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RESEARCH ARTICLE

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

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Abstract Towards 2050, climate change is one of the possible drivers that will change the farming landscape, but market, policy and technological development may be at least equally important. In the last decade, many studies assessed impacts of climate change and specific adaptation strategies. However, adaptation to climate change must be considered in the context of other driving forces that will cause farms of the future to look differently from today's farms. In this paper we use a historical analysis of the influence of different drivers on farm structure, complemented with literature and stakeholder consultations, to assess future structural change of farms in a region under different plausible futures. As climate change is one of the drivers considered, this study thus puts climate change impact and adaptation into the context of other drivers. The province of Flevoland in the north of The Netherlands was used as case study, with arable farming as the main activity. To account for the heterogeneity of farms and to indicate possible directions of farm structural change, a farm typology was developed. Trends in past developments in farm types were analyzed with data from the Dutch agricultural census. The historical analysis allowed to detect the relative importance of driving forces that contributed to farm structural changes. Simultaneously, scenario assumptions about changes in these driving forces elaborated at global and European levels, were downscaled for Flevoland, to regional and farm type level in order to project impacts of drivers on farm structural change towards 2050. Input from stakeholders was also used to detail the downscaled scenarios and to derive historical and future relationships between drivers and farm structural change. These downscaled scenarios and future driver-farm structural change relationships were used to derive quantitative estimations of farm structural change at regional and farm type level in Flevoland. In addition, stakeholder input was used to also derive images of future farms in Flevoland. The estimated farm structural changes differed substantially between the two scenarios. Our estimations of farm structural change provide a proper context for assessing impacts of and adaptation to climate change in 2050 at crop and farm level.

Keywords Agriculture · Adaptation · Climate change · Farm structural change · Flevoland

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Introduction

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

Impacts of future climate change are usually projected on current farms and cropping systems (Easterling et al. 2007). Since the impacts of climate change will be relatively minor in the short term, assessments must be performed for a long time horizon (2050 in present study), when climate change will likely be more manifest. For such time horizon effects of other drivers must be considered. At the same time, assessments of impacts and adaptation strategies have focused primarily on food production (Easterling and Apps 2005; Easterling et al. 2007), while in The Netherlands and Europe as a whole, multifunctionality has become more important. Effective adaptation strategies thus need to consider additional economic, social and environmental objectives, associated with the multifunctionality of agriculture. Therefore, one has to take into account that the farms in the future are not the same as the current ones: they will evolve through structural changes.

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

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

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

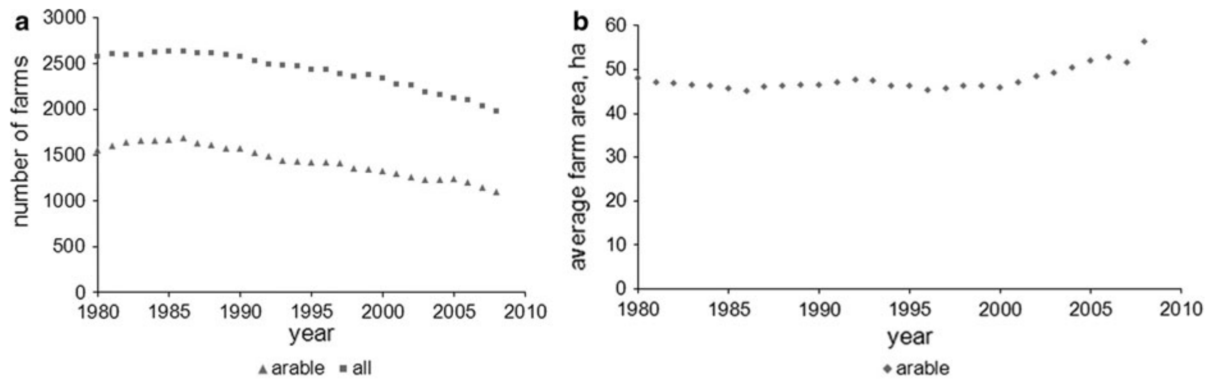

Fig. 1 Dynamics in **a** farm population in Flevoland in 1980–2008; **b** average area of arable farms in Flevoland in 1980–2008. *Source*: CBS

Materials and methods

Case study

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

Agriculture in Flevoland plays a key role for development and spatial planning. About 75% of the area in the province (90,820 ha) is used for agriculture (CBS 2009). Agriculture provides 5.5% of the Gross Regional Product and 6% of employment in Flevoland (in 2007 for The Netherlands these indicators were 1.8 and 3%, respectively). The dominating farm type is arable farming which comprises 70% of the total farm population and occupies 65% of utilized agricultural area (CBS 2009). In the past decades the agricultural area has decreased due to urbanization, expansion of infrastructure and natural areas.

Farms in Flevoland have been changing considerably during the last 30 years due to the changing economic and social environment in which they are embedded. We observe a decline in number of farms and increase in farm size over the past decades (Fig. 1). In the period 1980–2010 the number of arable farms decreased by 30%, whereas the average farm area increased by 20% (CBS 2009).

General procedure

The procedure to assess structural change of farms for 2050 includes several steps (Fig. 2). In the first step we identified current farm types and their distribution using a farm typology. In the second step, a historical analysis was performed to assess the impact of important drivers (technology, policy, market and climate change) on the farm structure. The outcome of this step is the relative contribution of each driver to the changes in each of the farm structural dimensions (orientation, size, intensity, specialization). In the next step, socio-economic and climate scenarios were downscaled to the regional level to explore effects of changes in the drivers and subsequent changes in farm dimensions and characteristics towards 2050. We first obtained the results on changes in farm dimensions at regional level. Subsequently, we downscaled these to the farm level using transition rules, resulting in scenarios of farm structural change.

Stakeholder input

To develop images on future farms in Flevoland, besides data and literature, we additionally used information from stakeholders (farmers, representatives of water boards, local policy makers). The stakeholder workshop was organized in the study area on the 1st of March 2010. The participants of the workshop contributed to the assessment of historical

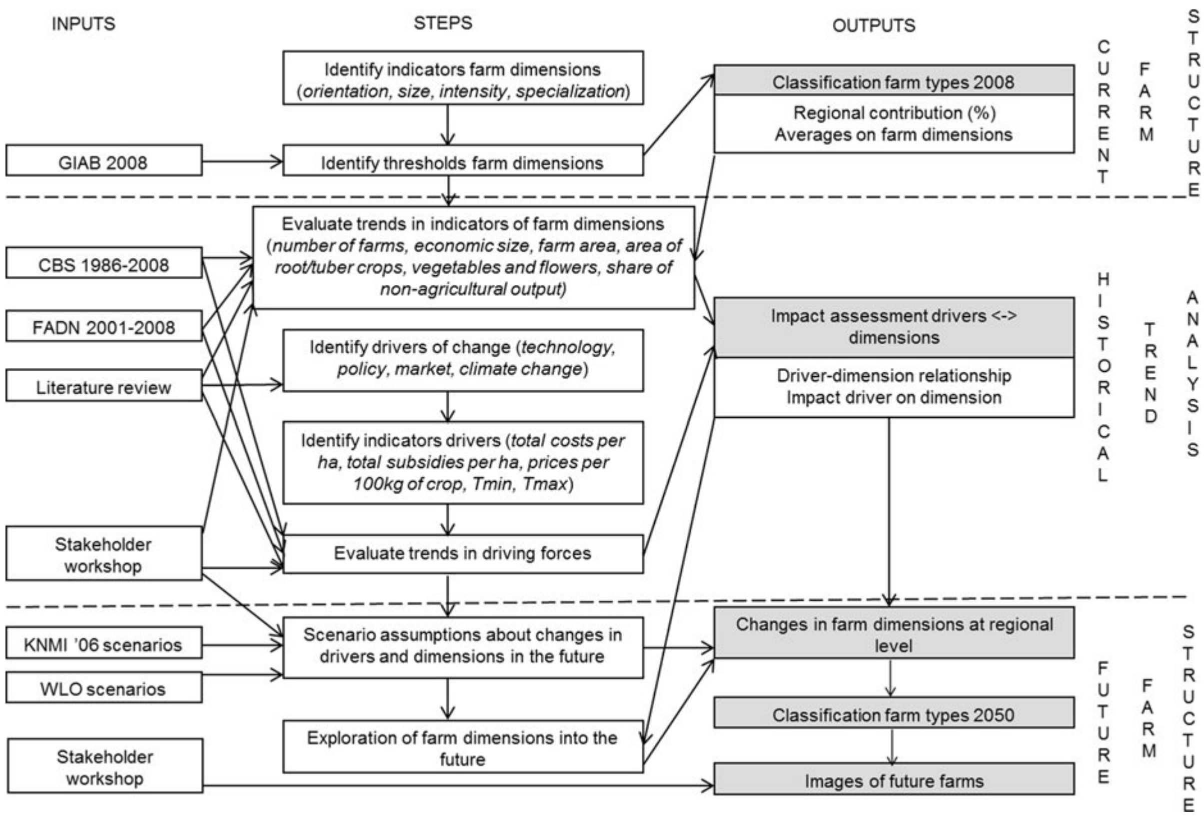

Fig. 2 Overview of the methodological approach to assess farm structural change. Abbreviations are explained in the text

relationships between drivers and farm structural dimensions and to projections on future impacts of drivers on farm structural change in the scenarios. Their input was also used to derive images of future farms for the two scenarios.

Classification farm types in 2008

To capture the variability in arable farming systems in Flevoland and their structural change in the future, the farm typology for farms in the European Union proposed by Andersen et al. (2007) was further specified for the region. The typology is based on the combination of four dimensions of which size, intensity, and specialization are similar to Andersen et al. Orientation (see below) was added as an extra dimension as it influences decision making of farmers and the landscape. An overview of the typology including thresholds for the dimensions is provided in Table 1.

The units of the dimensions of size, intensity and specialization and their thresholds are taken from the Dutch agricultural census. Farm size refers to the economic size of an agricultural holding and is measured in NGE. In 2008 1 NGE equaled to €1,420. It is a Dutch version of the European Size Unit (ESU), used to measure farm size across the EU and record it in the Farm Accountancy Data Network (FADN). Intensity is measured in NGE per ha and thus refers to output intensity. Specialization is defined by the crops with the highest share in the standard gross margin (SGM) grown on a farm. Orientation was identified through the share of output from non-agricultural activities. We hypothesize that farms having different orientations adopt different adaptation measures when confronted with external changes, since orientation can point at farmers' objectives, or farming styles as defined by van der Ploeg et al. (2009). We distinguish three farm types based on their major objectives, or orientations: production-oriented,

Table 1 Farm typology (dimensions and thresholds) used in the research

Dimension	Division/class	Thresholds/description
Size (NGE)[a]	Small	<20
	Medium	20–70
	Large	70–150
	Extra large	>150
Intensity (NGE/ha)	Low	<1.3
	Medium	1.4–2.0
	High	>2.1
Specialization	Specialized root crops	Sugar beets and potato >2/3 SGM[b]
	Specialized flower bulbs	Flower bulb >2/3 SGM
	Specialized vegetables	Vegetables >2/3 SGM
	Diverse mainly root crops	1/3< sugar beets and potato ≤2/3 SGM and cereals, maize, peas, rapeseed, sunflower, natural area and vegetables >2/3 SGM
	Diverse arable	All arable >2/3 SGM and not in above groups
Orientation	Production	No multifunctional activities or ≤10% output from 1 multifunctional activity
	Nature conservation	Farmer participates in nature conservation
	Entrepreneur	>10–50% output from multifunctional activities or <10% + minimum 2 different activities (except nature conservation)

Each farm type is defined by a size, intensity, specialization and orientation dimension

[a] NGE is a national size unit, representing gross income from cultivation of a certain crop or from keeping a certain animal (CBS 2008), equaling €1,420 in 2008

[b] SGM is a standard gross margin of a crop

entrepreneur-oriented and nature conservation-oriented. These farm categories are recognized by Dutch policy makers (Jongeneel et al. 2008; Dokter and Oppewal 2009; Venema et al. 2009). To account for other functions agriculture can provide to a society, an entrepreneur-oriented type of farmers was included into the typology. These farmers diversify their income with alternative societal functions of agriculture: sustainable energy production, housing goods or animals (garaging), processing of agricultural products, recreation, education and care farming. Nature conservation farmers represent a separate orientation due to the significant role nature conservation plays in Dutch agriculture (Daniel and Perraud 2009). For assigning all individual farms to the farm typology the Geographical Information System for Agricultural Businesses (GIAB) was used, containing all 1,114 arable farms in Flevoland for the year 2008.

Historical trend analysis

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

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

Changes in values of each of the dimensions over time were assessed through selected indicators. For size and intensity these were the same as used for the farm typology (Table 1), but for the categorical dimensions, numerical variables needed to be selected. For specialization we selected area of root crops, flower bulbs, and vegetables (% in total arable and non-greenhouse horticultural land); and for orientation: the share of non-agricultural output (% from total economic output). For farm size additionally we considered the farm size in ha.

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

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

Assessing future farm structural change

Scenarios

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

Drivers at regional level

Per scenario, we analyzed possible developments in drivers impacting structural change. We used the same indicators for drivers as in the historical trend analysis. Applying scenario assumptions on changes in technology, policy, market and climate (Table 2) we projected the impact of two scenarios on the indicators for these drivers.

Developments in technology will be of a different nature in the two scenarios. While in A1 technological progress will be related to further increase crop productivity accompanied with necessary intensification of production, in B2 the focus will be on clean and energy saving technology, which does not necessarily lead to higher production intensity. The Common Agricultural Policy (CAP) is assumed to develop differently in A1 and B2. In A1 we assume adoption of option 3 proposed by the European Commission (EC) in November 2010, which implies abolishment of direct payments and introduction of small payments for environmental public goods. In B2 we see the CAP to be similar to option 1 as proposed by the EC:

Table 2 Assumptions on development of drivers and dimensions per scenario

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

[a] Estimations in Ewert et al. (2005) referred to technology development represented by yield changes. In B2 yield changes were assumed to remain stable. We assume a slight increase in total costs, considering the development of clean and energy saving technology

[b] Too few data were available to extrapolate. These general assumptions are further detailed in the downscaling to farm level

maintaining levels of payments for social and environmental services. Future market developments in these scenarios are assessed through changes in prices for agricultural commodities using the CAPRI model (Britz 2005; Ewert et al. 2011). The simulated price scenarios comprise changes on the supply side (yield changes due to climate change and technological development) as well as on the demand side (population and GDP). While in A1 there will be considerable increase in prices for wheat and ware potato due to large increase in demand, in B2 the prices will slightly increase (potato) or decrease (wheat).

Dimensions at regional level

At regional level, farm structural change is represented by changes in regional average values of each of the typology dimensions. These were estimated using three steps. First, we extrapolated historical trends (see e.g. Fig. 1) in the farm structural dimensions towards 2050, considering different types of functions (linear, exponential, logarithmic) and time periods. The best fitting and explanatory function and time period were used for extrapolation. Scenario assumptions in A1 (B2) on changes in dimensions were used to adjust these extrapolations (Table 2). This method yields first estimations based on historical trends.

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

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

Classification farm types in 2050

The current farm typology together with projections on changes in regional averages of structural dimensions towards 2050 were used to assess farm structural change, resulting in a classification of farm types in 2050. Transition rules were developed for the downscaling of regional to farm type level. The structural dimensions for which projected regional averages had a solid statistical basis, were used as a starting point. As this differed for the A1 and B2 scenarios, the resulting rules were slightly different. Overall, the rules can be summarized as follows:

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

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

Results

Classification farm types in 2008

In Fig. 3 and Online supplementary material we summarize the distribution of farm types in Flevoland in 2008. The currently dominant farm type is production oriented—large—medium intensive—diverse: mainly root crops (19.3% of area). This farm type has an average economic size of 104 NGE and area of 64 ha. At regional level, the vast majority of farms is production-oriented (88.5%). Large and medium intensive farms are prevailing. In terms of specialization, most farms are diverse, with mainly root and tuber crops.

Regional level: historical trends of dimensions

The outcomes of the historical trend analyses over 1986–2008 per farm structural dimension show that there was a slight increase in farm size, which was related to an increase in intensity up to 2001, and to an increase in farm area in the last years (Fig. 4a, b). With farm area increasing faster than NGE, intensity decreased in the last decade. One of the reasons for an increase in average area is that the number of farms with the size of 50–100 NGE decreased dramatically (Fig. 4c). There have been clear changes in specialization (Fig. 4d). Area of root and tuber crops is currently decreasing in Flevoland (mainly sugar beet) after a period of slight increase (potato) and stabilization (sugar beet) in the 1980's and 1990's. The areas of vegetables and flower bulbs increased, but the latter remains low in comparison to other crop areas. As to orientation, for the last 10 years (since the data is available) the percentage of farm output from multifunctional activities has varied significantly (Fig. 4e). This variation is most likely due to a change in the way data are collected. Currently, the most popular multifunctional activities, according to CBS (2009), include work loan, nature conservation, and garaging (keeping goods or animals on the farm).

Historical driver—dimension relationship

Changes in farm type dimensions were mainly attributed to technological progress, market development, and policy; climate seemed to have less influence (Table 3; Fig. 5). In some cases the relationship

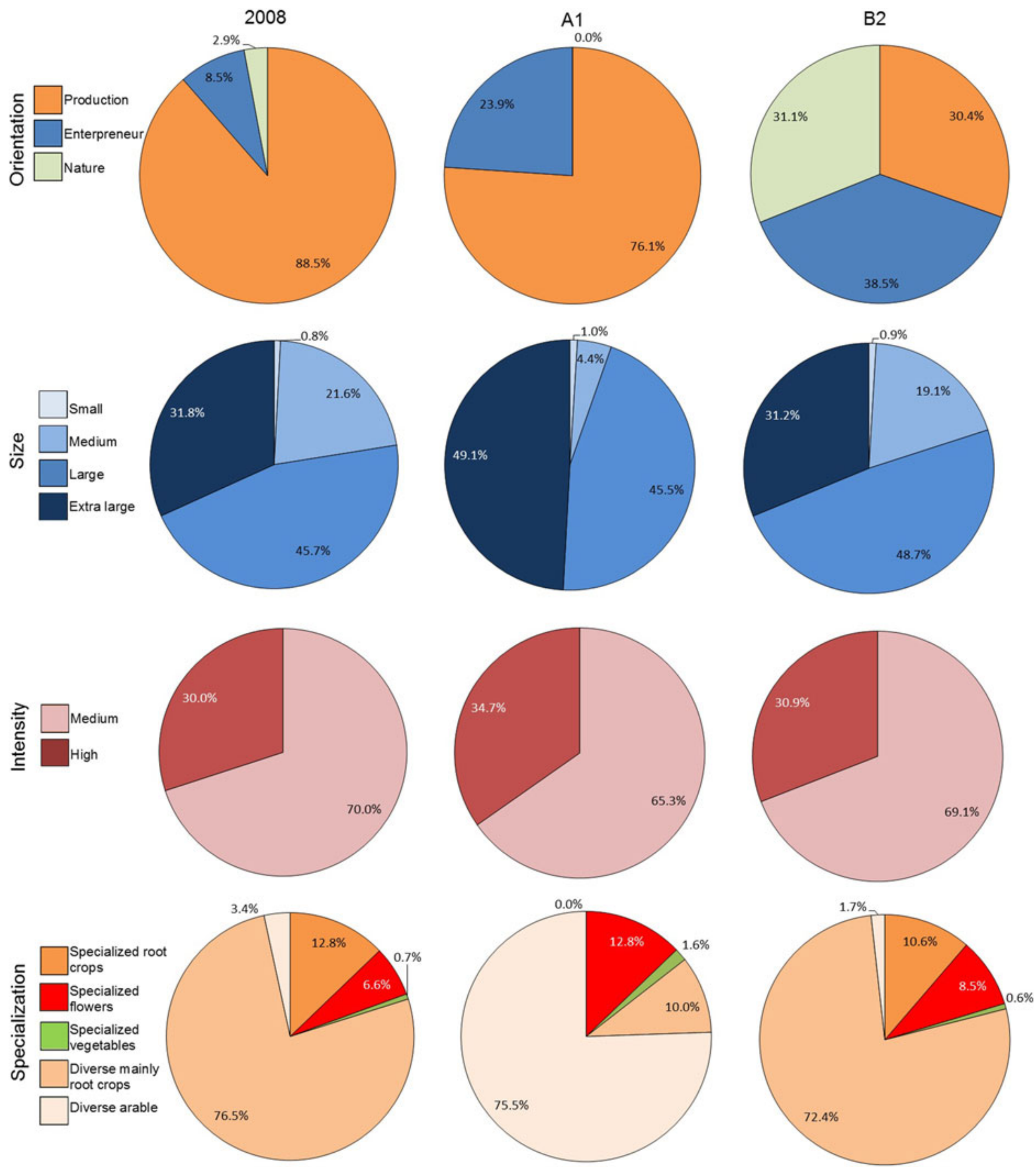

Fig. 3 Regional farm type distribution and structural change in % from utilized arable area

between a driver and dimension was not confirmed by the statistical analyses, whereas literature review and stakeholder interactions had pointed at a relationship.

Regarding orientation, literature (e.g. Roest et al. 2010) and stakeholders learned us that policy incentives stimulated adoption of non-agricultural activities (Table 3). The impact from market was indirect: the farmers looked for alternative sources of income due to a decrease over time in prices for the major crops. Both relationships were not reflected in

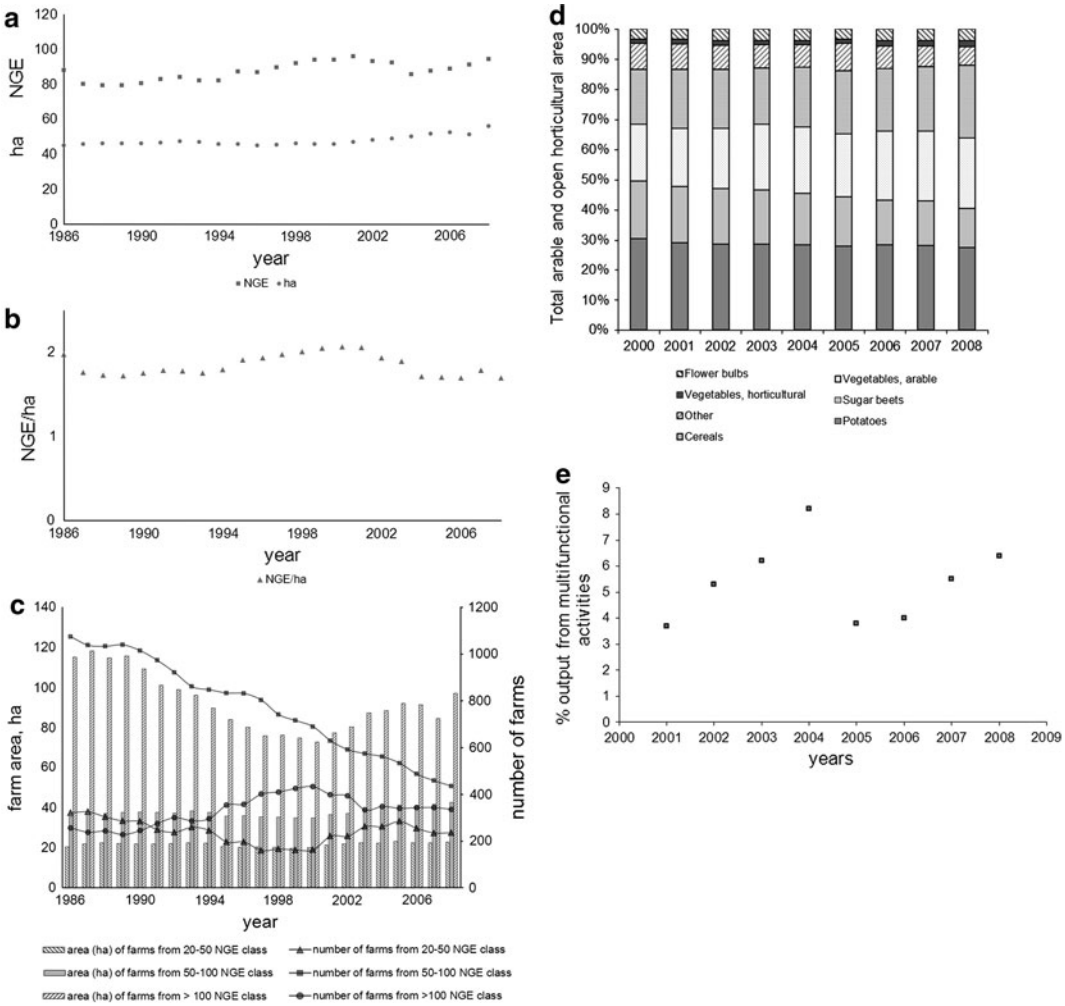

Fig. 4 Changes in structural dimensions in time: **a** farm size (NGE and ha); **b** farm intensity (NGE/ha); **c** numbers of farms in different size classes and their average farm area (ha); **d** areas (%) of crop types; **e** percentage of farm output from multifunctional activities. *Source*: CBS

statistics (Fig. 5) due to short time series and unreliable data on multifunctional activities.

Farm size was influenced by technology and market (Table 3). Increase in crop productivity was mainly caused by technological advances (input intensity, efficient machinery, new crop varieties with higher yields and pest/disease resistance, new management techniques). The output prices define to a large extent farm gross income and therefore they influence farm economic size. While prices for the major crops in Flevoland decreased over time, farmers took some advantage of economy of scales to increase farm size and compensate for low prices. The correlation between farm size and temperature is not considered causal (Fig. 5), as both gradually increased over past decades.

Intensity was only influenced directly by policies (Table 3). Although productivity increased, the NGE unit is adapted over time to reflect developments in technology and markets. Farmers receiving more subsidies, however, have less need to intensify, and subsidies can also be made dependent upon stopping intensification (cross-compliance).

As to specialization, technological developments in crop production (e.g. machinery for large scale vegetable production) and market prices influence crop choice. Crops with high gross margins like root and tuber crops, vegetables and flower bulbs increased

Table 3 Contribution of drivers to farm structural change based on historical analysis

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

0 No significant impact on structural change

\+ Impact on structural change

++ Strong impact on structural change

their share in a typical rotation in Flevoland. Specific crop subsidies or quotas (f.e. for sugar beets) also influenced crop choice on farms (van Bruchem and Silvis 2008). So far, in Flevoland there is no strong evidence of climate change impact on crop choice or any of the other dimensions of the farm typology. Figure 5 shows a correlation between temperature and area of root and tuber crops, but the increase in these crops over time is attributed to other factors (literature, stakeholders) and not related to the simultaneously increasing temperature. Nevertheless, as shown in Olesen and Bindi (2002) and Reidsma et al. (2007) there is spatial variability in yields and crop choice within Europe through impact of climate conditions.

Future driver-dimension relationship

Applying the scenario assumptions on changes in technology, policy, markets, and climate (presented earlier in Table 2) we projected the impact of drivers per dimension in two scenarios (Table 4). Overall, impacts are similar to Table 3, but the size depends on the change in drivers, which is different for the A1 and B2 scenario. Next to size of impact, types of impact can also differ. As mentioned earlier, in B2 the technology changes will be in the direction of energy-saving and environmentally friendly, which will have less influence on farm structure than in A1. For orientation, policy is the major driver that has a different focus per scenario with respect to stimuli for adoption of particular non-agricultural activities on the farm.

Future farm structure

Dimensions at regional level

As different methods were combined to derive regional averages of farm structural dimensions (Table 5), we first describe the procedure and present results of intermediate steps. Although our aim was to provide a transparent and consistent methodology, heterogeneity in data availability and ambiguous relationships between dimensions, drivers and time, required also decisions based on expert knowledge and qualitative interpretation.

When linearly extrapolating farm size in NGE for A1, we obtain a value of 118 NGE (25% of this for B2 is 101 NGE; Fig. 6a). Considering the regressions with technology (Fig. 6b) and markets (the drivers impacting farm size; see Table 4) and scenario assumptions for these drivers (Fig. 6c), results in slightly lower values (Fig. 6d). NGE is however a difficult unit; it depends mainly on the type of crops cultivated and the farm area used for this. We had to investigate this before coming to a final value.

If the increase in farm area since 1995 continues, this results in an average farm area of 84 ha (see Fig. 4a). Using the relationship with technology (Fig. 5), we obtain a lower value, and we use the average of both, 75 ha, as the projection for A1 (59 ha in B2) (Table 5). As the statistical relationship between farm area and input costs (technology) is much stronger than the relationship with product prices (market) (Fig. 5), the latter is not used for the projections.

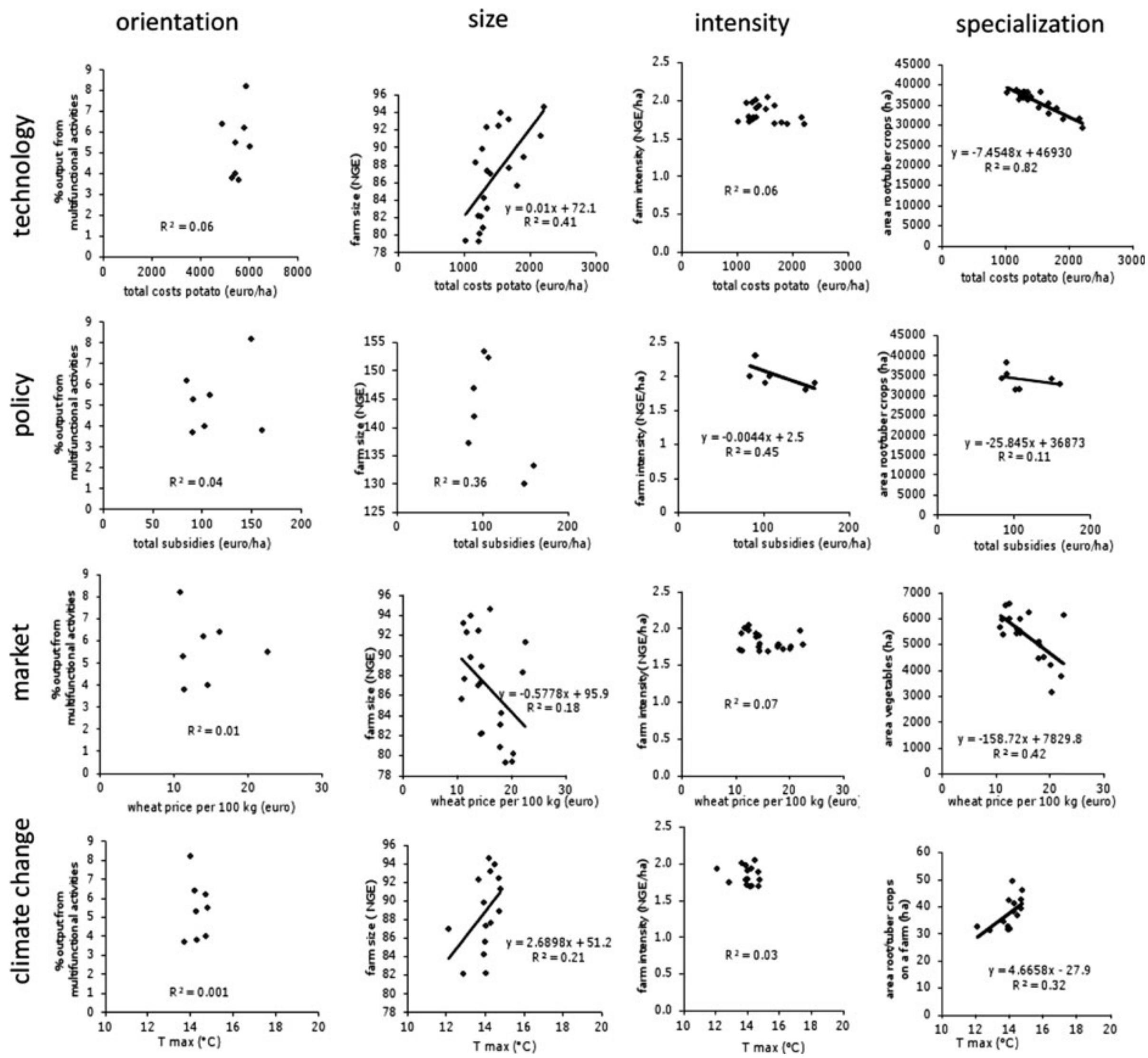

Fig. 5 Statistical relationships (correlation) between drivers and structural dimensions. *Source*: CBS, except for the indicator for driver of policy (total subsidies) and the indicator for dimension of orientation (% output from multifunctional activities) which were taken from FADN. Regression function is shown only in cases when the relationship is significant ($p < 0.05$)

Using values on changes in NGE and in ha as calculated with these two quantitative methods, results in a faster increase in area than NGE, and therefore a decreasing intensity. However, in A1 with increasing areas of vegetables and flower bulbs, it is likely that intensity remains stable. Therefore we calculate the final value for farm size based on the projected value for farm area and a stable intensity (Fig. 6a; Table 5). In B2, intensity can decrease (Table 2), and values for farm size and farm area are used to calculate change in intensity.

With regard to specialization, it is clear that potato area is relatively stable (Fig. 4d), sugar beet area is quickly decreasing, while projecting change in vegetable area depends on the statistical relationship (linear, exponential, logarithmic) and time period taken. It is likely that in A1 sugar beet will disappear (following the trend, further liberalization) and will be replaced by vegetables like onion and carrots (possible due to technological development and high market value). For flower bulbs a linear trend is extrapolated. In the B2 scenario projected changes will be 25% of the historical trend, resulting in similar but smaller changes.

Lastly, orientation will change. In A1 there are no subsidies for nature conservation, so these farms will

Table 4 Impact of drivers on farm structural change in future scenarios

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

0 No significant impact on structural change

+ Impact on structural change

++ Strong impact on structural change

Magnitude in change in drivers (*0* no change, + slight change, ++ significant change) is derived from Table 3

disappear. Increase in share of entrepreneurial, or multifunctional farming happens, since farmers seek alternative sources of income due to changes in the agricultural policy paradigm (abolishment of payments and little alternative subsidies). It is assumed that 30% of the farmers will be entrepreneur in 2050. In B2, multifunctional activities become profitable when alternative income and subsidies exceed gross margin of crops. It is assumed that also in this scenario 30% will become entrepreneur, and another 30% will become nature oriented. These assumptions are made on the basis of literature review (e.g. Jongeneel et al. 2008; European Commission 2010), and were discussed with stakeholders.

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

Farm level structural change and classification farm types in 2050

At regional level, several changes are very clear in the A1 scenario. Already now, medium sized farms are quickly reducing in number (Fig. 4c), and it is projected that medium sized production oriented farms cannot remain viable (e.g. Reilly 2005). If all these medium sized farms except for the ones specialized in vegetables and flower bulbs disappear, we come close to the 384 farms that were projected to stop (Table 5), and to projected regional averages of size in NGE and ha.

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

With regard to specialization, in A1 it is projected that all sugar beets are replaced by vegetables. This implies that ‘specialized: root crops’ become ‘diverse: mainly root crops’ and the latter become ‘diverse: arable’. Farms specializing in vegetables are mainly the horticultural ones, and not much change in area is foreseen here (see Fig. 4d). Using regional average changes in dimensions as boundaries for changes, we have to conclude that the increase in area of flower bulbs has to come from an increase in the average area of very large farms.

Table 5 Regional averages of farm structural dimensions

Dimensions	Structural characteristics	2008	A1	Change (%)	B2	Change (%)
	Arable UAA, 10^3 ha	78[a]	68[b]	−13	72[b]	−8
	Number of arable farms	1,100[a]	716[c]	−35	962[c]	−13
	Average farm area, ha	56[a]	75	+34	59	+6
Size	Average size, NGE	95[a]	128	+34	98	+4
Intensity	Average intensity, NGE/ha	1.7[a]	1.7	0	1.7	−2
Specialization	Area root/tuber crops, % arable UAA	40[a]	26	−36	37	−9
	Area vegetables, % arable UAA	26[a]	38	+51	29	+13
	Area flower bulbs, % arable UAA	4.0[a]	6.4	+60	4.6	+15
Orientation	Entrepreneur oriented farms, % of farms	8[d]	30	+275	30	+275
	Nature oriented farms, % of farms	2[d]	0	−100	30	+1,400

[a] CBS

[b] Extrapolated from 2040 values as projected by Riedijk et al. (2007)

[c] Calculated by dividing future arable UAA by projected average farm area. It is assumed that the % arable UAA in arable farm types remains stable, as was the case in the past

[d] GIAB

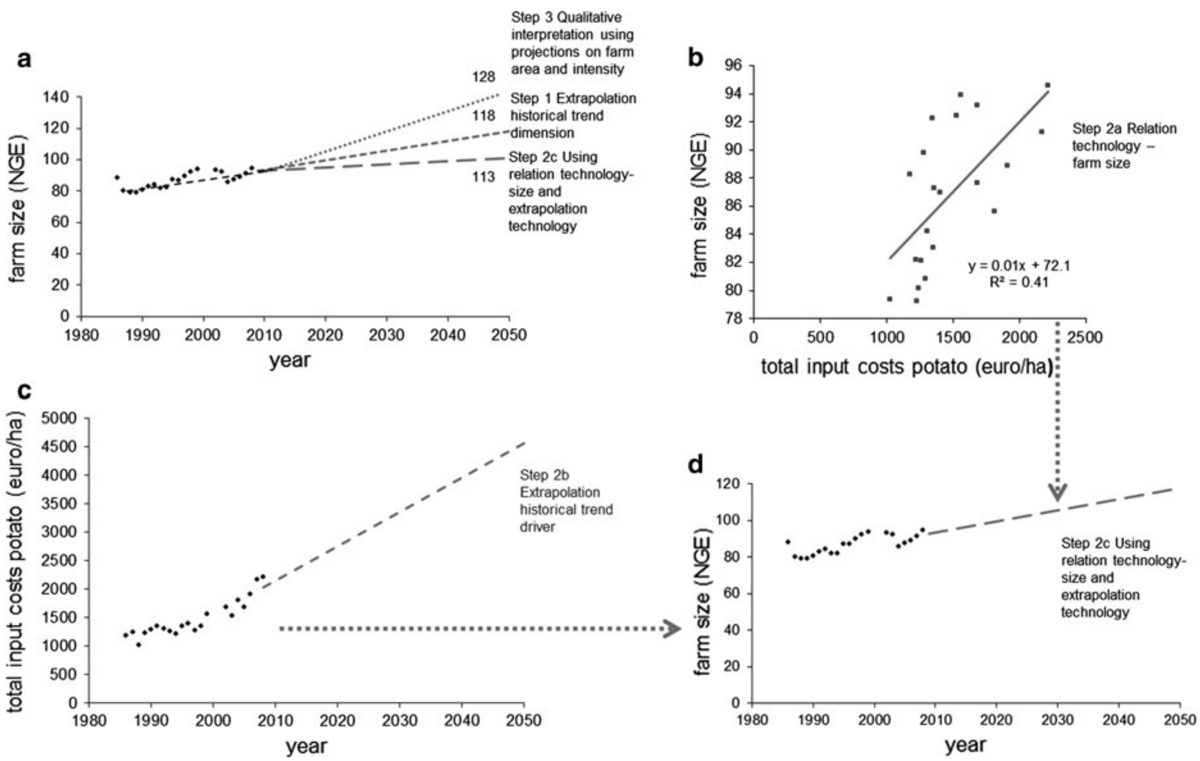

Fig. 6 Schematic representation of procedure to derive future farm size in A1 scenario, with **a** summary of all steps; **b** Step 2a relationship driver-dimension; **c** Step 2b extrapolating historical trend driver; **d** Step 2c projection dimension based on driver. *Source*: CBS

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

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

The results on classification of farm types in 2050 in two scenarios are given in Online supplementary material. The most important farm type in A1 is production oriented—very large—medium intensive—diverse: arable (16%), similar to current, but one size class larger and a change from ‘diverse: mainly root crops’ to ‘diverse: arable’ due to disappearance of sugar beets. In B2 the largest type is entrepreneur oriented—large—medium intensive—diverse: mainly root crops (15%). The aggregated farm level results are shown in Fig. 3.

Images of future farms

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

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

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

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

Discussion and concluding remarks

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

Limitations and qualifications of the methodology

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

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

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

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

Implications of the estimated farm structural change

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

This paper does not explicitly addresses landscape impacts. However, Fig. 3 indicates the implications of farm structural change for the landscape in Flevoland towards 2050 in different scenarios. Arable farming occupies a large area of Flevoland and therefore largely influences the landscape. In A1 in Flevoland we can expect large scale farming systems specializing in intensive crops. In B2 there is still place for smaller farms. In general this scenario is characterized by a higher diversity in farming landscape with focus on local crops and markets, more nature conservation and provision of alternative functions to the society. Therefore, the two scenarios will be quite contrasting in terms of implications for nature and other landscape functions in Flevoland.

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