis

FADN: Farm Accounting Data Network

IPCC: the Intergovernmental Panel on Climate Change

KNMI: the Royal Dutch Meteorological Institute

LIAISE: Linking Impact Assessment Instruments to Sustainability Expertise

PAD: Percentage Absolute Deviation

PMP: Positive Mathematical Programming

SEAMLESS: the integrated modelling framework of the System for Environmental and Agricultural Modelling: Linking European Science and Society

SRES: the Special Report on Emissions Scenarios

WLO: *Welvaart en Leefomgeving* in Dutch. 'Prosperity, wellbeing and quality of the living environment'

<Models>

BEFMs: Bio-economic farm models

CAPRI: Common Agricultural Policy Regionalized Impact modelling system

FSSIM: Farm System SIMulator

SIMPLACE: Scientific Impact assessment and Modelling PLatform for Advanced Crop and Ecosystem management

WOFOST: WOrld FOod STudies

<Sub-scenarios>

BS: Base year
C: Climate (Yield) change
CT: Climate and Technology change
CP: Climate and Market/Policy change
CTP: Climate, Technology and Market/Policy change

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1. Introduction

The increasing world population demands more agricultural production. Yields might be affected by climate change, and therefore many studies analyzed the impact of climate change on crop yields (Parry et al., 1999; Lobell et al., 2008; Ray et al., 2013; Challinor et al., 2014). However, crop yields are also affected by technological developments (Ewert et al., 2005), while farm performance is also affected by the market situation and agro-environmental policy (O'Brien and Leichenko, 2000; Van Ittersum et al., 2008; Schneider et al., 2011; Reidsma et al., 2015). In order to consider the integrated impacts of changes in climate, markets, technology, and policies, studies were conducted by using integrated scenarios including climate and economic changes (Parry et al., 2004; Abildtrup et al., 2006; Westhoek et al., 2006; Riedijk et al., 2007). However, the focus has been mainly at regional level, while much of the adaptation of agricultural practice to climate and socio-economic changes is determined by decisions at farm level (Easterling et al., 2007; Reidsma et al., 2009; Reidsma et al., 2010; Wheeler and von Braun, 2013). Bio-economic farm models (BEFMs) are potentially suitable to assess the integrated impact of climate and socio-economic changes on agriculture. A BEFM is defined as "a model that links formulations describing farmers' resource management decisions to formulations that represent current and alternative production possibilities in terms of required inputs to achieve certain outputs, both yield and environmental effects" (Janssen and van Ittersum, 2007). Many research projects were conducted by using BEFMs; however, the transferability of BEFMs is low because BEFMs are usually specific for a location or a farm type and the model settings are different from each other (Janssen and van Ittersum, 2007). One of the BEFMs, Farm System SIMulator (FSSIM) was therefore developed to generalize the farm plan modeling and to be re-used for different bio-physical and socio-economic contexts (Janssen et al., 2010; Louhichi et al., 2010).

Two research projects – AgriAdapt (Kanellopoulos et al., 2014) and LIAISE (Wolf et al., 2015 submitted) focused on evaluating the effects of climate change in arable farming in Flevoland, a province in the Netherlands. Both projects used FSSIM to simulate farmer's decision making, and both were linked with crop and market models that simulate yield and price changes under the certain scenarios. Flevoland is located in the north of the Netherlands and was reclaimed from the sea. Farmers in this area achieve high yields that are very close to the potential yield (Wolf et al., 2012; Reidsma et al., 2015). FSSIM was used for both studies to assess the impact of climate change and associated socio-economic scenarios on arable farming in Flevoland in 2050. In these two studies, FSSIM produced farm plans under certain resource and policy constraints, where profit maximization was incorporated as main objective. Although AgriAdapt and LIAISE used FSSIM for arable farming in Flevoland for the same research aim, many factors were different: modelling frameworks (objective function, activities, farm types, data source, and constraints), climate and socio-economic scenarios, and linked crop and market models that simulated the yield and price changes respectively. It has not been investigated so far how these differences affected the simulation results between AgriAdapt and LIAISE.

When a model is utilized for decision support, it is important to estimate the uncertainty of the outcomes (Uusitalo et al., 2015). Uncertainty was classified into six classes (inherent randomness, measurement error, systematic error, natural variation, model uncertainty, and subjective judgement) by Regan et al. (2002). Model uncertainty comes from uncertainty of the model parameters and/or uncertainty about the model's structure. Uncertainty of the model parameters can be considered by the range of possible values and their probabilities, while uncertainty about the model's structure (i.e. the relationship between cause and effect) is very difficult to quantify (Regan et al., 2002). One method to assess the structural uncertainty is to use multiple models developed to describe the same domain (Uusitalo et al., 2015).

While crop and market models are being considered to assess uncertainty, little attention has been given to assessing uncertainty of BEFMs to date. For crop models, simulated crop yields are inherently uncertain, firstly because of uncertainty in climate change scenarios (Moss et al., 2010). Uncertainty also arises from the crop model that is used and therefore multi-crop-model comparisons are performed (e.g. Asseng et al., 2013). Regarding market models, model inter-comparisons have also been performed (Rosenzweig et al., 2013; Nelson et al., 2014). Regarding BEFMs, recently uncertainties in specific BEFMs were examined (Troost and Berger, 2014; Holzkämper et al., 2015), but multi-model comparisons have not been performed.

Because AgriAdapt and LIAISE utilized one of the BEFMs, i.e. FSSIM, to assess the impact of climate change and associated socio-economic scenarios on arable farming in Flevoland in the Netherlands, and because these two studies were independently developed related to the structure of FSSIM, we can compare these two models and evaluate the uncertainty in the specification of FSSIM and its results. The aim of this research is to get insight in the uncertainty of the impact of climate change and associated socio-economic scenarios on arable farming in Flevoland as simulated by FSSIM. Research questions are: (1) What are the effects of uncertainties in the input from crop and market models on farm plans and gross margins? (2) What are the effects of uncertainties in the model's structure – how do the different modeling frameworks affect the farm plans and gross margins? (3) What are the effects of uncertainties in model parameters, i.e. assumptions regarding resource constraints (4) Considered together, what are plausible futures for arable farming in Flevoland in 2050? To this end, first, we compared the FSSIM inputs and outputs between AgriAdapt and LIAISE. Second, the yield and price changes of AgriAdapt were applied to LIAISE and *vice versa*, to assess the influences of uncertainties in yield and price changes and also to assess the influences of modelling frameworks on the farm plans and gross margins. Third, the resource constraints of FSSIM were altered to evaluate the influences of farm resources on FSSIM output. Finally, all uncertainties were evaluated to assess the robustness of predicted futures, and to conclude on plausible futures for arable farming in Flevoland.

2. Methods

The AgriAdapt and LIAISE projects both used FSSIM (Farm System SIMulator) to assess impacts of climate and socio-economic changes on farm performance towards 2050. AgriAdapt was a project that aimed to assess the adaptive capacity of agriculture in the Netherlands to the impacts of climate change under different market and policy scenarios (Kanellopoulos et al., 2014; Reidsma et al., 2015). LIAISE was a project aiming to link impact assessment instruments to sustainability expertise in Europe, and one of the studies within this project had similar aims as AgriAdapt (Wolf et al., 2015). Both projects included Flevoland in the Netherlands as a case study, and therefore we compared the AgriAdapt and LIAISE studies for this region.

FSSIM is a generic bio-economic farm model that has been developed to assess, ex-ante, the economic, environmental and social impacts of policies, technological innovations, price and climate change on farms across the EU (Janssen et al., 2010; Louhichi et al., 2010; Kanellopoulos et al. 2014). FSSIM simulates farm plans and gross margins by choosing a combination of agricultural activities, which maximize profit (objective) subject to several constraints (Fig. 1). Agricultural activities are whole-farm activities (all input and output data per farm; e.g., sugar beet 10 ha + potato 20 ha + soft wheat 10 ha, costs 150k€/farm, labour 5khours/farm) for AgriAdapt and crop rotations (e.g., sugar beet 1/4 + potato 2/4 + soft wheat 1/4, costs and labour use are calculated for each crop) for LIAISE. Represented farms (or farm types) choose activities. Farm related input data can be based on quantitative data sources or surveys among experts (details to be mentioned later). To calculate the profit, yield and price data are needed. FSSIM is linked with crop and market models that simulate yield and prices in 2050, which are under the influence of climate and associated socio-economic scenarios and several assumptions. Results of FSSIM further depend on the "modelling-framework", including the specification of objectives, activities, farm types, data sources, and constraints. The AgriAdapt and LIAISE projects both used FSSIM to assess impacts of climate and socio-economic changes on farm performance towards 2050, but there were many differences, and thus simulated results were also different. Differences included the modelling frameworks, the adopted climate and socio-economic scenarios, the linked crop model used to project crop yield changes, and the version of the market model used to project price changes.

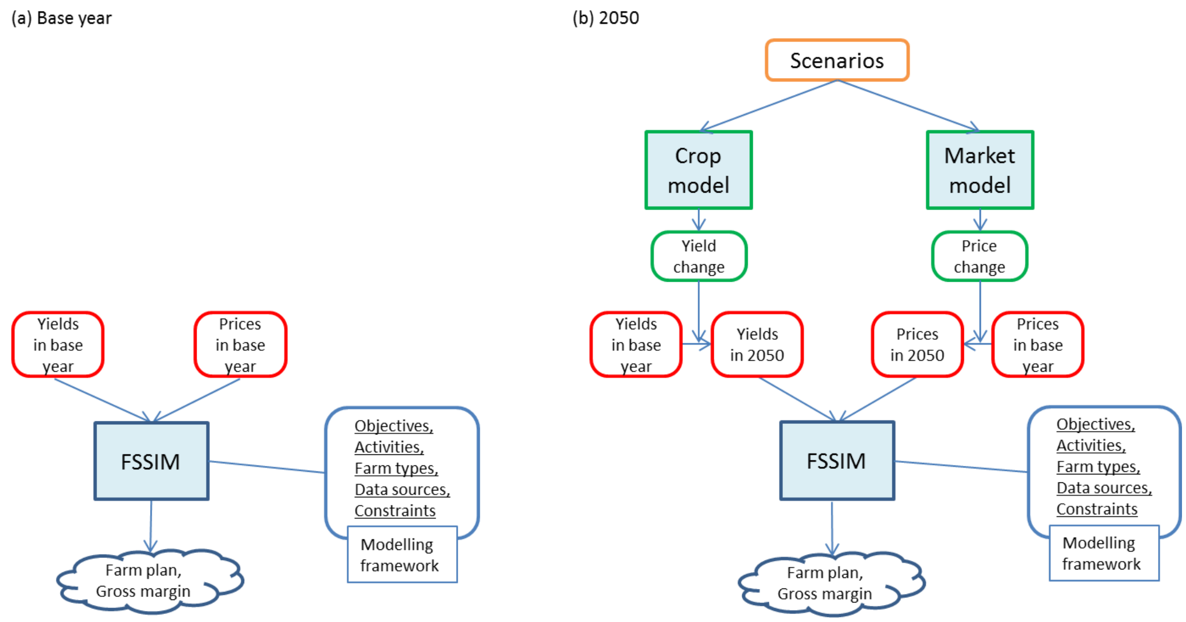


Fig. 1. Schematic presentation of FSSIM and linked crop and market models in the base year and 2050.

2 - 1. Climate and socioeconomic scenarios for 2050

2 - 1 - 1. Integrated scenarios of climate and socio-economic changes

AgriAdapt used the Dutch Climate Scenarios (W, W^+, G and G^+) that have been published by the Royal Dutch Meteorological Institute (KNMI) in 2006 (Van den Hurk et al., 2006). "G" means the Dutch word "Gematigd" (= moderate) and "W" is taken from "Warm". "+" indicates strong change of air circulation resulting in less precipitation in summer. These climate scenarios include temperature, precipitation, potential evaporation and wind for 2050, and sea level rise for 2050 and 2100.

The climate scenarios of the KNMI were linked with the socio-economic scenarios developed by the study 'Prosperity, wellbeing and quality of the living environment' (*Welvaart en Leefomgeving* in Dutch) (WLO; Riedijk et al., 2007) using the Special Report on Emission Scenarios (SRES-scenarios) of the Intergovernmental Panel on Climate Change (IPCC). While SRES-scenarios directly base climate change scenarios on socio-economic scenarios, KNMI climate change scenarios were based on model ensembles representing similar climate change patterns. Riedijk et al. (2007) suggested linking the climate scenarios G and G^+ to the socio-economic scenario Regional Communities (RC) of the SRES B2 family. This scenario represents intermediate levels of economic development causing a moderate increment of CO_2 resulting in a moderate increase in temperature. The climate scenarios W and W^+ were connected to the socio-economic scenario Global Economy (GE) of the SRES A1 family. In this scenario very rapid economic growth produces more CO_2 resulting in a higher temperature increase (Riedijk et al., 2007). AgriAdapt simulated the combined scenarios B2G (G + RC), B2G^+ (G^+ + RC), A1W (W + GE) and A1W^+ (W^+ + GE) (Kanellopoulos et al., 2014).

LIAISE did not use the Dutch climate scenarios, but the socio-economic and climate scenarios by IPCC (2007), with the concentration of atmospheric CO_2 set based on IPCC (2001) (IPCC, 2007). Three different scenarios were analyzed; a base line (B1) scenario for 2050, strong (A1-b1) and weak (B2) economic growth scenarios.

2 - 1 - 2. Crop and market models

FSSIM was linked with crop and market models. Yield changes were calculated by the crop model WOFOST in AgriAdapt and SIMPLACE in LIAISE. SIMPLACE in LIAISE considered nitrogen and water limitation, while WOFOST in AgriAdapt did not consider these limitations.

Expected price changes were estimated with a market model CAPRI (Common Agricultural Policy Regionalized Impact) in both studies, but by different versions. The CAPRI version of AgriAdapt (Ewert et al., 2011) had not taken into account that price elasticities in developing countries would decrease when income would go up. The projected price changes related to the B1 scenario, which was considered as the baseline in CAPRI. LIAISE used the upgraded version of CAPRI (Wolf et al., 2015). The price elasticities in developing countries were assumed to get closer to the ones in developed countries. Further, projected price changes were directly related to the base period, and therefore price changes were corrected for inflation before using them in FSSIM.

These relative changes in yields and prices were accordingly used for calculation of yields and prices as input for FSSIM. In AgriAdapt, it was assumed that only the top 25% of the yields would be influenced by climate, as lower yields were limited by other conditions. In LIAISE, yields of all activities increased.

2 - 1 - 3. FSSIM sub-scenarios

FSSIM simulations were conducted for the following sub-scenarios:
BS: base year
C: Climate (yield) change
CT: Climate and Technology changes
CP: Climate and Market/Policy changes
CTP: Climate, Technology and Market/Policy changes

C considered yield change because of the climate change. CT included yield increase by technological change that improves crop varieties and management. CP considered market (price) and policy changes in addition to the yield change by climate change. Price changes were calculated by the market model and policy changes were based on assumptions (will be described in detail later). CTP included all of these; yield change by climate change and technological improvement, and market and policy change.

2 - 2. Modelling frameworks

2 - 2 - 1. AgriAdapt

The objective function of FSSIM in AgriAdapt is profit maximization.

$$max\ \{z = r'x - c'x\}, \qquad s.t.\ Ax \leq b\ \ [\pi], \qquad e'x = 1, \qquad x \geq 0, \tag{1}$$

where z is the objective value (total gross margin) of a certain farm (or farm type); x is an n×1 vector of whole-farm activities; r is the n×1 vector of activity revenues; c is the n×1 vector of variable costs; A is the m×n matrix of the coefficients; b is the m×1 vector of upper bounds of the resource and policy constraints; π is the m×1 vector of shadow prices of the resource and policy constraints; and e is an n×1 vector of ones.

In FSSIM, for 75 representative farms, which represent 12 to 104 farms each (2770 farms in total), the value of z (gross margin) was maximized by combining whole-farm activities.

The whole farm activities, which include all inputs and outputs for each whole-farm, were based on representative farms observed in the Farm Accountancy Data Network (FADN) and were processed by Data Envelopment Analysis (DEA). DEA produced the technical efficient farm practices; being technically efficient implies that a farm cannot increase yields more without additional input or cannot decrease input without reducing yields. After the DEA procedure, 64 activities out of 75 were used for the base year simulation (Kanellopoulos et al., 2014). For the simulation in 2050, only for the upper quartile of 75 activities for each crop yield were increased. It was assumed that yields in this quartile were limited by climate, while others cannot increase yields due to limiting factors related to management. After that, all 75 activities were processed by DEA. Because farms can choose also the activities used in the base year simulation, in total 111 activities were used for simulation in 2050.

Profit maximization by FSSIM was subject to several constraints. The total utilized agricultural area constraint restricts area to less than the observed level. The hired labour constraint limits the hired labour to less than the observed level. The capital constraint sets an available capital level at the same value as in the base year. The sugar beet quota constraint restricts sugar beet production as the observed activity level. Livestock, other arable output and other output constraints restrict the level of these outputs to less than the observed levels. Observed levels for each constraint were based on FADN data (2001-2006).

Constraint $e'x = 1$ ensures that farms select a linear combination of activities (e.g. farm A chooses activity A 20% + activity B 40% + activity C 40% = 100%).

AgriAdapt assumed that technology change increased yields by 10% in B2G$^{(+)}$ and by 30% in A1W$^{(+)}$ (CT, CTP). These yield changes by technological improvement were only applied to activities that ranked in the upper quartile of productivity (ton per ha) per crop. Abolishment of sugar beet quota policies and subsidies were included in A1W$^{(+)}$ but not in B2G$^{(+)}$ (CP, CTP).

2 - 2 - 2. LIAISE

The objective function of LIAISE includes a quadratic cost function. A Positive Mathematical Programming (PMP) term is incorporated in order to calibrate crop areas to observations in the base year simulation. Thus, FSSIM of LIAISE is a PMP model (calibrate to observed activity levels), although the first step is profit maximization (normative model).

$$max\ \{z = r'X - k'X - 0.5X'QX\}, \qquad s.t. \quad AX \le b \quad [\pi], \qquad X \ge 0, \tag{2}$$

where z is the objective value (total gross margin) of a certain farm type; X is an $n \times 1$ vector of production activities; r is the nx1 vector of activity revenues; k is the $n \times 1$ vector of parameters associated with the linear term of variable costs; Q is the symmetric $n \times n$ positive semi-definite matrix of parameters associated with the quadratic terms of the cost; A is the $m \times n$ matrix of the coefficients; b is the $m \times 1$ vector of upper bounds of the resource and policy constraints.

In LIAISE, the resulting total gross margin is shown by $z = r'X - k'X$. This means that the quadratic term is excluded, as this term represents unobserved costs. Activities were crop rotations per soil type based on FADN data (2003-2005). Mono-crop activities (e.g. produce only potato every year) were added and allowed only for rented lands, because rented lands were assumed to be from dairy farms, therefore, farms do not need to consider crop rotations. Without mono-crop activities, FSSIM could not reproduce the observed farm plans in the base year. The profit maximization including PMP calibration was conducted for two farm types that were based on the SEAMLESS (the integrated modelling framework of the System for Environmental and Agricultural Modelling: Linking European Science and Society) database (Van Ittersum et al., 2008).

Yields per soil type, required inputs and prices of products were collected by local experts, and available resource endowments per farm type were defined by FADN data.

Area constraints restrict the cultivated area per soil type to less than the observed area per soil type. The family labour constraint limits the family labour to the observed family labour level. The rented land constraint sets the mono-crop area to less than the rented land area. Because farms rent land from dairy farms, farms do not need to consider crop rotation constraints on rented land. For own land, farms have to rotate several crops every year to prevent soil diseases. The set aside constraint sets the lower bound for fallow area. The sugar beet quota constraint limits sugar beet production area to less than the observed area, because it is assumed that farms produce sugar beet only when the production price is guaranteed.

Technological improvements increasing yields were based on extrapolating historical yield trends to 2050 (Ewert et al., 2005; Angulo et al., 2013; Wolf et al., 2015) (CT, CTP). These yield changes were applied to all activities. Set-aside and sugar quota policies were abolished by policy changes for both of B2 and A1-b1 (CP, CTP).

Table 1 shows the overall modelling frameworks, scenarios, crop and market models for AgriAdapt and LIAISE.

Table 1. The differences between the two studies assessing the impact of climate and socio-economic changes on arable farming in Flevoland.

	AgriAdapt	LIAISE
Modelling framework		
Objectives	Profit maximization	Profit maximization + PMP
Activities	Whole-farms (FADN) processed by DEA No mono-crop activity	Crop rotations from SEAMLESS Mono-crop activity is allowed for rented land
Farm type	75 individual farms from FADN (2001-2006)	Two farm types from SEAMLESS (Van Ittersum et al., 2008)
Data source	FADN (2001-2006). Product prices in base year were from SEAMESS.	FADN (2003-2005) + Survey among experts (Zander et al., 2009). Product prices in base year were collected by local experts.
Constraints	FADN (2001-2006)	FADN (2003-2005), SEAMLESS
Scenarios	B2G, B2G$^+$, A1W, A1W$^+$	B1, A1-b1, B2
Crop growth model	WOFOST	SIMPLACE
Climate scenarios	KNMI (G, G+, W, W+)	IPCC (2007) (SRES B1, SRES A1B, SRES B2)
Weather data	KNMI, Lelystad	SEAMLESS database
Nitrogen limitation	-	CAPRI database
Water limitation	-	Global irrigation map
Market model	CAPRI of AgriAdapt	CAPRI of LIAISE (upgraded)
socio-economic scenario	WLO (RC≈B2, GE≈A1)	IPCC (2007) (SRES B1, SRES A1B, SRES B2)
Technology	10% in B2G$^{(+)}$ and by 30% in A1W$^{(+)}$	Extrapolating historical yield trends (Ewert et al., 2005)
Yields changes	Only for the activities that ranked in the upper quartile of productivity for each crop	For all activities
Policies	Abolishment of subsidies and sugar beet quota policy in A1W$^{(+)}$.	Abolishment of subsidies and sugar beet quota policy in B2 and A1-b1.

2 - 3. Comparing scenarios, input and output for FSSIM

The differences in scenarios, inputs (yields and prices) and outputs between FSSIM as used in AgriAdapt and LIAISE were compared, to investigate the differences between scenarios and inputs, and to assess the influence of inputs on outputs. Input data were extracted from an Access file of FSSIM for both studies. Yields and price changes were expressed by the relative change against the base year in order to compare the influences of crop growth and market models. Absolute values of yields and prices for each crop were also compared because these were the input data for FSSIM. For AgriAdapt, yields per activity were shown by box plot. For LIAISE, because yields were different depending on soil types (Supplementary table 2), weighted average (soil types and farm types) of yields were shown (Fig. 4).

Output data were available after running FSSIM with the original setup. Observations in the base year were compared with FSSIM outputs, because the profit maximization of FSSIM produced different outputs compared to observations. For the simulation in 2050, the comparison focused on farm plans and gross margins, because the farm plans were the basic results of farmers' decision-making and gross margin was the main indicator of farm performance and therefore impact of changes.

Farm plans were indicated by area share (%) for each crop, as land areas (ha per farm) differed between AgriAdapt and LIAISE. In order to quantify the farm area change, the Percentage Absolute Deviation (PAD, %) was used as described previously by Kanellopoulos et al (2010).

$$PAD\ (\%) = \frac{100 \times \left(\sum_i |x_i \ - x_i^0|\right)}{(\sum_i x_i^0)} \qquad (3)$$

where, x_i is the area share per crop, and x_i^0 is that of the reference. Also the gross margins in 2050 were shown by the relative change against the base year because the gross margins in the base year were very different between AgriAdapt and LIAISE.

In LIAISE, to investigate the reason why FSSIM allocated more area to some specific crops, the gross margin per crop (euro per ha) was calculated by the following formula:

$$Gross\ margin = Sales + Subsidy - \sum_i (Cost\ of\ activity_i * \ Level\ of\ activity_i) \qquad (4)$$
$$Sales = \sum_i (Yield\ of\ activity_i * \ Level\ of\ activity_i) * Price$$

Subsidies and prices were taken from input data. " Yield * Activity levels" and costs were taken from results of FSSIM. For these calculations for each crop, costs did not include the rented land nor labour cost. For AgriAdapt, it was impossible to calculate gross margin per crop, because data for cost and subsidy per crop were not available.

2 - 4. Assessing the effects of different crop and market models

To assess the effects of different crop and market models on FSSIM output, yields and price changes in AgriAdapt were applied to the input data in LIAISE, and *vice versa.*

In general, this was straightforward, but two calculations needed to be made. Firstly, yields and price changes of 'other arable crops' in AgriAdapt were calculated by the average of expected changes of spring barley and tulips in LIAISE. Secondly, for AgriAdapt, increase of fertilizer application was calculated as presented below (Kanellopoulos et al., 2014):

*increase of fertilizer application = (yields increment) * fer50* (5)
fer50 = ((current fertilizer application)/ (current yields))(1+ (yield increase)/0.8)*

where *yields increment = yields increment (ton) per ha*
fer50 = fertilizer application rate ((fertilizer application)/ (yields)) in 2050
yield increase = (relative change of the yield) – 1

The data of current fertilizer application and current yields were taken from SEAMLESS crop management data (Borkowski et al., 2007; Zander et al., 2010). The value of 0.8 was used here because AgriAdapt assumed that "20% of the actual crop nutrient uptake is supplied by the soil, the actual fertilizer nutrient application is related to 80% of the actual yield".

To evaluate the influence of different yield and price changes, farm plans and gross margins were compared. To compare the effects of climate and technology changes (CT) with additional price changes (P), scatter plots were presented.

2 - 5. Assessing the effects of constraints

Evaluating the impact of differences in model set up, scenarios and inputs between two modelling studies can give an indication of the robustness of the impacts of climate and socio-economic change on farm performance. However, also specific assumptions within a modelling study can largely influence results, and therefore it is interesting to evaluate these. Because resource constraints were different between AgriAdapt and LIAISE (Table 2), performing sensitivity analyses on the same constraints was not possible. Therefore the effects of constraints were examined separately.

Table 2. Constraint differences between AgriAdapt and LIAISE. "+" means included and "–" means not included.

	AgriAdapt		LIAISE	
	Indicator	Constraint	Indicator	Constraint
Rented land	–	–	+	+
Mono crop	–	–	+	+ (Rented land)
Hired labour	+	+	+	–
Capital	+	+	–	–
Livestock	+	+	–	–
Other arable output	+	+	–	–
Other output	+	+	–	–

For AgriAdapt, to assess the effects of resource constrains, some constraints were changed or removed in the base year simulation. The constraint of total utilized agricultural area (E_TUAA) limits the area to less than base year available land. To see the effects of E_TUAA on the FSSIM results, E_TUAA was removed, or altered to restrict the area to the same as the base year observation. Likewise, the constraints of hired labour (E_HLABR) and capital (E_CAPITAL) were removed, and the constraints of livestock output (E_LIVOUT), other arable output (E_OAROUT) and other output (E_OTHOUT). In addition, to understand the effects of the constraints on the simulation output in 2050, some constraints were removed for FSSIM simulation in 2050; E_TUAA and/or E_HLABR & E_CAPITAL. Differences compared to simulation output with original setting of constraints in farm plans were represented by the Percentage Absolute Deviation (PAD, %), and in gross margins by the % difference.

For LIAISE, restriction on rented land was included in the model. Because mono-crop activities were allowed only for the rented land, we expected more profit with more rented land due to mono-crop activities with high-profit crops. To see the effects of the rented land, the resource of rented land was changed. The original values of the rented land were increased or decreased by 25% for each farm type. Because the model showed infeasible solutions under the smaller value of the rented land (this might be because FSSIM could not produce base year farm plans without mono-crop activities), the simulations were conducted only for feasible solutions (> 26.2 ha (-3%) for FT3203, > 14.1 ha (-56%) for FT3303). Differences in farm plans were compared to the base year simulation output by the Percentage Absolute Deviation (PAD, %), and gross margins were compared based on the % difference.

2 - 6. Assessing the effects of Positive Mathematical Programming (PMP) in LIAISE

In the PMP term used in LIAISE, α is a parameter that determines the weights of the linear and the non-linear costs of the activities in the objective function. This parameter is responsible for elasticity of model predictions; the larger the value of α the larger the quadratic term of the objective function which results in less "jumpy" behavior of the model. As shown in Kanellopoulos et al. (2010), α influences the forecasting performance of the model. α can be calibrated in an ex-post experiment, but as this is often not possible, the standard value of 1 is generally used. In LIAISE, the value of 1 was used for α, which enabled the model to produce results in a flexible way. Nevertheless, the value of α can largely influence results (Kanellopoulos et al., 2010), and therefore we evaluated the influence of this parameter.

To assess the effects of the value of α in PMP, different values of α (= 0.25, 0.50, 0.75, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 20, 30, 40, 50) were tried for FSSIM simulation in LIAISE. The results were shown by the Percentage Absolute Deviation (PAD, %) compared to AgriAdapt, and also the area share change against the base year.

3. Results

3 - 1. Input output comparison between AgriAdapt and LIAISE

3 - 1- 1. Farm types

Farm data from the Farm Accounting Data Network (FADN) were used in both AgriAdapt and LIAISE. In AgriAdapt, 2770 observed farms were represented by 75 individual observed farms in the base year (Kanellopoulos et al., 2014). In LIAISE, the SEAMLESS farm typology was adopted, where there were only two farm types: F532030910_NL23 (FT3203) and F533030910_NL23 (FT3303). Four digits codes were used for farm typology. The second digit refers to the farm intensity: (2) Medium intensity (500 €/ha ≤ output ≤ 3000 €/ha), (3) High intensity (output > 3000 €/ha).

The frequency and cumulative distribution of total available land per farm were different between AgriAdapt and LIAISE (Fig. 2). The mode was much lower in AgriAdapt than in LIAISE (i.e. 22 vs 62.7 ha). Nevertheless the weighted averages of total available land were 49.3 ha for AgriAdapt and 60.7 ha for LIAISE. This is because a few farms have a much larger area in AgriAdapt. The two farm types in LIAISE have 62.7 ha and 59.4 ha, for FT3203and FT3303 respectively.

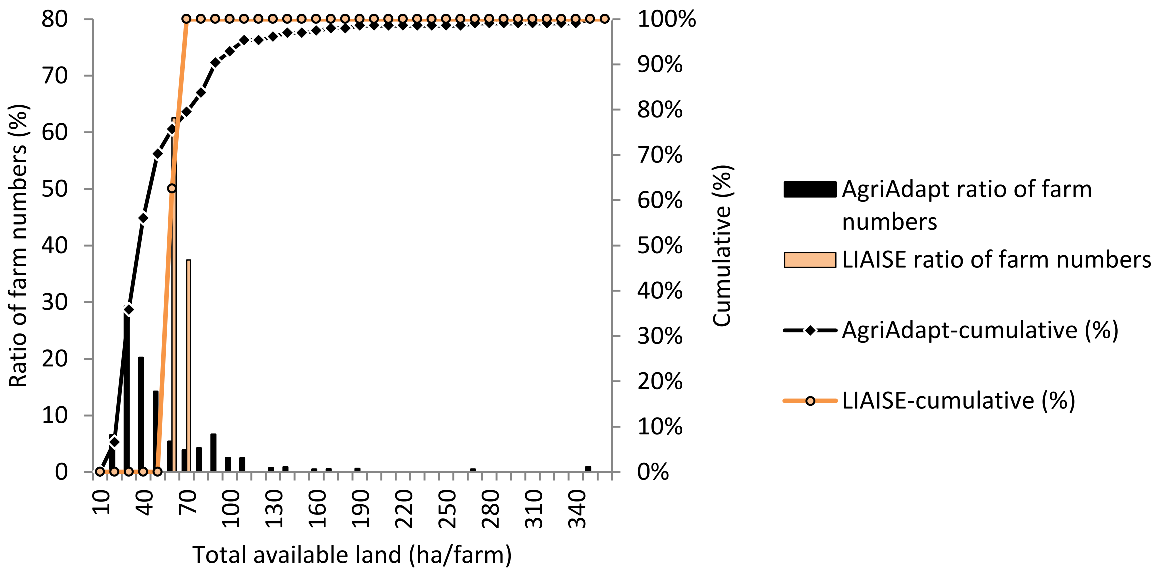


Fig. 2 The frequency distribution of total available land (ha) per farm in the base year in AgriAdapt and LIAISE. In AgriAdapt, 2770 observed farms were represented by 75 individual observed farms. In LIAISE, the average farms of two different farm types were used for simulation. Weighted average of farm area was 49.3 ha for AgriAdapt and 60.7 ha for LIAISE.

3 - 1- 2. Climate scenario

AgriAdapt and LIAISE adopted different climate scenarios (Table 3). The base year of climate scenarios was different among two studies; 2000 (1992-2008) for AgriAdapt and 2003-2005 for LIAISE. The base year temperature was assumed to be similar between the two studies; maximum annual temperature was 0.4°C lower in LIAISE, while minimum annual temperature was 0.4°C higher in LIAISE. While the annual precipitation was similar, the precipitation in summer in the base year of LIAISE was 14% less than that of AgriAdapt.

When comparing the climate scenarios used in both studies, it is clear that the KNMI'06 scenarios used in AgriAdapt captured a wide temperature range; from +0.9 in B2G to +2.6 in $A1W^+$, while for the IPCC scenarios used in LIAISE the range was from +1.4 in B1 to +1.8 in A1. This implies that for the B2 scenarios, temperature increases in AgriAdapt were smaller than LIAISE (with G^+ being closer than G) and for the A1 scenarios, temperature increases were larger than in LIAISE (with W being closer than W^+).

Regarding precipitation, the LIAISE scenarios only showed increases relative to the base year in annual precipitation, while AgriAdapt scenarios also projected decreases in the + scenarios. This is mainly due to the large reduction in summer precipitation. It should nevertheless be noted that summer precipitation was already lower in the base year in LIAISE.

AgriAdapt utilized CO_2 concentration data from IPCC (2001) as with LIAISE. However, CO2 concentration of $A1W^{(+)}$ in AgriAdapt was higher than that of A1-b1 in LIAISE.

Table 3. Climate scenarios in Flevoland in the Netherlands used in two studies.

		AgriAdapt (Kanellopoulos et al. 2014)					LIAISE (Wolf et al., 2015)		
Scenarios		B2G	B2G^{+}	A1W	A1W^{+}		B1	B2	A1-b1
	The Royal Dutch Meteorological institute (KNMI)						IPCC (2001, 2007)		
Climate change scenarios	Base year (2000; 1992-2008)	G	G^{+}	W	W^{+}	Base year (2003-2005)	BCCR_BCM 2_0/SRES B1	SRES B2 15-model ensemble mean	SRES A1B 15-model ensemble mean
Average annual maximum temperature (°C)	14.0	14.9	15.3	15.8	16.6	13.6	15.0	15.2	15.4
Temperature rise compared to base year (°C)		(0.9)	(1.3)	(1.8)	(2.6)		(1.4)	(1.6)	(1.8)
Average annual minimum temperature (°C)	6.1	7.0	7.4	7.9	8.7	6.5	7.8	8.1	8.2
Temperature rise compared to base year (°C)		(0.9)	(1.3)	(1.8)	(2.6)		(1.4)	(1.7)	(1.8)
Average maximum temperature in summer	21.6	22.6	23.1	23.5	24.5	21.4	22.3	23.0	23.1
Temperature rise compared to base year (°C)		(0.9)	(1.5)	(1.8)	(2.9)		(0.9)	(1.6)	(1.8)
Average minimum temperature in summer	11.8	12.8	13.3	13.7	14.7	12.3	13.3	13.9	14.1
Temperature rise compared to base year (°C)		(0.9)	(1.5)	(1.8)	(2.9)		(1.0)	(1.6)	(1.8)
Average annual precipitation (mm)	842.0	879.6	833.3	907.3	817.5	839.3	919.3	890.1	895.6
Precipitation rise compared to base year (%)		(4%)	(-1%)	(8%)	(-3%)		(10%)	(6%)	(7%)
Average summer precipitation (mm)	254.7	264.9	231.0	273.1	206.9	219.0	216.8	218.0	217.8
Precipitation rise compared to base year (%)		(4%)	(-9%)	(7%)	(-19%)		(-1%)	(0%)	(-1%)
CO_2 concentration (ppm)	369	478	478	567	567	369	488	478	532
Air circulation		Weak	Strong	Weak	Strong				
Socio-economic scenarios		Regional Communities (RC) associated with the SRES B2 family	Regional Communities (RC) associated with the SRES B2 family	Global Economy (GE) associated with the SRES A1 family	Global Economy (GE) associated with the SRES A1 family		BCCR_BCM 2_0/SRES B1	SRES B2 15-model ensemble mean	SRES A1B 15-model ensemble mean

3 - 1- 3. Yield and price changes

AgriAdapt and LIAISE used WOFOST and SIMPLACE respectively, to simulate the yield changes in 2050 compared to the base year. The market model CAPRI was used to simulate the price changes in 2050 for both studies, but the assumptions of CAPRI were different. Relative changes in yields, prices and sales are compared in Fig. 3. The multiplication of yield (ton per ha) change and price (euro per ton) change represents the sales (euro per ha) change (see also supplementary table 1). The xy =1 line shows the marginal line at which the sales (euro per ha) remain the same as in the base year.

Climate change (C) increased yields of all crops in all scenarios in AgriAdapt, whereas potato and vegetable yields could also slightly decrease in LIAISE. Yield changes due to C in the B2 scenario were higher in AgriAdapt compared to LIAISE, although LIAISE showed a higher temperature increase than AgriAdapt (the increment of CO_2 concentration was the same among both studies in the B2 scenario). Also the yield changes of A1W and A1W$^+$ in AgriAdapt were always higher than that of A1-b1 in LIAISE, although the temperature increase in the A1W scenario in AgriAdapt (1.8°C) was the same as that of the A1-b1 scenario in LIAISE (the CO_2 concentration was slightly higher in AgriAdapt (567 ppm) than in LIAISE (532 ppm) in the A1 scenario). The differences in temperature and CO_2 concentration changes between B2 and A1 were larger in AgriAdapt than in LIAISE, resulting in larger yield differences between B2 and A1 in AgriAdapt than in LIAISE, except for soft wheat. In AgriAdapt, the strong air circulation changes (+ scenario) resulted in lower yields than in scenarios with weak air circulation changes, except for sugar beet, where the yield was the same regardless of the air circulation.

The additional technological change always increased the yields in AgriAdapt and LIAISE. In AgriAdapt, the price change in CP (Climate and Market/Policy change) and CTP (Climate, Technology and Market/Policy change) were the same, while in LIAISE they were different. The sugar beet price decreased in CP and CTP in both studies, although the decrement was larger in LIAISE than in AgriAdapt. The potato price increased in CP and CTP in AgriAdapt, while the price increment in CP was canceled in CTP in LIAISE. The soft wheat price in AgriAdapt decreased in B2 while it increased in A1; however in LIAISE, the soft wheat price increased in CP in both B2 and A1, and this increment was diminished in CTP. The vegetable price showed the same pattern as the soft wheat price, except that the price change in CTP in B2 was negative in LIAISE. Sales (euro per ha) changes were generally positive, except for a few cases (AgriAdapt: sugar beet in B2 CP & CTP, soft wheat in B2 CP; LIAISE: sugar beet in B2 and A1 CP & CTP, potato in B2 C, vegetables in B2 CTP).

The crop and market model produced relative changes in yields and prices respectively (Fig. 3), which were used for calculation of yields and prices as input for FSSIM (Fig. 4). Because simulated farm plans (crop rotation, which is reflected by farm area allocation among crops) were based absolute values of yields and prices, we compared yields and prices between AgriAdapt and LIAISE (Fig. 4). In AgriAdapt, yields were different among activities. In LIAISE, yields were different among soil types (Supplementary table 2). As one soil type (AENZ12993) was dominant (more than 85%), we calculated the weighted average of yields for comparison (Fig. 4).

Overall, yields as input for FSSIM, both in the base year and in the 2050 scenarios, were similar for AgriAdapt and LIAISE. However, AgriAdapt assumed that only yields of high productive activities (ranked in the top 25%) would increase in 2050 whereas LIAISE assumed that yields of all activities would increase in 2050. This was because

AgriAdapt assumed that activities with lower yields were limited by management instead of climate, and to benefit from possible yield changes, adaptation of management (i.e. activity) was needed. The main differences in yields and prices were that the price of seed potato in LIAISE was much higher than the price of potato in AgriAdapt (including seed and ware potatoes), and that the abolishment of sugar beet quota policy affected prices more negatively in LIAISE than in AgriAdapt.

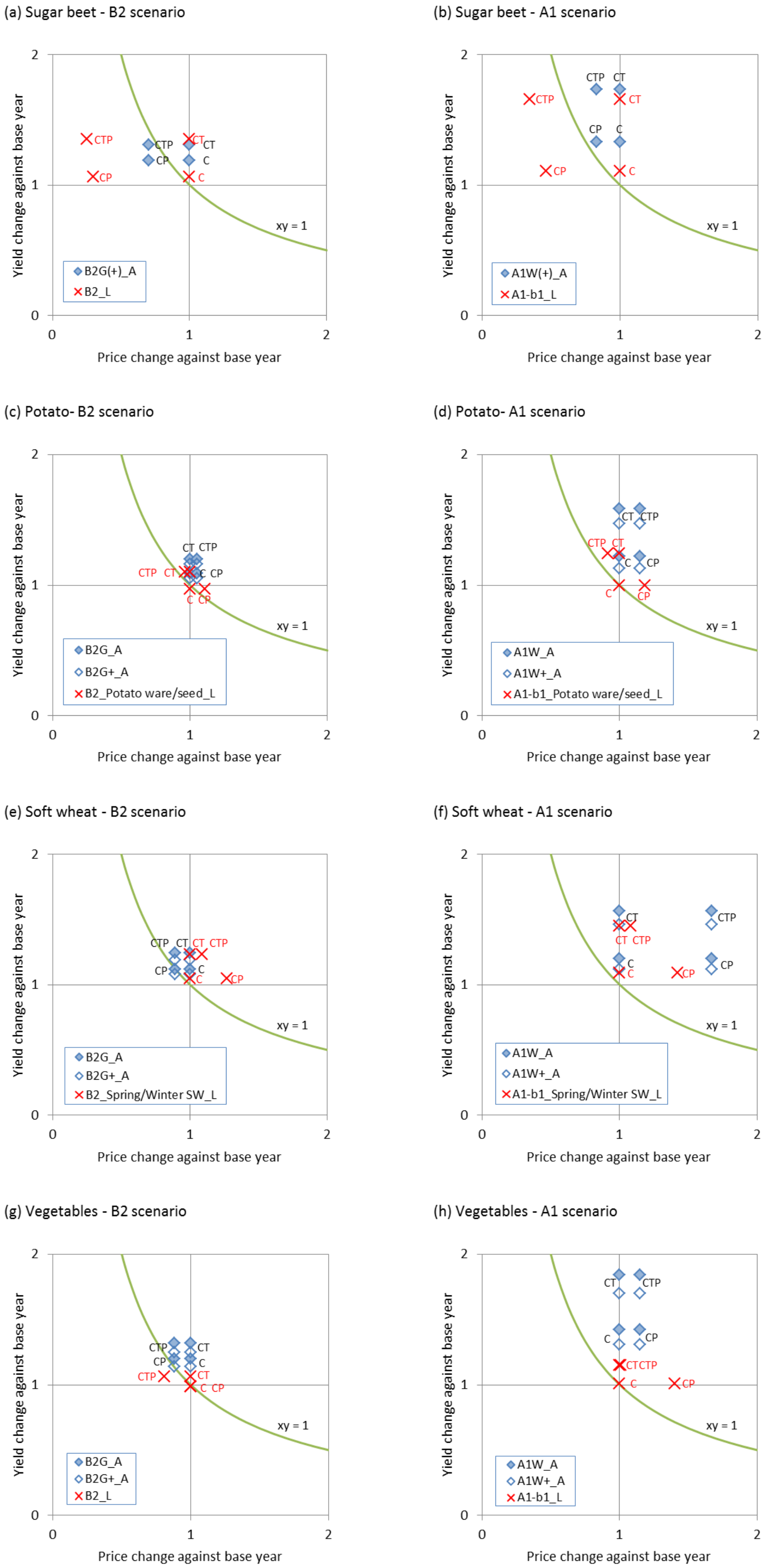


Fig. 3 Relative changes of yields and prices in 2050 against the base year. Yield changes were simulated by the crop growth model (WOFOST for AgriAdapt, SIMPLACE for LIAISE) and price changes were simulated by the market model (CAPRI). The x-axis shows the relative change in price and the y-axis shows the relative change in yield against the base year (BS, x=y=1). The diamonds show AgriAdapt and the crosses show LIAISE for each sub-scenario (C, CT, CP and CTP). Each panel represents for B2 (a, c, e, g) and A1 (b, d, f, h) scenarios for sugar beet (a, b), potato (c, d), soft wheat (e, f), and vegetables (g, h). The xy=1 line shows the marginal point at which "Yield x Price" remains the same as in the base year.

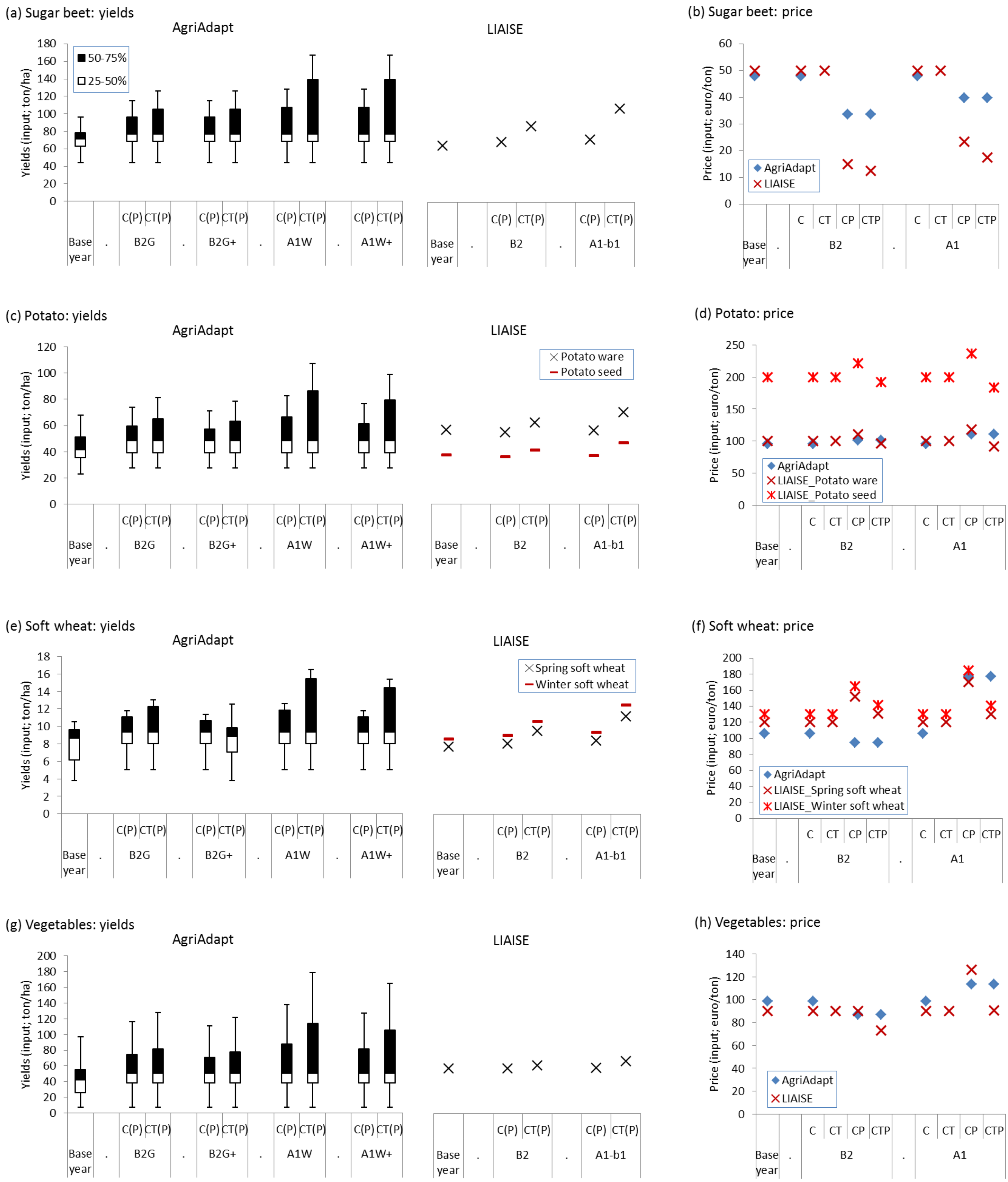


Fig. 4. Input data comparison for yields (a, c, e, g; ton per ha) and price (b, d, f, h; euro per ton) in the base year and 2050. Yields per activity are shown by boxplot for AgriAdapt, and the weighted average of yields is shown by cross in LIAISE. Price data are shown by diamonds in AgriAdapt and crosses in LIAISE for each sub-scenario (C, CT, CP, CTP). The panels represent sugar beet (a, b), potato (c, d), soft wheat (e, f), and vegetables (g, h).

3 - 1- 4. Farm plan and gross margin

3 - 1 - 4 - 1. Observations and output comparison in the base year

In AgriAdapt, FSSIM was used for simulation of farm plans based on profit maximization. Profit maximization objective in the model for the base year produces output different from actual observations, because not all farms achieve maximum profit in practice. Thus we compared farm plans and gross margins between the observations and simulation output in the base year (Fig. 5).

In AgriAdapt, the average of simulation output of all farms showed a smaller total agricultural area with higher gross margin compared to the average of observations (49.3 ha per farm in observations and 41.3 in simulation output; 40900 euro per farm in observations and 77217 in simulation output) (Fig. 5). The area of vegetables and other arable crops mainly were lower in the simulations.

In LIAISE, the positive mathematical programming (PMP) calibrated the simulation output of crop area to the base year observation as mentioned before (Fig.5). Gross margins might be different between observations and output because of the different yields, costs and labour per soil types (Supplementary table 2); however the observed activity levels per soil type were not available. Hence, gross margin for the observed farm types were not known.

In this study, we wanted to compare the simulation outputs in 2050 between AgriAdapt and LIAISE; however, simulation outputs in the base year were already different. The weighted average total agricultural area per farm was smaller in AgriAdapt (41.3 ha) than in LIAISE (60.7 ha). The weighted average total gross margin was also smaller in AgriAdapt (77217 euro/farm) than in LIAISE (136032 euro/farm), even per unit of area (1870 euro/ha for AgriAdapt, 2243 euro/ha for LIAISE). The observed farm plan (crop area share) of AgriAdapt was different from that of LIAISE, while the simulated farm plan of AgriAdapt was more similar to LIAISE; potato and soft wheat area increased, vegetables and other arable area decreased. However, LIAISE still showed a larger area share for potato and soft wheat, and a smaller area share for vegetables and other arable compared to the simulation outputs in AgriAdapt.

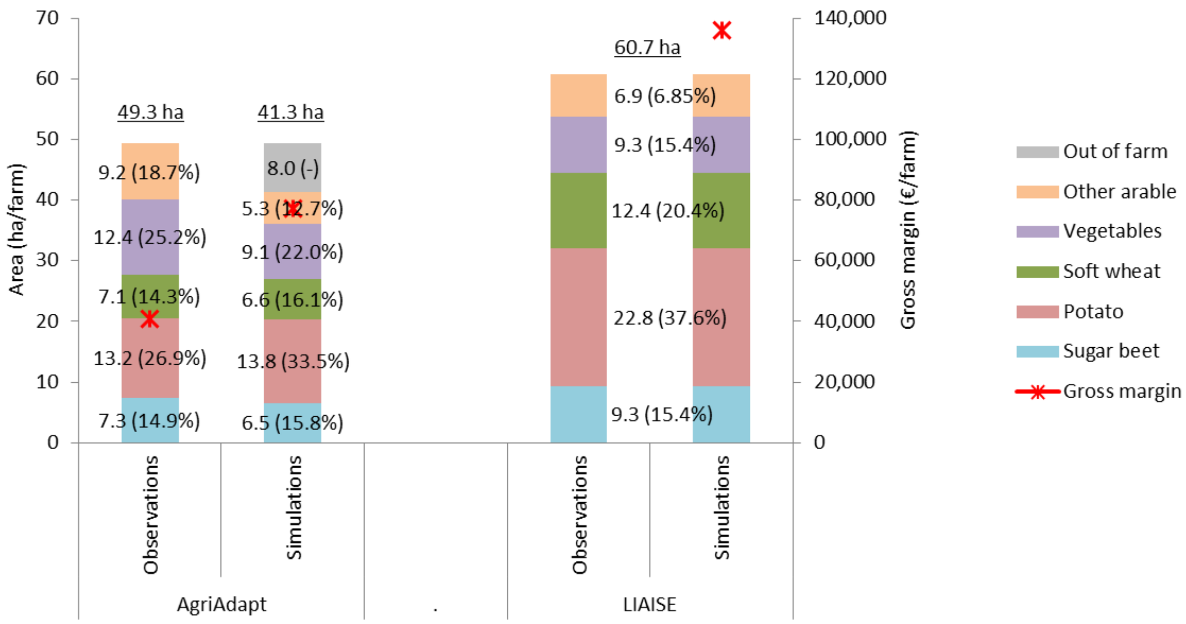


Fig. 5. Base year comparison between observation and FSSIM output for crop area (ha per farm) and gross margin (euro per farm). The data are shown by weighted average. Crop area is shown by bar graph and gross margin is shown by a cross. The value inside brackets shows the percentage of the area share. Observation data of gross margin in LIAISE are not available.

3 - 1 - 4 - 2. Output comparison in 2050

Because the farm area and gross margin were lower in AgriAdapt than in LIAISE, I compared the simulation output in 2050 by cropping pattern and the relative change of gross margin against the base year (Fig.6).

The cropping pattern in 2050 changed less in AgriAdapt compared to LIAISE, while in the base year cropping patterns were relatively similar. In LIAISE, potato could increase its share to a maximum of 60% of the area in A1 CT. This can happen because choosing mono-crop activities is allowed on rented lands. The area constraints keep the same total area as in the base year; therefore renting land implies land exchange with dairy farms. The resource of rented lands is large enough to occupy around half of the total farm areas – 27 ha for FT3203 and 32 ha for FT3303.

The different definitions of activities in both studies may have influenced results. Fig. 7 shows the activities as included in FSSIM in the base year, and the area share of each crop in these activities. AgriAdapt used 64 activities, without any mono-crop activity. The frequency of area share shows different patterns for different crops with potatoes having the largest area on average. In LIAISE, activities were defined by AgriEnvironmental Zones (AEnZ) and crop rotations. LIAISE used 281 activities from the SEAMLESS database, where 221 activities were crop rotations and the rest of 60 were the artificial mono-crop activities. The 221 activities from FADN also included mono-crop activities of onion, tulip and peas. The frequency of area share shows a similar pattern between crops. Hence, in LIAISE in theory all combinations of crops are possible, while AgriAdapt is limited by the combinations observed on farms.

Regarding gross margins, increases were observed in the C scenario in AgriAdapt (14.2% for B2G, 9.32% for B2G$^+$, 30.0% for A1W, 19.8% for A1W$^+$ compared to the base year) but small changes were observed in LIAISE (-2.7% for B2, 3.3% for A1-b1 compared to the base year). Comparing C with CP, AgriAdapt and LIAISE showed the opposite direction. For B2 and A1 scenarios, gross margins became smaller in AgriAdapt but larger in LIAISE from C to CP. Comparing CP with CTP, AgriAdapt and LIAISE also showed an opposite direction. For B2 and A1 scenarios, gross margins became larger in AgriAdapt but smaller in LIAISE from CP to CTP. This might be because, from CP to CTP, the prices kept the same values in AgriAdapt but decreased in LIAISE (see Fig. 3). As a result, in the CTP scenario, AgriAdapt showed a larger range in gross margin changes: in B2 the decrease was larger (-68.3% for B2G, -72.7% for B2G$^+$), but in A1 the increase was larger (99.0% for A1W, 77.4% for A1W$^+$) compared to in LIAISE (3.8% for B2, 28.2% for A1-b1).

Fig. 6. FSSIM results of the average farm plans and percent change of gross margin in 2050 against the base year in AgriAdapt (a) and LIAISE (b). Bar graphs show area share by each crop, crosses show percentage change of gross margin, and triangles show area share by mono-crop for each sub-scenario (BS, C, CT, CP and CTP) for B2 and A1 scenarios.

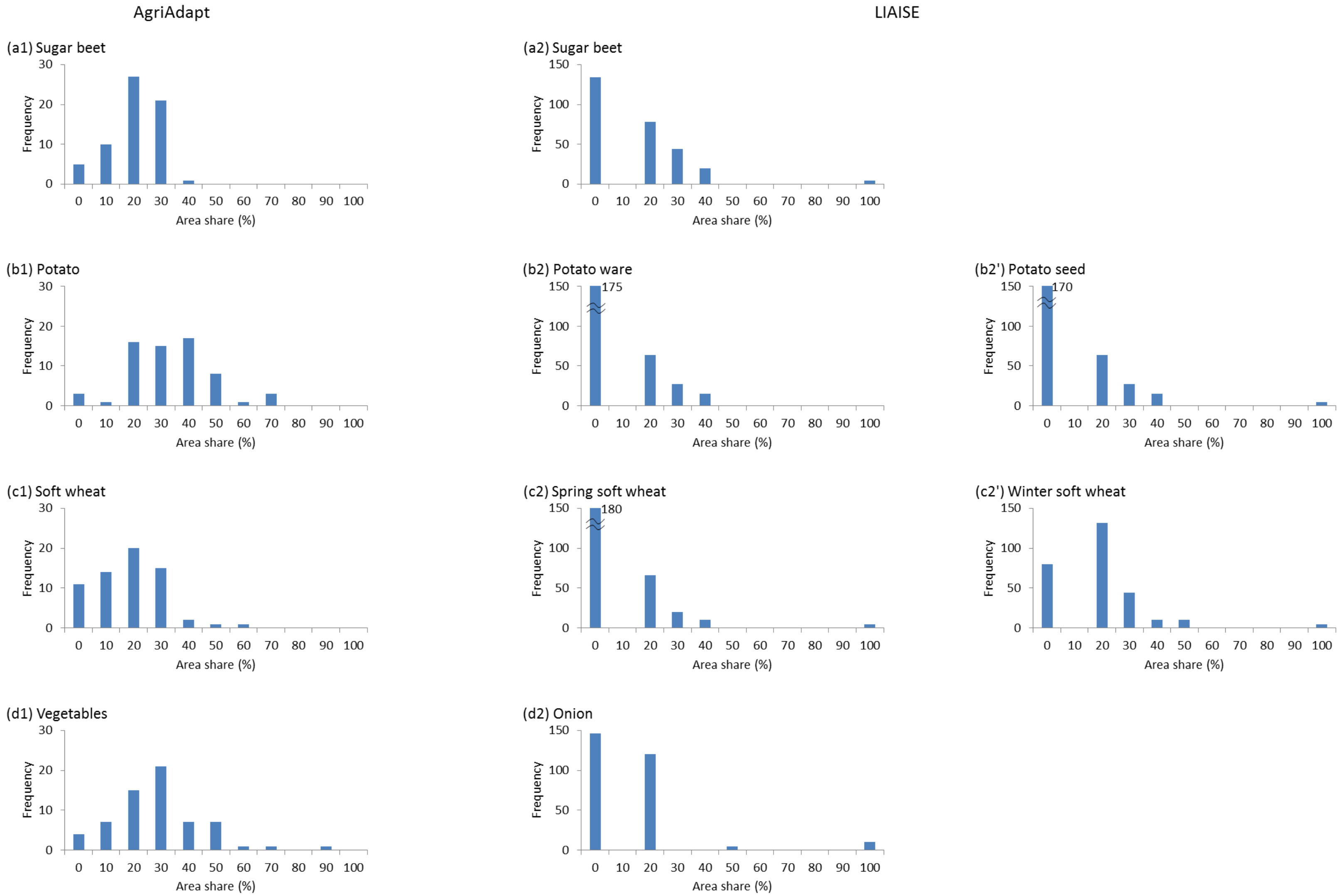


Fig. 7 Frequency distribution of area share (%) per activity for each crop for AgriAdapt (a1, b1, c1, d1) and LIAISE (a2, b2, b2′, c2, c2′, d2). AgriAdapt used 64 activities and LIAISE used 281 activities.

3 - 1- 5. Influence of input on simulation output

Different changes in farm plans can be evaluated based on differences in profit changes among crops. Regarding LIAISE, we can calculate the gross margin per crop based on sales, subsidies and costs, while for AgriAdapt we can only observe the sales (because AgriAdapt used whole farm activities, the data for cost and subsidy per crop were not available) (Fig. 8, Supplementary figure 1). Costs of labour and rented land were not included. Bar graphs show gross margins for each crop under each sub-scenario (BS, C, CT, CP and CTP). The higher gross margin of potato ware/seed and vegetables explained why LIAISE selected a larger area for potato and vegetables compared to other crops. We observed that also in AgriAdapt the sales of these crops were higher than for other crops. In CP in the A1-b1 scenario, FSSIM chose the largest area for vegetables, which could be explained by gross margins of vegetables being closest to potato. Soft wheat hardly made a gross margin (-79 to 371 euro per ha for B2, -79 to 604 euro per ha for A1-b1). Gross margins of sugar beet were close to potato and vegetable, but they decreased much in the P scenarios (CP and CTP).

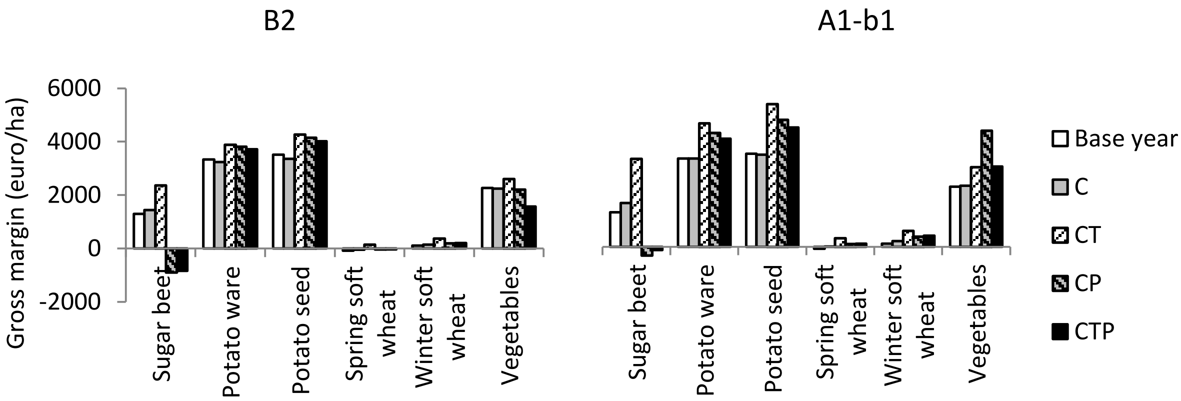


Fig. 8. Gross margin (euro per ha) of different crops in the base year scenario and sub-scenarios (C, CT, CP and CTP) for B2 and A1-b1 scenario in LIAISE.

3 - 2. Uncertainty analysis of important model parameters, model structure and assumptions

Because we observed there were input and output differences between AgriAdapt and LIAISE (section 3-1), we tried to identify what was the most crucial reason for different output among two studies. We examined (1) how much the crop and market model uncertainties affected the FSSIM output compared to modelling frameworks; (2) the influences of constraints on simulation output; (3) the effect of objective function on the simulation regarding the Positive Mathematical Programing (PMP) in LIAISE. Here, we use the terminology of 'uncertainty analysis', although it was difficult to change the values of inputs over their whole distribution range. This uncertainty analysis could give us some insight how much uncertainty in model outputs is induced by uncertainty or assumption in inputs.

3 - 2 - 1. The effects of uncertainties in yield and price changes compared to modelling frameworks

Crop and market models used in AgriAdapt and LIAISE simulated different yield and price changes among two studies (Fig. 3). Therefore, there were uncertainties from crop and market models. To know the influences of these uncertainties from crop and market models on FSSIM output, we applied yield and price changes in both studies to both modelling frameworks in CT and CTP in 2050 (Fig. 9).

In the AgriAdapt modelling framework (black bars), different yield and price changes (B2G, B2G+, B2; A1W, A1W+, A1-b1) resulted in smaller changes in CT than in CTP. This indicated that the effect of uncertainty from the crop model was smaller than the effect of the uncertainty from the market model. Market model uncertainty in CTP, in some cases, showed opposite effects on crop area (e.g. area of potato and soft wheat decreased in A1W(+) (AgriAdapt yield and price changes) but increased in A1-b1 (LIAISE yield and price changes)).

In the LIAISE modelling framework (orange bars), the effect of uncertainty from the crop model had a large impact on vegetables; area of vegetables increased in B2G(+) and A1W(+) (AgriAdapt yield and price changes) but decreased in B2 and A1-b1 (LIAISE yield and price changes). Market model uncertainty also affected area of vegetables. Comparing CT and CTP in vegetables, uncertainty from additional price changes in CTP cancelled the effect of the uncertainty from the crop model; the area change showed closer values in CTP than in CT between yield and price changes in AgriAdapt (B2G(+) or A1W(+)) and LIAISE (B2 or A1-b1).

Thus, the uncertainties by crop and market models produced different FSSIM output. However, the different modelling frameworks had larger effects on crop areas; the most prominent difference was that LIAISE increased potato area, while AgriAdapt did not.

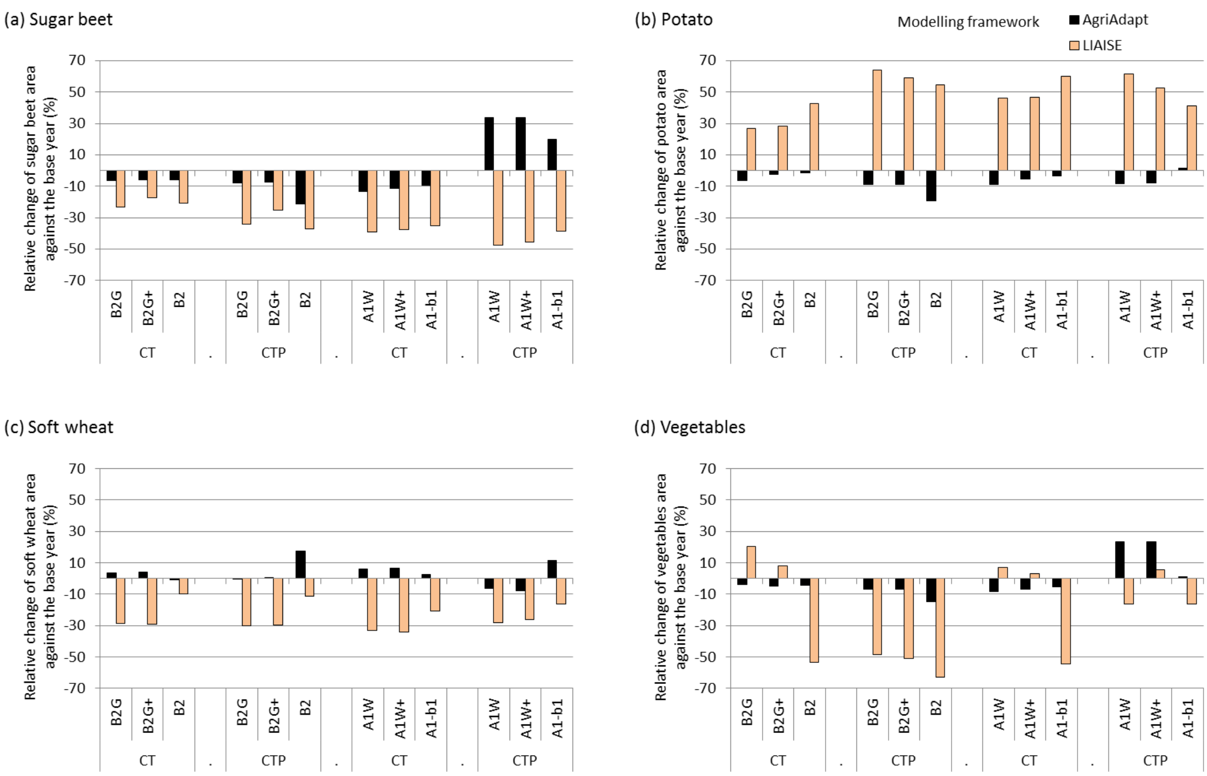


Fig. 9 The effects of different yield and price changes on simulated farm area of each crop. Black bars show modelling framework of AgriAdapt and orange bars show that of LIAISE. Yield and price changes of AgriAdapt (B2G, B2G+, A1W, A1W+) and yield and price changes of LIAISE (B2, A1-b1) were applied.

To capture the change in total farm plans, the Percentage Absolute Deviation (PAD) in crop areas and gross margins were compared (Fig. 10). PAD was calculated for area share change against the base year. The different yield and price changes produced different farm plans in both studies; however, the differences within the same modelling framework were much smaller (1.1 – 13.8% of PAD) than the differences between AgriAdapt and LIAISE modelling frameworks (21.4 – 44.7% of PAD) (Fig. 10 (a)).

The gross margin changes with yield and price change of AgriAdapt (B2G(+), A1W(+)) were always higher than that of LIAISE (B2, A1b1) (range between 13.4 – 211.7%) (Fig. 10 (b)). This might be because the yield changes multiplied by price changes were higher in AgriAdapt than in LIAISE; except for soft wheat in the B2 scenario (Fig. 3), but soft wheat had small gross margin (Fig. 8). The modelling framework affected the gross margin changes in the opposite way; gross margins were always higher in LIAISE than in the AgriAdapt modelling framework (range between 17.3 – 140.8%). This leads to the interesting result that the impact of modelling framework compensated for the impact of yield changes (CT), and that simulated impacts of AgriAdapt and LIAISE were relatively similar when original simulations were compared, but would be more different when yield changes of the other project would be used. The modelling framework also compensated for the impact of price changes (CTP), but differences in price changes between the two CAPRI versions were relatively larger than yield changes.

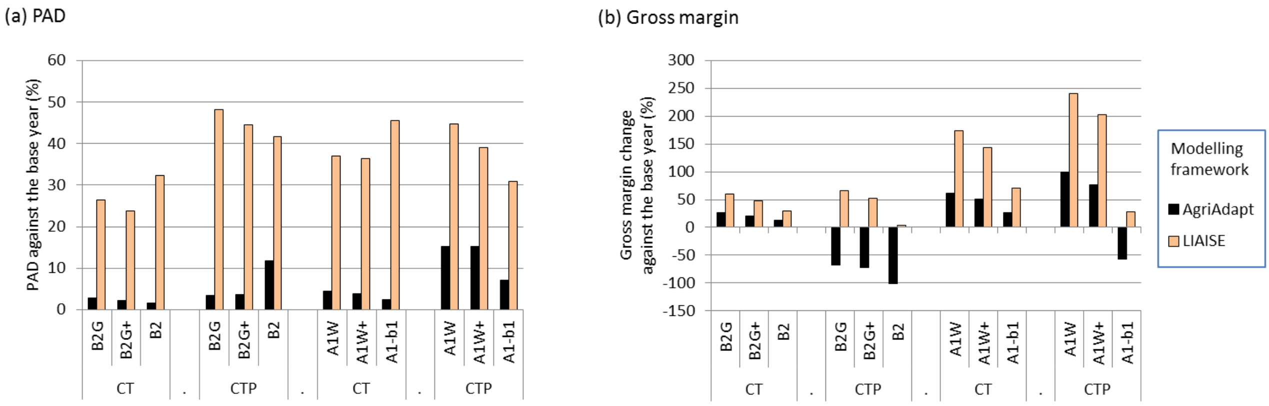


Fig. 10 Relative change against the base year simulation output of farm plans (Percentage Absolute Deviation; PAD) and gross margins with application of different yield and price changes of two studies. Black bars show modelling framework of AgriAdapt and orange bars show that of LIAISE. Yield and price changes of AgriAdapt (B2G, B2G+, A1W, A1W+) and yield and price changes of LIAISE (B2, A1-b1) were applied.

In order to distinguish the effects of climate and technology changes (CT) and additional price changes (P), scatter plots were drawn for PAD (Fig. 11(a)) and for the relative change of gross margin (Fig. 11 (b)). In the AgriAdapt modelling framework, the effects of CT were smaller than that of P; farm plans changed by less than 5% from base year to CT, and additional price changes (CTP) altered the farm plans more (Fig. 11 (a)). On the other hand, in the LIAISE modelling framework, the effects of CT were larger than that of P except for B2G(+); farm plans changed by more than 32% from base year to CT, and additional price changes (CTP) altered the farm plans less than 16%, except for

B2G(+) where the effects of CT and additional P were almost the same. Because the yield and price changes of B2G(+) were from AgriAdapt, the different crop and market models had effects on FSSIM outputs. This can also be seen in the AgriAdapt simulations, where results for A1 and B2 scenarios were closer together when based on LIAISE changes (B2, A1-b1). In general, the effect of the modelling framework was larger however.

Regarding the gross margin, the effects of CT were larger than P for all cases in the LIAISE modelling framework and A1W(+) in AgriAdapt framework (Fig. 11 (b)). For AgriAdapt modelling framework except for A1W(+), the effects of CT were smaller than that of additional P changes. While for farm plans, the impact of modelling framework was larger than the impact of yield and price changes, for gross margin changes, the input of yield and price changes is at least as important. Also here it can be observed that the original simulations of AgriAdapt and LIAISE are closer together than the new simulations.

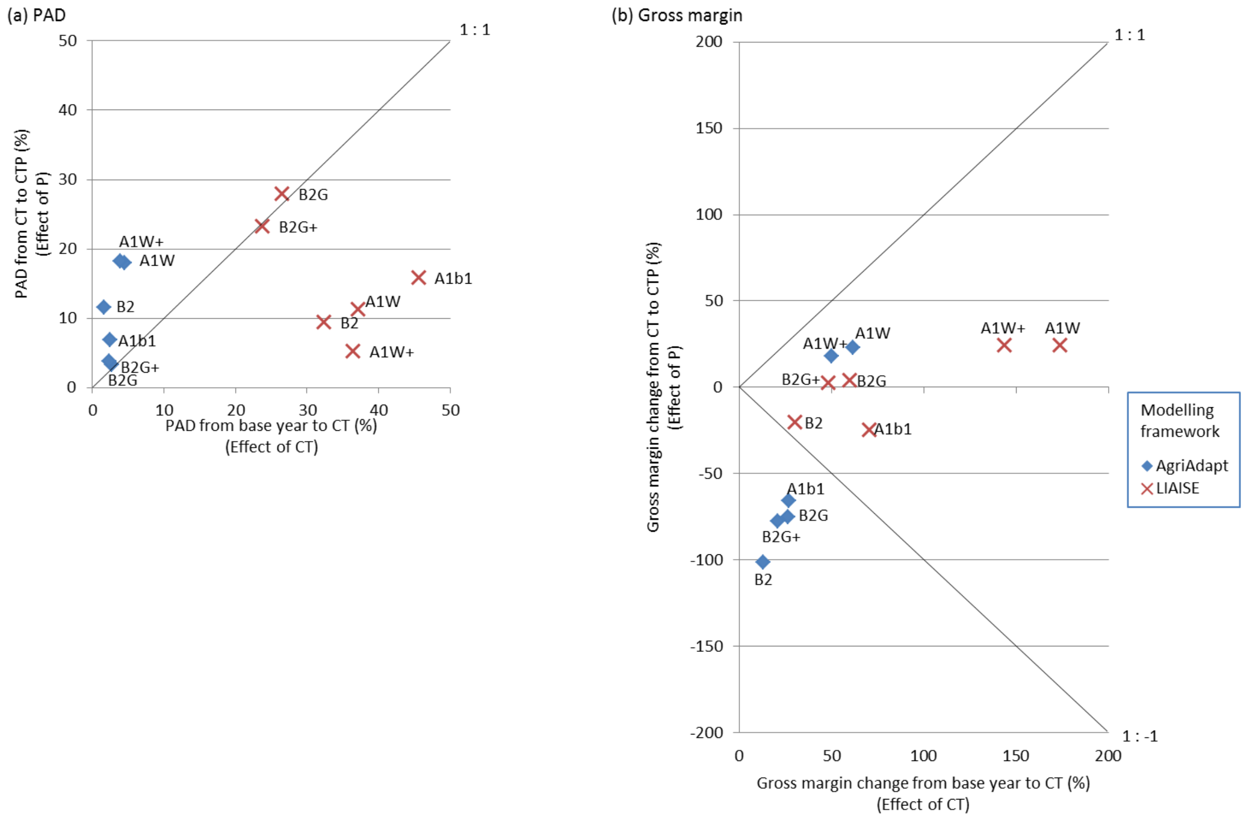


Fig. 11 The effects of CT (climate and technology changes) and additional P (market and policy changes) on the farm plans (a) and gross margin (b) in 2050. Percentage Absolute Deviation (PAD, %) was used to quantify the changes of farm plans. The x-axis shows the changes from the base year to CT and y-axis shows the changes from CT to CTP. The diamonds show AgriAdapt, the crosses show LIAISE modelling frameworks respectively. B2G(+) and A1W(+) indicate yield and price changes of AgriAdapt, B2 and A1b1 indicate the yield and price changes of LIAISE respectively.

3 - 2 - 2. The effects of constraints

Next, we examined the effects of constraints on FSSIM output. There were some differences in constraints between AgriAdapt and LIAISE (Table 2). AgriAdapt did not explicitly include rented land and mono-crop activities, whereas farms in LIAISE could rent lands where mono-crop activities were allowed. The amount of hired labour was limited in AgriAdapt but not limited in LIAISE. Farm activities were limited by capital, livestock, other arable output and other output in AgriAdapt but not included in LIAISE.

Because the constraints were different between AgriAdapt and LIAISE, it was impossible to conduct the same sensitivity analysis on constraints in both studies. Hence, the effects of constraints were analyzed separately.

The constraint changes in AgriAdapt showed that the constraints affect the simulation results in the base year (Fig. 12). The alterations of constraints were conducted independently (after each treatment, all constraints were reset before the next treatment). The constraint of Total Agricultural Area (E_TUAA) restricts the agricultural area to less than observed available area (a, b). Gross margin maximization used less area (b) than the observed available area (a). When it was imposed to use the same area as original, many farms chose for their own activities (26 farms out of 75), resulting in less gross margin (c). When E_TUAA was removed, farms increased the gross margin and total agricultural area (45.5 ha) that was still within the resource area on average (d). Removing the hired labor (E_HLABR) and capital constraints (E_CAPITAL) affected the farm area and gross margin, but the effect was less than for other constraints (e). Removing the constraints of livestock output (E_LIVOUT), other arable output (E_OAROUT) and other output (E_OTHOUT) intensively increased the other arable area and gross margin (f).

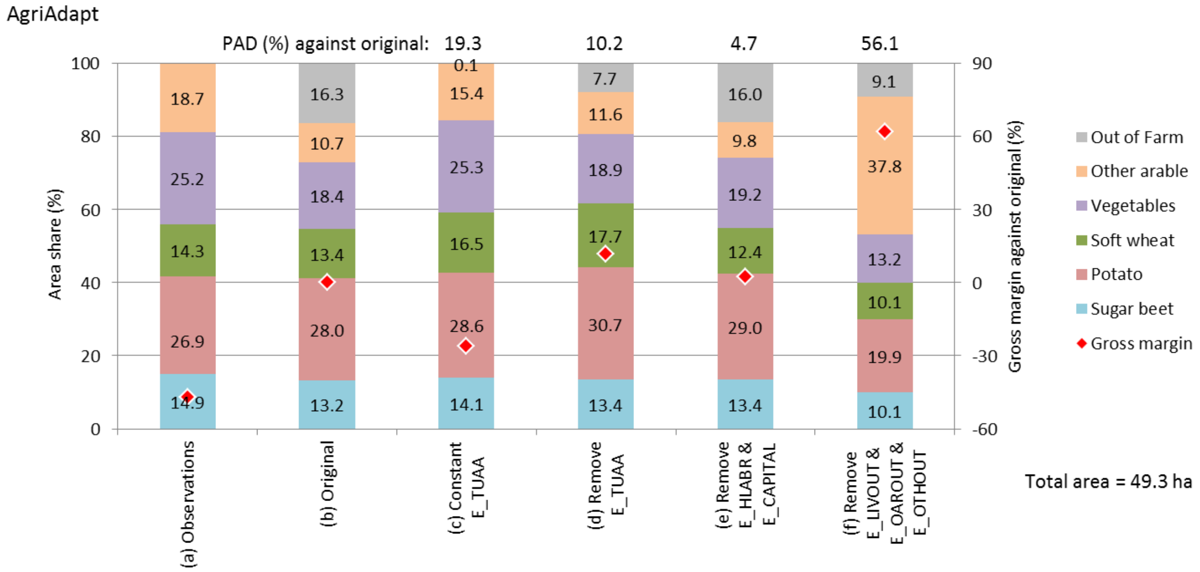
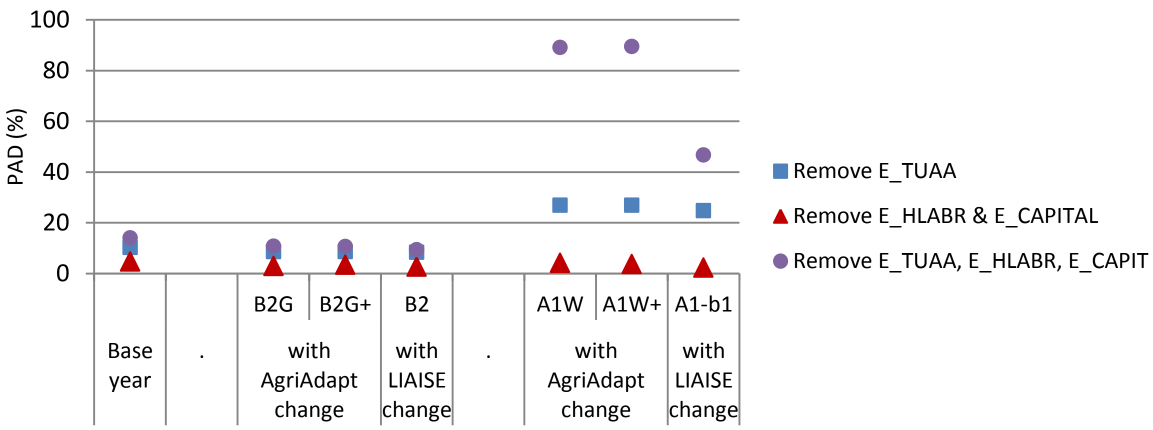


Fig. 12. Area share (%), gross margin change (%) and Percentage Absolute Deviation (PAD, %) against original simulation output with changing constraints in the base year in AgriAdapt. Constraints include total utilized agricultural area (E_TUAA), hired labour (E_HLABR), capital (E_CAPITAL), livestock output (E_LIVOUT), other arable output (E_OAROUT) and other output (E_OTHOUT). Bar graphs show area share, diamonds show the relative change of gross margin, and the values written above bar graphs show PAD.

We also checked the effects of constraints in CTP in 2050 in AgriAdapt (Fig. 13). Although towards 2050 changes in E_LIVOUT, E_OAROUT and E_OTHOUT may be possible, completely removing these constraints seemed unrealistic (Fig. 12 (f)). Farms need special techniques for these productions, and completely change their specialization. Therefore, we did not examine the effect of these constraints in 2050.

In the B2 scenario, the constraint change did not affect the simulated farm plans much; however the gross margin showed a large increase under B2 scenario (yield and price changes of LIAISE). This is because the original gross margin was a negative value. In the A1 scenario, removing the hired labor (E_HLABR) and capital (E_CAPIT) constraints did not affect the farm plans and gross margin so much as in B2 scenario. However, eliminating the area constraint (E_TUAA) altered the cropping pattern with increasing the gross margin, although the total agricultural area was beyond the resource (49.2 ha) on average (55.8 ha for A1W, 55.7 for A1W$^+$, 53.5 for A1-b1). Removing all E_TUAA, E_HLABR and E_CAPIT constraints extremely changed the cropping pattern and increased gross margin, however, the total agricultural area was beyond the resource on average (83.1 ha for A1W, 83.1 for A1W$^+$, 62.8 for A1-b1). These farm plan changes were larger with yield and price changes in AgriAdapt (A1W(+)) than with yield and price changes in LIAISE (A1-b1).

(a) Percentage Absolute Deviation (PAD) for farm area compared to the original



(b) Gross margin change compared to the original

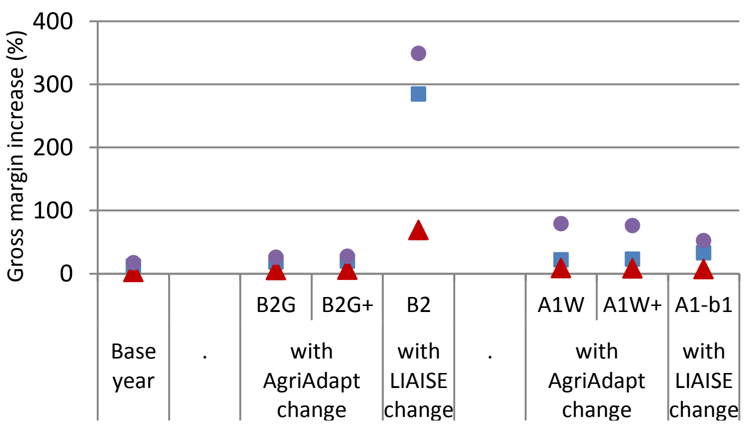


Fig. 13. The influences of constraint changes on the simulation output of farm plans and gross margin with different yield and price changes in CTP in 2050 in AgriAdapt. Constraints were removed for the base year and 2050 with yield and price changes of AgriAdapt (B2G, B2G+, A1W, A1W+) and LIAISE (B2, A1-b1). Percentage Absolute Deviation (PAD, %) (a) and gross margin increase (b) were calculated against the farm plans or gross margins with original constraints respectively. Squares show removal of constraint for total utilized agricultural area (E_TUAA), triangles show removal of constraints for hired labour (E_HLABR) and capital (E_CAPITAL), and circles show removal of constraints for all of E_TUAA, E_HLABR and E_CAPITAL.

In LIAISE, mono-crop activities that were allowed in rented land seemed to have large effects on simulation results. Therefore a sensitivity analysis of rented land was performed (Fig. 14, 15). The original values of rented land were 27 ha for FT3203 and 32 ha for FT3303 based on Farm Accounting Data Network (FADN). Changing the resource of rented land altered the farm plan and gross margin in CTP in 2050 in LIAISE. The simulation output showed an infeasible solution under less rented land (less than 26.2 ha (-3%) for FT3203 and 14.1 ha (-56%) for FT3303). For farm type FT3203, more rented land altered the cropping pattern more (increased potato seed) with increasing gross margin under the yield and price change of AgriAdapt, while there were no effects under the yield and price changes of LIAISE. For FT3303, the percentage absolute deviation showed a saturation curve, which indicates there might be another restriction for the farm plans.

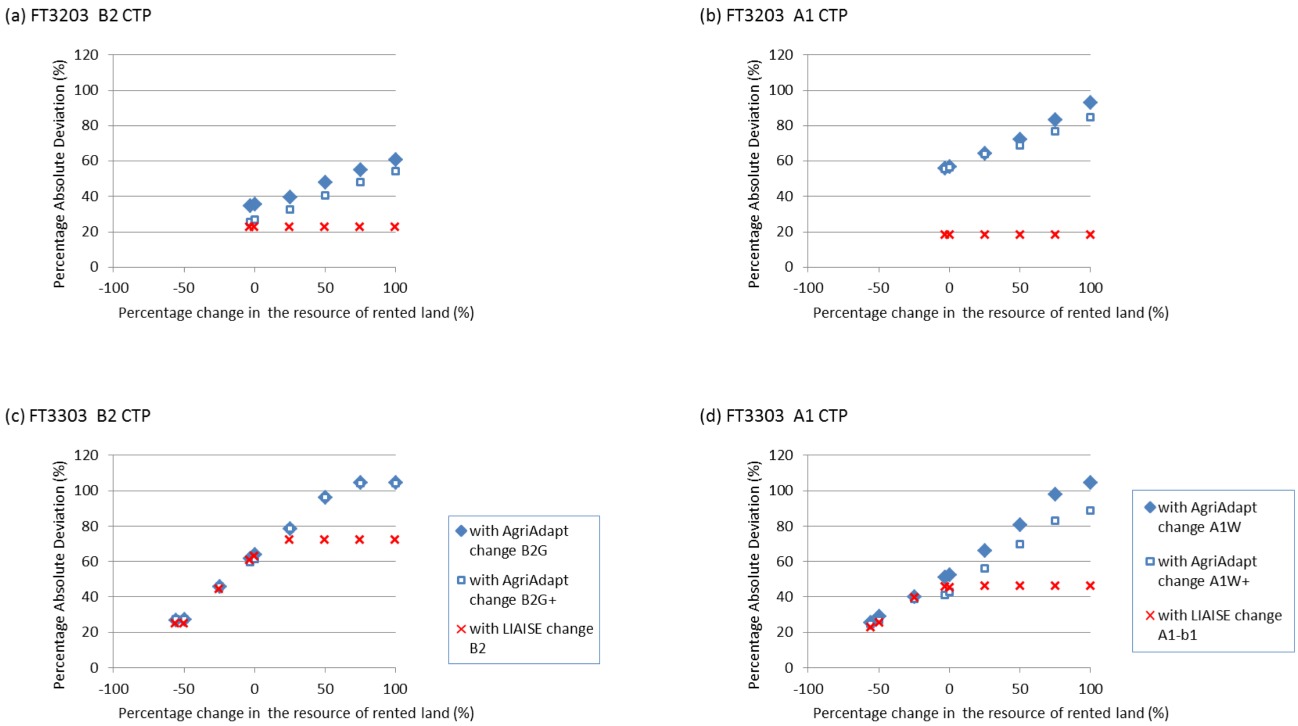


Fig. 14 The sensitivity of the percentage absolute deviation for farm plans (PAD, %) against the base year to changes in the rented-land resource constraints in CTP for B2 (a, c) and A1 (b, d) scenarios for two farm types (FT3203: a, b; FT3303: c, d) in LIAISE. The resources of rented land were altered from the original value (27 ha for FT3203, 32 ha for FT3303). Diamonds and squares show that the simulation with yield and price changes of AgriAdapt (B2G, B2G+, A1W, A1W+), and crosses show that of LIAISE (B2, A1-b1).

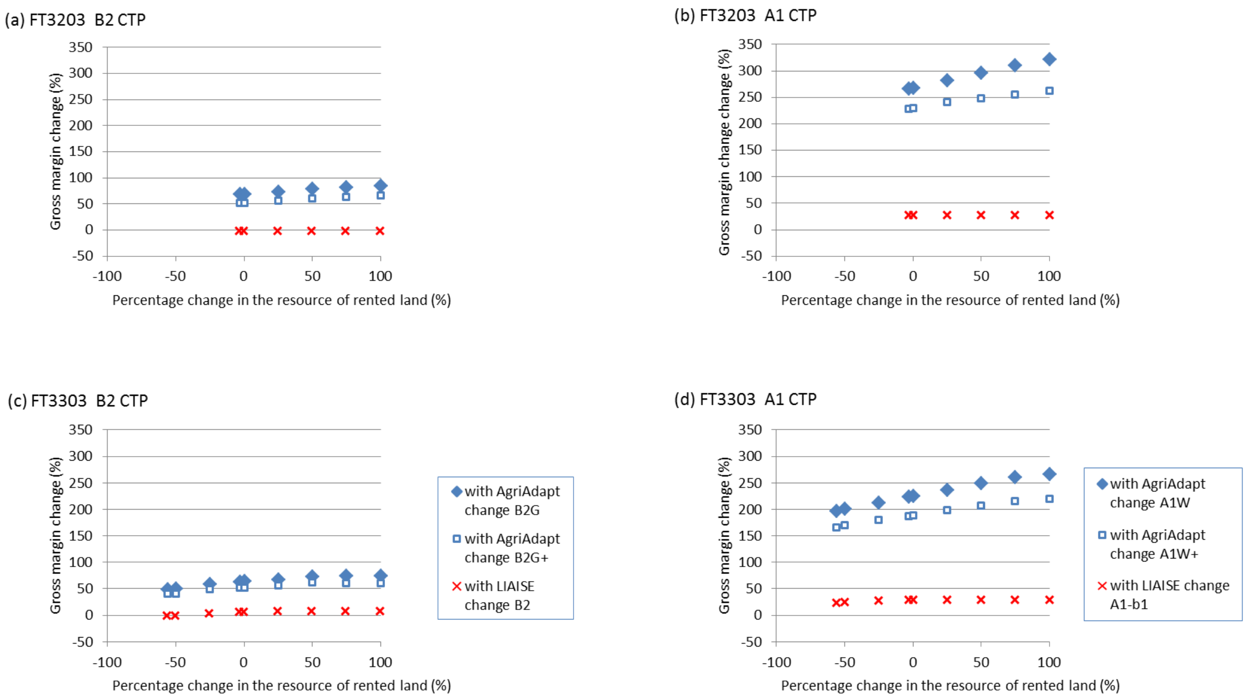


Fig. 15 The sensitivity of the gross margin change (%) against the base year to changes in the rented-land resource constraints in CTP for B2 (a, c) and A1 (b, d) scenarios for two farm types (FT3203: a, b; FT3303: c, d) in LIAISE. The resources of rented land were altered from the original value (27 ha for FT3203, 32 ha for FT3303). Diamonds and squares show that the simulation with yield and price changes of AgriAdapt (B2G, B2G+, A1W, A1W+), and crosses show that of LIAISE (B2, A1-b1).

3 - 2 - 3. The effects of Positive Mathematical Programming (PMP) in LIAISE

In LIAISE, the Positive Mathematical Programming (PMP) was used; the objective function includes a quadratic cost function. The sensitivity of the model to price and yield changes is regulated by parameter α (Kanellopoulos et al., 2010). A larger value of α makes the quadratic part larger, resulting in making the model less sensitive to price changes.

To investigate the effects of the value of α, the value of α was changed from the original value of 1 (Fig. 16). The Percentage Absolute Deviation (PAD) compared to the AgriAdapt results became smaller with a larger value of α. Because the PAD compared to AgriAdapt got closer to the PAD of the base year with larger value of α (except for A1W(+) CTP) (less change in farm plans compared to the base year), we expected that under larger values of α, LIAISE might show similar changes in farm plans as AgriAdapt. To assess this, the area share changes for each crop against the base year were plotted (Fig. 17). The potato area share increased compared to the base year in LIAISE (Fig. 17 (a)). These increments of potato area share became smaller with larger value of α, but still the change of potato area share kept positive values (Fig. 17 (b)). These farm plan changings never showed a similar pattern as that of AgriAdapt, where the potato area did not largely increase but decreased in some scenarios, especially for A1W(+) CTP (Fig. 17 (c)).

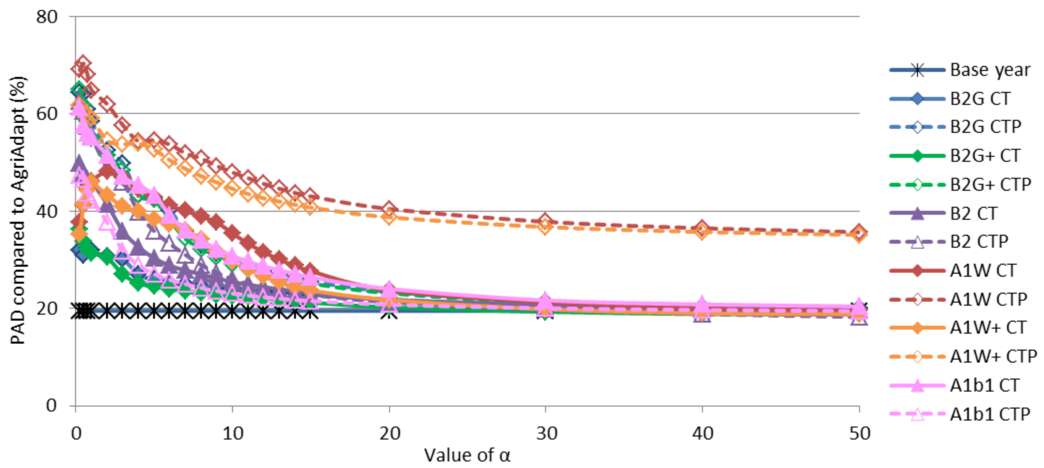


Fig. 16 The effects of the value of α in positive mathematical programming on farm plans in LIAISE. Percentage absolute deviation (PAD, %) was calculated for farm plan differences compared to AgriAdapt with different values of α for each scenario in LIAISE. The value of α was changed from the original value of 1. B2G(+) and A1W(+) used the yield and price changes of AgriAdapt, B2 and A1b1 used the yield and price changes of LIAISE respectively.

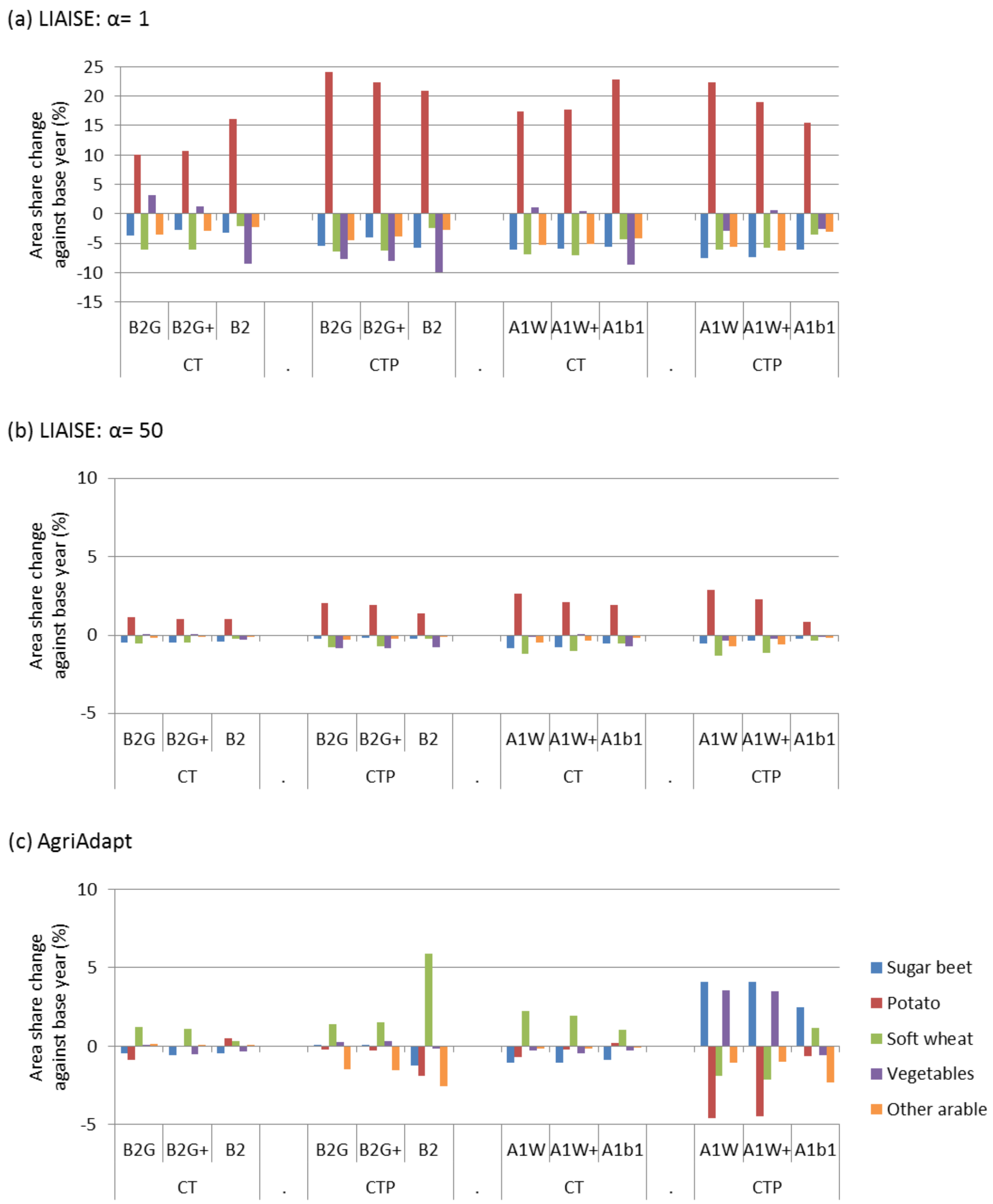


Fig. 17 Area share changes for each crop against the base year in case of (a) α =1 in LIAISE, (b) α =50 in LIAISE, and (c) AgriAdapt.

4. Discussion

In this study, we tried to identify the uncertainty of FSSIM. Uncertainty is often expressed in the form of probability distribution that presents how probable each of the possible outcomes is (Uusitalo et al., 2015). However, from the management point of view, uncertainty is the deficiency of exact knowledge (Refsgaard et al., 2007). According to Regan et al. (2002), uncertainty can be classified into six classes: inherent randomness, measurement error, systematic error, natural variation, model uncertainty, and subjective judgement. In this study, we assessed the model uncertainty that includes uncertainty of the model parameters and uncertainty about the model's structure. Uncertainty of the model parameters can be accounted for with the range of possible values and their probabilities. Uncertainty about the model's structure is very difficult to quantify in general (Regan et al., 2002).

We found that uncertainties from the modelling frameworks (objectives, activities, farm type, data source, and constraints) had more effects on the simulated farm plans than uncertainties in linked crop and market models (yield and price changes) (Fig. 10 (a)). Although there were large differences in scenarios (Table 3) and inputs from linked models (yield and price changes) between AgriAdapt and LIAISE (Fig. 3, 4), these differences were overcome by the differences of modelling framework (Fig. 10 (a)). This result is similar with the crop model case; Asseng et al. (2013) found that a greater proportion of the crop model uncertainty in climate change impact projections was due to variations among crop models compared to variations among downscaled climate scenarios. Regarding gross margins, the LIAISE modelling framework allowed more increases in gross margins than AgriAdapt, which was partly compensated by larger increases in yield and price changes with AgriAdapt compared to with LIAISE (Fig. 10 (b)). Therefore, if yield and price changes had been applied in the opposite way, the differences in FSSIM output of gross margins among the two studies would have been larger. Differences in modelling frameworks between AgriAdapt and LIAISE were mainly from mono-crop activities in LIAISE. As mono-crop activities were related to activities, objective function (Positive Mathematical Programming (PMP) calibrated the simulation output in the base year to the observation, which needed mono-crop activities), and farm resources (mono-crop activities were permitted only for rented land, therefore the resource level of rented land affected the results), these are discussed in more detail below.

4 - 1. Activity and rented land

We presented that more rented land altered simulated farm plans more in LIAISE, except for FT3203 with LIAISE yield and price changes (Fig. 14). LIAISE incorporated rented land, where a mono-crop (highest profitable crop) activity was allowed. Potato seed had the highest profit in LIAISE (Fig. 8); therefore, if farms have more rented land, they increase potato seed area. This was a crucial different point from AgriAdapt, which did not include mono-crop activities explicitly (Fig. 7).

AgriAdapt uses whole farm activities based on observations, which were processed by Data Envelopment Analysis (DEA). Therefore the simulated farm plans were combinations of current farm plans. Moreover, these activities did not explicitly include mono-crop activities; hence the farm plans in 2050 did not change much from the base year. On the other hand, LIAISE used crop rotations as activities, adopted Positive Mathematical Programming (PMP), and enabled farms to rent lands where mono-crop activities were allowed. For the PMP procedure, the mono-crop activities on rented land are necessary in order to calibrate the simulated farm area to the base year observation. As a consequence, LIAISE can produce more substantial changes in farm plans (Fig.6, 9). The effect of the rented land was subject to scenario; under larger yield and price changes in the A1W$^{(+)}$ scenario, a larger rented land area altered farm plans more, and produced more gross margin (Fig. 14, 15). The area of rented land was based on the base year observation; however, our results (Fig. 14, 15) showed that if farms rent more land in 2050, this will largely affect the simulation result, especially under higher yield and price changes scenarios.

AgriAdapt assumed that yields would increase in 2050 only for activities that ranked in the upper quartile of 75 activities for at least one crop (Fig. 4). This was because it was assumed that yields in this quartile were limited by climate, while others could not increase yields due to limiting factors related to management. It was not tested whether this assumption was reasonable or not. According to the definitions, potential yields are limited by temperature, radiation, CO2 and crop characteristics, water- and nutrient-limited yields by limiting factors (water and nutrients), and actual yields are further reduced by reducing factors (weeds, pests and diseases, pollutants) (van Ittersum et al., 2013). As actual average yields are close to the potential yields, it is likely that in Flevoland a higher percentage of farms can increase their yield. In many regions where actual yields are much lower than the potential yields, farmers can however not increase their yields when climate conditions allow this.

There are also some notifications about activities. In LIAISE, total agricultural area per farm was constant even though farms rent land. This implicates arable farms exchange lands with dairy farms. Exchange of lands does not increase the total agricultural area, and farms can produce a mono-crop on exchanged land because they do not need to take into account crop rotation that is common practice to prevent soil diseases. Because the rented land is from dairy farms, the area of rented land should be smaller than the area of dairy farms at regional level.

The whole-farm activities in AgriAdapt were based on 75 representative individual farms. The distribution of utilized agricultural area per activity was the same as that of total available land per farm (Fig. 2). We can recognize that there were only a few whole-farm activities that have more than 100 ha. Because farms select a linear combination among activities (e.g. Farm A chooses activity A 20% + activity B 40% + activity C 40% = 100%), it is more likely a farm chooses activities that have a similar area as its own area. Thus, large-area farms might have limited options to select activities; for example, if a large-area farm (100 ha) chooses a combination of activities that have a smaller area (activity A 60ha 50% + activity B 80ha 25% + activity C 100ha 25%), then this farm cannot use his whole land (60ha*0.5 + 80ha*0.25 + 100ha*0.25= 30ha + 20ha + 25ha= 75ha, 100ha – 75ha= 25ha cannot be used). Therefore, it seems AgriAdapt needs more activities for large farms. However, there is a possibility that a large-area farm selects smaller-area activities if the input-output efficiency (Data Envelopment Analysis; DEA) shows a saturation curve; if a farm increases area but output keeps the same level, then the farm would decide to choose smaller-area activities. This might be a reasonable choice for farms, because farming in a very large area (e.g. >200ha) is generally inefficient.

Potato ware and potato seed had similar gross margins per ha, but both sales and costs were higher for potato seed (Supplemental figure 1). This means potato seed needs more capital than potato ware. If farms want to reduce the risk (e.g. bad harvest), farms might choose ware instead of seed. LIAISE did not include a capital constraint, but a capital constraint could restrict the cultivation of potato seed. In addition, LIAISE includes only activity of mono-potato-seed but not mono-potato-ware. This may be due to some reasons in SEAMLESS crop management survey (Borkowski et al., 2007; Zander et al., 2010). It might be a reason that stakeholders expect that Flevoland should guarantee its position in export of seed potato by maintaining the high quality of the product (Mandryk et al., 2012), and therefore farms in Flevoland focus on the production of potato seed but not potato ware. Activity of mono-potato-ware might be needed for other regions.

Some studies indicated the possibility of production zone shift due to climate change (Olesen and Bindi, 2002; Wheeler and von Braun, 2013). Future farm plans might be very different from plans in the present. Activities in FSSIM were based on the base year observations and therefore did not include possible combinations of new crops (e.g. rice, soya). Possible alternative rotations should be included in the activities to explore future adaptation. This is relatively easier for LIAISE because activity is rotation. For AgriAdapt, incorporating new activities is a difficult procedure because activity is whole-farm-activity; there are no available farm data in this region.

4 - 2. Objective function

AgriAdapt and LIAISE have a profit maximization term in the objective function. Bio-economic farm models (BEFMs) are generally normative approaches that try to find the optimal solutions and alternatives to the problem of resource management and allocation. AgriAdapt applied the normative approach, and optimal solutions were simulated by profit maximization. On the other hand, LIAISE used a positive approach (which tries to model the actual behaviour of farmers) (Janssen and van Ittersum, 2007); PMP calibrated crop areas to observations in the base year simulation by introducing a quadratic cost term to the objective function besides profit maximization.

Although FSSIM in AgriAdapt assumed profit maximization, the activities of AgriAdapt might have been the selection of other farms' objectives (e.g. soil fertility, erosion, and eco-friendly). AgriAdapt used the whole-farm-activity that includes whole input (e.g. fertilizer per farm) and output (e.g. production per farm) of the representative farm. These activities were based on observations, which were processed by Data Envelopment Analysis (DEA). Because a whole-farm-activity is based on observations, it seems a whole-farm-activity implicitly includes other objectives. Even though FSSIM combined several activities to maximize profit, the simulation results might include other objectives besides profit maximization because only observed activities are included, implicitly considering other objectives. In LIAISE, the simulation results of each crop area were calibrated to the base year observation; therefore, other objectives except for profit maximization were implicitly incorporated in the quadratic term.

Future farms might not be oriented to maximization profit only, but also other objectives: for example, it was estimated that 30% of the farms will be oriented to entrepreneurship, and no farms and 30% of farms will be oriented to nature for A1 and B2 scenario respectively (Mandryk et al., 2012). Farmers focus on economic result maximization in practical decision-making, but for strategic decision making, they consider long-term objectives associated with sustainability (e.g. soil organic matter) (Mandryk et al., 2014). According to Holzkämper et al. (2015), the importance of climate or crop model uncertainties can differ depending on the prioritization of objectives (yield, erosion or leaching). If we know other objectives besides profit maximization, we might produce a more precise farm model. However, although some farms were interviewed by Mandryk et al. (2014), we do not know how many objectives farms have nor the priority order of objectives for all the farms in the analysis.

In PMP in LIAISE, a smaller α makes the farm model stronger orientated towards profit maximization in 2050, and a larger α keeps the simulation output of farm plan (crop rotation) more similar as that in the base year. Kanellopoulos et al. (2010), which assessed the forecasting performance of FSSIM with PMP, revealed that the values of α=10.8 and 11.8 for farm type F3203 and FT3303 respectively achieved the best prediction in 2003 compared to 1999. However, for the exploration in 2050 (far future), a smaller α might be suitable if we assume the farm plan will change more based on stronger orientation of maximizing profit in 2050. Thus, α=1, which was used in LIAISE, seems an appropriate choice.

Even if a smaller α is used, resulting outcomes are still influenced by the base year farm plan. If farms use a small area for tulip production in the base year, FSSIM will not allocate a large area to tulip production in 2050, even though tulip is very profitable.

Because the more substantial farm plan changes in LIAISE seem to come from the rented-land system and mono-crop activities on the rented land (Fig. 14), we thought a larger value of α (this means the area of rented land in 2050 will be closer to that in the base year) might make the simulation results in LIAISE similar to the results in AgriAdapt. With a larger value of α, the Percentage Absolute Deviation (PAD) against AgriAdapt became smaller (farm plan became closer to AgriAdapt); however, the farm plan never came closer to AgriAdapt than in the base year situation (Fig. 16). The area share change against the base year with the largest value of α (=50) in LIAISE, was still not similar to the area share change in AgriAdapt; the potato area still increased for all sub-scenarios in LIAISE, although decreased in AgriAdapt except for two sub-scenarios (B2 CT, A1-b1 CT) (Fig. 17).

Janssen and van Ittersum (2007) suggested that PMP was more suitable for short to medium term simulation. I think the AgriAdapt framework also looks more suitable for short term simulation than long term. Both approaches did not include a shift of prioritization of objectives. More importantly, the farm plan (crop rotation) of whole-farm-activities in AgriAdapt was fixed, which did not allow substantial changes in 2050.

4 - 3. Farm type and resource constraints

The farm typology was very different between AgriAdapt and LIAISE. AgriAdapt treated 75 representative individual farms, whereas LIAISE used only two farm types. LIAISE adopted the farm typology from the SEAMLESS project, which was based farm size, intensity and specialisation/ land use (Andersen et al., 2007; Van Ittersum et al., 2008). Consequently, the frequency distributions of total available land per farm between AgriAdapt and LIAISE were very different (Fig. 2). Two farm types in LIAISE had 62.7 ha and 59.4 ha respectively, although only 24% of farmers had more than 60 ha in AgriAdapt. Because farm types in AgriAdapt were based on FADN data (2001 - 2006) and

LIAISE farm typology from SEAMLESS were also based on FADN data (2003 - 2005), it seems the SEAMLESS farm typology ignored small farms.

One notification was that gross margin in the base year of AgriAdapt was smaller than that of LIAISE even per area, although AgriAdapt maximized profit and LIAISE calibrated crop areas to the base year observation (Fig. 5). The differences in gross margin might come from the different farm typologies between AgriAdapt and LIAISE. Kanellopoulos et al., (2014) showed that the gross margins of small farms would decrease but that of large farms would increase under the climate and socio-economic changes in 2050.

Like in most other BEFMs studies, farm types and the resource of total available land per farm were kept constant in the simulations towards 2050, both in AgriAdapt and LIAISE. However, Mandryk et al. (2012) assessed farm structural change based on historical analysis and scenario development, and projected 34% (75 ha) arable area change per farm in A1 and 6% (59 ha) in B2. Considering economic scenarios, it indeed seems conceivable that farm area increases in the A1 scenario compared to the B2 scenario in 2050. Kanellopoulos et al. (2014) also indicated that increases in farm size can be expected, because the gross margins increase much more for larger farms and larger farms are more likely to increase area, whereas medium farms can only stay viable if there is enough technological development. Our results showed that farm area might change in 2050; when all the area, hired labour and capital constraints were removed in AgriAdapt, the total agricultural area increased on average, 76.4% (83.1 ha) for $A1W^{(+)}$ and 33.3% (62.8 ha) for A1-b1 against the base year optimization (47.1 ha), whereas decreased -10.8% (42 ha) for $B2G^{(+)}$ and -18.9% (38.2 ha) for B2 (Fig. 13). Therefore, FSSIM in AgriAdapt can be used to evaluate possible changes in farm areas.

One notification is that, in AgriAdapt, the simulations resulted in smaller agricultural areas compared to observations (Fig. 5), as the resource constraint of total utilized agricultural area limited the total area to less than base year available land. However, while some farms cultivated less area, others showed shadow prices for agricultural area (hence if the farm has more agricultural area, then this farm can increase the objective value (gross margin) more). Therefore the unutilized area can be used for another farm, as it is not likely that this land will remain fallow. Including land exchange might be an interesting next step to better understand such processes.

As is the case with land area, the number of farms was assumed to be constant toward 2050 in AgriAdapt and LIAISE. However for 2050, some of them might stop farming. According to Mandryk et al. (2012), the number of arable farms in Flevoland will decrease by 13% in B2 and 35% in A1 scenarios, with increasing the average farm area from 56 ha in the base year (2008) to 59 ha (6%) in B2 and 75 ha (34%) in A1.

Resource constraints had impacts on simulation output (Table 2, Fig. 12, 13, 14, and 15). In AgriAdapt, hired labour (E_HLABR) and capital (E_CAPITAL) constraints did not restrict the farm plan so much (Fig. 12, 13). However, the combination with a constraint of total utilized agricultural area (E_TUAA), E_HLABR and E_CAPITAL restricted the farm plan in the A1 scenario. Removing these constraints had more effects on simulation results under A1W(+) (yield and price changes in AgriAdapt) than A1-b1 (yield and price changes in LIAISE) (Fig. 13). In LIAISE, as mentioned before, increment of rented land changed farm plan and increased gross margin (Fig. 14, 15). These things imply that resource change in the future might have a large impact on farm plan, and the significance of impact depends on yield and price changes due to climate and socio-economic changes.

AgriAdapt and this study assumed that farms could not produce more livestock output, other arable output and other output than observation levels, because farms need special techniques for these production. However, in 2050, it might be possible for farms to get these techniques. The area of other arable increased (account for 37.8% of total area), when the constraints of livestock output (E_LIVOUT), other arable output (E_OAROUT) and other output (E_OTHOUT) were removed in the base year in AgriAdapt (Fig. 12). Other arable mainly includes spring barley and tulips. The Netherlands is the largest producer of tulips (more than 80% of world production (Buschman, 2004)); therefore, the sales price of tulip might be dependent on the amount of production in the Netherlands. If farms in the Netherlands produce more tulips, the price of tulip might become lower and tulip production might be less profitable. Therefore, it looks reasonable to keep the constraint of other arable output.

Thus, although the number of farms and farm area per farm were expected to change toward 2050, these changes were not incorporated in AgriAdapt and LIAISE as with other BEFMs. To keep results transparent and considering the large input of changing resource constraint, it is logical to keep them constant; by presenting results for different farm sizes, the impact of constraints can also be presented. We should however be aware of the importance of resource constraints and more research is needed to evaluate these.

4 - 4. Climate scenario and crop model

In this study, we focused on FSSIM but not the crop and market models. However, here, we want to add some notification. The climate scenarios were based on the data from KNMI’06 and WLO/SRES for AgriAdapt, and IPCC (2007) for LIAISE (Table 3). However, AgriAdapt used CO_2 concentration data from IPCC (2007), just like LIAISE, which was because KNMI’06 did not include CO_2 concentration data. As a result, the climate scenarios of AgriAdapt and LIAISE showed almost the same CO_2 concentration (except for A1) with different temperature increases. Difference in yield increment in 2050 between AgriAdapt and LIAISE should thus mainly be related to temperature differences. The climate scenarios in AgriAdapt showed different temperature increments between strong and weak air circulation scenarios with the same CO_2 concentration. The yield increment towards 2050 for C3 crops is generally due to the increment of CO_2 concentration, whereas temperature effects generally produced negative impacts except for sugar beet (Vries et al., 2014; Reidsma et al., 2015). Therefore, higher yield increments in AgriAdapt than in LIAISE for B2 scenario (Fig. 3) might be because of a lower temperature rise in AgriAdapt with the same level of CO_2 concentration. However, for the A1 scenario, temperature rise is the same or higher in AgriAdapt (1.8°C for A1W, 2.6°C for A1W$^+$) than in LIAISE (1.8°C) with higher CO_2 concentration in AgriAdapt (567 ppm) than in LIAISE (532 ppm). Therefore, yield increments in A1W in AgriAdapt were higher than in LIAISE due to higher CO_2 concentration with the same temperature increase. Regarding A1W$^+$ in AgriAdapt, the effect of higher CO_2 concentration might be stronger than the negative effect of higher temperature. Comparing strong and weak air circulation scenarios in AgriAdapt, strong air circulation resulted in lower yield than weak air circulation, except for sugar beet. The lower yield in the strong air circulation scenario might be due to the higher temperature with the same level of CO_2 concentration. This also might be due to the less precipitation in summer in the strong air circulation scenario, but water limitation was not considered as potential yield were used.

Another likely reason is the differences in factors considered in the crop models. SIMPLACE in LIAISE incorporated nitrogen limitation, which could be a reason why the yield changes in LIAISE were lower than in AgriAdapt (Fig. 3). However, nitrogen budgets showed surplus for the Netherlands case (Leip et al., 2011), thus it seems there is no nitrogen limitation for Flevoland. Farmers in Flevoland achieve high yields that are very close to the potential yields (Wolf et al., 2012). Actually, AgriAdapt assumed there is no nitrogen or water limitation, and therefore only high productive farms can increase yields because management (e.g. sowing date, pest and disease controls, weed management) is the only one reducing factor (Kanellopoulos et al., 2014). According to Webber (in prep.) water and nitrogen limitation did not have a large influence on yields in Flevoland.

Overall, uncertainties in yield changes might have arisen partly from different climate scenarios. Uncertainties in yield changes might be also from different crop models; this would be revealed when WOFOST and SIMPLACE simulate the yield changes under the same climate scenarios.

4 - 5. Uncertainties from crop and market models

Even though the inputs from linked crop and market models (yield and price changes) were less important than modelling framework of FSSIM, these uncertainties still had effects on FSSIM outcome (Fig. 9, 10 and 11). Recently some studies integrated the simulation studies that assessed the impact of climate change on crop yields and economic responses (Asseng et al., 2013; Nelson et al., 2014). The yield and economic changes vary between studies. Our results show these variabilities and uncertainties of crop and market models affect FSSIM output but these effects on farm plans are smaller than that of modelling framework (Fig. 10).

We could not assess the influences of the absolute values of yields and prices on FSSIM results. There is a possibility that potato seed was more profitable than other crops in LIAISE, but potato (sum of ware and seed) was not so profitable in AgriAdapt. In AgriAdapt, potato increased its area share in simulation output in the base year compared to observation (Fig. 5); however, potato area share did not increase in the simulations in 2050 compared to the base year (Fig. 6 (a)). There were some activities (18.8% of total activities) that had more than 40% of potato area share in AgriAdapt (Fig. 7 (b1)), but FSSIM selected around 30% of area share for potato. Apparently these activities with a high potato share were not as profitable as in LIAISE. Still potato accounted for larger area than other crops in AgriAdapt; the relative profits of crops might be more similar between LIAISE and AgriAdapt compared to the absolute profits. Nevertheless, it was shown that the effect of modelling framework of FSSIM itself was more important than linked models (crop and market models) for farm plan simulation, because the same linked model outputs (yield and price changes) affected the farm plan in different way between AgriAdapt and LIAISE modelling frameworks.

Wheeler et al. (2000) indicated that many crop studies capture the impacts of mean changes in climate, but are less accurate for changes in weather extremes, which might be more important for crop yields. Up to now, farm plans do not consider the influences of extreme weather, although this might have effects on farm planning in the future.

Comparing the effect of yield and price changes, the farm plans were more influenced by additional price changes than by yield changes in AgriAdapt, but this relationship was opposite in LIAISE (Fig. 11). One notification is that farm plan changes by yield change (CT) in LIAISE might be also influenced by modelling structure; because the farm plan can largely change in LIAISE, if we change price first, then the effect of price change might be larger than that of additional yield change.

4 - 6. Plausible farm plans in 2050

We compared two studies that use FSSIM. Two studies showed different farm plans (crop rotations) (Fig. 6), so the question is "what is a plausible image of farms in 2050?" Relative change of area of each crop against the base year showed totally different patterns between AgriAdapt and LIAISE (Fig. 9); LIAISE increased potato area by more than 26% for all sub-scenarios, whereas AgriAdapt decreased potato area except for the A1-b1 CTP sub-scenario (yield and price changes of LIAISE), where potato area was increased by 1.7%. Because the farm plans were simulated in opposite direction between AgriAdapt and LIAISE (AgriAdapt decreases but LIAISE increases potato area), we cannot assert what is the plausible farm plan in 2050.

Researchers try to get plausible values for future simulations by calculating averages with uncertainties among studies for climate scenarios (Moss et al., 2010), crop models (Asseng et al., 2013; Challinor et al., 2014) and economic models (Nelson et al., 2014). Thus the average of the BEFMs might be a plausible image of Flevoland in 2050. However, only two studies (AgriAdapt and LIAISE) are not enough to get the confidential interval. In addition, AgriAdapt and LIAISE showed opposite direction about farm plans mentioned above, thus it is not appropriate to calculate the average, but more BEFMs need to be simulated in Flevoland. However, because BEFMs request huge specific data for farms, no other research has been conducted in Flevoland so far.

5. Conclusion and perspectives

This study compared the bio-economic farm modelling studies in the AgriAdapt and LIAISE projects, which assessed the impact of climate change and associated socio-economic scenarios on arable farming in Flevoland province, the Netherlands in 2050. Although the simulations were conducted using one of the bio-economic farm models, FSSIM, in both projects, many factors were different: scenarios, linked crop and market models and modelling frameworks (objective function, activities, farm types, data source, and constraints). By comparing AgriAdapt and LIAISE, uncertainties of FSSIM were investigated.

In the LIAISE modelling framework, potato area increased in all of the CT and CTP scenarios, even when yield and price changes of AgriAdapt were used. These increases in potato area did not occur in the AgriAdapt framework. In other words, uncertainties in farm plans arising from uncertainties in linked models (yield and price changes: range between 1.1 – 13.8% of Percentage Absolute Deviation (PAD)) were overwhelmed by different modelling frameworks (range between 21.4 – 44.7% of PAD).

Regarding gross margin, changes with yield and price change settings of AgriAdapt were always higher than that of LIAISE (range between 13.4 – 211.7%). However, the modelling frameworks affected the gross margin changes in the opposite way – gross margin changes were always more positive in LIAISE than in the AgriAdapt modelling framework (range between 17.3 – 140.8%). Therefore, the impact of modelling framework compensated for the impact of yield and price changes, when gross margin changes in original simulations were compared.

The LIAISE modelling framework could easily increase the area of profitable crops (e.g. potato) because mono-crop activities were explicitly included. Mono-crop activities were allowed only on rented land, and the sensitivity analysis to increases in rented land showed a resultant increase in gross margin (subject to yield and price changes) made possible by altered farm plans. On the other hand, the AgriAdapt modelling framework did not explicitly include mono-crop activities, and simulated farm plans were always combinations of the current whole-farm activities. Therefore, farm plans in 2050 did not change as much when compared to LIAISE. In AgriAdapt, changing the resource constraints (land area, capital, hired labour) altered farm plans (2.3 – 89.1 % of PAD) and gross margins (2.5 – 349.1%), subject to the yield and price changes.

In order to better understand possible farm plans in 2050, more research is needed to investigate future changes, e.g. changes in farm structure, resources, activities and objectives, since these factors can affect the simulation results of FSSIM.

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Appendix

Supplementary table 1. The relative change against base year for Yield (ton per ha), Price (euro per ton) and Yield x Price (euro per ha) for each crop in each scenario in 2050. The values show the relative change against the base year.

	Sugar beet						Potato							
	AgriAdapt		LIAISE (L)	AgriAdapt		LIAISE (L)	AgriAdapt		L_ Potato ware	L_ Potato seed	AgriAdapt		L_ Potato ware	L_ Potato seed
	B2G	B2G+	B2	A1W	A1W+	A1-b1	B2G	B2G+	B2	B2	A1W	A1W+	A1-b1	A1-b1
Yield (ton/ha) change														
C	1.19	1.19	1.06	1.33	1.33	1.11	1.09	1.05	0.97	0.97	1.22	1.13	1.00	1.00
CT	1.31	1.31	1.35	1.73	1.73	1.66	1.20	1.16	1.10	1.10	1.59	1.47	1.24	1.24
CP	1.19	1.19	1.06	1.33	1.33	1.11	1.09	1.05	0.97	0.97	1.22	1.13	1.00	1.00
CTP	1.31	1.31	1.35	1.73	1.73	1.66	1.20	1.16	1.10	1.10	1.59	1.47	1.24	1.24
Price (euro/ton) change														
C	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
CT	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
CP	0.70	0.70	0.30	0.83	0.83	0.47	1.05	1.05	1.11	1.11	1.15	1.15	1.18	1.18
CTP	0.70	0.70	0.25	0.83	0.83	0.35	1.05	1.05	0.96	0.96	1.15	1.15	0.92	0.92
Yield x Prices (euro/ha) change														
C	1.19	1.19	1.06	1.33	1.33	1.11	1.09	1.05	0.97	0.97	1.22	1.13	1.00	1.00
CT	1.31	1.31	1.35	1.73	1.73	1.66	1.20	1.16	1.10	1.10	1.59	1.47	1.24	1.24
CP	0.83	0.83	0.32	1.10	1.10	0.52	1.14	1.10	1.07	1.07	1.40	1.30	1.18	1.18
CTP	0.92	0.92	0.34	1.44	1.44	0.58	1.26	1.22	1.06	1.06	1.82	1.69	1.14	1.14

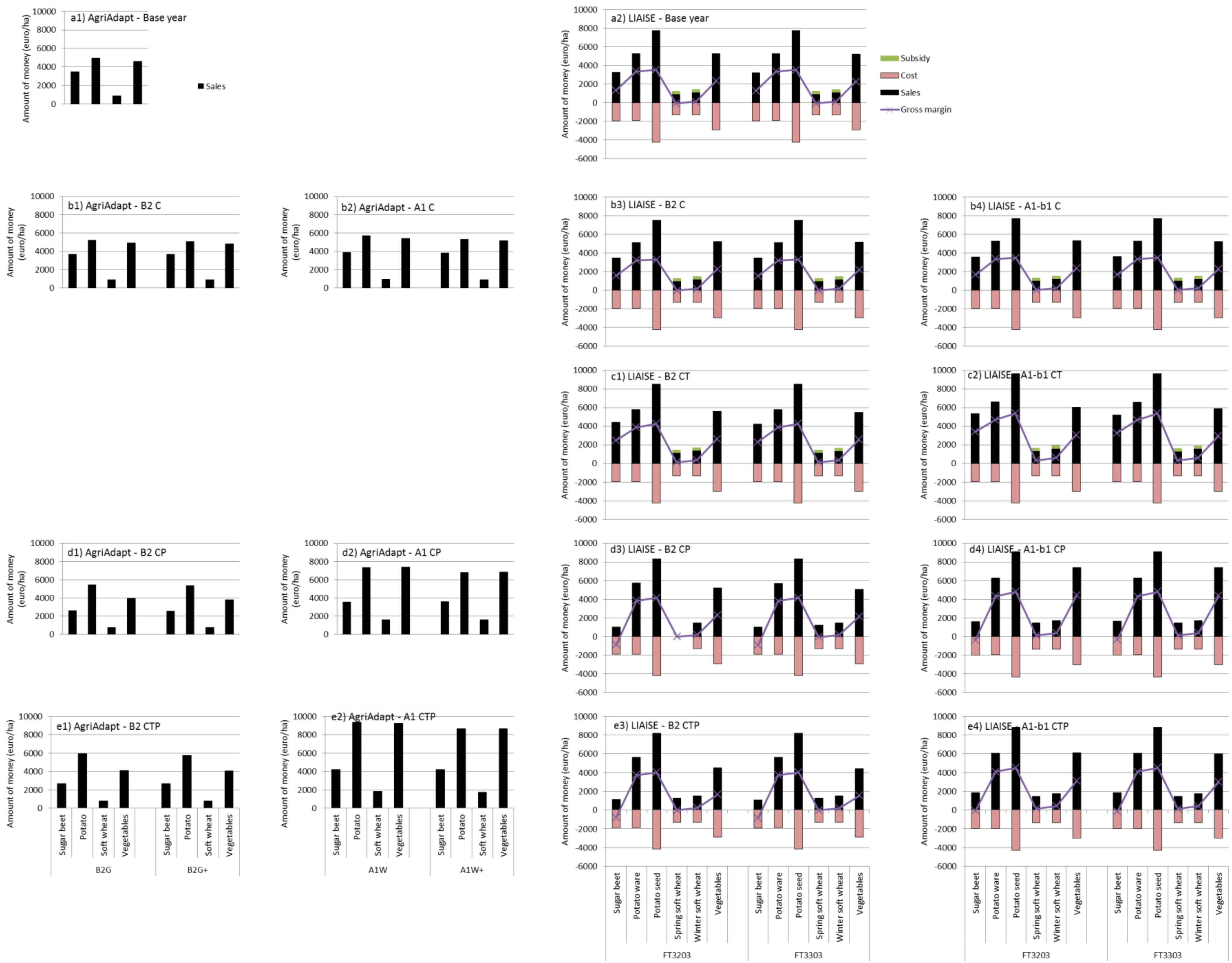
	Soft wheat								Onion					
	AgriAdapt		L_ Spring soft wheat	L_ Winter soft wheat	AgriAdapt		L_ Spring soft wheat	L_ Winter soft wheat	AgriAdapt		LIAISE (L)	AgriAdapt		LIAISE (L)
	B2G	$B2G^{+}$	B2	B2	A1W	$A1W^{+}$	A1-b1	A1-b1	B2G	$B2G^{+}$	B2	A1W	$A1W^{+}$	A1-b1
Yield (ton/ha) change														
C	1.12	1.08	1.05	1.05	1.20	1.12	1.09	1.09	1.20	1.14	0.99	1.42	1.31	1.01
CT	1.24	1.19	1.23	1.23	1.57	1.46	1.45	1.45	1.32	1.25	1.06	1.84	1.70	1.15
CP	1.12	1.08	1.05	1.05	1.20	1.12	1.09	1.09	1.20	1.14	0.99	1.42	1.31	1.01
CTP	1.24	1.19	1.23	1.23	1.57	1.46	1.45	1.45	1.32	1.25	1.06	1.84	1.70	1.15
Price (euro/ton) change														
C	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
CT	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
CP	0.89	0.89	1.27	1.27	1.67	1.67	1.42	1.42	0.88	0.88	1.00	1.15	1.15	1.40
CTP	0.89	0.89	1.09	1.09	1.67	1.67	1.08	1.08	0.88	0.88	0.81	1.15	1.15	1.01
Yield x Prices (euro/ha) change														
C	1.12	1.08	1.05	1.05	1.20	1.12	1.09	1.09	1.20	1.14	0.99	1.42	1.31	1.01
CT	1.24	1.19	1.23	1.23	1.57	1.46	1.45	1.45	1.32	1.25	1.06	1.84	1.70	1.15
CP	1.00	0.96	1.33	1.33	2.00	1.87	1.55	1.55	1.06	1.00	0.99	1.63	1.51	1.41
CTP	1.10	1.06	1.34	1.34	2.61	2.44	1.57	1.57	1.16	1.10	0.86	2.12	1.96	1.16

	Spring barley		Tulip		Maize fodder		Maize grain		Peas		Rape seed	
	L	L	L	L	L	L	L	L	L	L	L	L
	B2	A1-b1	B2	A1-b1	B2	A1-b1	B2	A1-b1	B2	A1-b1	B2	A1-b1
Yield (ton/ha) change												
C	1.00	1.05	0.99	1.01	1.01	1.02	1.03	1.04	0.98	1.01	0.98	1.03
CT	1.23	1.50	1.06	1.15	1.01	1.02	1.18	1.33	1.13	1.30	1.16	1.36
CP	1.00	1.05	0.99	1.01	1.01	1.02	1.03	1.04	0.98	1.01	0.98	1.03
CTP	1.23	1.50	1.06	1.15	1.01	1.02	1.18	1.33	1.13	1.30	1.16	1.36
Price (euro/ton) change												
C	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
CT	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
CP	0.96	1.10	1.00	1.40	1.09	1.18	1.44	1.65	0.81	0.94	1.79	1.87
CTP	0.81	0.82	0.81	1.01	0.99	0.99	1.22	1.21	0.76	0.83	1.57	1.43
Yield x Prices (euro/ha) change												
C	1.00	1.05	0.99	1.01	1.01	1.02	1.03	1.04	0.98	1.01	0.98	1.03
CT	1.23	1.50	1.06	1.15	1.01	1.02	1.18	1.33	1.13	1.30	1.16	1.36
CP	0.96	1.15	0.99	1.41	1.09	1.20	1.49	1.72	0.79	0.95	1.76	1.93
CTP	1.00	1.23	0.86	1.16	0.99	1.01	1.44	1.61	0.85	1.08	1.82	1.94

Supplementary table 2. Area (ha), yield (ton/ha), cost (euro/ha) and labour use (hour/ha) of each crop per AgriEnvironmental Zones (AEnZ).

AEnZ	Area (ha) FT3203		FT3303	
AENZ11317	7.8	(12.5%)	6.6	(11.1%)
AENZ11319	0.3	(0.5%)	0.2	(0.4%)
AENZ12993	53.5	(85.3%)	51.6	(86.8%)
AENZ12994	0.3	(0.5%)	0.3	(0.5%)
AENZ12995	0.8	(1.2%)	0.8	(1.3%)
Sum	62.7		59.4	

AEnZ	Sugar beet	Potato ware	Potato seed	Spring soft wheat	Winter soft wheat	Onion
Yields (ton/ha)						
AENZ11317	58.3	53.4	30.3	7.1	8.1	52.4
AENZ11319	51.0	50.0	21.9	6.4	7.8	46.4
AENZ12993	65.5	56.8	38.7	7.8	8.7	58.4
AENZ12994	65.5	56.8	38.7	7.8	8.7	58.4
AENZ12995	51.0	50.0	21.9	6.4	7.8	46.4
Cost (euro/ha)						
AENZ11317	1935	1923	4229	1312	1309	2943
AENZ11319	2149	1925	3147	1285	1394	2864
AENZ12993	1935	1923	4229	1312	1309	2943
AENZ12994	1935	1923	4229	1312	1309	2943
AENZ12995	2149	1925	3147	1285	1394	2864
Labour (hour/ha)						
AENZ11317	19.6	27.5	90.0	9.6	10.4	37.6
AENZ11319	17.8	25.8	71.0	8.5	9.6	37.9
AENZ12993	19.6	27.5	90.0	9.6	10.4	37.6
AENZ12994	19.6	27.5	90.0	9.6	10.4	37.6
AENZ12995	17.8	25.8	71.0	8.5	9.6	37.9


a1) AgriAdapt - Base year
Sales
a2) LIAISE - Base year
Subsidy
Cost
Sales
Gross margin
b1) AgriAdapt - B2 C
b2) AgriAdapt - A1 C
b3) LIAISE - B2 C
b4) LIAISE - A1-b1 C
c1) LIAISE - B2 CT
c2) LIAISE - A1-b1 CT
d1) AgriAdapt - B2 CP
d2) AgriAdapt - A1 CP
d3) LIAISE - B2 CP
d4) LIAISE - A1-b1 CP
e1) AgriAdapt - B2 CTP
e2) AgriAdapt - A1 CTP
e3) LIAISE - B2 CTP
e4) LIAISE - A1-b1 CTP
Amount of money (euro/ha)
Sugar beet
Potato
Soft wheat
Vegetables
B2G
B2G+
A1W
A1W+
Potato ware
Potato seed
Spring soft wheat
Winter soft wheat
FT3203
FT3303

Supplementary figure 1. Sales, cost, subsidy and gross margin (euro/ha) of the simulation output per crop. Gross margin was calculated as presented below:

Gross margin = sales + subsidy – cost

Costs of labour and rented land are not included. For AgriAdapt, the data for cost and subsidy per crop were not available because AgriAdapt uses the whole farm activity. Bar graphs show sales, cost and subsidy, and line graphs show gross margins for each crop under each sub-scenario (Base year; C: Climate change; CT: Climate and technology changes; CP: Climate and price changes; CTP: Climate, technology and price changes) for B2 and A1 scenario. The data were shown for average of total farms in AgriAdapt and for each farm type (FT3203, FT3303) in LIAISE.