Impacts of climate and socio-economic change on economic viability and land use of dairy farms in 'de Baakse Beek', the Netherlands.

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List of abbreviations

ACC:	Agro Climate Calendar
APS:	Animal Production Systems
Av:	Average
BY1	Base year simulation with short and long-term constraints
BY2:	Base year simulation with long-term constraints
CARE:	Climate Adaptation for Rural Areas
CC:	Simulation including general climate change
EE:	Simulation including extreme events
FADN:	Farm Accountancy Data Network
G:	Climate change scenario with 1°C global temperature rise and no change in atmospheric circulation. In this report combined with RC.
GE:	Global Economy scenario for 2050. In this report combined with W^+.
JC:	Simulation including juridical change
K:	Potassium
LEI:	Landbouw Economisch Instituut
KfC:	Knowledge for Climate program.
LP-model:	Linear Programming Model
MOD:	Modulus
N:	Nitrogen
NA:	Data not available
NB:	Non-binding constraint (shadow price = 0)
NGE:	Dutch Size Unit (Nationaal Grootte Eenheid; measure of size for farms that is related to standard gross income)
P:	Phosphorus
PC:	Simulation including price changes
PPS:	Plant Production Systems
PPO:	Plant Praktijk en Omgeving
PRI:	Plant Research International
RC:	Regional Community scenario for 2050. In this report combined with G.
TC:	Simulation including technological change
W^+:	Climate change scenario with 2°C global temperature rise and change in atmospheric circulation. In this report combined with GE.

Clarification of concepts

Activity:	Variable element in LP-model that is limited by constraints. In this study all agricultural practices are collated in 'whole farm' activities, which are specified by their inputs and outputs.
Binding constraint:	A constraint in an LP-model that turns out to be constraining for the selection of activities that will further increase the value of the objective function. Loosening a binding constraint implies an increase in objective value.
Convexity-constraint:	In this report the convexity constraint accounts for the concept that the ratio between inputs and outputs changes at increasing inputs.
LP-model:	Mathematical optimization model in which the most optimal solution for a problem is calculated with aid of linear programmed and predefined objectives, activities and constraints.
Shadow price:	The increase in objective value after a constraint is loosened with one unit. The shadow price of a binding constraint will always be bigger than zero and the shadow price of a non-binding constraint will always be zero.

Abstract

Keywords: Dairy farming, climate change, socio-economic change, scenarios, exploration, land use.

Climate change happens in the broader context of society. Together, climate and socio-economic change will affect the economic viability and land use of Dutch dairy farms. Effective agricultural and environmental policies are required to enable adaptation of farms to these changes. These adaptations need to be coherent with developments in the domains of nature and water management. Explorations for the future that include climate and socio-economic change are necessary to perform ex-ante policy assessment.

This study uses a bio-economic farm model to assess impacts of cl;imate and socio-economic change on medium (<70 Dutch Size Unit; NGE) and large (>70 NGE) dairy farms in 'de Baakse Beek', a dry rural area in the Netherlands. The model is a linear programming model (LP-model) with maximizing gross margin as objective, subjected to constraints. 'Whole farms' are main activities in the LP-model. The methodology of using 'whole farms' covers the variable returns to scale and farm specific interactions. Farm data from the Farm Accountancy Data Network (FADN) provided information on the current available productivity levels and resources of 20 specialized dairy farms from 2001-2006. First, the current situation was simulated to study the scope for improving the current situation. Second, simulations for two predefined integrated scenarios were included: a Global Economy with 2^{o}C global temperature rise (GE) and a Regional Community with 1^{O}C global temperature rise (RC). Sub-scenarios included impact of: gradual climate change on water limited maize and grass yields (CC), extreme events on water limited maize and grass yields (EE), juridical change (JC; including abolishment milk quota), technological change on milk, maize and grass yields (TC) and price changes (PC). For the explorative simulations extra activities and constraints were included in the LP-model.

Currently, medium and large farms could increase profit by reducing inputs and becoming more efficient. In GE, large farms increase the area of grass while medium farms focus on producing maize, while in RC the current grass ratio is expected to be maintained. In both scenarios medium farms benefit more in JC and better adapt to negative and positive impacts of climate change compared to larger farms. The value of land increases significantly in TC in both scenarios. In both GE and RC dairy farms will intensify production and fertilizer use. Abolishment of legislation on nitrogen application (N-legislation) in GE leads to an excess of manure application, which will lead to high pressure on the environment. In TC in RC pressure of N-legislation on standard gross margin is high. Still, fertilizer use in RC is not coherent with the storyline of a regional community. After abolishment of the milk quota, milk production is restricted by feed availability for TC in GE. However, for TC in RC the milk production is restricted by milk yield increase potential, while in JC it was still restricted by feed supply. Technological change is not only important in both scenarios to obviate negative impacts of climate change, but is also important in RC where negative price developments have to be compensated.

All studied climate and socio-economic changes in this research turned out to be of importance. The used methodology gives an insight about improvements that can be made in the current situation and in the future. Adaptation activities and technological development to increase production and resilience are important. However, it should be noted that increase in feed supply increases the additional gross margin that can be gained with extra land, which will increase the cost for nature policies that require agricultural land. More adaptation activities need to be included in the model to evaluate policy options. Also nitrogen application rules need to be revised in the model. The proposed adaptations to the model will improve the insight in the way in which agricultural, nature and environmental policies should co-develop to achieve higher sustainability.

Preface

This document is the result of a research on the impact of climate, legislative, economic & technical change on dairy farms in 'De Baakse Beek', de Achterhoek, the Netherlands. Chapter 1 starts with the relevance of the research and the guiding research questions. Chapter 2 gives an introduction to the study area: *de Baakse Beek, the Netherlands.* Chapter 3 presents the methodology that is used to answer the research questions. In Chapter 4 the results of the study are presented. Chapter 5 discusses the results and the validity of the methodology and provides recommendations to improve the methodology. Chapter 6 draws conclusions from the results and discussion.

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1. Introduction

Agriculture in the Netherlands has faced, and still is facing, persistent problems, especially considering the environment (Oenema *et al.* 2006; Rotmans, 2003) and economic viability (Rotmans, 2003). According to Rotmans (2003), the Dutch agriculture is in a transition to a more sustainable situation in the environmental, sociologic and economic perspective. However, this transition process is still vulnerable, due to the phase in which it currently is. Besides, the transition of agriculture is dependent on the developments in other domains of society. Especially nature conservation and water management are strongly intertwined with agriculture, as they compete for space and often have opposing stakes. The domains of nature conservation and water management also face sustainability challenges and are in transition. However, the transitions in these domains are at a different phase than the transition of agriculture: the latter is already in the take-off phase, while the former two are in 'pre-development' (Rotmans, 2003). For a complete transition to a more sustainable future of society it is of vital importance that at micro, meso and macro level processes of change stimulate and strengthen each other (Rotmans, 2003). For agriculture this implies a development that is coherent with development in other domains.

Predictability and stable physical conditions could enhance a transition process. However, on top of the challenges and the accompanying transition processes, climate is changing, partly due to human influence. It is expected that this rise in temperature and the coherent climate change will continue, even with a reduction of human activities that induce part of the climate change. The climate change will have an impact on the earth and hence human activities. Climate change is per definition a process with a long time horizon (Riedijk et al., 2007). Therefore it is necessary to include climate change impacts in the long-term decision making for a transition to a more sustainable future. That is the reason that the Dutch government initiated the '*Knowledge for Climate Research Programme*' (KfC). *KfC* develops supportive (scientific) knowledge and services that are intended to make The Netherlands climate proof.

KfC selected nine areas, the so-called hotspots, for research. The areas are chosen based on 1) economic importance, 2) expected climatic impact, 3) ambitions for innovation and adaptation and 4) degree in which knowledge can be transferred at a national and international level. Dry rural areas are marked as a hotspot and are included in the Climate Adaptation for Rural Areas project (CARE). '*De Baakse Beek*' (situated in '*De Achterhoek*', *The Netherlands*) is one of the main case study areas in CARE. See Figure 1 for a topographic representation of the area. This area is transforming to a more multifunctional landscape and current policies aim to strengthen this process. Climate change however, puts a high pressure on the process of transformation, mainly due to increased water dynamics: In the future different amounts of precipitation and longer periods of drought are expected in '*De Baakse Beek*'. In '*De Baakse Beek'* policies focus on sustainable use of land and water. Policy making is performed in the domains of agriculture, nature conservation and water management. *KfC* aims to connect the different domains of policy making involved in this project by an integrated approach supported by scientific knowledge. Knowledge for Climate (2012; www.knowledgeforclimate.climateresearchnetherlands.nl).

Figure 1: Topographic map of '*De Baakse Beek*'. Legend: red=urban area, green=nature area. Source: Baakse Beek Veengoot (2012; www.baaksebeek.nl)

Climate change has an impact on the cultivation activities as well as on other on-farm activities. Main impacts are changes in crop yields, increased risk, adaptations to prevent inundation and/or drought. Besides climate change there is also an impact from technological innovation, changing markets and changing policies. Impact from climate change as well as technical innovation and changing markets and policies is expected to lead to a change in agricultural activities in '*De Baakse Beek*'.

It is not sure whether this change is coherent with the intentions of the climate adaptation policies, that aim for viable agriculture in a resilient multifunctional landscape. Direct goals are preventing land from inundation and to increase drought resistance in '*De Baakse Beek'*. A provides a table with preliminary agricultural, nature and environmental policy options to make 'de Baakse Beek' climate proof. It is uncertain whether the change in agricultural activities will comply with the policy options for existing nature conservation, in particular the policy on the national ecological network. Also the water management policy options might conflict with the direction that agriculture is heading for in the changing environment. Considering the prevalent uncertainties, design of well-functioning policies is tough. Especially when it comes to long-term policies as climate adaptation and nature management. To some extent, uncertainties can be overcome by ex-ante assessments on effects of (global) change and policies. By overcoming uncertainties, policy making can be supported. That is the ultimate aim of this research. A tool for such assessments is a simulation model that explores the change of agricultural activities over time.

As a start for 'De Baakse Beek', a simulation for 2050 is conducted for *specialized dairy farming*, which is the predominant farm type in the area. In addition the expected economic returns are of importance: although the relative importance of the dairy sector has decreased in the last decades (Westhoek, 2006), the worldwide demand for dairy products is increasing (van Well and Rougoor, 2008). After abolishment of the milk quota there is a chance that international trade is increasing (Westhoek, 2006). That is mainly due to a rising demand of dairy products by Asian countries, because it is expected that the domestic demand will not be completely fulfilled by domestic production in these countries (Fuller, 2006). Also the degree of potential knowledge transfer is high as within the Netherlands and Europe dairy farming is a widespread agricultural activity. A lot is known about the causality in specialized dairy farming (See for instance the work on dairy livestock systems of Berendsen & Giesen (1995), van Calker et al. (2004), Thorne et al. (2009), Groot & Oomen (2011)). However, the time span still causes lot of uncertainties. The knowledge on causality and the uncertainty imply that research can be systematic, but with a high 'what if' content, which is defined as exploratory (Becker & Dewulf, 1989 cited in van Ittersum et al. 1998). The 'what if' content of this exploratory study is translated into two scenarios. Simulations are run for these two different scenarios, which represent the most extreme combinations of climate and socio-economic change.

The guiding research questions that lead to supportive knowledge for policy making are:

How could farmers adapt in the current situation to perform better from an economic perspective?

What is the expected farm activity and indicator change for the different classes of specialized dairy farms in 'De Baakse Beek' for two extreme scenarios of climate and socio-economic change in 2050?

What factors determine the simulated activity change and how can understanding of these factors support regional climate and nature policy making in 'De Baakse Beek'?

Research question 1 helps to get an insight in the current performance of the different classes of the dairy farming systems in '*De Baakse Beek'*.

Research question 2 demarcates the scope of the simulations in the sense that a restricted amount of farm classes and scenarios are used, only for specialized dairy farms in 2050. The choice for scenarios is explained in the methodology of this research.

Research question 3 gives scope for both new simulations at farm level (which may include adaptation activities) and ex-ante regional and national policy assessments at regional level. Currently, the answer to this research question is only partly answered. In Chapter 5 in which the results of this study will be discussed, recommendations for and limitations of the model will be presented to indicate how and to what extent Research Question 3 can be answered.

2. Introduction to the area

'*De Baakse Beek*' is characterized as a dry rural area in which sandy soils are predominant. The main soil type is sandy soil with a sand fraction of roughly 85% and clay and silt accounting for roughly 15%. This soil type is particularly prevalent in the north of the area and has a rooting depth till 30 cm. The northern and eastern part of the area is relatively dry, with an average ground water level of up to 10 meters. In the middle of '*De Baakse Beek'* there is a soil with a sand fraction of about 90% and a rooting depth of 30-50 cm. In the west there are sandy soils with a high silt and/or clay fraction. The rooting depth for these soils is more than 50 cm. In the middle and the west the average highest ground water level is less than 0.5 meter. The average lowest ground water level is between 1 and 1.5 meter. (Reidsma, 2011). Drought as well as extreme wet conditions occur in some spots of the area. However, it seems that the extreme wet conditions are perceived as much more disturbing than the extreme dry conditions. (Moorman, 2012; Personal communication).

The rural aspect of the area is to a large extent expressed by the presence of specialized dairy farming: 443 dairy farms which cover 59% of the total area of roughly 30000 ha. Other grazing livestock activities cover another 17% of the area. Intensive livestock keeping is also an important agricultural activity: 154 farms. Intensive livestock keeping farms cover only 4.2% of the area. Arable farms cultivate 7.3% of the area. In total there are 1213 farms that have a stake in the area of '*De Baakse Beek*'. (Reidsma, 2011b). Important land use activities for the specialized dairy farming are grass and maize cultivation. Besides grass and maize, many dairy farms cultivate a few hectares of cereals, potatoes and/or beets (FADN, 2006). See Figure 2 for an indication of the cultivation pattern in the area. The spread of different farm sizes is not homogeneous over the study area: in the north-western part there are relatively more smaller farms and in the south-eastern part there are relatively more larger farms (Notes of CARE-meeting, 2012; pers. comm.). Nature areas are more prevalent in the north-western part.

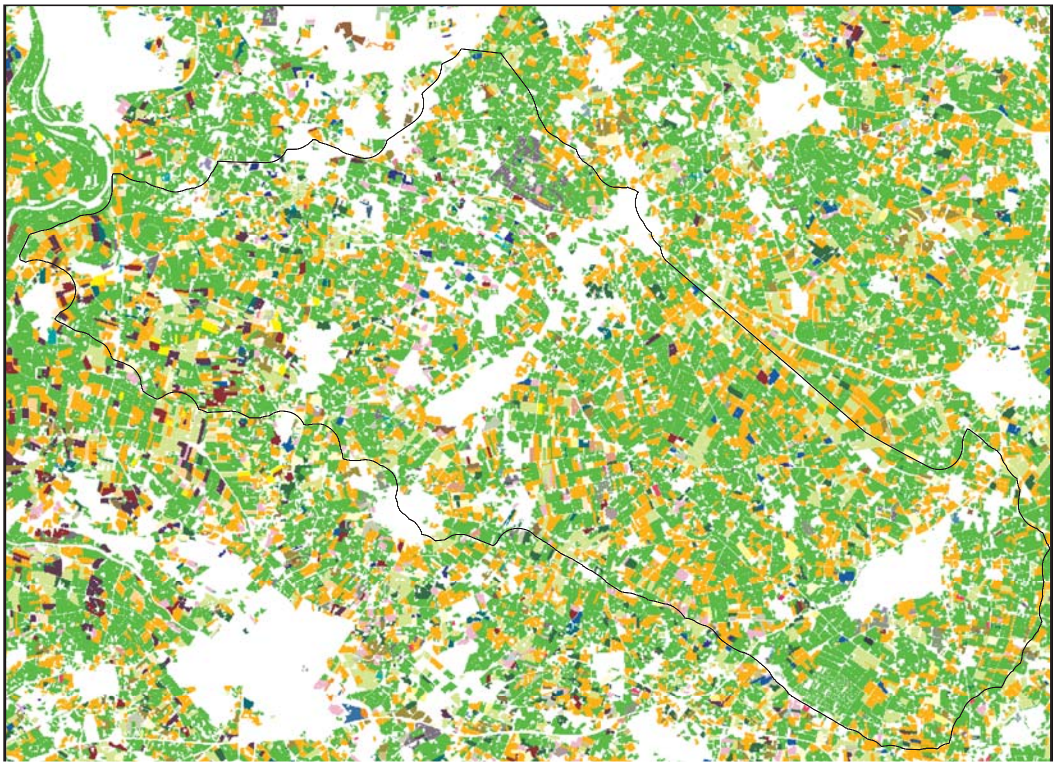

Figure 2: Agriculture in '*De Baakse Beek*' in 2008 according to the '*Basis Registratie Percelen*'. Cultivation legend: Green = grass, orange = maize, other colours = arable and horticulture crops, white= urban and nature area. Source: Reidsma (2011a).

3. Methodology

For this research a linear programming model (LP-model) is used to acquire information that help to answer the research questions. A LP-model uses an optimization technique (simplex method) to maximize an objective subjected to constraints. The elements of a LP-model are basically the weights, activities, coefficients and resources. The connection between these elements results in the general mathematical formula that is presented in Equation 1.

Equation 1

$$Max\{Z = w'x\}\ subject\ to\ Ax \leq b, x \geq 0$$

Where *Z* is the objective function (in this study is that the total gross margin), *w* is the vector of the parameters that is defined by monetary outputs minus monetary inputs per activity *x*, *x* is the vector of agricultural activities, *A* is the matrix of technical coefficients of input and output, *b* is a vector of available resources.

For the LP-model that is used in this research the connection between the elements is featured by the Farming System SIMulator (FSSIM; Louhichi et al., 2010). FSSIM is developed within the System for Environmental and Agricultural Modelling: Linking European Science and Society Project (SEAMLESS; van Ittersum et al., 2008). SEAMLESS aims to support ex-ante evaluation of agricultural and environmental policies with an integrated modelling framework (van Ittersum et al., 2008). The general structure of FSSIM has evolved in time. The version used in this study is based on Kanellopoulos et al. (In review). Currently, FSSIM is a framework that connects a database (Microsoft Access; Microsoft Corporation, 2010) with a mathematical solver (GAMS 22.5; GAMS Development Corporation, 2007). In the database the elements and the connections between them are stored. The database supplies a function that allows the stored data to be inserted directly into the mathematical solver. After simulation the solver displays the results in the interface and also exports the results to a spread sheet (Microsoft Excel; Microsoft Corporation, 2010). For this research the graphical visualization of the results is made generic in the spread sheet to allow for quick analysis after simulation.

FFSIM is used to simulate an average farm, i.e. after simulation the results of the individual farms are averaged per farm type, taking into account the relative number of farms per farm type. In the LP-model for this research the agricultural activities are defined as whole farm activities. Defining activities as whole farm activities makes it possible to include specific interactions at farm level. It is assumed that there are no differences between farms that cannot be bridged by adaptations. That implies that each farm is able to achieve the crop and milk yield level of other farms by adopting the farm practices of that farm. Simulations for 2050 contain extra constraints. Later on in this chapter, the extra constraints are treated per simulation run. Besides determining the optimum farm performance, extra quantitative outputs (like manure production) can be derived from the outcome of the model. Besides the objective of profit maximization it is implicitly assumed that dairy farms strive for self-sufficiency, i.e. where possible a farmer will choose to grow his own grass and maize.

3.1 LP-model

A linear programmed optimization model (LP-model) is used to make projections for the size classes of dairy farms in '*de Baakse Beek*'. The objective of the LP-model is to maximize gross margin. Gross margin is defined as all direct monetary outputs (meat, dairy products, crops, subsidies, other outputs) minus all direct monetary inputs (energy, feed, other inputs). Main activities in the LP-model are 'whole farms' with their monetary inputs and outputs, land use, labour, manure production, fertilizer use, grass and maize yields, fodder purchase. Hired labour is inserted as a separate activity.

The maximization of gross margin is in the current situation constraint by:

1. **Maximum amount of capital that can be invested in the farm.** It is assumed that a farm has limited access to capital. Capital is defined as the input of machinery and buildings expressed in monetary value. The level of maximum capital is determined as the average capital that is currently invested in the farm.
2. **Milk quota.** Currently milk production per farm is limited by the milk quota. The milk quota is defined as the level of current milk production.
3. **Maximum amount of available area.** It is assumed that a farm cannot adopt activities that require more area than the farm possesses. The maximum area is determined as the current level and expressed in unit hectare.

4. **Total labour.** It is assumed that a farm has limited access to labour. Labour is expressed in unit hour. The level of total labour is determined as the average sum of family and hired labour that is currently invested in the farm. Total labour minus hired labour should be less than available family labour.
5. **Maximum amount of available hired labour.** It is assumed that a farm has limited access to hired labour. Hired labour is expressed in unit hour. The level of maximum hired labour is determined as the average sum of hired labour that is currently invested in the farm.
6. **Convexity.** It is assumed that the efficiency (output/input) of 'whole farm' activities in the LP-model is dependent on the rate of input. Hence, it is impossible that increasing any input can result in an efficiency that is higher than currently existent for that rate of input. See Figure 3 for an illustration or Appendix B for the mathematical formulation of this constraint.
7. **Maximum other output.** It is assumed that a farm cannot gain other output, e.g. output from recreation activities. The maximum other output is determined as the current level and expressed in euros.
8. **Cow holding capacity.** It is assumed that a farm cannot exceed the cow holding capacity of its own facilities. The cow holding capacity is determined as the current level and expressed in (milk producing) dairy cows.

The constraints 1, 7 and 8 are constraining short-term decision making, but are assumed to be negligible in long-term decision making. The general mathematical formulation of the model is presented in Equation 1. For the specific basic formulation of the model see Appendix B. For explorations in the future the model is expanded and presented in Appendix C. The parameter explanation is presented in Appendix D. Appendix E provides a list with quantitative outputs of the model.

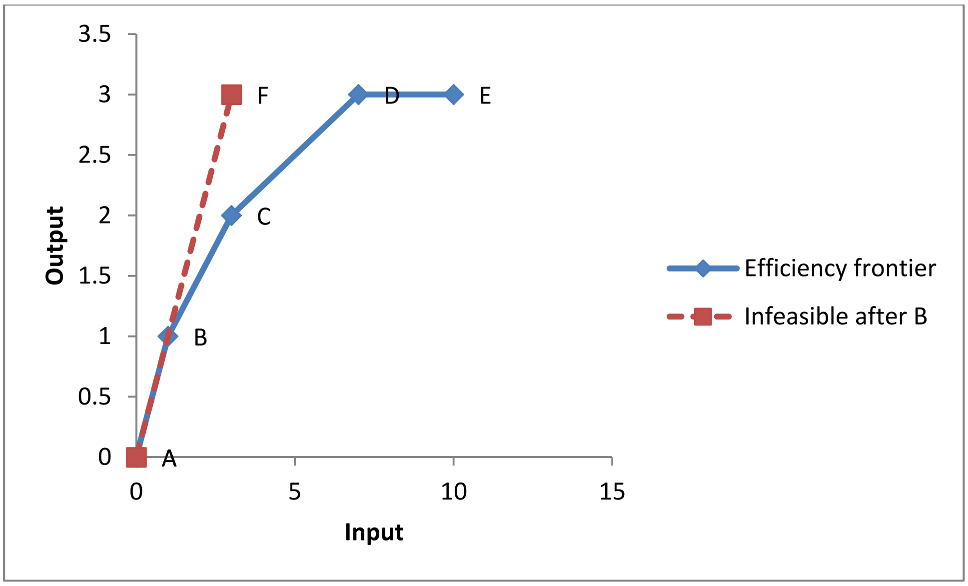

Figure 3: Illustration of the convexity constraint. This constraint forces the LP-model to go along the line of the efficient frontier. Any point above the line ABCDE is infeasible.

3.2 Data and data management

The available farm specific data that are used in this research are subtracted from the Farm Accountancy Data Network (FADN). The values from the FADN-database that are used in this research are average values that are calculated by dividing the sum of the observed levels for a certain variable in an observed year by the number of observed years in the period 2001-2006. In total data of 39 dairy farms are available. These farms are all situated in 'de Achterhoek' (NUTS222), but not all are situated in 'de Baakse Beek'. The research focusses on the behaviour of specialized dairy farms. Therefore, only farms are selected that have dairy livestock activities and no other livestock activities like pig and poultry activities. Out of the 39 farms with dairy livestock activities, 20 farms are selected. 2 of the 20 farms are not recognized by LEI, who delivers Dutch farm data to FADN. One of these farms does not have reasonable input and output values (Daatselaar, 2012; pers. comm.). The average values for the period

2001-2006 are referred to as 'current situation'. Not all farms have the same number of observations; also the specific years of observation differ. Appendix F provides an overview of the specific years of observation per selected farm. Each of the selected farms represents a number and area of the specialized dairy farms in '*de Achterhoek*'. Relative representation of selected dairy farms is presented in Table 1. The low relative representation of the selected dairy farms in relation to the total farms while area representation is much higher is due to the fact that farms are included in the FADN-data that have little to zero area. It is assumed that the representativeness of the selected farms for NUTS222 is comparable to the situation in '*De Baakse Beek*'.

Table 1: Relative representation of farms and area by selected dairy farms.

	Farms	Area
Selected dairy farms/Total dairy farms	46%	69%
Selected dairy farms/Total farms	24%	45%

3.3 Classification

Besides individual simulation runs for each farm, projections are produced for average farms per class, based on the typology that is presented in Mandryk et al. (2012). This typology distinguishes between farm size according to standard gross margin from crop cultivation and/or animal husbandry. The unit for gross income is Dutch Size Unit (*NGE)*. *NGE* has a value between 1375 and 1400 euro in the period 2001-2006 (Appendix G; to compare NGE: European Size Unit equals 1200 Euro). Average *NGE* is calculated per farm by summing up the *NGE* for the observed years and divide that sum by the number of observed years. As there are not enough farms to represent each farm class, the classes *small* and *medium* are combined and are represented as *medium* (*NGE<70*). The classes *large* and *extra large* are combined as well and represented as *large* (*NGE>70*). 13 farms are classified as medium, 7 farms as large. Mandryk et al. (2012) provided also a classification for farming intensity according to gross NGE per area. Appendix G provides the description for the size and intensity classifications.

3.4 Scenarios

Simulations are made for the current situation and for 2050. Scenarios are used for the simulations of the situation in 2050. Riedijk et al. (2007) proposes four relevant integrated climate socio-economic scenarios for the future. These integrated scenarios are based on climate scenarios presented by van der Hurk et al. (2006) and socio-economic scenarios that are presented in CPB et al. (2006). Two of the integrated scenarios of Riedijk et al. (2007), are considered as the most extreme scenarios. These extreme scenarios are used. The first scenario assumes a globalized economy (GE) and a high degree of climate change (W^+) in 2050. W^+ comprises a 2^oC global temperature rise with a change in atmospheric circulation, and is related to a CO_2 concentration of 567 μmol mol^{-1} as described in Wolf et al. (2011); GE represents a society in which subsidies, N-regulations and the milk quota are abolished. Farmers have access to extra labour. The second scenario assumes the development to a society that is focussed on regional communities (RC) and a society that experiences a moderate degree of climate change (G). G takes into account 1^oC global temperature rise without change in atmospheric circulation, and is related to a CO_2-concentration of 478 μmol mol^{-1} (Wolf et al., 2011); in RC, subsidies and N-regulations are maintained, there is no access to extra labour. The integrated scenarios (GE/W^+ and RC/G) include assumptions on climate change on a local scale (KNMI predictions for the Netherlands; van der Hurk et al., 2006; see Table 2 and Appendix H). The integrated scenarios also have a general storyline (Appendix I) in which the policy changes, price changes and changes in technological development are described.

Table 2: Predicted local climate change effects for the Netherlands for G and W^+ (Source: van der Hurk et al., 2006)

	G	W+
Winter		
Mean temperature	+0.9C	+2.3C
Mean precipitation	+4%	+1.4%
Summer		
Mean temperature	+0.9C	+2.8

Mean precipitation	+3%	-19%
Potential evaporation	+3%	+15%

3.5 Simulation runs

The assumptions that are made in the scenarios are processed in the simulation runs. The different runs are presented in Table 3 and Figure 4. The changes in the parameters or constraints in each simulation are on top of the changes of the previous run. Additional activities are implemented to allow farmers to adapt on changes. First of all, there are the activities to increase or decrease grass and maize yields. Next to that extra or less milk production is inserted as an activity. To maintain a certain degree of feed self-sufficiency, activities to purchase and sell less fodder are included, while activities to purchase and sell more rough fodder are not included. Also the export of manure can be increased or decreased. Finally, N, P and K fertilizer purchase can be increased or decreased.

Table 3: Simulation runs. Each run includes a change in model parameters in respect to the previous run.

Run	Description	Code
1	Simulates the current situation as derived from the averaged data for the period 2001-2006, including short and long-term constraints.	BY1
2	Simulates the current situation as derived from the averaged data for the period 2001-2006, including long-term constraints	BY2
3	Simulates the effect of climate change in 2050	CC
4	Simulates the effect of extreme events in 2050	EE
5	Simulates the legislative change in 2050	JC
6	Simulates the effect of technological changes in 2050	TC
7	Simulates the effect of price changes in 2050	PC

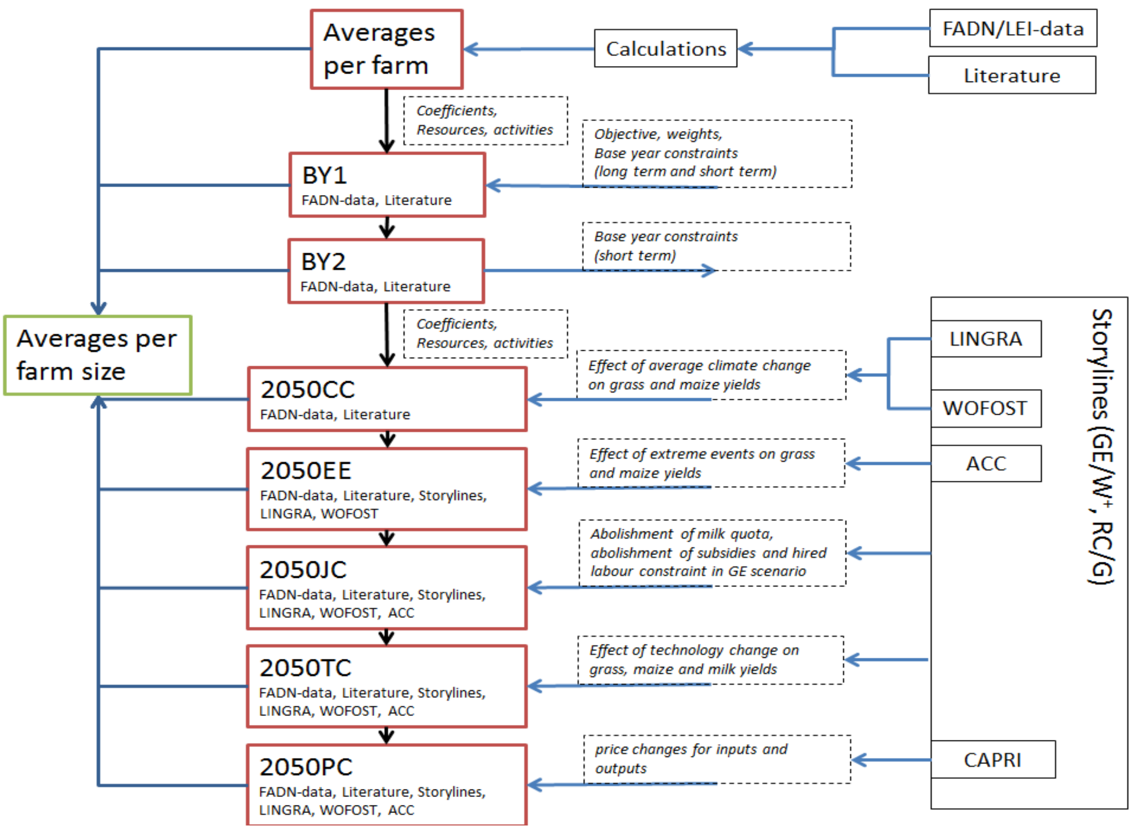

Figure 4: Schematic representation of the different simulation runs and the of data inputs.

In the text below all consecutive assumptions are presented per simulation run. Run 1 and Run 2 refer to the base-model presented in Appendix B. Run 3-7 refer to the 2050-model, which is an extension of the base model. The 2050 model is presented in Appendix C. The parameter explanation of the base-model and 2050-model is presented in Appendix D.

Run 1

In run 1 the constraints 1-8 are used. Direct input (capital, feed, cows, area, other input) and output (milk, meat, subsidies, other output) parameters are directly derived from FADN data. Original wages paid for labour are subtracted from the direct input 'other inputs'. Instead of the original wages, an average wage was charged for the activity of 'hired labour'. The average wage is determined as the labour wage of farms that hired labour divided by the number of that farms.

From the choice of 'whole farm' activities in each individual farm simulation the area under profit maximization is derived: it is assumed that the extent in which a farm chooses its own activity is indicative for the area under profit maximization. Other outputs are presented and simulated farm performance is compared with the average in the current situation. Other calculations included the following indicators:

1. For the manure production per farm, milk production of the dairy cows and total number of cattle is taken into account. Values for manure excretion are derived from 'Handboek Melkveehouderij 2011' (Remmelink et al., 2011) and an excretion table (Dutch: 'excretie forfait tabel') of Dienst Regelingen Ministerie van Economische Zaken, Landbouw en Innovatie (2012; www.hetlnvloket.nl). See Appendix J for the specific assumptions and used formulas.
2. Maize yields per hectare are determined with help of experimental findings of Aarts et al. (2008). Aarts et al. (2008) provides maize yields per hectare in dry matter (kg) and in energy (kVEM) per farm intensity class for dry sandy areas in the period 2001-2006. The intensity classes used in Aarts et al. (2008) are determined according to the milk production per hectare. Appendix K provides an overview of the average yields and yields per intensity class per year.
3. Grass yields are estimated according to the method of Aarts et al. (2008). The method takes the energy from grass yields as the factor that closes the energy gap that is left after energy of other course fodders and concentrates are subtracted from the energy demand of the dairy herd. In Appendix L the assumptions are presented and formulas are presented in mathematical form. Also the outcome is tested with calculations on average grass yields according to LEI (Daatselaar, 2012; personal communication). Next to that the outcome is tested with the rate in which the protein demand is fulfilled. An average of 105% coverage of demand, with the individual demands between 95% and 115% is a common range for protein coverage (Tamminga, 2005). Also the amount of dry matter per cow per day is calculated and compared with the prescribed dry matter intake according to van Duinkerken (2007).

Run 2

Run 2 omits the short-term constraints on 'Maximum amount of capital that can be invested in the farm', 'Maximum Other Output' and 'Cow Holding Capacity' (Resp. Cnstr. 1,7,8). It is assumed that these constraints are not constraining in the long term because a farmer can get access to capital in the future and invest in bigger stables or in infrastructure that facilitates other activities. Area under profit maximization is calculated again. Also other outputs are presented again and compared with the average in the current situation and with the outcome of run 1.

Run 3

Run 3 simulates the situation in 2050, taking into account the projected climate induced yield changes for crops under water limitation, in respect to the base year situation. The potential yield change for grass and maize is translated into a constraint (Constr. 23 and 30 respectively in GE/W+ and constr. 26 and 33 in RC/G) which allows a positive change to be partly used. The constraint also forces to fully apply a negative yield change.

Individual farms are given the opportunity to increase or decrease the production of milk. Two constraints make sure that the milk production and profit stay positive (Constr. 9 and 14 resp.). A change in milk production induces a change in energy and protein demand. It is assumed that a change in milk production has a linear relation with energy and protein intake (Derived from van Duinkerken, 2007; Appendix M). Although there is a linear relation, farms can still have a higher ratio of concentrates in the total diet, because the linear relation only accounts for the change in milk production and not for the total milk production. Another assumption is that the amount of weight of concentrates in the diet is changed linearly according to the change in milk production (Derived from van Duinkerken, 2007; Appendix M). A constraint is included to assure that the change in energy demand is covered (Constr. 10). For the protein demand two constraints (for an upper and lower bound of respectively 100% and 110% of the calculated requirements of the changed demand; Appendix M) are guiding the supply of protein (Constr. 11 and 12, resp.).

The amount and mixture of concentrates can be changed by purchasing less of the current mixture and/or purchase standard, enriched, or highly enriched concentrates. A constraint prevents the amount of the currently used mixture to become negative (Constr. 15). Purchasing net extra or less weight of concentrates (kg) is dependent on the change in milk yield (Constr. 47). Rough fodder availability can be realized by a change in farming system intensity, i.e. that a change in output flows induces a change in input flows to keep the nutrient balance stable. Current amount of sold and purchased rough fodder cannot be expanded, based on the assumption of self-sufficiency concerning rough fodder. It is possible to reduce the amount of sold and purchased rough fodder. The nutrient balances for N, P and K are included as constraints in the LP-model (Constr. 39, 40 and 41, resp.). In RC/G there is potentially an extra output of manure that has to be deported due to laws on manure application. It is assumed that farms in RC/G will apply within the boundaries of manure laws. In the LP-model the maximum amount of applied manure N is restricted as well as the maximum amount of total applied N (Constr. 45, 46), according to the current legislation that is based on the Nitrates Directive. The thresholds for N-application laws are calculated per farm. Farms with more than 70% grassland are allowed to apply 250 kg manure N ha^{-1}, other farms can only apply 170 kg manure N ha^{-1}. A surplus of manure is assumed to be deported without imposing extra costs on the farmer. In the total N-application law, every kg of applied manure N only accounts for 0.45 kg. Thresholds for total applied N are presented in Table 4. In GE/W+ the extra manure is applied to the crops, and there is also an opportunity to reduce the current deported manure. A constraint prevents that the amount of less deported manure is not bigger than the currently deported manure (Constr. 48). Farms also get the opportunity to reduce the output and input of grass and maize (coherent with the idea of self-sufficiency; constr. 16-19).

Table 4: Total N-legislation for different crops.

Crop	Total N (kg ha^{-1})
Grass	320
Maize	140
Other	140

Via the outflow of milk, manure (losses) and changes in rough fodder purchase and selling there is a change in nutrient flows of N, P and K. In order to keep the nutrient flows of the farming system in balance, inputs should increase as well. The increased inputs should, after taking into account the nutrient use efficiency, break even with the change in nutrient output. The change in input of concentrate is known. The nutrient balance of the system eventually has to be restored by a change of fertilizer input. Average nutrient use efficiencies of the inputs are derived from Schröder (2003, 2010, 2012; personal communication). See Appendix N for nitrogen use efficiencies and for nutrient content of different inflowing and outflowing products. Efficiency of extra nitrogen in fertilizer is assumed to be independent of the rate of fertilizer (organic and inorganic) application. Nutrient use efficiency of phosphorus is 100% according to the projections for a whole farming system (Oenema et al., 2006). Three constraints (for N, P and K) prevent the fertilizer application from becoming lower than zero. In analogy to phosphorus, the nutrient use efficiency of potassium is 100%.

For the change in maize silage yields, the simulations of a case study in Flevoland (Wolf et al., 2011; specific results are not presented) are taken. These simulations are made with WOFOST (Boogaard et al. 2011, van Diepen et al. 1989). WOFOST is a biophysical crop model at field level that is source driven. The model contains three components: soil, crop, climate. The relative change in water limited yields is used to calculate the change in actual yields. See Appendix O for the specific assumptions. For the change in grass yields, simulations (Wolf, 2012; personal communication) from the LINGRA model (Bouman et al. 1996, Schapendonk et al. 1998) are used. These simulations originate in the Flevoland case study, but results cannot be found in Wolf et al. (2011). LINGRA is a biophysical crop model at field level that is source driven. It is specially developed for grass production to take into account the several harvesting moments. The relative change in water limited yields is used to calculate the increase of actual yields. See Appendix P for the specific assumptions of the LINGRA runs. See Table 5 for the expected effect of climate change on maize and grass yield. It is expected that yield changes induced by any factor are not requiring a change in labour.

Table 5: Yield change inducing factors that are multiplied with current yields in the different simulation runs. CC refers to the individual effect of gradual climate change, EE refers to the individual effect of extreme events and TC to the individual effect of technological change.

		Yield change inducing factor					
Scenario	**Crop**	**CC**	**EE**	**TC**	**CC+EE**	**CC+TC**	**CC+EE+TC**
GE/W+	***Maize***	1.01	0.89	1.3	0.89	1.31	1.16
	Grass	0.98	0.90	1.3	0.88	0.86	1.14
RC/G	***Maize***	1.09	0.91	1.1	0.99	1.20	1.09
	Grass	1.23	0.97	1.1	1.20	1.36	1.32

Run 4

Run 4 includes the influence of extreme events (Constr. 23 and 30 are substituted by constr. 24 and 31 resp. in GE/W+ and constr. 26 and 33 are substituted by constr. 27 and 34 resp. in RC/G). Extreme events are taken into account by using the Agro Climate Calendar (ACC), presented in Schaap et al. (2009). Changes in frequencies of extreme events are provided by calculations using current and projected data of the weather station of Deelen. The relative effect of a change in extreme events on yields is presented by Equation 2. Because the original yield without extreme events is not known (in the period 2001-2006 also extreme events occurred), the equation only provides relative yield changes based on the ratio of current and future frequency of occurrence of extreme events. The modulus function (MOD) is used to make sure that yield reduction is subtracted from the remaining part of the harvest in case that an event happens more than once in a year. For the derivation of this equation see Appendix Q.

$$Eq.2 \;\; Relative\ yield = 1 + \sum_E \frac{(1-D_E)^{fF_E - MOD(fF_E,1)} * (1 - MOD(fF_E,1) * D_E}{(1 - fC_E * D_E)} - 1$$

Where:

E = Set for extreme events that have an influence on crop yield, $E \in$ {*event 1, event 2, etc.*}
D_E = Yield damage per extreme event E (*fraction between 0 and 1*)
fF_E = Future expected frequency of occurrence of extreme event E (*year*$^{-1}$)
fC_E = Current frequency of occurrence of extreme event E (*year*$^{-1}$)

Relative yield decreases per extreme event for maize are provided by an expert (Groten, 2012; personal communication) of Praktijkonderzoek Plant en Omgeving (PPO). For relative grass yield decreases information from de Wit et al. (2009) is used. See Table 5 for the calculated effect of extreme events on grass and maize yields for the two scenarios in. Table 5 provides also the combined effects of climate change and extreme events, which will be used in Run 4. Appendix R presents the extreme events that influence the yields and their current and projected frequency of occurrence.

Run 5

Run 5 includes the abolishment of the milk quota (Constr. 2 omitted). Milk increase beyond the milk quota can only be achieved by choosing other 'whole farm' activities as a constraint prevents farms from increasing milk production by just feeding more to the herd (Constr. 36). In addition, in GE/W$^+$ all subsidies and N-application laws are abolished (Constr. 45 and 46 omitted) and the constraint on hired labour is omitted (Constr. 5 omitted). Subsidies in the LP-model are simply not accounted for in the calculations of the objective function by the LP-model.

Run 6

In addition to the climate induced potential change of crop yields run 6 takes into account the effect of technological development on crop and milk yields. For the GE/W$^+$ and the RC/G scenario the technologically induced potential crop yield increase is assumed to be 30% and 10% respectively (Wolf et al., 2011). These increases are estimated to be possible due to genetic improvement, i.e. the increase in potential and/or water limited yields. Table 5 provides also the combined effects of climate change, extreme events and technology change, which will be used in Run 6 (Constr. 24 and 31 are substituted by constr. 25 and 32 resp. in GE/W+ and constr. 27 and 34 are substituted by constr. 28 and 35 resp. in RC/G). Technology development is assumed to have no direct effect on the closure of the yield gap in crop production. Instead, by farms getting the opportunity to 'choose' different activities in the LP-model, the potential closure of the yield gap is dependent on the economic viability of the activity that is required. Higher milk yields are expected to require not more or less labour. In GE/W+ and RC/G the expected yield increase is 53% and 18%. The yield increase is in a similar way included in the LP-model as the yield changes of grass and maize (Constr. 36 is substituted by 37 and 38 in respectively the GE/W+ and RC/G-scenarios). The yield increase for the GE/W$^+$ is calculated by extrapolating the current trend in yield increases that is derived from data of LEI (2012; www3.lei.wur.nl), in analogy with Ewert et al. (2005) who did this for arable crops in Europe. The relative difference between the technological induced yield increase in milk of GE/W$^+$ and RC/G is deduced from the relative difference between technological induced yield increase of crops (3:1). See Appendix S for the extrapolations on milk yield and the calculations on the expected increases.

Run 7

Run 7 includes the projected price changes for 2050. Price changes are provided by outcomes of the CAPRI-model (Britz, 2005; CAPRI, 2012, www.capri-model.org) that were used before in LIAISE (de Vries et al., 2013). This model has provided local price changes for the Netherlands for the GE/W$^+$ and RC/G-scenario. CAPRI takes into account the effects of climate change and technological development and food supply, food demand according to the scenarios. Table 6 provides projected relative price changes. The time between the FADN-dataset (2001-2006) and the price projections (2010) is neglected.

Table 6: Relative price changes for two scenarios in 2050.

		Scenario	
		GE/W+	**RC/G**
Input	Energy	238%	238%
	Feed*	*131%*	*131%*
	Other input	238%	238%
Output	Crops*	*145%*	*155%*
	Meat	208%	160%
	Milk	196%	133%
	Other output	238%	238%

*Price changes of feed and crops are calculated by taking into account the relative presence of the different contributors (Appendix T).

4. Results

This section of the report presents outcomes of calculations and model runs. In the FADN-data not all data was directly available. Calculations and assumptions had to be made. These calculations and assumptions are processed in the methodology and appendices. In the first part of this section the current situation is evaluated. Next, the explorations for 2050 are presented.

4.1 Current situation

In this subchapter first average grass yields are presented. After that some general farm indicators are presented that describe the current situation. Then milk production levels and their standard deviations are presented per farm size. In addition correlation values are presented for some important input and output indicators. At last the simulation runs BY1 and BY2 are presented in relation to the current average.

Grass yields and cow diet

Grass yield average for the set of selected farms deviates from calculations by Daatselaar (2012; pers. comm.). Calculations of Daatselaar (2012; pers. comm.) tend to give higher estimates of grass yields (see Table 7). Simulations with LINGRA result in lower water limited yields than the average yields of all selected farms from the FADN-data (7.2 vs. 7.8 ton ha^{-1}; after 15% losses). In the current situation farmers already irrigate their crops. There is also a peak in irrigation noticed in the dry years of 2003 and 2006 (Daatselaar, 2012; pers. comm.), which could explain the difference between the LINGRA results and the calculated average. Average protein content in the diet is 107%, which is close to the average of 105% found in dairy farms in the Netherlands (Tamminga, 2005). Also the average protein content is well within the bounds of the minimum of 95% and the maximum of 115% of the protein requirements (Tamminga, 2005). However three individual farms trespass the boundaries. Intake of dry matter in the current diet is 17 kg day^{-1} cow^{-1}. Van Duinkerken et al. (2007) estimated 18 kg day^{-1} cow^{-1}, with a confidence interval of 16-20 kg day^{-1} cow^{-1}.

Table 7: Comparison between grass yield calculations (after accounting for yield losses) of LEI and this study,

	LEI	St.dev LEI*	This study**	St.dev this study***
Total grass (kg DM ha^{-1})	8976	708	8329	1571
Total grass (kVEM ha^{-1})	8006	677	7515	1418

*Standard deviation of grass yields from Daatselaar (2012; pers. comm.) originates from differences between averages per year **The grass yields for this study that are compared in this table are averages of selected farms, which could be coupled with LEI-data. Hence it is possible that the mentioned yield in this table is higher than mentioned elsewhere in the report. ***Standard deviation of grass yields as calculated in this study originates from differences between averages per farm.

Farm indicators in current situation

In the current situation large farms have more than twice as much profit as medium farms. The output/input ratio is higher for large farms compared to medium farms (1.90 vs. 1.67 resp.). The area of medium farms is almost half the area of large farms. Labour requirements on medium farms are 72% of the labour requirements on large farms, hence the return to labour is much lower on medium farms. Medium farms have a marginal amount of hired labour (<2%, where hired labour for large farms is >10% of total labour). Large farms have relative more grassland per total area.

Milk production levels and milk prices between large and medium farms do not differ significantly. However, the range of milk production per cow and milk prices is much bigger for medium farms (Table 8).

Table 8: Milk production indicators and milk prices for the selected farms.

Indicator	Unit	All farms		Large farms		Medium farms	
		Average	St. Dev	Average	St. Dev	Average	St. Dev
Milk production	Kg cow^{-1} day^{-1}	19.8	4.4	20.3	2.2	18.8	6.5
Milk production	Ton ha^{-1} $year^{-1}$	11.9	4.0	12.7	3.9	10.8	4.1
milk price	€ kg^{-1}	0.33	0.03	0.33	0.02	0.32	0.05

When important input and output data were plotted in a scatterplot there was no suggestion for higher order relations. Hence, only linear correlations were estimated (Table 9). The selection for indicators for statistical analyses on linear correlations is not made arbitrary. The analysis is meant to get a general idea about correlation between single inputs and outputs. Although it gives biased estimates, the linear regression with multiple variable indicators might reveal more information. A notion that can be perceived from the single variable regression (Table 9) is that the amount of area hardly influences the feed purchase. Another point is that the amount of subsidy seems to be more correlated with total output of other products than to the total profit without subsidy. Overall it is not possible to connect the amount of subsidy to one other input or output indicator that is analysed or to milk production intensity. The correlation between feed purchase and total milk production or total output is strong. However, the correlation between feed and profit is much weaker. Overall these non-arbitrary statistical analyses suggest that although there are some strong correlations, it is very likely that most input and output indicators are dependent on a multiplicity of variables.

Table 9: Linear correlation between individual farm indicators.

Indicator *X*	Unit	Indicator *Y*	Unit	R-squared
Feed purchase	€	Total output	€	0.78
Area	Ha	Feed purchase	€	0.30
Subsidy	€	Feed purchase	€	0.45
Subsidy	€	Milk production	Kg	0.43
Subsidy	€	Area	Ha	0.42
Subsidy	€	Total input	€	0.45
Subsidy	€	Profit minus subsidy	€	0.24
Subsidy	€	Total output minus subsidy	€	0.42
Feed purchase	€	Milk production	Kg	0.84
Feed produced on farm	Kg	Purchased feed	€	0.29
Milk production per cow	Kg cow^{-1}	Subsidy	€	0.26
Milk production per ha	Kg ha^{-1}	Subsidy	€	0.03
Purchased feed	€	Profit	€	0.53

Model output for current situation

In this study the assumption of profit maximization can roughly be evaluated by looking at how much the activity choice of individual farms in BY1 and BY2 is determined by their original activities (Table 8). The output of the model suggests that mainly large (in the sense of area) farms are under profit maximization in BY1, because the relative area under profit maximization is bigger than the relative number of farms (Table 10).

Table 10: Area and farms under profit maximization.

	Simulation	
	BY1	BY2
Area under profit maximization	47%	27%
Farms under profit maximization	37%	23%

In BY2 all individual farms under profit maximization are classified as large farms (model output, which is not presented). That indicates that especially medium sized farms can improve on economic performance. That is clearly visible in Table 11, which shows that the relative change of profit is much higher in BY1 and BY2 for medium sized farms. The profit increase for medium sized farms is especially big when short-term constraints are not considered. The presence of these short-term constraints are the reason that more farms and area are indicated as under profit maximization (Table 10). Profit can be increased for both large and medium sized farms (Table 11). If the current average is assumed to be a product of clearly defined and achieved objectives other than (or besides) profit maximization, then the economic cost of those objectives relative to the potential profit are roughly between 4% (BY1) and 8% (BY2) for large farms and between 11% (BY1) and 26% (BY2) for medium sized farms. However, it can also be technical inefficiency that has nothing to do with objectives. The derivation of the ultimate costs of having other/more objectives are dependent on how realistic the long-term constraints are defined in the model. Total profit differs substantially between large and medium farms. However, the relative difference in profit between large and medium farms decreases along with BY1 and BY2, implying that under profit maximization the difference between farm sizes becomes less distinctive. The amount of required labour is less for medium farms in comparison to large farms (72% and 70% for resp. BY1 and BY2 compared to large farms). In general, both farm size classes can become much more efficient: increased profit under profit maximization is mainly due to an increased output/input ratio when short-term constraints are considered (Table 11). For large farms the o/i-ratio even increases more in BY2. Also total labour can be decreased with 4-8%.

Table 11: Economic indicators to evaluate the effect of profit maximization with and without long-term constraints.

			Absolute			Relative		
Indicator	Unit	Size	Average	BY1	BY2	Average	BY1	BY2
Profit	€ x1000	Large	133	139	144	100%	104%	108%
O/I*	€/€	Large	1.90	2.05	2.10	100%	108%	111%
Milk/Total output**	€/€	Large	0.82	0.83	0.83	100%	101%	100%
Profit	€ x1000	Medium	55	62	70	100%	111%	126%
O/I	€/€	Medium	1.67	1.85	1.84	100%	111%	111%
Milk/Total output	€/€	Medium	0.76	0.75	0.73	100%	99%	96%

*Output/input ratio ** milk output/total monetary output ratio

Total current labour requirements can decrease with 4-8% for all farms (Table 12). That has an effect on the amount of family and hired labour. It is possible to decrease both and still increase total profit. Hence, labour productivity can increase. When short-term constraints are omitted, total labour requirements increase for large farms relative to BY1, but labour requirements decrease even further for medium farms. The latter fact is striking, because the number of dairy cows increases. However, there is relatively less young livestock on the medium farms. Also, medium farms become much more dependent on external sources of food, while in large farms there is an opposite development. (Table 12).

Table 12: Labour indicators for the current situation and BY1 and BY2.

			Absolute			Relative		
Indicator	**Unit**	**Size**	**Av.**	**BY1**	**BY2**	**Av.**	**BY1**	**BY2**
Total labour	hour	Large	5107	4800	4898	100%	94%	96%
Family labour	hour	Large	4459	4337	4440	100%	97%	100%
Hired labour	hour	Large	648	463	458	100%	71%	71%
Total labour	hour	Medium	3713	3450	3412	100%	93%	92%
Family labour	hour	Medium	3666	3422	3369	100%	93%	92%
Hired labour	hour	Medium	48	28	43	100%	59%	90%

In BY1 and BY2 milk production is decreased relative to the current average for the large and medium farms. In medium farms, a smaller part of the total output is expected to originate from the milk production (Table 11), which could be seen as an indicator for lower specialization. For large farms, the milk output relative to total output increases slightly (Table 11). In the simulations, the milk production per cow decreases considerably for the medium farms. The decrease in production in medium sized farms is partly compensated by the increased herd size (Table 13).

Table 13: Milk and herd indicators for the current situation and BY1 and BY2.

			Absolute			Relative		
Indicator	**Unit**	**Size**	**Av.**	**BY1**	**BY2**	**Av.**	**BY1**	**BY2**
Milk	Ton	Large	703	678	684	100%	96%	97%
Herd	#cows	Large	94	90	93	100%	96%	99%
Milk/cow	Kg cow^{-1} $year^{-1}$	Large	7453	7498	7323	100%	101%	98%
Cow/herd	#cows $\#TL^{-1}$*	Large	0.72	0.74	0.75	100%	102%	104%
Milk	Ton	Medium	326	310	321	100%	95%	99%
Herd	#cows	Medium	46	46	57	100%	100%	122%
Milk/cow	Kg cow^{-1} $year^{-1}$	Medium	7039	6687	5676	100%	95%	81%
Cow/herd	#cows $\#TL^{-1}$*	Medium	0.70	0.68	0.71	100%	98%	102%

*number of cows per number of total livestock.

Manure excretion can be reduced in BY1 and BY2 for large farms. However, fertilizer use is increased (Table 14). Medium farms increase the manure production in BY2, this is induced by the higher number of cows that are made possible by omitting the 'cow holding capacity' constraint.

Table 14: Manure excretion and fertilizer use.

			Absolute			Relative		
	Unit	**Size**	**Average**	**BY1**	**BY2**	**Average**	**BY1**	**BY2**
Manure	m3	Large	2932	2785	2819	100%	95%	96%
FertilizerN	Kg ha^{-1}	Large	82	83	85	100%	102%	104%
FertilizerP	Kg ha^{-1}	Large	8	8	8	100%	102%	104%
FertilizerK	Kg ha^{-1}	Large	95	97	99	100%	102%	104%
Manure	m3	Medium	1453	1453	1621	100%	100%	112%
FertilizerN	Kg ha^{-1}	Medium	83	85	71	100%	102%	85%
FertilizerP	Kg ha^{-1}	Medium	8	8	7	100%	102%	85%
FertilizerK	Kg ha^{-1}	Medium	97	99	82	100%	102%	85%

Remarkable is the total area decrease for large farms. Decreased total area of large farms in combination with shadow prices of land can be explained by the way in which information from the individual farm simulations is collated: shadow prices are average shadow prices and for some farms land is not constraining. The area of grass is above 70% of the total area for large farms; however in BY2 the area of grass is only 58% of the total area for medium farms. That indicates that the derogation regulations do not necessarily contribute to achieving profit maximization in all situations. Grass production per hectare is 11% higher for medium farms in the current situation compared to large farms. Maize and grass production per hectare is increased at large farms in BY1 and BY2. (Table 15).

Table 15: Area and grass and maize yields.

Indicator	Unit	Size	Absolute Average	BY1	BY2	Relative Average	BY1	BY2
Total area	ha	Large	58.9	56.4	56.3	100%	96%	95%
Grass	ha	Large	43.8	41.2	42.0	100%	94%	96%
Maize	ha	Large	12.2	10.9	10.2	100%	89%	84%
Grass/Total	ha/ha	Large	0.74	0.73	0.75	100%	98%	101%
Grass yield	ton/ha	Large	7.3	7.5	7.8	100%	102%	106%
Maize yield	ton/ha	Large	13.7	14.0	14.1	100%	102%	103%
Total area	ha	Medium	29.9	29.9	29.9	100%	100%	100%
Grass	ha	Medium	20.9	20.8	17.2	100%	99%	82%
Maize	ha	Medium	6.7	6.6	8.3	100%	99%	124%
Grass/Total	ha/ha	Medium	0.70	0.69	0.58	100%	99%	82%
Grass yield	ton/ha	Medium	8.1	8.7	8.5	100%	107%	105%
Maize yield	ton/ha	Medium	13.8	13.8	14.2	100%	100%	103%

*Area of grass in respect to the total area.

Farmers tend to choose activities that give higher prices for milk, especially medium farms in BY2 (Table 16).

Table 16: Milk prices

	Absolute Av	BY1	BY2	Relative Av	BY1	BY2
Large	0.330	0.332	0.332	100%	101%	101%
Medium	0.322	0.325	0.347	100%	101%	108%

In the base year simulations the self-sufficiency in terms of energy and protein provision to the herd stays approximately on the same level for large farms (Table 17). Medium farms are becoming more dependent on external sources for energy and protein in BY2 (Table 17). The increase in herd size on medium sized farms has a clear negative drawback on self-sufficiency.

Table 17: Indicators of feed self-sufficiency.

Indicator	Unit	Size	Absolute Average	BY1	BY2	Relative Average	BY1	BY2
Own feed/Total feed	VEM/VEM	Large	0.66	0.65	0.66	100%	99%	100%
Own feed/Total feed	DVE/DVE	Large	0.58	0.58	0.59	100%	99%	101%
Own feed/Total feed	VEM/VEM	Medium	0.71	0.74	0.67	100%	104%	95%
Own feed/Total feed	DVE/DVE	Medium	0.64	0.66	0.59	100%	103%	92%

Influence of short term constraints

The shadow prices for land increase tremendously when short term constraints are omitted in the base year simulations, especially for medium farms (Table 18). Also the shadow prices for labour increase when short term constraints are omitted (Table 18). From the perspective of the LP-model it is logic that shadow prices of remaining constraints will increase, as the space for improvement is increased when certain constraints are omitted. Also from the perspective of a farmer it is expected that when there is room to increase the number of cows and develop activities that increase other output, and when the capital for that is available, more labour is required to look after the herd, but that the demand for area also increases to feed the herd and have space to develop other activities.

Instead of expanding with area, a farmer might also want to achieve a higher efficiency. This can be noticed in the shadow price of the convexity-constraint for large farms, which increases with 71%. For medium farms there is no shadow price for the convexity constraints, which indicates that efficiency wise, medium farms have not much to improve considering the current range of possibilities. Instead they have a much stronger incentive to expand in area (BY1 and BY2) and cows (BY1) than large farms.

Table 18: Shadow prices for base year constraints in BY1 and BY2.

Size	Constraints	Unit	BY1	BY2
Large	Area	€ ha^{-1}	835	967
Large	Capital	€ $€^{-1}$	0.034	NA*
Large	Convexity	€ 'whole farm'$^{-1}$	11177	19048
Large	Dairy Cows	€ cow^{-1}	104	NA
Large	Family Labour	€ $hour^{-1}$	12.60	20.14
Large	Hired Labour	€ $hour^{-1}$	2.47	9.74
Large	Milk Quota	€ ton^{-1}	14	36
Large	Other Output	€ $€^{-1}$	5.60	NA
Medium	Area	€ ha^{-1}	1137	1697
Medium	Capital	€ $€^{-1}$	NB	NA
Medium	Convexity	€ 'whole farm'$^{-1}$	NB**	NB
Medium	Dairy Cows	€ cow^{-1}	1769	NA
Medium	Family Labour	€ $hour^{-1}$	2.03	5.42
Medium	Hired Labour	€ $hour^{-1}$	NB	1.38
Medium	Milk Quota	€ ton^{-1}	40	140
Medium	Other Output	€ $€^{-1}$	0.34	NA

*NA: Data not available because the constraint was not included in the simulation runs. **NB: Constraint is non-binding, resulting in a shadow price of 0.

4.2 Exploration simulations

In this sub chapter, the changes in indicators and activities for each simulation will be treated. Also here, changes are related to the previous simulation run, unless explicitly referred to other simulations. All changes that are mentioned in the this subchapter are derived from Tables 19-22, where Table 19 and Table 21 supply the absolute and relative indicators of large farms, respectively, and Table 20 and 22 represent the absolute and relative indicators, respectively, of medium sized farms. Shadow prices which are referred to in the text can be found in Table 23. Table 24 provides an input-output balance of the current situation and all simulations.

GE/W+

In the GE/W+-scenario the small reduction in grass yields in combination with an potential increase in maize yields due to gradual climate change (CC) does not restrict large farms in increasing milk production and making a little bit more profit. Also medium farms are able to increase the milk yield level. Self-sufficiency is lightly decreased for medium and large farms. Increase in milk production is achieved by increasing the production per cow. The milk quota is suppressing profit, each extra ton of milk would yield €60 and €130 for large and medium farms, respectively. The area covered with grass remains approximately the same and stays above 70%. At large farms grass yields are declined more than can be ascribed to the gradual climate change directly. Maize yields have increased considerably. Along with the increase in milk production, more manure is produced. Also more fertilizer N is used.

When extreme events are taken into account (EE), where the yield decrease is around 10% for both, maize and grass, stronger effects can be noticed in the simulations. Profit decreases with more than 10% and is lower than the current average, input use efficiency decreases, and self-sufficiency decreases, especially in terms of energy. One medium farm has a negative income (this farm is the one with the assumed unreasonable values, mentioned in the methodology). All other medium farms have still allowable rates of income above the modal income (€31100 per year in 2009 according to Vermeij et al., 2009). The shadow prices of the milk quota constraint are reduced by almost 4 times for large farms and more than two times for medium farms. That is due to the reduced feed availability from own production. Surprisingly, the total area also decreases. Grass cover of the area becomes less than 70% for large and medium farms. That is coherent with the lower self-sufficiency: maize contains a lot of energy and cultivation of maize is the most efficient way to get that energy. The area under maize cultivation increases with more than 20% for large and medium farms. Fertilizer use decreases significantly, especially for N.

When the milk quota, subsidies and fertilizer laws are abolished and the hired labour constraint is omitted (JC), a further decrease in profit is recorded, because the loss in subsidy is big. Although the influence of extreme events in the previous simulation had lowered the pressure of the milk quota, milk and hence manure production, increase a lot. Medium farms realize a small loss in profit by compensating loss of subsidy with milk production. Large and medium farms tend to become more dependent on milk production as means of income. Milk production is increased by more production per cow, but also by increasing the herd size. The total area is even more decreased for large farms. Large farms do not make use of the extra labour that is available. Medium farms increase the total labour with 11% relative to the current average.

When technological development advances (TC), all previous negative effects of climate change on crop yields are obviated. There is a yield increase expected even. Also the milk production per cow can increase. Milk yield is increased (more than 25%) by expanding the herd and by increasing the production per cow. That milk yield increase is not more, is due to the constraining factor of rough fodder purchase that should counterbalance the purchased concentrates in the diet. The increased milk production results in a lot of manure production. But even then, chemical fertilizer use of N goes to unprecedented heights to maintain the N flows on the farm. In terms of self-sufficiency in protein, farms are still dependent on external sources. Also in relation to labour, medium and large farms are more dependent on hired labour. Large farms increase the area of grass, also the grass ratio increases. Total land use is increased with about 9% for large farms. Land use does not change for medium farms.

In PC there is no change in farm activities for medium farms. Also, there is hardly any difference in farm activities at large farms. The same activities yield a profit that is almost twice as high for large and medium farms. In TC there was already a very high O/I-ratio; also there was a high dependence on milk as contributor to the gross revenue. In GE the prices for feed increased less than the prices for other inputs. Feed is the main expenditure and milk is the main source of revenue. Milk prices increased approximately three times as much as feed prices, where crop price increase was approximately three times less compared to the increase of other inputs. Hence, it is logic that dairy farms stay focussing on dairy production and that the previous optimum remains most optimal in this simulation.

RC/G

CC in RC/G results in increased yields of grass and maize. There is a substantial increase in profit and milk production for large farms. Medium farms produce the same amount of milk, but still increase the profit. Farms are becoming more efficient and more self-sufficient. There is relatively and in the absolute sense more grass (area) for large farms. There is still a difference between large and medium farms in area covered with grass: 75% vs. 58%, respectively. However, this difference was already noticed in BY2.

In EE, the negative impacts on yields from extreme events are not big compared to yield change inCC. The profit decreases a few thousand euros, but is still higher than BY2. Land use is even more dominated by grass at large farms, and also medium farms have relatively more grass. Opportunities to increase milk production yield €60 and €120 for large and medium farms respectively.

In JC, the abolishment of the milk quota is used to increase milk production. Medium farms choose activities that reduce the amount of subsidy. Legislation on total N application and manure N application becomes more constraining in the new situation for large farms. Also the extra gain from more available labour is increased.

In TC, the changes that started in JC, become stronger: higher shadow prices for all constraining factors. Farms become much more specialized in milk production. Protein becomes a bigger concern, as medium and large farms become more dependent on external sources of protein. Area covered by grass becomes less, below the current average for large and medium farms. Milk production is increased, as well as manure production and fertilizer use.

In PC, much of the profit increase in TC is counterbalanced by less advantageous input-output price ratios. Milk price increases are hardly more than feed prices. In this simulation farms choose to dedicate more area to crops, and also the output of meat increases. Price increases are much stronger for crops and meat than for milk. It is in this simulation run that the shadow prices on manure and total N application increase for medium farms. That is logical, because more area dedicated to crops implies a lower amount of manure that can be applied, even when the relative cover by grass is over 70%, because total N applied to crops is just 140 kg ha^{-1} compared to 320 kg ha^{-1} for grass (Table 4).

In both GE/W^{+} and RC/G, JC results in a higher grass cover of the area, especially for medium farms. The common factor in both scenarios is the abolishment of the milk quota system. Difference between medium and large farms are their scope for improvement: medium farms rather increase their milk production, where large farms mainly look for opportunities to increase their efficiency by reducing the inputs. In TC milk production is a promising opportunity for both farm sizes, however in GE yield increase of grass and maize is not enough to supply the potential milk increase, where in RC the increase in milk yield potential is not enough to fully take advantage of the possible increase in grass and maize yields.

Table 19: Absolute indicators for performance and land use of large farms.

Indicator	Unit	Current Av.	BY1	BY2	GE/W+ CC	EE	JC	TC	PC	RC/G CC	EE	JC	TC	PC
Economic														
Profit	€ x1000	133	139	144	145	118	103	207	399	155	152	154	193	165
O/I	€/€	1.90	2.05	2.10	2.08	1.85	1.63	2.25	2.18	2.22	2.19	2.12	2.27	1.76
Milk/Total output	€/€	0.82	0.83	0.83	0.83	0.84	0.94	0.93	0.92	0.83	0.83	0.84	0.87	0.83
Labour														
Total labour	hour	5107	4800	4898	4898	4738	4930	5589	5560	4952	4919	5026	4930	4598
Hired labour	hour	648	463	458	458	279	471	1130	1101	512	477	567	470	139
Self-sufficiency														
Own feed/Total feed	VEM/VEM	0.66	0.65	0.66	0.65	0.61	0.59	0.65	0.65	0.70	0.68	0.65	0.65	0.69
Own feed/Total feed	DVE/DVE	0.58	0.58	0.59	0.58	0.55	0.53	0.54	0.54	0.67	0.65	0.63	0.57	0.61
Milk & Cows														
Milk	ton	703	678	684	695	667	791	1074	1075	700	700	750	933	690
Herd	#cows	94	90	93	94	94	103	109	109	96	95	99	100	82
Milk/cow	kg/cow/year	7453	7498	7323	7428	7101	7656	9821	9860	7268	7332	7550	9350	8439
Area & Yield														
Total area	ha	58.9	56.4	56.3	56.6	55.0	52.4	57.3	57.1	56.1	56.1	56.2	56.0	56.6
Grass	ha	43.8	41.2	42.0	41.7	38.7	36.6	44.8	44.4	42.8	43.2	43.6	41.2	41.4
Maize	ha	12.2	10.9	10.2	10.8	12.9	14.7	11.7	11.9	10.1	9.9	10.5	12.7	9.2
Grass/Total	ha/ha	0.74	0.73	0.75	0.74	0.70	0.70	0.78	0.78	0.76	0.77	0.78	0.74	0.73
Grass yield	ton/ha	7.3	7.5	7.8	7.5	6.2	6.5	9.4	9.4	10.1	9.8	9.8	10.0	9.2
Maize yield	ton/ha	13.7	14.0	14.1	15.3	13.8	13.9	17.9	17.9	15.3	13.9	13.9	15.5	15.3
Manure & Fertilizer														
Manure	m3	2932	2785	2819	2830	2709	2948	3686	3677	2931	2919	3064	3284	2727
FertilizerN	Kg ha^{-1}	82	83	85	89	57	63	146	140	151	135	140	169	90
FertilizerP	kg ha^{-1}	8	8	8	8	6	5	6	4	14	13	13	14	7
FertilizerK	kg ha^{-1}	95	97	99	92	76	74	66	59	126	119	126	140	103

Table 20: Absolute indicators for performance and land use of medium farms.

Indicator	Unit	Current			GE/W+					RC/G				
		Av.	BY1	BY2	CC	EE	JC	TC	PC	CC	EE	JC	TC	PC
Economic														
Profit	€ x1000	55	62	70	71	59	60	117	230	75	73	86	108	85
O/I	€/€	1.67	1.85	1.84	1.87	1.71	1.55	2.03	2.02	2.00	2.00	1.99	2.07	1.91
Milk/Total output	€/€	0.76	0.75	0.73	0.73	0.74	0.88	0.91	0.93	0.74	0.75	0.82	0.90	0.87
Labour														
Total labour	Hour	3713	3450	3412	3412	3522	4121	4121	4121	3427	3436	3662	3662	3662
Hired labour	Hour	48	28	43	43	43	506	506	506	43	43	47	47	47
Self-sufficiency														
Own feed/Total feed	VEM/VEM	0.71	0.74	0.67	0.67	0.60	0.52	0.56	0.56	0.74	0.74	0.63	0.60	0.63
Own feed/Total feed	DVE/DVE	0.64	0.66	0.59	0.59	0.54	0.45	0.43	0.43	0.69	0.69	0.58	0.49	0.55
Milk & Cows														
Milk	Ton	326	310	321	321	315	477	663	663	321	321	435	575	496
Herd	#cows	46	46	57	57	57	68	68	68	55	54	62	64	60
Milk/cow	kg/cow/year	7039	6687	5676	5676	5500	7008	9741	9741	5793	5912	7061	8967	8244
Area & Yield														
Total area	Ha	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9
Grass	Ha	20.9	20.8	17.2	17.2	18.0	19.8	19.8	19.8	18.1	19.0	21.3	19.6	21.2
Maize	Ha	6.7	6.6	8.3	8.3	8.6	9.3	9.3	9.3	7.8	7.3	6.7	9.6	6.6
Grass/Total	ha/ha	0.70	0.69	0.58	0.58	0.60	0.66	0.66	0.66	0.61	0.64	0.71	0.66	0.71
Grass yield	ton/ha	8.1	8.7	8.5	8.4	6.7	6.7	8.7	8.7	10.9	10.9	10.9	10.0	11.7
Maize yield	ton/ha	13.8	13.8	14.2	15.4	13.8	14.0	18.2	18.2	15.5	13.9	14.2	15.8	15.6
Manure & Fertilizer														
Manure	m3	1453	1453	1621	1621	1631	2028	2344	2344	1600	1579	1891	2123	1988
FertilizerN	Kg ha^{-1}	83	85	71	83	56	75	157	157	140	126	156	0	75
FertilizerP	Kg ha^{-1}	8	8	7	8	6	4	4	4	13	12	15	15	5
FertilizerK	Kg ha^{-1}	97	99	82	86	75	77	55	55	110	107	136	161	145

Table 21: Relative indicators for performance and land use of large farms.

Indicator	Current Av.	BY1	BY2	GE/W+ CC	EE	JC	TC	PC	RC/G CC	EE	JC	TC	PC
Economic													
Profit	100%	104%	108%	109%	89%	77%	156%	300%	116%	114%	116%	145%	124%
O/I	100%	108%	111%	110%	98%	86%	119%	115%	117%	116%	112%	120%	93%
Milk/Total output	100%	101%	100%	100%	102%	114%	112%	112%	100%	101%	102%	106%	101%
Labour													
Total labour	100%	94%	96%	96%	93%	97%	109%	109%	97%	96%	98%	97%	90%
Hired labour	100%	71%	71%	71%	43%	73%	175%	170%	79%	74%	87%	73%	21%
Self-sufficiency													
Own feed/Total feed	100%	99%	100%	99%	93%	90%	100%	99%	107%	103%	100%	99%	105%
Own feed/Total feed	100%	99%	101%	99%	95%	91%	92%	92%	115%	111%	107%	97%	104%
Milk & Cows													
Milk	100%	96%	97%	99%	95%	112%	153%	153%	99%	99%	107%	133%	98%
Herd	100%	96%	99%	99%	100%	110%	116%	116%	102%	101%	105%	106%	87%
Milk/cow	100%	101%	98%	100%	95%	103%	132%	132%	98%	98%	101%	125%	113%
Area & Yield													
Total area	100%	96%	95%	96%	93%	89%	97%	97%	95%	95%	95%	95%	96%
Grass	100%	94%	96%	95%	88%	84%	102%	102%	98%	99%	100%	94%	95%
Maize	100%	89%	84%	88%	105%	121%	96%	97%	82%	81%	86%	104%	76%
Grass/Total	100%	98%	101%	99%	95%	94%	105%	105%	103%	104%	104%	99%	99%
Grass yield	100%	102%	106%	102%	84%	88%	128%	128%	138%	134%	134%	136%	125%
Maize yield	100%	102%	103%	111%	100%	102%	130%	130%	112%	101%	101%	113%	111%
Manure & Fertilizer													
Manure	100%	95%	96%	97%	92%	101%	126%	125%	100%	100%	105%	112%	93%
FertilizerN	100%	102%	104%	110%	70%	77%	179%	172%	186%	166%	172%	207%	111%
FertilizerP	100%	102%	104%	104%	69%	56%	69%	54%	174%	155%	162%	175%	87%
FertilizerK	100%	102%	104%	96%	80%	78%	70%	62%	133%	125%	133%	147%	109%

Table 22: Relative indicators for performance and land use for medium farms.

Indicator	Current Av.	BY1	BY2	GE/W+ CC	EE	JC	TC	PC	RC/G CC	EE	JC	TC	PC
Economic													
Profit	100%	111%	126%	128%	107%	109%	211%	415%	135%	132%	156%	195%	154%
O/I	100%	111%	111%	112%	103%	93%	122%	122%	120%	120%	120%	124%	115%
Milk/Total output	100%	99%	96%	96%	97%	116%	120%	122%	98%	99%	108%	119%	114%
Labour													
Total labour	100%	93%	92%	92%	95%	111%	111%	111%	92%	93%	99%	99%	99%
Hired labour	100%	59%	90%	90%	90%	1062%	1062%	1062%	90%	90%	100%	100%	100%
Self-sufficiency													
Own feed/Total feed	100%	104%	95%	95%	85%	73%	79%	79%	105%	105%	89%	84%	90%
Own feed/Total feed	100%	103%	92%	92%	84%	70%	67%	67%	107%	108%	90%	77%	85%
Milk & Cows													
Milk	100%	95%	99%	99%	97%	146%	203%	203%	99%	99%	134%	176%	152%
Herd	100%	100%	122%	122%	124%	147%	147%	147%	120%	117%	133%	138%	130%
Milk/cow	100%	95%	81%	81%	78%	100%	138%	138%	82%	84%	100%	127%	117%
Area & Yield													
Total area	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Grass	100%	99%	82%	82%	86%	95%	95%	95%	87%	91%	102%	94%	101%
Maize	100%	99%	124%	124%	129%	139%	139%	139%	117%	109%	100%	143%	99%
Grass/Total	100%	99%	82%	82%	86%	95%	95%	95%	87%	91%	102%	94%	101%
Grass yield	100%	107%	105%	103%	82%	82%	107%	107%	134%	134%	135%	123%	143%
Maize yield	100%	100%	103%	112%	100%	102%	132%	132%	113%	101%	103%	115%	113%
Manure & Fertilizer													
Manure	100%	100%	112%	112%	112%	140%	161%	161%	110%	109%	130%	146%	137%
FertilizerN	100%	102%	85%	100%	67%	90%	188%	188%	167%	151%	187%	0%	90%
FertilizerP	100%	102%	85%	101%	69%	50%	52%	52%	159%	143%	177%	187%	65%
FertilizerK	100%	102%	85%	88%	77%	79%	57%	57%	113%	110%	140%	166%	149%

Table 23: Shadow prices of some binding constraints for large and medium farms in all simulations. Constraints that are related to nutrient balances and protein levels in the diet are omitted.

Size	Constraints	Unit of constraint	Current BY1	BY2	GE/W+ CC	EE	JC	TC	PC	RC/G CC	EE	JC	TC	PC
Large	Area	ha	835	967	936	625	511	1838	3295	1219	1347	1550	1715	1317
Large	Capital	€	0.034	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Large	Convexity	#	11177	19048	20551	33215	35999	69411	113866	21703	9743	8402	43255	12153
Large	Dairy Cows	#	104	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Large	Family Labour	hour	12.60	20.14	13.83	18.17	11.37	11.52	28.04	15.10	15.26	23.40	24.89	35.10
Large	Hired Labour	hour	2.47	9.74	3.52	7.09	NA	NA	NA	4.56	4.74	11.22	13.14	6.97
Large	K Balance	kg	NA	NA	0.38	0.38	0.38	0.25	0.61	0.38	0.38	0.38	0.38	0.83
Large	Manure N Legislation	kg	NA	NA	1.07	0.90	NA	NA	NA	1.23	1.07	1.10	2.20	3.78
Large	Milk Quota	ton	13.75	36.25	58.42	15.30	NA	NA	NA	60.68	59.80	NA	NA	NA
Large	N Balance	kg	NA	NA	1.04	0.95	0.95	1.04	2.47	1.20	1.12	1.12	1.77	2.47
Large	Other Output	€	5.60	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Large	P Balance	kg	NA	NA	0.98	0.80	NB	0.62	1.19	1.07	1.07	1.07	1.07	2.23
Large	Total N Legislation	kg	NA	NA	NB	NB	NA	NA	NA	0.10	0.05	0.05	0.44	NB
Medium	Area	ha	1137	1697	1709	1676	3286	5703	11235	2541	2398	2856	4351	4115
Medium	Dairy Cows	#	1769	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Medium	Family Labour	hour	2.03	5.42	5.68	14.28	10.47	8.98	21.35	5.10	4.87	21.87	22.67	23.88
Medium	Hired Labour	hour	NA	1.38	1.45	5.35	NA	NA	NA	1.38	1.25	11.40	13.69	2.53
Medium	K Balance	kg	NA	NA	0.38	0.38	0.38	0.29	0.69	0.38	0.38	0.38	0.38	0.91
Medium	Manure N Legislation	kg	NA	NA	1.21	0.93	NA	NA	NA	1.50	1.23	1.28	2.51	4.21
Medium	Milk Quota	ton	40.22	139.63	131.25	61.96	NA	NA	NA	103.74	119.93	NA	NA	NA
Medium	N Balance	kg	NA	NA	1.04	0.80	1.04	1.04	2.47	1.25	1.19	1.04	1.99	2.47
Medium	Other Output	€	0.34	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Medium	P Balance	kg	NA	NA	1.07	0.82	NA	0.26	0.62	1.07	1.07	1.07	1.07	2.07
Medium	Total N legislation	kg	NA	NA	NB	NB	NA	NA	NA	0.13	0.09	NB	0.57	NB

*For medium farms, the convexity constraint is non-binding (NB) and the capital constraint is non-binding (NB) in BY1 and not included (NA) in the other simulations.

Table 24: Input-Output balance for large and medium farms in the different simulations.

Unit:	Current			GE/W+					RC/G				
€ X 1000	**Av.**	**BY1**	**BY2**	**CC**	**EE**	**JC**	**TC**	**PC****	**CC**	**EE**	**JC**	**TC**	**PC****
Large													
Energy	10	10	10	10	10	12	12	12	10	10	11	11	8
Feed	41	40	39	38	43	49	51	52	26	29	33	42	34
Other input	97	82	82	86	86	102	102	102	90	88	93	99	64
Sub total	***148***	***132***	***131***	***134***	***139***	***162***	***166***	***166***	***126***	***127***	***137***	***152***	***106***
Crops	4	3	3	4	2	1	1	1	2	2	2	2	3
Meat	17	19	19	18	13	8	20	19	21	21	21	15	22
Milk	232	225	227	230	215	248	345	346	232	232	245	301	234
Other output	11	6	8	9	8	8	7	7	9	8	7	8	5
Subsidies	17	17	17	17	19	0/20	0/19	0/19	17	17	17	19	17
Sub total	***281***	***270***	***275***	***279***	***257***	***264/284***	***373/392***	***373/392***	***281***	***279***	***291***	***344***	***282***
Profit	**133**	**139**	**144**	**145**	**118**	**102/122**	**207/226**	**207/226**	**155**	**152**	**154**	**193**	**176**
Medium													
Energy	5	5	5	5	5	7	7	7	5	4	7	7	7
Feed	18	17	20	19	24	38	40	40	12	13	23	33	31
Other input	60	50	57	58	53	65	66	66	58	56	57	61	53
Sub total	***83***	***72***	***83***	***82***	***83***	***109***	***113***	***113***	***75***	***74***	***87***	***101***	***90***
Crops	2	2	2	2	1	1	1	1	2	1	3	1	3
Meat	11	13	13	13	14	14	14	14	12	12	14	11	15
Milk	105	101	111	111	105	148	209	209	111	111	141	180	162
Other output	8	7	16	16	11	6	6	6	14	13	6	5	6
Subsidies	13	11	11	11	12	0/12	0/12	0/12	10	10	8	12	9
Sub total	***139***	***134***	***152***	***152***	***142***	***160/182***	***230/242***	***230/242***	***149***	***147***	***173***	***209***	***194***
Profit	**55**	**62**	**70**	**71**	**59**	**60/72**	**117/129**	**117/129**	**75**	**73**	**86**	**108**	**105**

*Results for JC, TC and PC in GE/W$^+$ are presented with and without contribution of subsidies. **As if the price changes are not included, which facilitates the comparison with other runs.

4.3 Specific Indicators

After presenting the effect of the scenarios in a common story it is good to look at some specific indicators. Figure 5 presents the return to family labour. Return to family labour is defined as total gross margin divided by the amount of family labour. It is clearly visible in Figure 5 that medium farms consistently have a lower return to labour. However, the relative gap between medium and large farms is projected to become smaller.

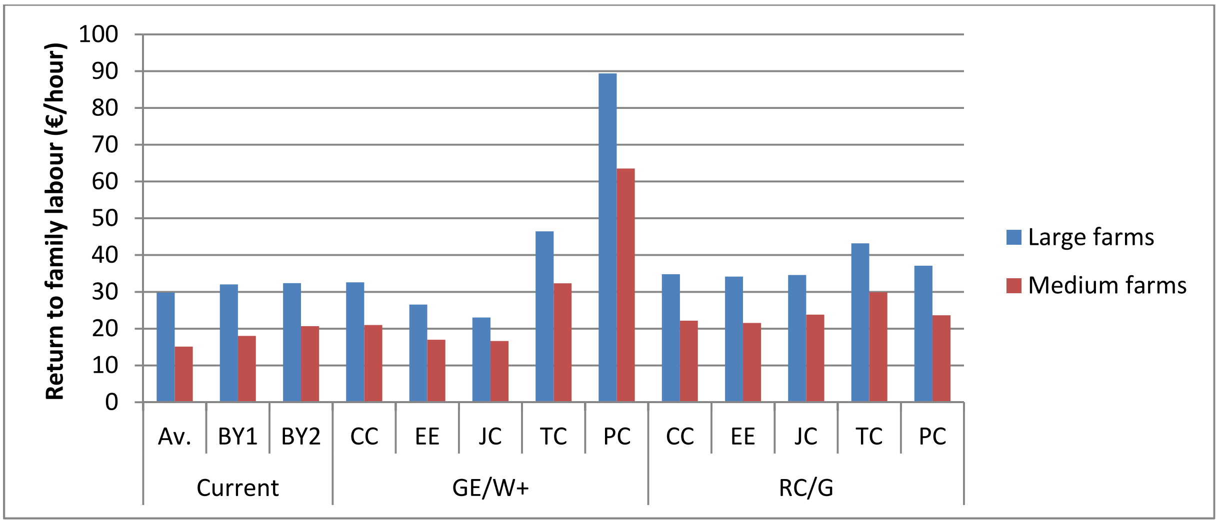

Figure 5: Return to family labour for the current average and all simulations.

Expenditure on fertilizer use per hectare does not differ much between farm classes over the simulations (Figure 6). In the long-term, medium farms can get a lower chemical fertilizer use intensity; however, medium farms will get a higher intensity than large farms when the milk quota are abolished. Fertilizer use is low in EE and JC in GE/W^+, where maize and grass yields are reduced considerably. The difference in fertilizer use between TC in GE/W^+ and RC/G is explained by the abolishment of N-legislation in GE/W^+, that reduces the need for chemical fertilizer. In TC and PC of RC, manure is deported from medium and large farms. In general, the high input of fertilizer in RC is a disadvantage in a regionalized economy. Moreover, environmental awareness most likely will emphasize on closed nutrient cycles. From the perspective of RC, current legislation leads to a activities that contradict the general concepts of a regional community.

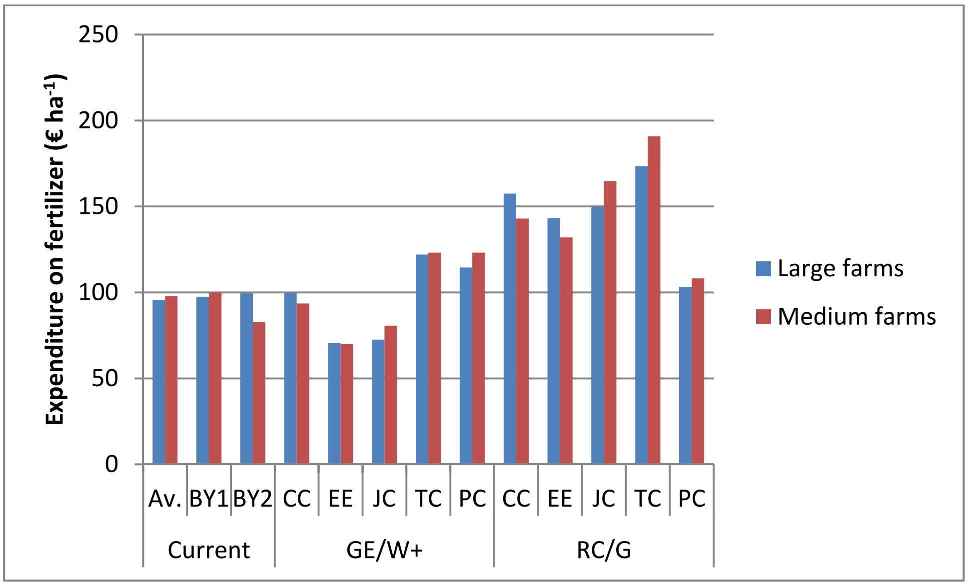

Figure 6: Expenditure on chemical fertilizer use per hectare for large and medium farms for the current average and all simulations.

The omission of the manure and total N regulation in JC in GE/W$^+$ can be seen as an ex-ante policy assessment. Table 25 presents the exceedance of N in manure and total N considering the current regulation. Abolishment of legislation on nitrogen does at most lead in TC to an additional 90 kg ha^{-1} above the current threshold of 170 kg ha^{-1}. That is 55% on top of the current threshold, while maize and grass yields potentially only increase with 16% and 14%, respectively. Roughly speaking the application of the extra manure leads to an additional 50 kg ha^{-1} loss to the environment if the application techniques and quality of manure are not improved and if losses (currently higher than 50%; Appendix N) at higher input ratios are not higher.

Table 25: Manure N and Total N applied in GE (JC, TC, PC) above current legislative thresholds.

Exceedance	Unit	Size	JC	TC	PC
Manure N beyond threshold	Kg ha^{-1}	Large	15	70	75
Total N beyond threshold	Kg ha^{-1}	Large	-	-	-
Manure N beyond threshold	Kg ha^{-1}	Medium	28	90	90
Total N beyond threshold	Kg ha^{-1}	Medium	-	14	14

For the current situation, the scope for management adaptation of farms was studied in BY1 and BY2, where farms could adopt other farms' practices to become more profitable. However, it might be that the choice that could be made in BY1 and/or BY2 would not be the actual choice when climate and socio-economic changes are taken into account. Table 26 presents the current profit of the selected 'whole farm' activities for the different simulation runs. These values can indicate something about the possibility to pro-actively adapt to changes. In GE the influence of extreme events forces large farms to adapt to activities that currently yield less profit. Medium farms in GE, however, see opportunity to select activities that depend more on external sources of feed (especially concentrates; see also Table 24). These activities result in a milk production above the milk quota, which is compensated by a milk yield decrease per cow. In JC in GE, medium farms select 'whole farm' activities that are 24% higher in profit then the activities selected under the current conditions, but this does not change when technology changes. This strong increase can be explained by the omission of the milk quota and labour constraint; these constraints were binding constraints in BY2. Large farms select activities in JC that marginally increase profit (+1%) compared to when selected in BY2.

In RC, where most yield changes are positive, the activities chosen to adapt to the combined effects of changed CO_2 concentration, temperature, precipitation, wind and extreme events, yield a similar profit if they are selected in the current situation. Table 21 and Table 22 show that simulated profit also only changes a little for CC and EE in RC. In JC in RC it is the medium sized farm that increases profit most by management adaptation rather than production increase by choosing the extra milk activity in the LP-model. In PC, large farms adopt activities which yield less profit in BY2. It seems that large farms have not much room for manoeuvre. That can be related to the high shadow prices for the convexity constraint (Table 23). At the other hand there are a lot of farms that achieve much more profit than in BY2, but their activities cannot be adopted because of milk production and labour and manure constraints. The consistent higher values in Table 26 when JC is involved in GE/W$^+$ compared to RC/G suggest that in RC something is still constraining farm income. The main constraint is most likely labour and N-legislation, considering the stronger increase in shadow prices for labour compared to N legislation (Table 23). In general it can be concluded that the current farm management choice is not aimed to be able to maximize profit under impacts of climate and socio-economic change. This is however largely due to constraints currently limiting the adoption of improved activities.

Table 26: Change in gross margin of future 'whole farm' choices as calculated with current input output relations compared to gross margin in BY2.

	GE/W+					RC/G				
Size	**CC**	**EE**	**JC**	**TC**	**PC**	**CC**	**EE**	**JC**	**TC**	**PC**
Large	0%	-1%	1%	6%	6%	0%	0%	2%	1%	-2%
Medium	0%	6%	24%	24%	24%	0%	0%	17%	16%	16%

Also the adaptability of a farm and the impediment by some constraints can be studied by looking at the extent into which activities from other size classes are selected (Table 27). Table 27 shows that large farms hardly incline towards medium sized farm activities. Selection of medium sized farm activities by large farms is 0% in both scenarios when the milk quota is abolished. Medium farms at the other hand can improve their profit a lot by choosing 'large farm activities'. In the current situation, selection of large farm activities is already 34% if only long-term constraints are taken into account. A next big change in activities happens in both scenarios when the milk quota is abolished (75% and 71% 'large farm activities' for resp. GE/W$^+$ and RC/G; Table 27).

There are two ways to change milk productivity per cow: the so called 'technological development', which is part of the scenario, and the change by choosing other farm activities, which is part of the structure of the LP-model. In Table 28 the importance of the two factors in the total productivity change are presented. Medium farms increase cow productivity the most. The optimization as 'source' of increased cow productivity is more important for medium farms than for large farms. In JC in GE, optimization as 'source' for increased cow productivity is important to compensate for lost subsidies under negative influence of climate on grass and maize yields.

Table 27: Extent into which size classes choose 'whole farm' activities from the own or other size class.

		Current		GE/W+					RC/G				
Size	**Activity choice**	**BY1**	**BY2**	**CC**	**EE**	**JC**	**TC**	**PC**	**CC**	**EE**	**JC**	**TC**	**PC**
Large	Large farms	99%	96%	95%	97%	100%	100%	100%	96%	94%	100%	97%	100%
Large	Medium farms	1%	4%	5%	3%	0%	0%	0%	4%	6%	0%	3%	0%
Medium	Large farms	2%	34%	34%	46%	75%	75%	75%	31%	25%	71%	61%	71%
Medium	Medium farms	98%	66%	66%	54%	25%	25%	25%	69%	75%	29%	39%	29%

Table 28: Sources of change in milk productivity per cow for the different simulations.

	Base Year		GE/W+					RC/G				
Milk yield change by:	**BY1**	**BY2**	**CC***	**EE***	**JC***	**TC**	**PC**	**CC**	**EE**	**JC**	**TC**	**PC**
Large												
Technological change	0%	0%	0%	-11%	-9%	28%	28%	0%	0%	0%	18%	18%
Farm activity choice	1%	-2%	0%	7%	13%	3%	3%	-2%	-2%	1%	6%	-4%
Total	1%	-2%	0%	-5%	3%	32%	32%	-2%	-2%	1%	25%	13%
Medium												
Technological change	0%	0%	-45%	-14%	-10%	25%	25%	0%	0%	0%	18%	18%
Farm activity choice	-5%	-19%	46%	-9%	11%	11%	11%	-18%	-16%	0%	8%	-1%
Total	-5%	-19%	-19%	-22%	0%	38%	38%	-18%	-16%	0%	27%	17%

* Milk yield change by negative technological change is possible in CC, EE and JC to compensate the reduced feed availability.

5. Discussion

From the perspective of overall sustainability in the future it is reasonable at the one hand to use scenarios to evaluate the most extreme developments. At the other hand, the use of scenarios complicates the evaluation, because values and norms considering sustainability change accordingly to the used scenarios. In this chapter the results are discussed from a perspective of sustainability that sees the values and norms in GE and RC as two different extremes. These extremes are believed to have the potential to evolve from the current situation within 40 years. Therefore, results in a certain scenario are compared to the general sense of values and norms that is prevalent in that scenario. That helps to evaluate the consistency of the scenarios with the model output, that also evolves from the current situation in the dairy sector. The order of the discussion is to a large extent coherent with the order in the simulations. However, sometimes this order is neglected to highlight certain influences. Preliminary recommendations for policy makers are integrated in the text. Recommendations for the methodology are also integrated in the discussion.

5.1 Improving farm performance in the current situation

The output of the model suggests that in the current situation profit can be increased, especially by medium farms. In general, resources can be used more efficient: input can be decreased and the output/input ratio can be improved. Reducing inputs and becoming more efficient is an acknowledged strategy that correlates with high resilience when milk prices are fluctuating (Oostindie et al., 2013). However, the suggested decrease in input of medium farms is mainly achieved by reducing the 'other input', while input of feed is even increased in BY2. This results in a lower degree of self-sufficiency. Self-sufficiency is an attribute of medium farms that have a high resilience to price fluctuations in the study of Oostindie et al. (2013). In terms of output, production levels of grass and maize increase, while milk production per cow and total milk production per farm decrease. Shadow prices show clearly that land, labour and milk quota are the main constraining factors for both farm sizes.

For the short-term perspective in the current situation, this study indicates that 47% of the area is under profit maximization. This is mainly valid for the larger farms (NGE>70). For the long-term, this research does not indicate that the assumption for profit maximization for medium farms is good/sufficient. The proposed specialization and intensification with lower self-sufficiency to achieve higher profit might exactly be something opposite to farmers' objectives, especially in RC where farmers are more aware of sustainability issues. Profitability is an indicator for economic sustainability. Reducing deviation of income (risk reduction) is also an indicator for economic sustainability. Risk reduction will become more important after abolishment of the milk quota when market prices are expected to fluctuate more (Oostindie et al., 2013; Zijlstra, 2011). Besides economic sustainability, van Calker et al. (2005) distinguish ecological sustainability and internal and external social sustainability. It is the complete sustainability picture that is the challenge for Dutch dairy farms in the transition to a more sustainable future (Rotmans, 2003). Therefore, more than one criterion should be involved.

Multi-criteria analysis with utility functions is used by van Calker et al. (2006) to include more sustainability indicators in a LP-model. Zijlstra et al. (2011) present information that suggests that not all farmers in the study area opt for profit maximizing and often have other objectives. In the FADN-data no information about farmers objectives and the perceived utility is available. Besides the presence of other objectives than gross margin maximization it can be due to the incapacity of intentional profit maximizing farmers that gross margin maximization is not achieved. Thus, even when other objectives will disappear in the future, farmers still may not be capable of choosing the right options to get the most out of it. Daatselaar (2012; pers. comm.) mentioned that he used LEI-data to look at the performance of farms throughout the years. It turned out that farm performance deviates after succession by a farmers' son. In other words: the consequences of the current laws that regulate succession rights may contradict with the assumption that profit maximization is possible for every farmer. At last, it is not only the objective function in the LP-model, but also the amount of constraints and the way they are translated into mathematical formulas that might not approach reality. In theory, positive mathematical programming (PMP; Howitt, 1995) can overcome the presence of obscure constraints and farmers' risk perception (Kanellopoulos et al., 2010). However, FADN-data does not provide enough information to calibrate the model. In addition, supply elasticities for inputs and outputs for 2050 are needed, which includes more assumptions. Finally, interpretation of the results is more complicated in the non-linear model of PMP compared to the current LP-model, while comparing relative effects of climate and socio-economic change can be done with the latter model as well.

5.2 Yield change by gradual climate change and extreme events

Farms turn out to be not very adaptable to compensate negative yield changes by changing land use and inputs. Medium farms, which are less specialized, are better in compensating adverse shocks than larger farms. That general notion is also found in Reidsma (2007) where adaptation to climate change in Europe is studied. Under the current legislation, the effect of grass and maize yield decline as is explored in GE reduces the pressure of the milk quota and N application legislation on profitability. In the outcomes of the model-runs there is no suggestion that farmers should choose for activities that yield more subsidies in order to compensate negative impacts of climate change. Strikingly, it is in JC in GE where subsidies are abolished that subsidies would be the highest (if provided) according to the activity choice for large farms. Negative shocks of climate change can also not be compensated enough by other farming practices that are currently making less profit.

To compensate for negative impacts of climate change, adaptation measures should be included in current farming activities, rather than loosening the constraints imposed by the social environment. Schaap et al. (2013) show that negative impacts of climate change on arable crops can be reduced by adaptation. Irrigation as adaptation strategy is not included in the model yet. However, quantitative information for irrigation is available (Vermeij et al., 2009; Schaap et al., 2013) to include this in the model. Also water requirements to achieve potential yield are known (Wolf et al., 2011). The output will give water use in average years. De Wit et al. (2009) also provides information for increasing soil moisture holding capacity as adaptation measure. Implementation of irrigation and soil moisture increasing capacities in the model is necessary to evaluate the sustainability of the developments in agriculture in the domains of nature and water management.

Another point is that the assumption that by merely adopting other farm activities, production efficiency can be increased. This assumption neglects the spatial variability in soil type that is mentioned in Chapter 2 of this study. Also depth of the ground water level is assumed to be not of influence on crop productivity, while there are areas in de Baakse Beek that have shallow water tables. Adapting the model to spatial uniform sub areas could give a more area specific solution, provided that enough 'whole farm' activities are available for that area, which is not the case. Therefore it will also be hard to evaluate the policy options in which water tables are changed (Appendix A).

Ranges of damage by extreme events are big, e.g. 'on-going wet conditions' in maize can reduce yields from 25% up to 100%. In this study an average is taken. That implies that yield losses through extreme events could be less or more. The assumption that damages of different types of events can be calculated separately and after that can be add up is made up out of practical necessity, because no information was available about probability of specific subsequent occurrence of different types of extreme events. Including the sequential aspect of different types of extreme events would improve estimations of the damage, and may affect results. Also, some extreme events, like dry conditions, will be partly covered by WOFOST and LINGRA as well. Hence, incompleteness of information on probability of occurrence and overlap in countenance for damage by water deficit probably leads to an overestimation or underestimation of the impact of extreme events. Another point is that farmers currently already apply adaptation activities by irrigating their crops, while change in yield due to extreme events assumes that current yields are the result of climate conditions without adaptation activities.

Average current grass yield in this study might have been underestimated, however, the standard deviation is too big to be positively conclusive on this matter. Some farms are averaged over just one or two years, which can result in under- or overestimations in the calculations. Feed for instance can be purchased in one year (which was not included) and be consumed in another year, which leads to an overestimation of grass yields in individual cases. In addition much of the data was supplied in monetary values, which has implications for the level of detail, e.g. whether and how much cows could graze or how much protein content there was in the purchased concentrates. Also information about farmers knowledge, objectives and perspectives was lacking. The assumptions that have to be made to obviate the lack of information can be improved by interviews. Assuming water limited yields in the future is acceptable because in the current situation most dairy farmers only irrigate their crops when crop failure is a threat. Effect of water shortage can be captured by LINGRA. Kroes and Supit (2011) studied the effect of water excess, drought and salinity on grass yields in the future for different scenarios at a regional scale in the Netherlands. With the model SWAP-WOFOST they found for all scenarios that water excess and salinity are minor stress factors compared to increased drought stress in the future. Actual yields simulated by Kroes and Supit (2011) are 10-14 ton ha^{-1}, which is much higher than water limited yields simulated with LINGRA for this study. However, the yield gap between actual and potential of Kroes and Supit (2011) is similar to the results from LINGRA, e.g. in the current situation the yield gaps are 52% and 48% for results of Kroes and Supit (2011) and results from LINGRA respectively. In the model is the assumption that increased production is not requiring more labour. For increased maize production that assumption is acceptable because maize is harvested at once. However, grass is harvested in several times. A common indicator for a farmer to harvest grass is the length of grass. That implies that with a change in production a farmer has to harvest the grass in less or more turns. However, it is hard to include that in the LP-model because time spend for harvesting goes step-wise, while 'charging' labour for extra production of grass will go gradually in the LP-model.

Influence of extreme events on cow productivity is not included in this research. With increasing temperatures and higher frequency of heat waves this is an important factor to consider in future studies. McGovern and Bruce (2000) predicted with a model at animal level that cows can maintain thermal balance even at 40 ^{O}C, but that feed intake and coherent milk production will be reduced. The existence of models that predict cow productivity levels under extreme conditions can supply the necessary information that either via a feed intake constraint or a milk production constraint can be implemented in the LP-model. Apart from heat stress, also the occurrence and spread of diseases might change. Most cow diseases are (in)directly linked to climate, however understanding on the relationships between climate (change) and animal diseases is still small (Henry et al. 2012) and hence is hard to quantify. Also new crops should be considered, because increased temperatures and reduced risk on night frost later than April implies more favourable conditions for some crops. Another shortcoming is that the effect of climate change on crops other than maize and grass is not included while there certainly will be an effect as can be seen in a study in Flevoland in the Netherlands of Wolf et al. (2011). Especially in PC in RC/G where dairy farms dedicate more area to arable crops it could become an important factor.

5.3 Juridical and technological changes

The situation in the dairy sector does not improve (much) when farmers have no milk quota, more access to labour and can apply more manure, while at the same time yields are negatively affected and subsidies are abolished in GE. However, medium farms still use the juridical change to increase milk production (higher specialization) and increase their income marginally. In RC, yields of maize are slightly negatively affected and grass yields are positively affected. In RC it are also the medium farms that profit the most from abolishment of the milk quota. Shadow prices in the RC scenario indicate that the current N-legislation is constraining when the milk quota is abolished. At the other hand it keeps the shadow prices for land relatively low. In TC, where milk and crop yields increase, the shadow prices manure N-legislation constraints double. Increase in fertilizer expenses in RC can be noticed in Figure 6, while part of the manure is exported. The proposed sovereignty in the regional community scenario (Appendix I) can be enhanced by increased self-sufficiency and closed nutrient cycles. Importing fertilizers and concentrates and exporting manure, while not all potential of grass and maize yields are used contradicts with the strive for sovereignty in RC. From the perspective of RC, it would be logic to at least allow more manure to be applied on the land, provided that application and storage efficiency increases. Also, the total N application regulations need revision or more ex-ante policy assessment because loosening the regulations might increase rough fodder production. The results of revision or more ex-ante policy assessment is heavily dependent on the actual development of prices, because in RC PC has an influence on the use of the potential of grass, maize and milk yields. In the global economy scenario there is also a development considering N-legislation. High manure use intensity in GE most likely leads to clearly noticeable pollution of local surface waters. The common storyline of GE as presented in Appendix I notes that global environmental initiatives will not have much support, but local environmental initiatives can expect support, especially when prosperity is high, which is the case in GE. Hence, total abolishment of N-legislation is too extreme. A relaxation of the legislation according to expected yield increase of maize and grass seems more suitable from the perspective of the storyline of global economy. More simulations with a change in N-legislation are also needed to evaluate the effect on land use. An effect of all legislative change in the simulations is that in both scenario's the grass area of medium farms is increased compared to CC and EE. However, in RC, TC can inverse the land use change. In PC the relative grassland cover that is the outcome in TC is either maintained or increased. Farms are very capable to benefit from yield increases; this capacity is mainly enlarged when farms have more access to labour and to a lesser extent, when they are not constrained by manure application laws. Self-sufficiency decreases in both scenarios, mainly due to the increase of milk yield potential, which makes farmers specialize more.

The milk/manure ratio decreases when milk production per cow goes up, which implies higher efficiency. However, in general it can be noted from this study that the herd size is likely to increase, except when negative climate change impact on crop yields is too big or when price developments develop negatively. With increased herd size and milk production, it is not likely that relative nitrogen losses will be reduced at the increased intensity, unless technological development also improves the efficiency. Moreover, extreme events might induce leaching and/or decreased uptake by plants. In RC, the nitrogen legislation limits the intensity a little, but that is really dependent on the development of the prices. The assumption of 100% resource use efficiency of P (Oenema et al., 2006) and K might be incorrect, especially on the predominant sandy soils in this study. The implemented nutrient balances in the LP-model are necessary to get an indication of specific fertilizer use. However, current legislation on P is not included yet, while on sandy soils P is prone to drain with seepage water to the surface waters. Hence, it will be a good addition. Also greenhouse gas emissions are not likely to be reduced in the future when conventional farming techniques are maintained. However, especially in RC this is a serious issue as currently 48% of the greenhouse gas emission in Gelderland (the province in which de Baakse Beek is situated) is caused by dairy farming (Lesschen, 2009). In other dairy farming models the losses to the environment are variable (for instance: Berentsen, 1995; Groot and Oomen, 2011), while the losses in the LP-model in this study are fixed. Scope for variability of nutrient losses in the current methodology is limited. To improve the model nutrient use efficiencies should be connected to the storylines. Another point of concern is the fixed protein content of milk, grass and maize, while the former depends on the diet and the latter can vary significantly, depending on the level of fertilization. Especially in GE, where there is no N-legislation an increase in protein content in grass can be expected. Also here the values for nutrient contents can be adapted according to and coherent with the scenario. Model output for a medium and large farm of the used LP-model could be implemented in another LP-model with separate farming activities to see the effect of climate and socio-economic change on the nutrient leaching, greenhouse gas emission and nutrient contents of milk, grass and maize. That will help in the iterative process of determining the values of nutrient use efficiencies and nutrient contents for the different scenarios. Considering the exportation of manure, much is dependent on technological development that is not included in the model. The assumption that manure can be exported for free could be maintained: Vermeij et al. (2009) give estimated prices for exporting one cubic meter manure (10-15 Euro m^{-3}). Exported manure in RC is at most 200 cubic meter for large farms in TC. Extra costs for exporting manure will be then €1500-2250. That is approximately 0.5-1% of the profit of large farms. It will not influence the outcome of this study much (derived from model runs that are not presented in this report). However, an extra run including exportation costs of manure becomes interesting when N-legislation is not abolished in GE.

Technological development is an important factor that has to be included in integrated climate change studies (Ewert et al, 2005; 2011). Ewert et al. (2005) expressed the lack of knowledge about the relationships that determine technological development already for arable crops. Dairy farming systems are more complex than arable systems in the sense that the ultimate main product (milk) is dependent on the ‘in between products’ (rough fodder production; arable crops) and the total diet and management. Hence, it is even more obscure where technological development comes from, especially when the values used for the statistics are averages. The linearity of the average milk increase over time (LEI, 2012) does not give insight in the distribution of the used data. It could be that over the past decade the distribution of the data became different because farms with lower productivity levels converge more and more to the optimal productivity level or that the mentioned farms simply disappear. It is logical to assume that in the latter case, the farms with on average higher productivity levels remain, which results in a higher productivity at national scale. In other words it means that certain technologies and farm activities are becoming more widespread. That is also an advantage of the LP-model where farms can chose more efficient activities. This study has revealed that increased production of milk on medium farms in the future can for a large part be supported by adopting currently existing (in the area) management, technologies, knowledge and perspectives. However, for large farms in general and for medium farms under negative price developments this adoption is less important. Still, for both farm sizes new technological development is most important to increase production in the future.

Potential milk yield increase is not fully used in GE/W+, while in RC/G all of the future potential is expected to be used. This indicates that apart from opportunities for new technologies there needs to be a supportive environment to enhance the full use of the potential. This is coherent with the philosophy of transition where it is acknowledged that the different 'cogs in the mechanism' need to work in a collaborative way in order to realize a transition (Rotmans, 2003). In GE/W+ the yield increase of grass and maize is not enough to supply enough energy and protein to achieve the potential milk yield, provided that the assumption of self-sufficiency holds and farms will keep cultivating their own feed at all. Dependent on the development of the prices for feed and the stability of the market and farmers perceptions of risk, potential yield increase might be achieved for milk, i.e. dependent on the other cogs in the mechanism. From another perspective the finding that yield increase potential will not be fully used, is interesting because the potential milk yield increase in the GE/W^+-scenario is an extrapolation of the current linear trend in milk production increase. Until now this extrapolation of steady growth was used in predictions for possible futures (Frouws and Broekhuizen, 2000). When production of rough fodder lags behind in the Netherlands, this means an end of this linear increase in case the cow density in the Netherlands remains at the same level. However, in a global economy the technological development might still increase, resulting in a higher cow density and/or higher specialization on the cow activities, i.e. only livestock and no rough fodder production. The latter options are not in the scope of the model, hence it looks like that the current paradigm is imposing the outcome of the explorations, while the idea of a scenario is that new possible paradigms are studied. Later on in this chapter, the assumptions and the scope of the model will be treated. Anyways, based on the gradual linear yield increase Frouws and Broekhuizen (2000) made accurate predictions for 2010, taking into account the imposing structure of the milk quota system. After the milk quota is abolished food supply becomes more determinant for the development of the Dutch dairy sector. Even when the assumption of maintained self-sufficiency is obsolete, it is not sure whether use of the full yield potential increase can be realized when also total milk production increases, even with very favourable market prices. For the future, this is a notion that gives uncertainty in prospects about productivity in livestock systems globally, as in a 'biomass restricted' world there will be competition between food, feed and fuel (Thornton, 2010). Hence, self-sufficiency can be used not only as a reference to dependency on own food supply, but also as a restriction for when a more competitive environment for biomass is expected in the future. In addition, more external sources of feed imply a higher pressure on the local environment, except when manure can be exported in a sustainable way. Also there is a certain point that it is not logical anymore to have a certain milk production when the (economic) distance to the feed source becomes too big. Nevertheless, from the perspective of climate and technological change impacts it can be concluded that rough feed production increases in the future. An improvement to the model would be to make the amount of rough feed purchase and selling flexible with the climate and technological change. Also activities to purchase and sell more rough feed have to be included. The introduction of these new activities will also give shadow prices for extra rough feed that can be sold or bought. Model runs without restrictions in rough feed purchase and supply can be conducted. However, carefulness with the interpretation of the results is necessary, because prices of grass and maize fluctuate, while the prices in the LP-model are fixed.

The output of the model suggests that technological development can give relief on climate stressed dairy farming systems. Nevertheless, it is questionable whether technological development goes in the same pace as the effects of climate change. Especially the extreme events differ from year to year and can impose big shocks which require ad hoc adaptation practices like irrigation, rather than dependency on the more step-wise, but also gradual development in technology. Hence, to maintain viable dairy farming systems in the future it is important to maintain part of the subsidies in the short term, or at least transform the subsidy system towards a system that focuses more on adaptation measures. In the long-term, technological development can take over the compensating function of negative yield impacts by climate change. The latter statement does not exclude long-term adaptation activities like permanent changing ground water levels in summer or increasing soil organic matter. It might even be very rewarding because more of the milk yield increase potential can be used when higher production of rough fodder is realized by long-term adaptation measures.

5.4 Price changes

For the studied scenarios, profitability of farms is not in danger as a result of climate and socio-economic changes. That is coherent with good prospects for the Dutch dairy sector (Jongeneel et al., 2011). However, subsidies are still an important contributor to revenue in RC/G, especially when the price-scenarios are taken into account. Jongeneel et al. (2011) and Oostindie et al. (2013) remark that price fluctuations still might cause a problem in liquidity. Also in that respect subsidy is important. Ultimate conclusions about economic viability of dairy farms should be taken with care, because the methodology has a high 'what if' content. Price scenarios for instance, can differ a lot. Other price prediction models give other values for price changes, see for instance Abildtrup et al. (2006), Wolf et al. (2011), de Vries et al. (2013). With the current price-scenarios the input prices do not differ between scenarios. Where conclusions about economic viability might be drawn with care, at least it can be concluded what the change in farm activities will be for certain input/output price ratios. Where output prices for milk increase relatively most, while milk price increase is more than input price increase for dairy activities, price-changes do not induce any change that was not yet caused by technological development in GE. The time from now to 2050 is long. In the meantime price-changes will have an effect on technological development and vice-versa. In that sense the more negative input/output prices in RC are coherent with the lower technological development. That beside the argument that in RC there is less circulation and interchange of ideas between 'introverted' areas.

Shadow prices for land give an indication for the actual value of land. Shadow prices for land vary a lot between simulations; the general trend is an increase. The increase is much higher for medium-sized farms, implying that it will not be possible to have an uniform compensation policy for green-blue services in preselected areas without overpaying the large sized farms. At the other hand nature organizations could be seen as competing agents for land among other agents like farmers who want to expand their area (Bakker, 2013; pers. comm.). From that perspective, currently and in the future, nature organizations seem to have a better chance to compete for land where density of large farms is relatively higher. However, output of shadow prices from the model are averages. The ultimate price is dependent on the location and agricultural productivity of the land. Most nature area is situated in the north-western part of the Baakse Beek. In that part there are also relatively more medium sized farms. Connection of new nature area with existing area is at the one hand a good idea, because actual land prices are negatively influenced by the presence of woody areas (Bakker, 2013; pers. comm.). At the other hand this means that the chance increases that nature organizations have to compete with medium farmers who can gain a lot with additional land. When nature organizations aim for a more fragmented nature area, they are less restricted, i.e. they can select areas where competition for land is low. If it is still better from an environmental perspective to join new nature areas with existing areas, than the south-western part where more larger farms would be better.

5.5 Remarks and recommendations for the methodology

The underlying assumption of the LP-model is that it accounts for a steady state in 2050. However, climate change is not stopping in 2050. In fact the projections for 2050 are an average for the years 2036-2065 and climate is by definition something dynamic (Riedijk et al., 2007). In addition the more frequent occurrence of extreme events will bring the farming system out of balance. Further it is acknowledged that farmers continually adapt (Reidsma, 2007). The simulations provide a static picture, but in fact is only a possible picture in a point of time. To get a better insight in the behaviour of the dairy farms, or the representation of them by the LP-model, intermediate steps are necessary. Climatic fluctuations and their impacts on grass and maize yields could be included, and price volatility impacting profitability. Intermediate steps might also support or deny the assumption that current existing farms and their farming practices are viable all the way towards 2050, or that they will be overtaken halfway the transition.

The method to use 'whole farm activities' covers the costs that are not clearly visible. Also it accounts for the variable returns to scale of input-output relations. It is questionable how it is possible to include extra activities that cover the two mentioned aspects that are assumed to be obviated by the 'whole farm activity' approach. For the current situation the used method gives a clear insight; it is a powerful tool to evaluate performance if certain objectives are to be met. New technologies and activities are harder to include and climate or socio-economic change impacts on the farm are hence restricted to the current spectrum of extrapolated possibilities. This is especially visible in the fact that the behaviour of the biggest farm in the dataset that consequently chooses its own activity. Another example is the lack of an activity to reduce the number of cows other than to choose a farm with a lower cow density. The current spectrum of cow density and milk production density is determinant for the future. Inclusion of farm data from other areas is a possible solution. However, still the number of cows per hectare in the Netherlands is indirectly linked to current legislation on manure application, while in the future feed supply seems to become more restrictive. So, in GE lower or higher cow density than currently existing could in theory be possible. In some sense it is an exploration, but it is still within the current paradigm of land-based dairy farming. In that sense also the assumption for self-sufficiency is a rather imposing one for an exploration: it excludes the option of farms without land, or the option of farms that merely produce rough fodder. However, supportive knowledge is necessary to evaluate whether higher dependency on external sources of feed can be realized, i.e. it is a question whether there will be enough feed production in the area, or the Netherlands, or even Europe if milk production per cow and the herd size is increased everywhere in the Netherlands and Europe.

With the simulation of an average farm with separate farming activities it is possible to make an exploration that is less fixed on the current paradigm; however, in that case the variable returns to scale are not included in the model. A model that is based on separate farming activities also does not give an insight in how many farms are for instance actually constrained by land and or labour. Instead such a model gives a 'yes' or 'no' to the question whether land is constraining or not.

The choice for 'whole farm' activities has some implications for the level of detail. Additional assets of the diet are not considered, like fibre and degradable protein balance (OEB) as can be found in Berentsen (1999) for instance. Also from the perspective of the FADN-data it is better to not include that level of detail: FADN provides yearly data, while OEB-content is season dependent. Fibre in diet is a more constant property that has to be met throughout the year. However, where energy and protein supply at a regional level might have restricted availability, fibre supply does not seem easily to be restricted. Another point in regard to the level of detail in the current methodology is the way in which protein requirements are formulated in the LP-model: the model gives opportunities to perform a kind of 'dilution operation' in which the model chooses the 'less milk production' at a protein level of 110% of the requirements and substitutes it with 'extra milk production' at 100% of the protein requirements. It would be better to just put one equality constraint instead of two constraints that provide a range. The equality constraint can best be put at 105% (Tamminga et al., 2005) of the requirements to account for the fact that some greedy cows take more than they need, while other cows still need to meet their requirements.

The inclusion of different climate and socio-economic changes in the methodology is important. Many studies that include climate or socio-economic change only focus on a few drivers. For instance only impact of climate change on dairy farms (Deusings, 2008), impact of gradual climate change and extreme events on arable crops (Rosenzweig, 2001), or impact of technology on labour use efficiency on dairy farms (Zijlstra and Roelofs, 2010) are considered. Wolf et al. (2011) and Ewert et al. (2011) are a positive exemption, but were restricted to arable crops. In the last decade, the need to integrate climate and socio-economic changes is recognized (Reidsma, 2007, Ewert et al., 2011). Also this study revealed that all climate and socio-economic changes that are included in the methodology turn out to be determinant for the future of dairy farms and their activities.

6. Conclusions

In the current situation farmers can become more efficient with their resources. Explorations along the storylines of two extreme climate and socio-economic scenarios suggest that dairy farms can remain economically viable in the future, provided they have profit maximization as their only goal. Extreme events can have a big impact on profitability. Medium sized farms have most opportunities to compensate the adverse shocks. In general dairy farms can better adapt to positive yield changes than negative yield changes, provided that the milk quota is abolished. Therefore it is important that in the long-term technological change/innovation will counterbalance the potential negative grass and maize yield reductions and their impact. Also less advantageous 'input-output price ratio' developments can be remediated with technological innovation in RC/G. In general, there is a tendency that manure production and fertilizer use will increase, i.e. the intensity of resource use will increase. Total abolishment of N-legislation in GE/W^{+} does not seem a viable option. Maintaining the current N-legislation in RC/G is also not viable. Loosening the current restrictions on application of manure N and total N is necessary for coherence between model output and storylines of both extreme scenarios.

Dependent on the feed supply and the development of input and output prices the full milk production potential of the farm will not always be used. In GE the restriction for increased milk productivity per cow by the milk quota will be substituted by a restriction in feed supply. Therefore, aside from dependency on technological development in crop productivity (long-term) adaptation activities that increase rough fodder production need to be considered to benefit from technological development in cow productivity. Land use is expected to change towards more grassland, except for medium farms in GE. Shadow prices for land vary a lot between simulations; the general trend is an increase. The increase is much higher for medium-sized farms, implying that it will not be possible to have an uniform compensation for green-blue services in preselected areas without overpaying the large sized farms. Based on the difference in shadow prices between medium and large farms it can be argued that new nature areas should be selected in areas where relatively more large farms are.

The integrated assessment of the impact of climate and socio-economic changes on dairy farming is important in an exploration towards 2050. All researched changes turned out to be of importance in either one or both studied scenarios. The used methodology gives a good insight about improvements that can be made in the current situation and how much the potential of currently existing management techniques can be used in the future. The use of 'whole farm' activities in the LP-model is not completely coherent with the idea of explorations. Therefore a hybrid solution will be more suitable, which allows for simulations that include other activities that do not exist in the current palette of opportunities. With this hybrid model more ex-ante policy assessments can be conducted that include adaptation strategies. A priority list of adaptations to the current methodology is presented in Appendix U. Results of the proposed model will improve the insight in the way in which agricultural, nature and environmental policies should co-develop to achieve.

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Appendix A: Policy options

Table A1: Compiled list of policy options, as summarized by researchers based on a first workshop in the CARE-project. Source: Reidsma (2011a).

Policy Question	Policy options
Is it possible to make the National Ecological network (EHS) resilient to climate change?	1.1 Farmers receive financial compensation for GBDA on their land (max of 500 ha).
1. the development of green infrastructure (groenblauwe dooradering; GBDA) 2. the development of several large areas	1.2 Payments for other landowners?
	1.2 GBDA zoning: financial compensation in specified zone only
	1.3 GBDA is obligatory
	1.4 Enlarge nature areas for a maximum of 500 ha
	1.5 No additional funding
How can inundation of the Baakse beek stream valley be used to avoid regional flooding during high water periods? What are the consequences for nature targets?	2.1 Farmers and other land-owners receive financial compensation for managing a flooding strip of ... M along the Baakse Beek stream.
	2.2 Zone is obligatory
Is it possible to avoid droughts in the area by regional water storage?	3.1 Farmers receive financial compensation for the transformation of waterways towards wider and more shallow streams.
	3.2 The Watertable will be elevated 30cm in the whole study area.
	3.3 The water table of the 5% of the wettest arable lands will no longer be lowered

Appendix B: Formulation of the LP-model for the current situation.

Explanation of sets and variables are presented in Appendix D.

Objective function:

$$W1 = max\{ \sum_{D,I,O} Value_O * Output_{D,O} * X_D - Value_I * Input_{D,I} * X_D \}$$

Subject to:

1. Capital constraint:

$$\sum_D Capital_D * X_D \qquad < Available\ Capital$$

2. Milk quota constraint:

$$\sum_D Milk_D * X_D \qquad < Milk\ Quota$$

3. Area constraint:

$$\sum_D Area_D * X_D \qquad < Available\ Area$$

4. Family labour constraint

$$\sum_D Labour\ Requirement_D * X_D - Hired\ Labour \ < Available\ Family\ Labour$$

5. Hired labour constraint:

$$Hired\ Labour \qquad < \ Available\ Hired\ Labour$$

6. Convexity constraint:

$$\sum_D X_D \qquad = 1$$

7. *Constraint on other output:*

$$\sum_D Other\ Output_D * X_D \qquad < \ Maximum\ Other\ Output$$

8. *Cow holding capacity constraint:*

$$\sum_D Cow_D * X_D \qquad < Cow\ Holding\ Capacity$$

Appendix C: Formulation of the LP-model for 2050

Explanation of sets and variables are presented in Appendix D.

Objective function

$$W2 = W1 + \max\{\sum_{F,Q,N} Milkprice * (EM - LM) + PurchasePriceRF_F * LPRF_F - SellingPriceRF_F * LSRF_F + PriceLMC * LMC - PriceConcentrate_Q * Concentrate_Q - PriceNutrient_N * (EN_N - LN_N)\}$$

1. *Constraint on capital (omitted)*
2. Milk quota constraint:

$$\sum_D Milk_D * X_D + EM - LM \quad < Milk\ Quota$$

3. Area constraint:

$$\sum_D Area_D * X_D \quad < Available\ Area$$

4. Family labour constraint

$$\sum_D Labour\ Requirement_D * X_D - Hired\ Labour \quad < Available\ Family\ Labour$$

5. Hired labour constraint:

$$Hired\ Labour \quad < Available\ Hired\ Labour$$

6. Convexity constraint:

$$\sum_D X_D \quad = 1$$

7. *Constraint on other output (omitted)*
8. *Cow holding capacity constraint (omitted)*
9. Minimum milk production (euro):

$$\sum_D Milk_D * X_D + Milkprice * (EM - LM) \quad > 0$$

10. Energy balance:

$$\sum_{C,F,Q} e_C * (EY_C - LY_C) + e_F * (LSRF_F - LPRF_F) + e_Q * Concentrates_Q - e_{LMC} * LMC - Energy\ Requirement * (EM - LM) \quad = 0$$

11. Minimum of protein content of additional feed (100% of requirements):

$$\sum_{C,F,Q} p_C * (EY_C - LY_C) + p_F * (LSRF_F - LPRF_F) + p_Q * Concentrates_Q - p_{LMC} * LMC - Protein\ Requirement100 * EM + Protein\ Requirement110 * LM > 0$$

12. Maximum of protein content of additional feed (110% of requirements):

$$\sum_{C,F,Q} p_C * (EY_C - LY_C) + p_F * (LSRF_F - LPRF_F) + p_Q * Concentrates_Q - p_{LMC} * LMC - Protein\ Requirement110 * EM + Protein\ Requirement100 * LM < 0$$

13. Minimum amount of fertilizer:

$$\sum_{D,N} Fertilizer\ Expenses_D * X_D - Fertilizer\ Price_N * LN_N > 0$$

14. Minimum milk production (ton):

$$\sum_D Milk_D * X_D + EM - LM > 0$$

15. Minimum amount of concentrates:

$$\sum_D Concentrates_D * X_D - LMC > 0$$

16. (17) Minimum amount of sold rough fodder:

$$\sum_D SRF_{D,F} * X_D - SellingPriceRF_F * LSRF_F > 0 \quad \forall\ F$$

18. (19)Minimum amount of purchased rough fodder:

$$\sum_D PRF_{D,F} * X_D - PurchasePriceRF_F * LPRF_F > 0 \quad \forall\ F$$

20. (21) Minimum own feed crop production:

$$\sum_D Crop\ Production_{D,C} * X_D - LY_C > 0 \quad \forall\ C$$

22. (23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35) Crop yield change balance:

$$\sum_D PotentialCropYieldChange_{D,C} * X_D - EY_C + LY_C > 0 \quad \forall\ C$$

(constraints 23-28 and 30-35 respectively refer to potential grass maize yields changes in the different simulations and scenarios; constraints 22 and 30 are constraints that can be used in simulation runs that do not include climate or technological induced yield change)

36. (37, 38) Milk yield change balance:

$$\sum_{D} PotentialMilkYieldChange_D * X_D - EM + LM \quad > 0$$

39. (40, 41) Nutrient balance

$$\sum_{\text{Q,F,D}} FeedLosses_C * FeedNutrient_{N,C} * (EY_C - LY_C) + (MilkNutrient_N * (EM - LM) + (1 - ManureUseEff_N) * (ManureNutrient_N * Manure * (EM - LM)) - RFNutrient_{N,F} * (LSRF_F - LPRF_F) - ConcentrateNutrient_{N,Q} * Concentrate_Q + LMCNutrient_N * LMC - FertilizerUseEff_N * (EN_N - LN_N) + EDManure - (1 - ManureUseEff_N) * ManureNutrient_N * LDManure = 0 \ \forall N$$

42. (43, 44) Fertilizer weight:

$$\sum_{\text{D}} CurrentFertilizerUse_{D,N} * X_D - LN_N + EN_N \quad > 0 \ \forall N$$

45. Manure nitrogen application legislation (RC/G):

$$\sum_{D} (ManureNProduction_D - MaxManureNApplication_D - DeportedManure_D) * X_D + ManureN * (EM - LM) - ManureNContent * (EDManure - LDManure) \quad < 0$$

46. Total nitrogen application legislation (RC/G):

$$\sum_{D} (AllowedTotalN_D - MaxManureNApplication_D * ManureEffCoeff - CurrentFertilizerApplication_D) * X_D - ManureN * (EM - LM) * ManureEffCoeff + ManureNContent * (EDManure - LDManure) * ManureEffCoeff - (EN_{Nitrogen} - LN_{Nitrogen}) \quad < 0$$

47. Concentrates in the diet (kg):

$$\sum_D ConcentrateWeight * (EM - LM) - Concentrate_Q + LMC \qquad > 0$$

48. Maximum amount of less deported manure:

$$\sum_D CurrentDeportedManure_D * X_D - LDManure \qquad > 0$$

Appendix D: Explanation of the model sets, variables and parameters

Sets:

C is index for feed crops, *C ϵ {maize, grass}*

D is index for the whole farm activities, *D ϵ {1, 2, 3, …, 20}*

F is index for rough fodder, *F ϵ {maize silage ,grass silage}*

I is index for inputs, *I ϵ {energy, feed, other input}*

N is index for nutrients, N ϵ {*nitrate, phosphorus, potassium*}

O is index for outputs, *O ϵ {milk, meat, crops, subsidies, other output}*

Q is index for concentrates, Q *ϵ{standard, enriched, highly enriched}*

S is index for simulation, *S ϵ {SIM1, SIM2, SIM3, SIM4, SIM5, SIM6, SIM7}*

Sc is index for scenario, *Sc ϵ* $\{GE/W^+, RC/G\}$

Variables:

X_D	= Whole farm activity (*fraction between 0 and 1*)
Hired Labour	= Hired labour (*hour*)
EM	= Extra milk (*ton*)
LM	= Less milk (*ton*)
EY_C	= Extra production of crop *C* (*ton*)
LY_C	= Less production of crop *C* (*ton*)
$LPRF_F$	= Less purchase of rough fodder *F* (*ton*)
$LPRF_F$	= Less selling of rough fodder *F* (*ton*)
$Concentrates_Q$	= Purchase of concentrate *Q* (*ton*)
LMC	= Less purchase of original mix of concentrates (*ton*)
EDManure	= Extra deported manure (*m3*)
LDManure	= Less deported manure (*m3*)
EN_N	= Extra purchase of nutrient *N* (*kg*)
LN_N	= Less purchase of nutrient *N* (*kg*)

Input parameters:

$Value_O$	= Value per unit of output O (*Euro/Euro for meat, crops, other output; Euro/kg for milk; This value is dependent on simulation and scenario, e.g. in PC in GE/W⁺ the value for meat becomes 2.08 Euro/Euro*)
$Output_{D,O}$	= Output O per activity D (*Euro for meat, crops, subisidies, other output; kg for milk*)
$Value_I$	= Value per unit of input I (*Euro/Euro*)
$Input_{D,I}$	= Input I per activity D (Euro)
$Capital_D$	= Capital input per activity D (*Euro*)
Available Capital	= Capital available in simulation (*Euro*)
$Milk_D$	= Milk production per activity D (*ton*)
Milk Quota	= Maximum allowed amount of milk produced (*ton*)
$Other\ Output_D$	= Other output per activity D (*Euro*)
Maximum Other Output	= Maximum amount of other output (*Euro*)
$Area_D$	= Area per activity D (*ha*)
Available area	= Area available (*ha*)
$Labour\ Requirement_D$	= Labour requirement per activity D (*hours*)
Available Family Labour	= Family labour available (*hours*)
Available Hired Labour	= Hired labour available (*hours*)
Cow_D	= Dairy cows per activity D (*cows*)
Cow Holding Capacity	= Dairy cow holding capacity (*cows*)
e_C	= Energy content of feed crop C (*kVEM/ton DM*)
e_F	= Energy content of rough fodder F (*kVEM/ton DM*)
e_Q	= Energy content of concentrate Q (*kVEM/ton DM*)
e_{LMC}	= Energy content of mix of original concentrates (*kVEM/ton DS*)
Energy Requirement	= Net energy requirement (after including the herd factor and subtraction of the standard required energy from concentrates)of activity *EM* and *LM* (*kVEM/kg*)
p_C	= Protein content of feed crop C (*kgDVE/ton DS*)
p_F	= Protein content of rough fodder F (*kgDVE/ton DS*)
p_Q	= Protein content of concentrate Q (*kgDVE/ton DS*)
p_{LMC}	= Protein content of mix of original concentrates (*kgDVE/ton DS*)
Protein Requirement100	= Lower limit of protein requirement of activities *EM* and *LM* (*kgDVE/kg*)
Protein Requirement110	= Upper limit of protein requirement of activities *EM* and *LM* (*kgDVE/kg*)
$Fertilizer\ Expenses_D$	= Fertilizer expenses per activity X_D (*Euro*)

Concentrates Expenses$_D$ = Concentrates expenses per activity X_D (*Euro*)

ChangeConcentrates = Concentrates use per activity *EM* and *LM* (*Euro*)

SRF$_{D,F}$ = Sold rough fodder *F* per activity X_D (*EURO*)

SellingPriceRF$_F$ = Selling price per activity *ESRF*$_F$ and *LSRF*$_F$ (*Euro/ton DS*)

PRF$_{D,F}$ = Purchased rough fodder *F* per activity X_D (*EURO*)

PurchasePriceRF$_F$ = Selling price per activity *ESRF*$_F$ and *LSRF*$_F$ (*Euro/ton DS*)

Crop Production$_{D,C}$ = Current production per activity X_D of feed crop *C* (*ton*)

PotentialCropYieldChange$_{D,C}$ = Potential crop yield change per activity X_D of feed crop *C* (*ton*)

PotentialMilkYieldChange$_D$ = Potential milk yield change per activity X_D (kg)

Milk Nutrient$_N$ = Content of nutrient *N* in milk (*kg/ton*)

Manure Nutrient$_N$ = Content of nutrient *N* in manure (*kg/ton*)

Manure Use Efficiency$_N$ = Nutrient *N* use efficiency of manure (fraction between 0 and 1)

Manure = Manure production per activity *EM* or *LM* (*kg/kg*)

RFNutrient$_{N,F}$ = Content of nutrient N in rough fodder (*kg/ton*)

ConcentrateNutrient$_{N,Q}$ = Content of nutrient *N* in concentrates (*kg/ton*)

LMCNutrient$_N$ = Content of nutrient *N* in the original mix of concentrates (*kg/ton*)

ManureNProduction$_D$ = Production of nitrogen in manure per activity X_D (*kg*)

MaxManureNApplication$_D$ = Maximum applicable amount of manure nitrogen per activity X_D (*kg*)

ManureN = Production of nitrogen per activity *EM* and *LM* (*kg*)

ManureNContent = Nitrogen content of activity EDManure and LDManure (*kg*)

ManureEffCoeff = Legislative manure efficiency coefficient *(kg/kg)*

AllowedTotalN$_D$ = Total allowed N for farm *D (kg)*

CurrentFertilizerUse$_D$ = Current fertilizer application of farm *D* (*kg*)

CurrentDeportedManure$_D$ = Current amount of deported manure (m^3)

Feedlosses$_C$ = Nutrient losses from feeding crop *C* (fraction between 0 and 1)

FeedNutrient$_{N,C}$ = Nutrient content *N* of crop *C* (kg/ton)

Appendix E: Model output

Table A2: Model output per category.

Section	Model output	Unit
Income	Subsidies	Euro
	Crops	Euro
	Milk	Euro
	Other output	Euro
	Meat	Euro
Expenses	Feed	Euro
	Energy	Euro
	Other input	Euro
Investment	Capital	Euro
Production	Milk	kg; kg/ha
	Manure	m3
	Manure N	kg; kg/ha
	Manure P	kg; kg/ha
	Grass	kg DM; kg DM/ha
	Maize	kg DM; kg DM/ha
Area	Grass	Ha
	Maize	Ha
	Crops	Ha
	Other	Ha
Applications	Concentrates	Euro
	Fertilizer	Euro
	Fertilizer use for N, P and K	Kg/ha
Ratio	Dairy cows/young stock	fraction
	Own feed energy/total feed energy	kVEM/kVEM
	Concentrate energy/total feed energy	kVEM/kVEM
	Own feed protein/total feed protein	kgDVE/kgDVE
	Concentrate protein/total feed protein	kgDVE/kgDVE
	Area grass/total area	ha/ha
	Area maize/total area	ha/ha
	Output/input	Euro/euro
	Milk/output	Euro/Euro
	Milk/output (price changes included)	Euro/Euro
Other	Net income (gross margin)	Euro

Appendix F: FADN-data

Table A3: Years of registration of farm data.

Farm	Years of observation (#)	Observed years
1	4	2003-2006
2	2	2005, 2006
3	2	2005, 2006
4	3	2001-2003
5	3	2001-2003
6	3	2001-2003
7	3	2001-2003
8	3	2001-2003
9	1	2006
10	2	2005, 2006
11	6	2001-2006
12	6	2001-2006
13	6	2001-2006
14	6	2001-2006
15	6	2001-2006
16	6	2001-2006
17	6	2001-2006
18	6	2001-2006
19	3	2004-2006
20	6	2001-2006

Appendix G: Farm typologies

Table A4: Farm class according to size and intensity. Source: Mandryk et al. (2012).

Dimension	Class	Thresholds	*New division of class*	*New thresholds*
Size (NGE)*	Small	<20		
	Medium	20-70	*Medium*	*<70*
	Large	70-150	*Large*	*>70*
	Extra Large	>150		
Intensity (NGE ha^{-1})	Low	<1.3		
	Medium	1.4-2.0		
	High	>2.1		

*NGE is the Dutch Size Unit, representing gross income from crop cultivation and/or animal husbandry. In the table below, the value of a NGE is presented per year.

Table A5: Value of NGE in the period 2001-2006.

Year	NGE (€)
2001	1390
2002	1390
2003	1375
2004	1375
2005	1400
2006	1400

Appendix H: Climate scenarios

Table A6: Climate change for the Netherlands under different scenarios. Source: van der Hurk et al., 2006; www.knmi.nl, 2013

2050		G	G+	W	W+
Global temperature rise		+1°C	+1°C	+2°C	+2°C
Change in air circulation patterns		no	yes	no	yes
Winter	average temperature	+0,9°C	+1,1°C	+1,8°C	+2,3°C
	coldest winter day per year	+1,0°C	+1,5°C	+2,1°C	+2,9°C
	average precipitation amount	+4%	+7%	+7%	+14%
	number of wet days (≥0,1 mm)	0%	+1%	0%	+2%
	10-day precipitation sum exceeded once in 10 years	+4%	+6%	+8%	+12%
	maximum average daily wind speed per year	0%	+2%	-1%	+4%
Summer	average temperature	+0,9°C	+1,4°C	+1,7°C	+2,8°C
	warmest summer day per year	+1,0°C	+1,9°C	+2,1°C	+3,8°C
	average precipitation amount	+3%	-10%	+6%	-19%
	number of wet days (≥0,1 mm)	-2%	-10%	-3%	-19%
	daily precipitation sum exceeded once in 10 years	+13%	+5%	+27%	+10%
	potential evaporation	+3%	+8%	+7%	+15%

Appendix I: Socio-economic scenarios

Global Economy (GE)

"*In the scenario 'Global Economy' the EU will expand towards the East. Apart from Turkey, also Ukraine will join. The WTO-negotiations are successful and international trade flourishes. However, political integration will not take off and international cooperation, other than trade negotiations, fails. …the Government will emphasize private responsibility; … the growth in labour productivity will get an extra impulse because of worldwide economic integration. The growth of material welfare and population, especially through immigration, will be highest in this scenario. … there is not going to be an agreement that deals with border-crossing environmental issues. This, together with the high economic global growth causes serious environmental pollution. But the higher welfare leads to local environmental initiatives.*" (Riedijk et al., 2007)

Regional Communities (RC)

"*In the scenario 'Regional Communities' countries strongly favour their own sovereignty; therefore the EU does not succeed to implement institutional reforms. International trade reform will not succeed either and as a consequence the world will fall apart in different trade blocks. International environmental issues will not be dealt with. However, environmental pressure will be low due to low population and economic growth. There will be few, if any reforms in the collective sector in this scenario. European countries rely on collective arrangements to maintain an equitable distribution of welfare. Because of lower incentives in social security and due to higher tax tariffs, labour participation will be relatively low and unemployment high. Less competition decreases the need for companies to innovate. Dispersed markets prevent fast knowledge transfer and the small differences in income prevent an increase in human capital. Yearly increases in labour productivity and economic growth are small.*" (Riedijk et al., 2007)

Appendix J: Manure production calculations

Used source: 'excretion table' (Dutch: forfaitaire excretie table) for a slurry system from Dienst Regelingen Ministerie van Economische Zaken, landbouw en Innovatie (2012; www.lnvloket.nl). This table provides estimates of N and P excretion as well as the volume of manure production per cow that produces milk, taking into account the urea content of the milk and the milk production of the cow. The excretion table with excretion values for N originally is derived from a linear formula with milk production per cow and urea content as variables (Daatselaar 2012; Personal communication).

For the calculations it is assumed that the urea content of the milk is 26 mg/L for all farms. 26 mg/L is the average value for the period 2001-2004 for the farm data of LEI that could be linked to the selected farms of the FADN-data. Another assumption is that all farms have a liquid manure storage.

Linear relations are derived from the 'excretion forfait table' for implementation in the LP-model. The 'excretion forfait table' does not provide values for the high milk production that can be expected in 2050 in some occasions. That is also a reason why linear formulas are derived from this table to provide values by extrapolation. The formulas are shown in Figure 7, Figure 8 and Figure 9 for respectively volume (m^3), P_2O_5 (kg) and N (kg) per dairy cow.

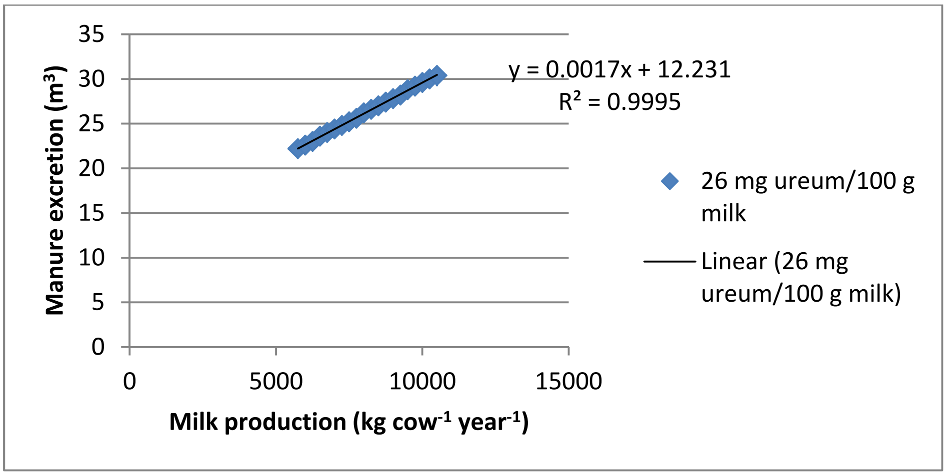

Figure A1: Volume of manure excretion as a function of milk production per cow. Source: Dienst Regelingen Ministerie van Economische Zaken, landbouw en Innovatie (2012; www.hetlnvloket.nl)

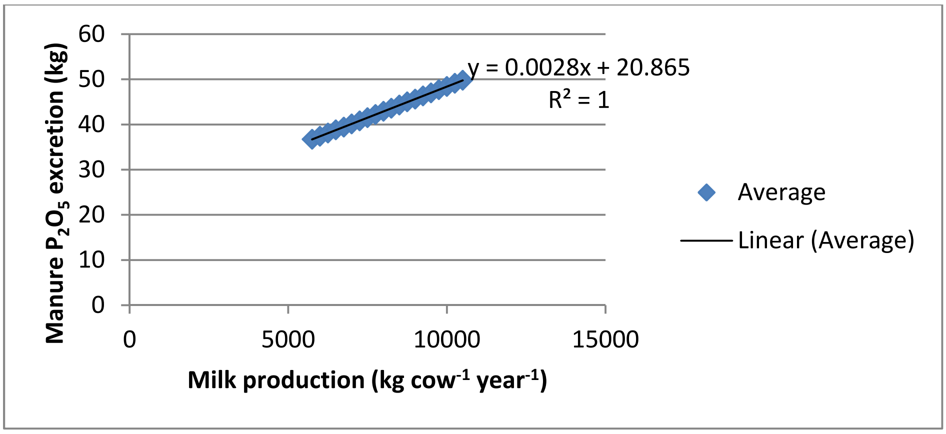

Figure A2: Manure P2O5 excretion as a function of milk production per cow. For the ultimate calculation on P excretion the parameters of the linear equation have to be adapted according to the relative weight of P in P_2O_5. Source: Dienst Regelingen Ministerie van Economische Zaken, landbouw en Innovatie (2012; www.hetlnvloket.nl).

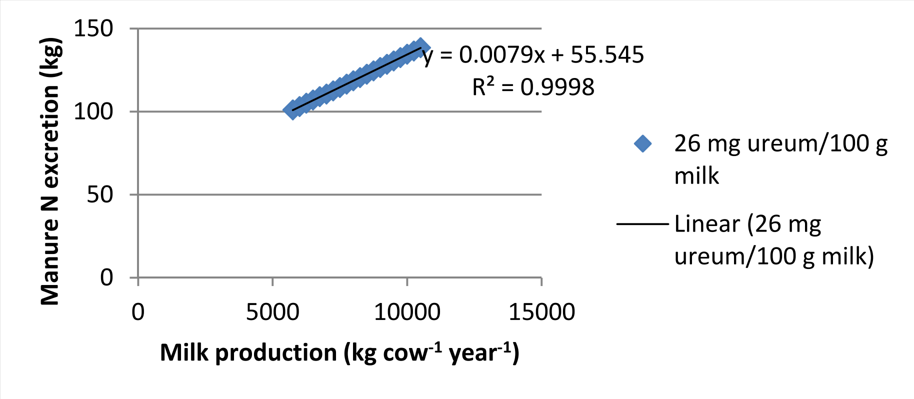

Figure A3:Nitrogen production as a function of milk production at an urea content level of 27 mg/L. Source: Dienst Regelingen Ministerie van Economische Zaken, landbouw en Innovatie (2012; www.hetlnvloket.nl).

Besides the manure/nitrogen production of milking cows, the manure production of the rest of the herd should be taken into account. Also here a slurry system is assumed. Table 26 provides values for manure production for the young stock. In the calculations the bulls that are older than 2 years are counted as young stock of 1-2 years.

Table A7: Manure excretion of young dairy stock per year (in a slurry system farm). Source: Vermeij et al. (2010), page 38 and 44.

	N (kg)	P (kg)	Volume (m^3)
young stock <1 year	35.1	5.5	5.2
young stock 1-2 year	66.7	12.6	13.2

Eventual formula for manure calculation is:

Volume (m^3): #Dairy-cows * (.0017*milk-production-per-cow-per-year+12.23) + 5.2* #Calves + 13.2* (#male-cattle+#female-cattle-1-2-years+#breeding-heifers)

N (kg): #Dairy-cows * (.0079*milk-production-per-cow-per-year+55.545) + 35.1* #Calves + 66.7* (#male-cattle+#female-cattle-1-2-years+#breeding-heifers)

P (kg): #Dairy-cows * (.0016*milk-production-per-cow-per-year+11.76) + 5.5* #Calves + 12.6* (#male-cattle+#female-cattle-1-2-years+#breeding-heifers)

The specific link to the excretion table of Dienst Regelingen Ministerie van Economische Zaken, Landbouw en Innovatie (2012) is:

http://www.hetlnvloket.nl/xmlpages/page/lnvloket/actueel/document/fileitem/2201983

Appendix K: Maize yields

Table A8: Maize yields in kg DM and energy for dry sandy areas in the Netherlands in the period 2001-2006. Source: Aarts et al. (2008).

Parameter	Intensity class (ton milk/ha)	Year 2001	2002	2003	2004	2005	2006	Average	Average after losses*
Dry matter (kg DM)	< 10			14532	15627	16231	14704	15274	14072
	10—14	14215	13446	14684	14894	15469	14509	14536	13233
	14—18	14521	14948	14658	14963	16194	15595	15147	13702
	>18	16867	15360		16157	15986	15407	15955	14644
Energy (kVEM)	< 10			13730	15025	15266	14336	14589	13353
	10—14	13543	12912	13997	14347	14538	14171	13918	12619
	14—18	13838	14293	13883	14380	15232	15225	14475	13036
	>18	16121	14606		15520	15084	14976	15261	13953

*Losses are assumed to be 9%, taking into account storage and feeding losses (Zwart et al., 2011).

Appendix L: Grass yield calculations

Set definition

T for type of other cattle, *T* ϵ {*calves < 1 years, female cow 1-2 years, male cows 1-2 years, heifers, bulls > 2 years*}

F for type of feed, *F* ϵ {purchased *rough feed, concentrates*}

G for type of crop, *G* ϵ {grass, maize}

C for type of feed content, *C* ϵ {VEM, DVE}

Net Energy Requirement $=1.02(\sum_T DairyCow*ReqCow + OthCattle_T*Req_T) - \sum_F Feed_F/Price_F*FeedContent_F - YieldMaize * AreaMaize$

$Yield_{Grass}$ $= (0.2*Net\ Energy\ Required/CropContentFreshGrass + 0.8*Net\ Energy\ Required/CropContentSilageGrass)/AreaGrass$

(0.2 and 0.8 stand for the respective ratio of energy that the herd gets from fresh grass and silage grass)

Declaration of variables:

$Yield_{Grass}$ = Yield of grass (*kg DM* ha^{-1})

$Area_G$ = Area of crop *G* (*ha*)

$Yield_{maize}$ = Yield of maize (*kg DM* ha^{-1})

$CropContent_{C,G}$ = Crop content *C* per crop *G* (*VEM or DVE kg* DM^{-1})

Dairy Cow = Number of dairy cows (#)

$ReqCow_C$ $= A_c + B_C * Factor_C + C_c * Factor_C^2$ = Formula to calculate requirement for content C per cow (VEM.cow^{-1}).

In which A_c *(for VEM containing the extra factor 1.02 for uncontrollability of intake per individual cow (Aarts et al., 2008) and a factor that takes into account the extra energy needed for grazing,* B_C and C_C are fixed values and $Factor_C$ has to be derived from the following formulas:

$Factor_{VEM} = FPCM = (0.337 + 0.116 * Fat + 0.06 * Protein) * Milk$

$Factor_{DVE} = E = Protein * Milk * 10$

In which *Fat* is the percentage of fat in milk (%) and *Protein* is the percentage of protein in Milk (%) and *Milk* is the production of milk (kg cow^{-1} day^{-1}).

$OthCattle_T$ = Number of other cattle *T* (#)

Req_T = Requirement of other cattle *T* (k*VEM.year*$^{-1}$)

$Feed_F$ = Money spend on feed *F* (€)

$Price_F$ = Price of purchased feed *F* (*€.kg*$^{-1}$)

$FeedContent_F$ = Content in purchased feed *F* (*VEM or DVE. Kg DS*$^{-1}$)

Energy & Protein content of feed

Energy content of the feed is equal to the demand of energy by the herd. Average protein content of feed in the current situation is calculated by adding the protein content of all feed per farm. Table A9-A12 present values for the different components in the energy and protein calculations.

Table A9: General quantitative assumptions.

Parameter	value	Source

Average %Fat in milk	4.51	Daatselaar (2012; pers. comm)
Average %Protein in milk	3.53	Daatselaar (2012; pers. comm)
Weight HF cow (kg)	650	Remmeling et al. (2011)
Calve weight at birth (kg)	43	Groot & Oomen (2011)

Table A10: Requirements other cattle per year. Source: Remmeling et al. (2011).

Other cattle (T)	kVEM	kgDVE
'average number other cattle < 1 yr'	1569.5	104.0
'average number male cattle 1-2 yr'	2299.5	82.1
'average number female cattle 1-2 yr'	2737.5	129.6
'average number breeding heifers'	3139	167.9
'average number male cattle >= 2 yr'	2993	60.2

Table A11: Protein and energy content of rough fodder.

Parameter	Value	Source
VEM/kg DS for grass silage	880	Derived from Aarts et al. (2009)
gDVE/kg DS for grass silage	70	Remmeling et al. (2011)
VEM/kg DS for maize silage	950	Derived from Aarts et al. (2009)
gDVE/kg DS for maize silage	48	van Schooten et al. (2011)
VEM/kg DS for fresh grass	980	Aarts et al.(2009)
gDVE/kg DS for fresh grass	76	Derived from Aarts et al. (2009)

Purchased rough feed is assumed to be 90% maize silage and 10% grass silage. Purchased concentrate is assumed to be a mix of standard, enriched and highly enriched concentrates (ratios of respective concentrate types in the diet are provided in Table A12).

Table A12: Concentrate properties. Source: Vermeij et al. (2009).

Concentrate properties	Value
Standard concentrate properties	
Price (€/kg)	0.14
Energy (kVEM/kg)	0.94
Protein (kg DVE/kg)	0.09
Ratio in diet	0.91
protein rich concentrate properties	
Price (€/kg)	0.16
Energy (kVEM/kg)	0.94
Protein (kg DVE/kg)	0.12
Ratio in diet	0.03
Highly enriched concentrate properties	
Price (€/kg)	0.18
Energy (kVEM/kg)	0.94
Protein (kg DVE/kg)	0.18
Ratio in diet	0.06

Due to the multitude of parameters involved in the grass yield calculations it is not possible to derive where the difference between this study and the calculations of Daatselaar (2012; pers. comm.) do originate. Increasing the price of concentrate will increase the grass yield and in addition lower the average protein intake of the herd. However, there is no reason to assume that the assumed concentrates should be priced higher. Also the assumption on the type of concentrates that has a big influence, as well as the maize yield per hectare per farm. These necessary assumptions highlight the main difference between the calculations of Daatselaar (2012; pers. comm.) and this study: where the former calculations are per year, with ample information on feed intake by the herd, this study uses an average for the years where data is available between 2001 and 2006, deducting the actual amounts of fodder intake from area maize and monetary inputs of fodder.

Appendix M: Linear relations of milk production with feed uptake

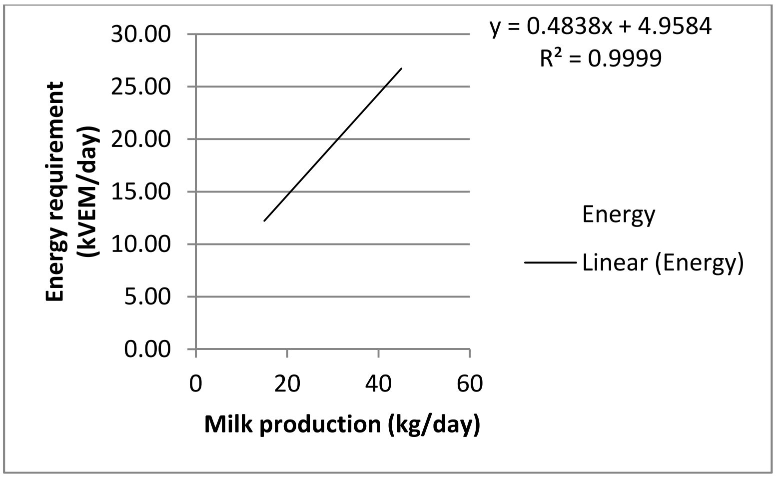

Figure 7: Energy requirement as a function of milk production. Source: van Duinkerken et al. (2007).

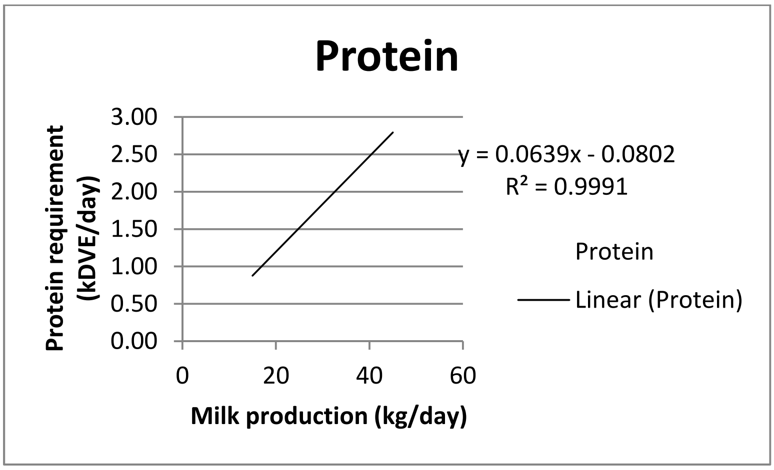

Figure A5: Protein requirement as a function of milk production. Source: van Duinkerken et al. (2007).

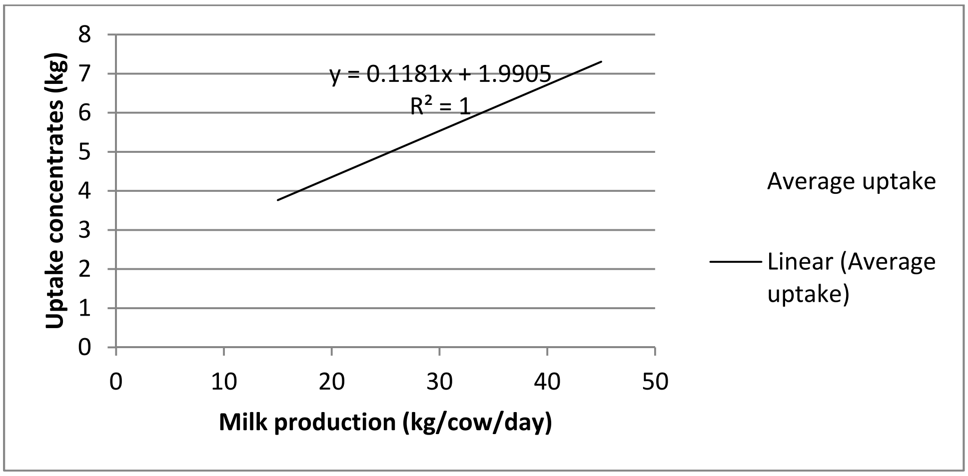

Figure A6: Concentrate uptake as a function of milk production. Source: van Duinkerken er al. (2007).

Appendix N: Nutrient balances

Table A13: Nitrogen use efficiencies on a dairy farm per farm component.

From	To	Losses	Efficiency	Source
Concentrates	Animal	None	100%	Own assumption
Animal	Milk and Manure	None	100%	Schröder (2010)
Manure	Soil	storage	70%	Schröder (2010)
Soil	Rough fodder	Leaching, ammonization	60%	Schröder (2010)
Rough fodder	Animal	Storage, feeding	processed in yield calculations	Vermeij et al. (2008)

Table A14: Fertilizer prices. Source: Vermeij et al. (2008)

Fertilizer price	2003	2004	2005	2006	Av.
Nitrogen per kg N	0.58	0.59	0.63	0.69	0.6225
Phosphate per kg P_2O_5	0.45	0.45	0.48	0.48	0.465
Potash per kg K_2O	0.29	0.3	0.33	0.35	0.3175

Table A15: Nutrient contents of different inflowing and outflowing products.

	RE* (g/kg)	P (g/kg)	N (g/kg)**	K (g/kg)	Source
Grass silage	173	4.2	27.68	34.1	Remmeling et al. (2011)
Grass fresh	227	4.3	36.32	36.6	Remmeling et al. (2011)
Mais silage	75	2	12	12	Remmeling et al. (2011)
Milk	33.05	0.91	5.29	1.42	Cameron et al. (2012)
Standard concentrate (90 g DVE)	150	4.25	24	16.5	Remmeling et al. (2011)
Enriched concentrate (120 g DVE)	195	6.25	31.2	18.75	Remmeling et al. (2011)
Highly enriched concentrate (180 g DVE)	273.75	7.38	43.8	19.69	Remmeling et al. (2011)
Highly enriched concentrate (200 g DVE)	300	7.75	48	20	Remmeling et al. (2011)
Original mix concentrates	159	4.50	25.4	16.75	Calculation***
Manure dairy farm******		0.69	4.38	5.12	Vermeij et al. (2009)

*RE is crude protein (Dutch: ruw eiwit)*N is calculated as N=0.16*RE. **According to the proportions of standard, enriched and highly enriched concentrates in the diet. ***The values are converted from kg m^{-3} to g kg^{-1} with a manure density of 1005 kg m^{-3} (Vermeij et al., 2010). The values for nutrient in manure are used to calculate the K-excretion of the whole farm, where it is assumed that the ratio of the values of P and K is constant (P and N-excretion are calculated with information from Dienst Regelingen Ministerie van Economische Zaken, Landbouw en Innovatie (2012); www.hetlnvloket.nl, see Appendix J)

Table A16: Allocation of budget to N, P and K fertilizer. Source: Vermeij et al. (2010), derived from page 168 and 170.

Fertilizer budget to:	Fraction
N	0.53
P_2O_5	0.09
K_2O	0.38

Appendix O: Specific assumptions WOFOST run

"The simulation runs with WOFOST have been done first for the main crops (13 in total; see Table 3) in Flevoland and the current weather conditions (period 1992-2008). These runs have been done for the current crop varieties and current sowing dates and next, the runs have been repeated for the four KNMI climate scenarios (Table 2) for a period around 2050. In all simulation runs the soil is at field capacity at the start of the year, has an available moisture fraction of 20% (being representative for the loamy and clay soils in Flevoland), is well-drained (hence, water excess practically does not affect crop growth), and is deep (hence, soil water availability is only limited by the maximal rooting depth as dependent on the crop type)."

Appendix P: Specific assumptions LINGRA run

"The simulation runs with LINGRA-N are done from Julian day 1 to day 365 for 17 years with the following input data: Soil data – maximally available soil moisture fraction of 20% (being representative for the loamy and clay soils in Flevoland); well-drained (hence, water excess practically does not affect crop growth); initial available soil moisture fraction is 15%.Crop data – initial and maximal rooting depth of 40 cm; radiation use efficiency (RUE) is maximally 3.0 g dry matter per MJ PAR; specific leaf area (SLA) is 0.0025 ha per kg leaf dry matter; correction factor for the RUE in dependence of the atmospheric CO_2 concentration (i.e. table COTB) is as given in Table 1 above; correction factor for the transpiration rate (i.e. CFET or RTRA) is as given Table 1 above. Management data – criteria for mowing of grass is 3000 kg dry matter per ha; leaf area index after mowing is set to 0.8 m^2/m^2."

"Direct effects of increasing atmospheric CO_2 concentration on the CO_2 assimilation and growth of the grass crop is incorporated in the LINGRA-N model as follows:

- *Increase in radiation use efficiency (RUE) with increasing CO_2 concentration;*
- *Limited decrease in transpiration rate." (Wolf, 2012; pers. comm.)*

"Table A17. Changes in radiation use efficiency (RUE) and in the reduction factor for potential transpiration (RTRA) for adaptation of the LINGRA-N model to doubling of the actual atmospheric CO2 concentration (i.e. increase by 360 µmol/mol) on grass-crop..."

$[CO_2]$ (µmol mol^{-1})	RUE factor (-)	RTRA factor (-)
355	1.00	1.000
720	1.25	0.900
1000	1.35	0.850

Appendix Q: Derivation of combined impact of extreme events

In the calculations it is assumed that the current average yields are not water or nutrient limited and at the same time already are influenced by the current occurrence of extreme events. This yield is lower than a theoretically defined average yield. The relation between the current average yield and the theoretically defined yield is:

$$Yield_o = \frac{Yield_C}{(1-f_C*D)}$$

The future average yield is then expected to be:

$$Yield_F = Yield_O * (1 - f_F * D) = \frac{Yield_C*(1-f_F*D)}{(1-f_C*D)}$$

Where:

$Yield_0$ = Theoretically defined yield relative to *$Yield_C$*
$Yield_C$ = Current average yield
Yield_F = Future average yield relative to *$Yield_C$*
D = Relative yield damage
f_C = Current frequency of occurrence
f_F = Future frequency of occurrence

The objective of the calculations is to achieve an outcome that presents the relative yield change in the future in relation to the current yield under influence of extreme events. Therefore the current yield is defined as 100%, i.e. *$Yield_C$* = 1. With the current yield defined as 1, the yield change ratio for the future can be expressed as:

$$Relative\ yield\ change\ ratio = \frac{(1 - f_F * D)}{(1 - f_C * D)}$$

The assumption that relative yield changes of different extreme events can be summed up results in:

$$Relative\ yield = 1 + \sum_E \left(\frac{(1 - f_{F_E} * D_E)}{(1 - f_{C_E} * D_E)} - 1 \right)$$

When an extreme event is expected to take place more than once a year on average an extra function is necessary in the formula: To assure that the yield reduction after the first time is relative to the remaining part of the harvest, and not to the original yield. Therefore:

$$Relative\ yield = 1 + \sum_E \left(\frac{(1 - D_E)^{f_{F_E} - MOD(f_{F_E},1)} * \left(1 - MOD(f_{F_E},1) * D_E\right)}{(1 - f_{C_E} * D_E)} - 1 \right)$$

Where:

E = Set for extreme events that have an influence on crop yield, *E* ϵ {*event 1, event 2, etc.*}
D_E = Relative yield damage per extreme event *E* (*fraction between 0 and 1*)
$f_{F,E}$ = Future expected frequency of occurrence of extreme event *E* (*$year^{-1}$*)
$f_{C,E}$ = Current frequency of occurrence of extreme event *E* (*$year^{-1}$*)
MOD =Modulus, which is the mathematical calculation that returns the remainder after a natural number is divided by a predefined divisor: MOD(x,y) where x is the number and y is the divisor.

Example for one type of extreme event→ Crop: Maize; Extreme event: Prolonged dry conditions; Scenario: G → Table A18 → Average damage per occurrence: (0%+10%)/2=5%; Current frequency: 1.00; Future frequency: 1.30 → Relative yield = 1+ ((1-0.05)$^{1.3-MOD(1.3,1)}$ * (1-MOD(1.3,1)*0.05))/(1-1*0.05) – 1 = ((1-0.05)*(1-0.015))/(1-0.05) = (0.95*0.985)/0.95 = 0.985 → Yield change = 0.985-1 = -0.015 = -1.5%

Appendix R: Occurrence and impact of extreme events

Table A18: Extreme events for maize production with (expected) occurrence and possible damage.

Maize	Yield damage (%)		Absolute occurrence (#/30y)					Frequency (Occurrence/year)					Yield Change (%)				
Extreme event	**Min.**	**Max.**	**1990**	**G**	**G+**	**W**	**W+**	**1990**	**G**	**G+**	**W**	**W+**	**1990**	**G**	**G+**	**W**	**W+**
Ongoing wet conditions	25	100	12	12	11	10	7	0.40	0.40	0.37	0.33	0.23	0	0.00	0.03	0.06	0.14
Warm and moist	25	100	29	27	22	24	22	0.97	0.90	0.73	0.80	0.73	0	0.11	0.37	0.26	0.37
Prolonged hot conditions	0	5	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00
Heat wave	25	75	22	29	36	39	59	0.73	0.97	1.20	1.30	1.97	0	-0.18	-0.29	-0.33	-0.59
Prolonged dry conditions	0	10	30	39	38	37	47	1.00	1.30	1.27	1.23	1.57	0	-0.02	-0.01	-0.01	-0.03
Night frost	0	10	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00
													Total (%)	**-0.09**	**0.09**	**-0.02**	**-0.11**
													Yield change ratio	**0.91**	**1.09**	**0.98**	**0.89**

Table A19: Extreme events for grass production with (expected) occurrence and possible damage.

Grass	Yield damage (%)		Absolute occurrence (#/30y)					Frequency (Occurrence/year)					Yield Change (%)				
Extreme event	**Min.**	**Max.**	**1990**	**G**	**G+**	**W**	**W+**	**1990**	**G**	**G+**	**W**	**W+**	**1990**	**G**	**G+**	**W**	**W+**
Tropical and moist conditions	0	10	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.00	0.00	0.00
Prolonged hot conditions	0	10	15	31	51	53	85	0.50	1.03	1.70	1.77	2.83	0.0	-0.03	-0.06	-0.06	-0.11
Prolonged dry conditions	5	10	0	0	1	0	0	0.00	0.00	0.03	0.00	0.00	0.0	0.00	0.00	0.00	0.00
Severe frost	20	40	2	2	1	1	1	0.07	0.07	0.03	0.03	0.03	0.0	0.00	0.01	0.01	0.01
													Total (%)	**-0.03**	**-0.05**	**-0.05**	**-0.10**
													Yield change ratio	**0.97**	**0.95**	**0.95**	**0.90**

Table A20: Meteorological information of extreme events.

Crop	Extreme Event	Meteorological translation
Grass	Tropical and moist	At least at two of three days in sequence with a temperature above 30°C there is more than 0.5 mm precipitation
	Prolonged hot conditions	At least three consequent days with a temperature above 30°C
	Prolonged dry conditions	To dry period of 30 days with less than 1 mm precipitation
	Severe frost	(severe) frost during night time, temperature lower than -10°C at any date
Maize	Prolonged wet conditions	At least 75% of 14 days more than 0.5 mm precipitation
	Warm and moist	At least a two of three consequent days with a temperature above 30°C there is more than 0.5 mm precipitation.
	Prolonged hot conditions	At least three consequent days with a temperature above 40°C
	Heat wave	Minimal more than three days with a temperature of more than 40°C in five consequent days (adapted definition of a heat wafe)
	Prolonged dry conditions	At least ten days with a precipitation of less than 5 mm
	Frost	Minimum temperature lower than -3°C

Appendix S: Milk yield increase

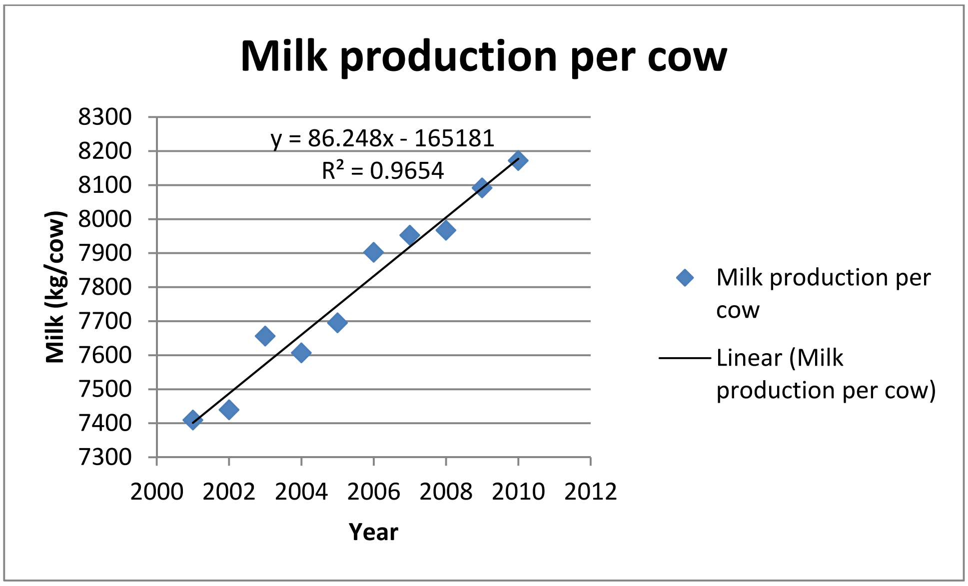

Figure A7: Historical milk yield per cow (2001-2010). Source: LEI (2012).

Average milk production 2006: 86.248 * 2006 – 165181 = 7574 kg/cow

Average expected milk production in 2050 by linear extrapolation: 86.248 * 2050 = 11627

Expected increase GE/W+ = (11627/7574 – 1) *100 = 54%.

Expected increase RC/G = 54/3= 18%.

Appendix T: Calculations on price changes

Table A21: Price change calculation for crops. *Source: de Vries et al. (2013).

			LIAISE price rel. change*	
Crop	**LIAISE equivalent**	**Rel. to total crop output**	**GE**	**RC**
Cereals	Soft wheat	31%	1.95	2.00
Sugar beet	Sugar beet	45%	0.52	0.69
Fodder plants	Maize	19%	2.41	2.45
Grass	Grass	5%	2.84	2.81
Average			**1.45**	**1.55**

Table A22: Price change calculation for feed. *Source: de Vries et al. (2013)

			LIAISE price rel. change*	
Feed	**LIAISE equivalent**	**Rel. to total feed input**	**GE**	**RC**
Concentrates	Feed rich protein	79%	1.02	1.02
Rough fodder	Maize	21%	2.41	2.45
Average			**1.31**	**1.31**

Appendix U: Priority list model adaptations

This appendix provides a priority list for actions that improve the LP-model. The actions are presented point-wise. In the Chapter 5 of this report the actions are discussed and explained.

1. Implement fixed protein level for cow diet to improve the model.
2. Change N-legislation laws for new explorations.
3. Implement irrigation activities for more explorations with adaptation measures.
4. Run model with prices for exported manure to improve model and explore more.
5. Include activities and constraint to purchase extra maize and grass to improve the model.
6. Implement soil moisture increasing activities for more explorations with adaptation measures.
7. Adapt nutrient use efficiencies according to scenarios to improve explorations.
8. Adapt nutrient contents according to scenarios to improve explorations.