Sustainability of Dutch dairy farming systems:
A modelling approach

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Sustainability of Dutch dairy farming systems: A modelling approach

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Abstract

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The transition towards more sustainable dairy farming systems is a central element on the Dutch agenda for the reconstruction of the livestock production sector. The concept of sustainability needs to be quantified to evaluate the effectiveness of a transition towards more sustainable farming systems and to quantify the sustainability of farming systems. Furthermore, the transition process can be supported with improved insight into the effects of management measures and farming systems on individual sustainability aspects and overall sustainability. The general objective of the research presented in this thesis was to quantify sustainability at farm level and to gain insight into the effects of management measures and farming systems on all aspects of sustainability in dairy farming using farm-level modelling. Stakeholders, i.e. primary producers, consumers, industrial producers, and policy makers, were consulted to quantify subjective elements of sustainability and experts were consulted to quantify objective elements of sustainability. Consultation of stakeholders and experts showed that economic and internal social sustainability can be approximated by one attribute. External social and ecological sustainability need multiple attributes to be described adequately. Indicators were used to measure the performance of attributes and were included in a dairy farm Linear Programming (LP)-model to determine how farm management measures and farming systems affect different sustainability aspects. Multi-Attribute Utility Theory (MAUT) was used to develop an overall sustainability function for Dutch dairy farming systems in which all attributes and aspects were weighted hierarchically by consulting stakeholders and experts. Especially consumers and primary producers attach considerably different weights to sustainability aspects. This limits the possibility for developing one overall sustainability function that satisfactorily includes preferences of all stakeholder groups. The overall sustainability function per stakeholder group was applied to four experimental dairy farms. Finally, the overall sustainability function per stakeholder group was included as objective function in the dairy farm LP-model resulting in a Weighted Linear Goal Programming (WLGP)-model. Analysis with the WLGP-model showed that conventional dairy farms have the potential to achieve similar sustainability scores in comparison with organic dairy farms (and vice versa).

Key Words: Stakeholders, Experts, Preferences, Sustainability, Multi-Attribute Utility Theory, Linear Programming, Weighted Goal Programming, Dairy Farming; The Netherlands.

Woord vooraf

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Contents

Chapter 1

General introduction

1.1 Background and scope

The current conventional way of Dutch dairy farming is under debate. Conventional Dutch dairy farming is highly productive through a high level of farm management (e.g. high milk and crop production) and high intensity, i.e. kg milk per hectare. Side-effects of the intensification of dairy farming became evident from the end of the 1970s and beginning of the 1980s onwards (Henkens and van Keulen, 2001). The ecological quality of many surface waters is poor and nitrate concentration of groundwater is exceeding 50 mg of nitrate per litre of groundwater in several areas. This is mainly due to relatively high discharges of nitrogen and phosphate from agriculture (Oenema et al., 2005). Moreover dairy farming contributes to global warming (emissions of methane, nitrous oxide and carbon dioxide; Oenema et al., 2001) and acidification (emission of ammonia; Bussink and Oenema, 1998).

Besides ecological sustainability, social sustainability of Dutch dairy farming is also under pressure. Food safety in dairy farming, for example, has become an increasing issue for consumers over the last decade (Noordhuizen and Metz, 2005). Non-grazing of dairy cows and/or young stock affects the image of dairy farming and is related to lower animal welfare (Van den Pol-van Dasselaar et al., 2002). Currently, still 85% of all dairy cows are allowed to graze. This number decreased the last few years as a result of a more strict environmental legislation (MINAS; Ondersteijn et al., 2002) and an increase in the size of dairy farms (Luesink et al., 2005). This trend negatively affects social sustainability of Dutch dairy farming.

Last but not least, economic sustainability of Dutch dairy farms is under pressure mainly due to decreasing milk prices and increasing production costs. Milk prices are expected to drop further resulting from changes in the Common Agricultural Policy (CAP). The CAP aims to shift monetary support away from product support towards direct income support and towards payments targeted at realising environmental and other objectives (Burrell, 2004). The total CAP budget, however, is expected to decrease while at the same time production costs are likely to increase. These changes will lead to restructuring of the dairy sector in the next few years and marginal dairy farms will disappear (Burrell, 2004).

According to policy makers, agricultural organisations, societal organisations and scientists sustainability can be a basis to address future developments for dairy farming. The transition towards more sustainable, i.e. economic, social and ecological, farming systems is a central element of the Dutch agenda for the reconstruction of the livestock production sector (Wijffels, 2001; VROM, 2003). The concept of sustainability needs to be quantified to evaluate the effectiveness of a transition towards more sustainable farming systems and to measure the sustainability of farming systems. Furthermore, the transition process can be supported with improved insight into the effects of management measures and farming systems on individual sustainability aspects and overall sustainability.

So far, several methods have been developed for identifying sustainability in agriculture (e.g. De Wit et al., 1995; e.g. Chandre Gowda and Jayaramaiah, 1998; Hanegraaf et al., 1998; Webster, 1999; Sands and Podmore, 2000; Rigby et al., 2001; Tzilivakis and Lewis, 2004; Zinck et al., 2004). Most of these approaches, however, do not focus on all aspects, i.e. economic, social and ecological, of sustainability and do not amalgamate all aspects of sustainability into one well-balanced overall sustainability index. The farm level is regarded as the most important starting point because economic, social and, ecological sustainability come together at farm level (De Koeijer et al., 1995) and because farmers mainly determine sustainability of agriculture (Webster, 1999).

1.2 Objectives of the research

The general objective of this research is to quantify sustainability at farm level and to gain insight into the effects of management measures and farming systems on all aspects of sustainability in dairy farming by using farm-level modelling. Different groups in society, like politicians, consumers, and producers, can view sustainability quite differently (e.g. Heinen, 1994; e.g. Bell and Morse, 1999; Rigby et al., 2001). This implies that the perceptions of different stakeholder groups should be taken into account when quantifying subjective elements of sustainability in dairy farming. Experts should be included to quantify objective elements of sustainability in dairy farming. This results in the following questions for this research:

1. Which attributes are relevant with respect to economic, social, and ecological sustainability of Dutch dairy farming?
2. Which indicators are suitable to quantify economic, social, and ecological sustainability and can be included in the dairy farm model?
3. What are the effects of farm management measures and farming systems on economic, social, and ecological sustainability indicators?
4. How can the selected indicators for economic, social, and ecological sustainability be amalgamated into one overall sustainability function by using the preferences of different stakeholders and expert knowledge?
5. What is the effect of maximising overall sustainability on the sustainability performance (i.e. overall sustainability, aspect sustainability, and attribute sustainability) of different dairy farming systems for different stakeholder groups?

1.3 Outline

To answer the research questions the study used the framework outlined in Figure 1.1.

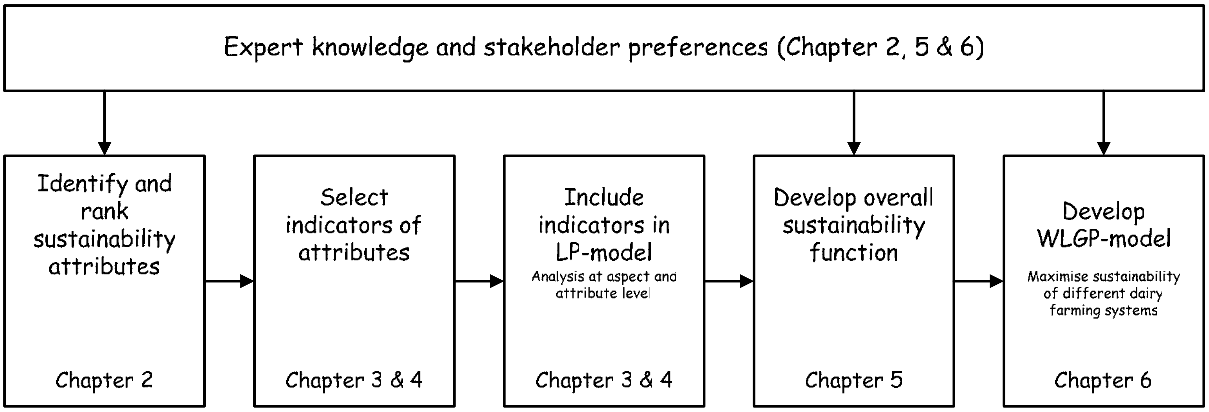

Figure 1.1 Framework used to answer the research questions

Chapter 2 presents several definitions of sustainability and explains the diversity in definitions. Next, sustainability attributes are identified and ranked by consulting a wide range of people, i.e. stakeholders and experts.

In Chapter 3 indicators for economic and ecological sustainability are selected and included in a dairy farm linear programming (LP) model. The model is used to analyse the effect of environmental policy and of environmental management measures as applied on experimental dairy farm “De Marke” on economic and ecological sustainability.

Chapter 4 describes the selection of indicators for social sustainability. The selected social indicators are included in the farm model which is then used to analyse possible differences in social sustainability between a conventional and an organic dairy farming system.

In Chapter 5 a multi-attribute overall sustainability function is developed by assessing stakeholder preferences and expert knowledge. The approach consists of: (1) determination of attribute utility functions, (2) assessing attribute weights to determine utility functions per aspect, and (3) assessing aspect weights to determine the overall sustainability function per stakeholder group. The overall sustainability function is applied to different Dutch dairy farming systems represented by four experimental farms.

In Chapter 6 the overall sustainability function developed in Chapter 5 is included in the dairy farm model by using Weighted Linear Goal Programming (WLGP) which maximises overall sustainability for different stakeholder groups. The WLGP-model is used to simulate a conventional and an organic dairy farming system to analyse the impact of: (1) maximisation of individual sustainability aspects and (2) maximisation of overall sustainability using stakeholder preferences on sustainability performance.

Chapter 7 discusses methodological issues of the thesis and applicability of the method. Finally, the main conclusions from the research are presented and recommendations for further research are given.

References

Bell, S. and Morse, S., 1999. *Sustainability indicators: measuring the immeasurable?* Earthscan, UK: London.

Burrell, A., 2004. The 2003 CAP reform - Implications for the EU dairy sector. *Outlook on Agriculture* 33: 15-25.

Bussink, D.W. and Oenema, O., 1998. Ammonia volatilization from dairy farming systems in temperate areas: a review. *Nutrient Cycling in Agroecosystems* 51: 19-33.

Chandre Gowda, M.J. and Jayaramaiah, K.M., 1998. Comparative evaluation of rice production systems for their sustainability. *Agriculture, Ecosystems and Environment* 69: 1-9.

De Koeijer, T.J., Renkema, J.A. and Van Mensvoort, J.J.M., 1995. Environmental-Economic Analysis of Mixed Crop-Livestock Farming. *Agricultural Systems* 48: 515-530.

De Wit, J., Oldenbroek, J.K., Vankeulen, H. and Zwart, D., 1995. Criteria for Sustainable Livestock Production - a Proposal for Implementation. *Agriculture Ecosystems & Environment* 53: 219-229.

Hanegraaf, M.C., Biewinga, E.E. and Van der Bijl, G., 1998. Assessing the ecological and economic sustainability of energy crops. *Biomass & Bioenergy* 15: 345-355.

Heinen, J.T., 1994. Emerging, diverging and converging paradigms on sustainble development. *International Journal of Sustainable Development and World Ecology* 1: 22-33.

Henkens, P. and van Keulen, H., 2001. Mineral policy in the Netherlands and nitrate policy within the European Community. *Netherlands Journal of Agricultural Science* 49: 117-134.

Luesink, H.H., Van Everdingen, W. and De Haan, M.H.A., 2005. Nieuw mestbeleid: Koe kan in de wei blijven. *Agri-Monitor* maart 2005: 1-2.

Noordhuizen, J.P.T.M. and Metz, J.H.M., 2005. Quality control on dairy farms with emphasis on public health, food safety, animal health and welfare. *Livestock Production Science* 94: 51.

Oenema, O., Velthof, G. and Kuikman, P., 2001. Technical and policy aspects of strategies to decrease greenhouse gas emissions from agriculture. *Nutrient Cycling in Agroecosystems* 60: 301-315.

Oenema, O., van Liere, L. and Schoumans, O., 2005. Effects of lowering nitrogen and phosphorus surpluses in agriculture on the quality of groundwater and surface water in the Netherlands. *Journal of Hydrology* 304: 289.

Ondersteijn, C.J.M., Beldman, A.C.G., Daatselaar, C.H.G., Giesen, G.W.J. and Huirne, R.B.M., 2002. The Dutch mineral accounting system and the European nitrate directive:

implications for N and P management and farm performance. *Agriculture Ecosystems & Environment* 92: 283-296.

Rigby, D., Woodhouse, P., Young, T. and Burton, M., 2001. Constructing a farm level indicator of sustainable agricultural practice. *Ecological Economics* 39: 463-478.

Sands, G.R. and Podmore, T.H., 2000. A generalized environmental sustainability index for agricultural systems. *Agriculture, Ecosystems and Environment* 79: 29-41.

Tzilivakis, J. and Lewis, K.A., 2004. The development and use of farm-level indicators in England. *Sustainable Development* 12: 107-120.

Van den Pol-van Dasselaar, A., Corré, W.J., Hopster, H., Van Laarhoven, G.C.P.M. and Rougoor, C.W., 2002. *Belang van weidegang*. PraktijkRapport Rundvee 14. Praktijkonderzoek Veehouderij, The Netherlands: Lelystad.

VROM, 2003. *Duurzame daadkracht. Actieprogramma duurzame ontwikkelingen. Nationale deel*. Ministry of Housing, Spatial Planning, and the Environment, The Netherlands: The Hague.

Webster, P., 1999. The challenge of sustainability at the farm level: Presidential address. *Journal of Agricultural Economics* 50: 371-387.

Wijffels, H.H.F., 2001. *Toekomst voor de veehouderij: agenda voor een herontwerp van de sector*. Ministry of Agriculture, Nature and Food Quality, The Netherlands: The Hague.

Zinck, J.A., Berroteran, J.L., Farshad, A., Moameni, A., Wokabi, S. and Van Ranst, E., 2004. Approaches to assessing sustainable agriculture. *Journal of Sustainable Agriculture* 23: 87-109.

Chapter 2

Identifying and ranking attributes that determine sustainability in Dutch dairy farming

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Abstract

Recent developments in agriculture have stirred up interest in the concept of "sustainable" farming systems. Still it is difficult to determine the extent to which certain agricultural practices can be considered sustainable or not. Aiming at identifying the necessary attributes with respect to sustainability in Dutch dairy farming in the beginning of the third millennium, we first compiled a list of attributes referring to all farming activities with their related side effects with respect to economic, internal social, external social and ecological sustainability. A wide range of people (i.e. experts and stakeholders) were consulted to contribute to our list of attributes. Our consultation showed that only one attribute was selected for economic and internal social sustainability: profitability and working conditions, respectively. The list for external social sustainability contained 19 attributes and the list for ecological sustainability contained 15 attributes. To assess their relative importance, the same experts and stakeholders ranked the attributes for external social and ecological sustainability by using a questionnaire. The most important attributes for external social sustainability were food safety, animal health, animal welfare, landscape quality, and cattle grazing. For ecological sustainability they were eutrophication, groundwater pollution, dehydration of the soil, acidification, and biodiversity. The presented method for identifying and ranking attributes is universal and therefore can be used for other agricultural sectors, for other countries, and during other time periods.

2.1 Introduction

Interest in the concept of "sustainable" farming systems has grown as a result of the continuous pressure on farm incomes, occurrence of animal diseases with a major impact (e.g. foot-and-mouth disease and BSE), concerns about animal welfare, and environmental problems caused by agriculture. Alternative farming systems, which include integrated farming, biodynamic farming, and organic farming, are often equated with sustainable agriculture (Hansen, 1996; Rigby and Caceres, 2001). Others, however, see sustainable farming as encompassing a wider range of systems. It is nevertheless difficult to determine the extent to which certain agricultural practices can be considered sustainable or not (Rigby and Caceres, 2001).

To characterise agricultural systems as sustainable, the concept of sustainability has to be made operational and appropriate methods need to be designed for its long-term measurement (Heinen, 1994). A method developed for assessing sustainability in agriculture should take into account all possible farming activities and all their side effects (De Graaf et al., 1996). Sustainability should be assessed on the basis of three aspects: economic, social, and ecological sustainability (e.g. Shearman, 1990; Heinen, 1994; Hansen, 1996). So far, several methods have been developed for identifying sustainability in agriculture (e.g. De Wit et al., 1995; Chandre Gowda and Jayaramaiah, 1998; Hanegraaf et al., 1998; Callens and Tyteca, 1999; Webster, 1999; Sands and Podmore, 2000; Rigby et al., 2001; Sulser et al., 2001). Most of these approaches, however, do not focus on farming activities and related side effects with respect to all aspects, i.e. economic, social and ecological. In addition, none of them are aimed particularly at assessing sustainability in dairy farming. Dairy farming is different from other sectors of agriculture, as it is a combination of two types of production processes, i.e. animal production and plant production. An assessment of sustainability in dairy farming requires four steps: 1) description of the (problem) situation; 2) identification and definition of relevant economic, social and ecological attributes or issues; 3) selection and quantification of suitable sustainability indicators; and 4) aggregation of indicator information into an overall contribution to sustainable development (Bell and Morse, 1999; De Boer and Cornelissen, 2002).

The aim of this paper is to develop a methodology for step 2 of this assessment, which means providing an overview of attributes within the context of Dutch dairy farming. Therefore, a comprehensive list of attributes concerning economic, social and ecological sustainability is first identified and then ranked by using the perceptions of different stakeholders and experts.

Definitions of sustainability are discussed in the second section of the paper. In the third section, the method used for identifying and ranking attributes for assessing sustainability in dairy farming is explained step by step. The results are discussed in the fourth section. The final section contains the discussion and major conclusions.

2.2 Definition of sustainability

During the past decade, sustainability has been on the agenda of government, agricultural organisations, and society-at-large. Much of the debate about the nature and potential of sustainable agriculture focuses on definitions (Francis and Youngberg, 1990). Two popular and widely used definitions of sustainable development are given in *Our Common Future* (Brundtland, 1987) and in *Caring for the Earth* (Munro and Holdgate, 1991). These are, respectively, “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” and “development that improves the quality of human life while living within the carrying capacity of supporting ecosystems.” Such broad definitions are likely to give rise to various different interpretations (Callens and Tyteca, 1999). The result is that at least 70 more definitions have been constructed, each different in subtle ways, each emphasising different values, priorities, and goals (Pretty, 1995). An overview of definitions of sustainability in agriculture can be found in Francis and Youngberg (1990), Bell and Morse (1999) and Hansen (1996).

The diversity of the definition of sustainability is largely explained by the position and the opinion of the user. Generally, two different ethical perspectives can be distinguished - biocentrism (or ecocentrism) and anthropocentrism (Thompson, 1992). The most prominent features of biocentrism are that humans are not inherently superior to other living beings (Barrett and Grizzle, 1999), and that various beings or entities, from individual organisms to the biosphere, have intrinsic value (Shearman, 1990). The anthropocentric view focuses on the sustainable welfare of humans (Barrett and Grizzle, 1999). The definition of sustainable development of the Brundtland report (1987), for example, is explicitly anthropocentric (Hardaker, 1997; Rennings and Wiggering, 1997). Without a doubt, the anthropocentric perspective dominates the paradigm of sustainable development (Shearman, 1990).

People from different disciplinary backgrounds can also view sustainability quite differently (Lowrance et al., 1986; Shearman, 1990; Heinen, 1994; Jaeger, 1995; Hardaker, 1997; Bell and Morse, 1999; Rigby et al., 2001). An important difference between economists and ecologists is the scope of substitution, particularly of human capital for increasingly scarce natural resources and environmental services. Economists are generally optimistic about substitution while ecologists have a pessimistic view of it (Hardaker, 1997).

Finally the variety of definitions with respect to sustainability in agriculture has been classified also on the basis of a specific economic, social or ecological concern (Douglass,

1984) and its historical and ideological roots (Kidd, 1992). This emphasises again that defining sustainability depends on the individual.

The meaning of sustainability varies along spatial and temporal scales (Fresco and Kroonenberg, 1992). Different spatial scales can be distinguished (e.g. field, farm, village, city, region, country and so on until the whole planet is considered) (Bell and Morse, 1999). Lynam and Herdt (1989) have pointed out that the sustainability of a system is not necessarily dependent on the sustainability of all its sub-systems. Invoking the Lynam and Herdt principle implies that individual sub-systems need not all be sustainable for global sustainability to be achieved (Hardaker, 1997). Although sustainability is an important concern on several spatial scales (Lowrance et al., 1986; Lynam and Herdt, 1989), it is particularly relevant at farm level (Hansen and Jones, 1996).

Societal views of sustainability change over time. In other words, definitions of sustainability are time specific (Pretty, 1995). Sustainability implies an ongoing dynamic development, driven by human expectations about future opportunities based on economic, social, and ecological information (Cornelissen et al., 2001). Planning horizons of ten or fifteen years are usually about as long as it is plausible to consider (Lynam and Herdt, 1989; Hardaker, 1997). Even over such lengths of time, the ability to account for upcoming changes in technological, social, political, and economic situation is very limited (Hardaker, 1997).

The perceptions of different stakeholders and experts are included in this research as a way to identify and rank sustainability attributes. By choosing this approach, we attempt to take into account different ethical perspectives. The farm level is regarded as the most important starting point because economic, ecological, and social attributes come together at farm level (De Koeijer et al., 1999). This research focuses, therefore, at the farm level. The research was and will continue to be conducted at the very beginning of the third millennium. Consequently, the results reflect the knowledge and the views of this period in time with respect to sustainability on Dutch dairy farms.

2.3 Methods

Step 2 for the assessment of sustainability in dairy farming concerns the identification and ranking of attributes (see Introduction). The method for identification and ranking of attributes for sustainability in dairy farming was performed in 2001 and consisted of three steps:

1. Developing a preliminary outline for determining sustainability
2. Making a list of attributes that determine sustainability
3. Assessing the relative importance of sustainability attributes

2.3.1 Developing a preliminary outline for determining sustainability

A preliminary outline of sustainability in dairy farming was developed based on literature research, and after consulting experts in the field of sustainability as it applies to dairy farming. Our assessment in this research focused on four aspects: economic, internal social, external social, and ecological sustainability.

Economic sustainability is defined as the ability of the dairy farmer to continue his farming business, i.e. economic viability. Internal social sustainability relates to working conditions for the farm operator and employees. External social sustainability has to do with societal impact of agriculture on the well being of people and animals. Ecological sustainability concerns threats or benefits to the flora, fauna, soil, water, and climate.

For each aspect, attributes were selected that contributed to or detracted from sustainability. An attribute, for this research, was defined as a particular feature of an aspect of sustainability (derived from Hardaker et al., 1997). Attributes equate with "issues" as used in other studies (e.g. De Boer and Cornelissen, 2002).

2.3.2 Making a list of attributes that determine sustainability

The method to identify and rank attributes is based on the expertise, experience, and knowledge of a group of respondents. The respondents, i.e. experts vs. stakeholders, who were chosen to identify attributes represented different aspects of sustainability (Table 2.1). Four different questionnaires were used: economic, internal social, external social, and ecological questionnaires. The questionnaires on economic, internal social and ecological sustainability were sent to scientific experts, as the assessment of attributes with respect to these aspects of sustainability is a matter of expert knowledge. The supervising committee of this research project proposed experts for the different aspects of sustainability. Selection took place through discussion in which the competence of the expert was the main criterion. Competence was judged mainly by looking at scientific papers written by the proposed experts. To ensure diversity, experts from different scientific institutions, and environmental, labour, and farmers' organisations were selected.

Table 2.1 Type and number of respondents per aspect of sustainability

Aspect of sustainability	Type of respondents			
	Experts	N[1]	Stakeholders	N
Economic	Yes	9	No	-
Internal social	Yes	7	No	-
External social	No	-	Yes	9
Ecological	Yes	10	No	-

[1] Number

Identification of external social sustainability attributes depends strongly on the preferences of stakeholders, as societal concerns differ between stakeholders. Based on Grimble and Wellard (1997:175), we define the term stakeholder as “any group of people, organised or unorganised who share a common interest or stake in a particular issue or system”. In this research, four stakeholders or interest groups are included: consumer and farmer organisations, industrial producers, and policy makers. These stakeholders, proposed by the supervising committee of the research project, were individuals who had shown social concern for the impact of agriculture on the well being of people and animals. This was judged by looking at the participation of the stakeholder in the public debate on future developments in dairy farming. The questionnaires on external social sustainability were sent to nine representatives within the stakeholder category.

After sending the questionnaires, an appointment was made with each responding expert or stakeholder, to talk things over. This served as a way to minimise the chances of misunderstanding or misinterpretation. Each questionnaire identified suggestions for attributes with respect to the particular aspect of sustainability. Respondents had the option of adding and removing attributes. This step resulted in a list of all attributes within each aspect of sustainability in dairy farming.

2.3.3 Assessing the relative importance of sustainability attributes

As a result of the chosen approach in the previous section, many sustainability attributes were likely to be listed. It was recognised that some attributes might overlap and that those attributes that appeared to be dependent on others should be excluded as far as possible to avoid redundancy. In cooperation with experts on the concerning aspect of sustainability seemingly dependent and independent attributes were indicated. In the second questionnaire sent to the same set of experts and stakeholders, respondents were first asked whether seemingly dependent attributes should be omitted or be used as separate attributes.

Next, the respondents were asked to rank the listed sustainability attributes. Two ranking methods were used, interval ranking and ordinal ranking (Churchill, 1999). In interval ranking, the respondents were asked to rank each attribute relevant to a particular aspect according to its perceived importance. A Likert scale of 1 to 5 was used, with 1 being not important for sustainability and 5 being very important. In ordinal ranking the respondents were asked to put the list of attributes in order of importance.

To compare the final ranking, the average and standard deviation of the relative importance weights of attributes were calculated for each respondent and ranking method. The relative importance weight W_{ijk}, for attribute i, respondent j, and ranking method k, was calculated as follows:

$$W_{ijk} = \frac{X_{ijk}}{\overline{X_{jk}}}$$

Where, X_{ijk} =the value of attribute *i* for respondent *j* and ranking method *k*, $\overline{X_{jk}}$ =the average ranking of all attributes for respondent *j* and ranking method *k*.

By using the relative importance weights of both ranking methods, each respondent was tested for internal consistency by using the Spearman Rank Correlation Coefficient. The results of non-consistent respondents were omitted from the analysis.

2.4 Results

First we will present the comprehensive list of attributes that determine sustainability in dairy farming, followed by the results of assessing the relative importance of sustainability attributes. These results are presented per aspect of sustainability.

2.4.1 List of attributes

Economic sustainability

Suggested attributes for economic sustainability were liquidity, profitability, and solvability of the dairy farm. Liquidity refers to the farm's capacity to generate sufficient cash to meet its financial commitments as they become due. Profitability is the difference between the value of goods and services produced by the farm and the costs of resources used in their production. Solvability is concerned with the relationship between the current market value of assets and the claims others have on the farm (Barry et al., 2000).

All the proposed attributes are highly interrelated. Indirectly, solvency and liquidity are linked to profitability. In deliberation with the respondents, therefore, it was decided that profitability would be selected as the only attribute for assessing economic sustainability in dairy farming. Profitability can be measured by using net farm income as an indicator.

Internal social sustainability

The respondents rejected the suggested attributes in the questionnaire, i.e. leisure time and disability. Arguing that disability in dairy farming is considered to be caused by poor working conditions, most respondents suggested that disability and leisure time should be replaced by "working conditions on a dairy farm." Working conditions can be measured by constructing an index, consisted of a quantitative dimension (i.e. time aspects) and a qualitative dimension (i.e. physical and mental burden). Working conditions on a dairy farm were selected as the only attribute within internal social sustainability, since this attribute subsumed all the subjects the respondents identified.

External social sustainability

Most respondents included the suggested attributes, i.e. food safety, animal welfare, and employment, in their list of attributes. The respondents added a further sixteen attributes covering a very wide range of concerns to the list of external social sustainability (Table 2.2). The reasons for including these attributes are presented in Appendix 2A.

Table 2.2 List of attributes for external social sustainability

No.	Independent attributes	No.	Dependent attributes
1	Food safety	10	Cattle grazing (2 and 5)[a]
2	Animal welfare	11	Use of pesticides (1 and 4)
3	Contribution to urban economy	12	Use of new technologies (4)
4	Degree of industrialisation	13	Use of Genetic Modified Organisms (4)
5	Landscape quality	14	Use of artificial fertiliser (4)
6	Multifunctionality	15	Intensity (4)
7	Use of by-products	16	Animal health (1 and 2)
8	Use of undisputed products	17	Level of milk production (4)
9	Land use in developing countries	18	Farm size (4)
		19	Employment (3)

[a] Numbers between parentheses refer to the independent attributes in the first column

It is clear that not all of these attributes are independent. For example, cattle grazing was mentioned as a separate attribute, but it is also part of animal welfare and landscape quality. Attributes in the first column of Table 2.2 are considered to be independent attributes, while those in the second column are considered to be dependent attributes. Associations shown in the table were provided by the respondents (e.g. “use of new technologies” with “degree of industrialisation”) and judged by the authors.

Ecological sustainability

Most respondents included the suggested attributes in the questionnaire, i.e. acidification, biodiversity, and use of energy, in their list of attributes. Respondents added 12 attributes to the list for ecological sustainability (Table 2.3). The reasons are presented in Appendix 2B.

Table 2.3 List of attributes for ecological sustainability

No.	Independent attributes	No.	Dependent attributes
1	Use of pesticides	12	Use of energy (3)[a]
2	Use of antibiotics	13	Use of water (6)
3	Global warming	14	Biodiversity (1, 2, 5, 6, 7, 8, 9 and 10)
4	Use of ozone depleting gases	15	Soil fertility (2 and 5)
5	Use of heavy metals		
6	Dehydration of the soil		
7	Acidification		
8	Wastewater disposal		
9	Groundwater pollution		
10	Eutrophication		
11	Genetic diversity of livestock		

[a] Numbers between parentheses refer to the independent attributes in the first column

Again, not all attributes are independent. Biodiversity, for example, was mentioned as a separate attribute, whereas it is affected (especially on grassland) by emission of acidifying gases and nitrate and phosphate concentration in surface water, i.e. eutrophication, among other things. Attributes in the first column of Table 2.3 are considered to be independent attributes, and those in the second column are considered to be dependent attributes.

2.4.2 Relative importance of sustainability attributes

For economic and internal social sustainability, only one attribute, i.e. profitability and working conditions, was identified and relative importance could be ignored. By contrast, in the case of external social and ecological sustainability, nineteen and fifteen attributes were identified respectively and assessment of relative importance was necessary. Next, we will discuss the consistency of the respondents and then present the results for external social and ecological sustainability.

Consistency of respondents

Each respondent was checked for internal consistency by using interval and ordinal ranking (Table 2.4). With respect to external social sustainability, two respondents, i.e. C and I, were judged inconsistent. This means that the order of relevance of the attributes differed significantly between the interval and ordinal ranking for these respondents. On the subject of ecological sustainability, only one respondent, i.e. 5, was found to be inconsistent, because this respondent was not able to do the ordinal ranking. The results of these three respondents, i.e. C, I, and 5, were not included in the analysis.

Table 2.4 Consistency of respondents

External social sustainability		Ecological sustainability	
Respondent	Correlation coefficients	Respondent	Correlation coefficients
A	0.66*	1	0.73*
B	0.81*	2	0.72*
C	0.52	3	0.88*
D	0.97*	4	0.95*
E	0.68*	5	X
F	0.83*	6	0.95*
G	0.75*	7	0.95*
H	0.84*	8	0.91*
I	0.44	9	0.96*
		10	0.68*
Average	0.69*	Average	0.82*

* There is an association between both ranking methods ($P < 0.05$)

Ecological respondents were more consistent than external social respondents. This was indicated by a higher average correlation coefficient, i.e. 0.82 vs. 0.69. Apparently ecological respondents, i.e. experts, were more familiar with these kinds of questionnaires than stakeholders.

External social sustainability

The following dependent attributes were selected by less than 50% of the respondents and were therefore excluded from the ranking procedure: employment, level of milk production, and farm size (not selected at all); use of artificial fertiliser, intensity, and use of new technologies (selected by 29% of the respondents); use of pesticides (selected by 43% of the respondents). Table 2.5 shows the average interval rankings and the average relative importance weights together with their standard deviations. Attributes are presented in order of average relative importance weight.

Table 2.5 Average and standard deviation of interval ranking and relative importance weights of attributes for external social sustainability

No.	Attributes	N[1]	Average interval ranking	Std.dev.[2] interval ranking	Average importance weight	Std.dev.[2] importance weight
1	Food safety	7	4.9	0.4	1.43	0.21
2	Animal health	5	4.6	0.9	1.35	0.25
3	Animal welfare	7	4.4	0.5	1.28	0.06
4	Landscape quality	7	4.3	0.8	1.24	0.16
5	Cattle grazing	5	4.2	0.4	1.24	0.23
6	Use of GMO	6	3.5	0.5	1.00	0.15
7	Use of undisputed products	7	3.3	1.0	0.94	0.20
8	Multifunctionality	7	3.0	1.2	0.85	0.25
9	Contribution to urban economy	7	2.7	1.0	0.80	0.31
10	Degree of industrialisation	7	2.4	0.8	0.72	0.27
11	Land use in developing countries	7	2.4	1.1	0.69	0.25
12	Use of by-products	7	2.1	1.1	0.62	0.29

[1] Number of respondents

[2] Standard deviation

Based on the interval ranking of external social sustainability, food safety proved to be the most important attribute. The average interval ranking was 4.9 and the corresponding relative importance weight was 1.43. The standard deviation of food safety was relatively small, which means that most respondents agreed on the importance of food safety. The average interval ranking of all attributes, including those not presented, was 3.4 and the average relative importance weight was by definition equal to 1.

The dependent attributes, i.e. animal health, cattle grazing, and the use of GMO, were not selected by all respondents as a separate attribute (as shown by N). Results of these dependent attributes were therefore based on fewer opinions. However, average interval rankings of these three dependent attributes were relatively high. This means that respondents who did select these attributes as separate attributes agreed on their relevance. In Table 2.6 the average ordinal rankings, i.e. order of relevance, and the average relative importance weights with their standard deviations are shown. Attributes are presented in order of average relative importance weight.

Table 2.6 Average and standard deviation of ordinal ranking and relative importance weights of attributes for external social sustainability

No.	Attributes	N[1]	Average ordinal ranking	Std.dev.[2] ordinal ranking	Average importance weight	Std.dev.[2] importance weight
1	Food safety	7	1.4	1.1	1.78	0.18
2	Animal welfare	7	2.6	1.1	1.61	0.19
3	Animal health	5	3.8	0.8	1.46	0.15
4	Landscape quality	7	5.0	2.4	1.25	0.36
5	Use of undisputed products	7	5.1	2.8	1.22	0.47
6	Cattle grazing	5	5.7	1.2	1.20	0.19
7	Degree of industrialisation	7	8.4	3.0	0.75	0.46
8	Multifunctionality	7	8.6	2.4	0.72	0.38
9	Contribution to urban economy	7	9.1	4.0	0.69	0.50
10	Use of by-products	7	9.1	3.0	0.66	0.36
11	Use of GMO	6	10.0	1.9	0.59	0.18
12	Land use in developing countries	7	10.1	4.0	0.53	0.45

[1] Number

[2] Standard deviation

Based on the ordinal ranking for external social sustainability, food safety was once again the most important attribute. The average ordinal ranking was 1.4 and the corresponding average relative importance weight was 1.78. The average ordinal ranking of all attributes was 6.9 and the average relative importance weight was by definition equal to 1. The difference in the order of relevance of the attributes between average ordinal rankings and corresponding average relative importance weights was hardly discernible. This was expected, as respondents all use the same levels, i.e. 1, 2, 3, etc., in ordinal rankings.

Differences were observed between the interval and ordinal ranking order of some attributes. In particular, the order of the use of GMO, i.e. number 6 in Table 2.5 and number 11 in Table 2.6, differs considerably. This difference is attributable to the internal inconsistency of each of the respondents.

Ecological sustainability

The following dependent attributes were selected by less than 50% of the respondents and were therefore not included in the ranking procedure, use of water (selected by 11% of the respondents), soil fertility (selected by 33% of the respondents), and use of energy (selected by 44% of the respondents).

Here too, there was scarcely a difference in the order of attributes in ecological sustainability between interval rankings and corresponding relative importance weights.

Moreover, there was scarcely a difference in the order of relevance of the attributes between ordinal rankings and corresponding relative importance weights. Therefore, Table 2.7 only presents averages and standard deviations of relative importance weights.

Table 2.7 Average and standard deviation of relative importance weights for interval and ordinal rankings for ecological sustainability attributes

		Interval ranking		Ordinal ranking	
Attributes	N[1]	Average	Std.dev.[2]	Average	Std.dev.[2]
Eutrophication	9	1.28	0.15	1.54	0.35
Groundwater pollution	9	1.09	0.26	1.43	0.42
Dehydration of the soil	9	1.19	0.19	1.38	0.24
Acidification	9	1.19	0.32	1.33	0.52
Biodiversity	9	1.28	0.19	1.30	0.36
Global warming	9	1.02	0.23	1.04	0.42
Use of pesticides	9	0.99	0.27	1.02	0.44
Use of heavy metals	9	0.93	0.27	0.83	0.44
Wastewater disposal	9	0.82	0.28	0.64	0.38
Genetic diversity of livestock	9	0.71	0.29	0.51	0.34
Use of antibiotics	9	0.74	0.23	0.48	0.31
Use of ozone depleting gases	9	0.73	0.27	0.47	0.33

[1] Number

[2] Standard deviation

The interval ranking for ecological sustainability revealed that eutrophication and biodiversity were the most important attributes, with both having an average relative importance weight of 1.28. Despite biodiversity's dependence on many attributes (see Table 2.3), it was selected by all respondents as a separate attribute. The reason why respondents insisted of having biodiversity as a separate attribute is probably that other factors (e.g. land use and cropping practice) govern the level of biodiversity more than the attributes mentioned in Table 2.3. The ordinal ranking showed eutrophication as being the most important attribute (average relative importance weight of 1.54). The order of some attributes (e.g. groundwater pollution) showed a difference between interval and ordinal ranking. This is the result of the inconsistency of the respondents.

2.5 Discussion and conclusions

In this paper, we introduced and applied a method to identify and rank attributes using a diverse set of respondents. Priorities could be set for aspects that relate to a high number of attributes. In this way, a workable number of attributes remains for further application. Lists of attributes pertaining to external social and ecological sustainability were identified and ranked. Results of the ranking were based on seven, i.e. external social sustainability and nine, i.e. ecological sustainability, questionnaires. The low standard deviations indicated that respondents highly agreed on the importance of attributes and that no harm was done by combining the perceptions of different stakeholders or experts. This also means that the low number of respondents was justified with respect to the ranking of the attributes. Furthermore, the number of respondents was sufficient to identify a comprehensive list of attributes.

Almost every article, paper, or book on sustainability bemoans the fact that the concept is broad and lacks consensus. This is usually followed by the authors' own preferred definitions which, in turn, add to the lack of consensus (Bell and Morse, 1999). In our research, we asked experts and stakeholders, and not the authors, to identify sustainability attributes. This ensured that the identified attributes were based broadly, and that most farming activities and all their side effects were taken into account. Stakeholders, however, were asked to identify only attributes with respect to external social sustainability. Asking them to identify attributes of economic, internal social, and ecological sustainability probably would not have affected the results of the research to any large extent. It is even likely that stakeholders would have identified the same main attributes. Nonetheless, stakeholders, in general, have insufficient knowledge on these specific aspects of sustainability to rank the attributes.

All aspects and the most important attributes per aspect are presented in Figure 2.1. Only one attribute was selected for economic and for internal social sustainability: profitability and working conditions respectively. External social and ecological sustainability could not be measured by one attribute alone. The attributes judged most important for external social sustainability were: food safety, animal health, animal welfare, landscape quality, and cattle grazing, while those for ecological sustainability were, eutrophication, groundwater pollution (especially nitrate), dehydration of the soil, acidification, and biodiversity.

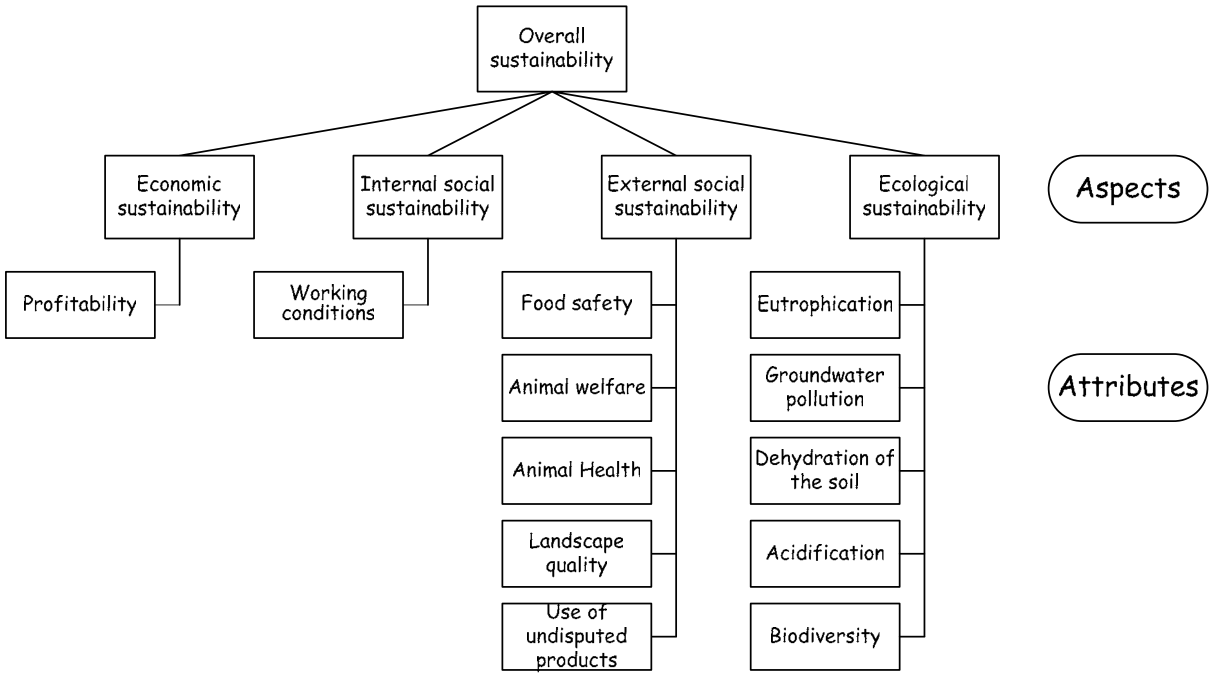

Figure 2.1 Analysis scheme of sustainability in Dutch dairy farming with aspects and the most important attributes

Several studies have been aimed at identifying attributes (or issues, or indicators, etc.) for measuring sustainability in agriculture (e.g. Rennings and Wiggering, 1997; Chandre Gowda and Jayaramaiah, 1998; Callens and Tyteca, 1999; Nijkamp and Vreeker, 2000; Rigby et al., 2001). Differences in the attributes of economic and ecological sustainability found in this paper and those in other studies are mainly a result of the chosen sector, i.e. dairy farming, and differences in spatial scale, i.e. farm level vs. region level. In two studies (Callens and Tyteca, 1999; Nijkamp and Vreeker, 2000), the attribute working conditions, is included. In some studies in the U.S., social sustainability refers to the structure of agriculture and the ability to sustain independent business (e.g. Bultena et al., 1995). Therefore, in general, differences in attributes for social sustainability relate to external social sustainability. External social sustainability in this study pertains to societal concern about the impact of dairy farming on the well being of people and animals. This part of social sustainability has not been included so extensively before. External social sustainability, however, is so important for the public image of dairy farming and for policy making that it should be included.

Results of the method presented are only valid in Dutch dairy farming in the beginning of the third Millennium. The method, however, can be used for other agricultural sectors, for other countries and for other time periods. The main benefit of the used method is that it gives insight into the sustainability attributes that are important for a particular agricultural sector. This knowledge can be applied by farmers and policy makers to develop new farming systems and farm policies.

The next step in this research consists of determining final sets of attributes for external social and ecological sustainability. These final sets are based on the rankings as well as on the possibilities of measuring each attribute on the farm and on the possibility that a farmer can influence the level of the attribute. The selected attributes will be measured by using indicators. These indicators can be used for developing policy with respect to dairy farming. Usually policy making focuses on only one attribute at a time (e.g. groundwater pollution), and the effect of the policy on other attributes is not taken into account. By using a multiple criteria, decision-making model that includes all sustainability attributes, the effect of new policy on the economic, internal social, external social, and ecological sustainability can be analysed. An optimal policy is dependent on attribute weights, which can differ among stakeholders.

Appendix 2A

Table 2A.1 Reasons for including attributes pertaining to external social sustainability

No.	Attribute	Description
1	Food safety	Food safety is included because products can contain components that can harm human health
2	Animal welfare	Society is increasingly concerned about animal welfare
3	Contribution to urban economy	Dairy farming contributes to the urban economy by providing employment and producing drinking water, among other things
4	Degree of industrialization	An industrialized dairy farm is associated with factory farming and unsustainable dairy farming systems
5	Landscape quality	Because dairy farming takes place in the rural environment it affects landscape quality
6	Multifunctionality	Dairy farms are more appreciated when involved in additional activities
7	Use of byproducts	Using by-products of the food industry helps solve a waste problem
8	Use of undisputed products	Producers (dairy farmers) are responsible for the use of materials that can have an impact on child labour and the environment
9	Land use in developing countries	A vast area of cultivated land in developing countries is claimed for production of concentrates. This decreases the area of nature in these countries and disrupts the nutrient balance at world level.
10	Cattle grazing	During grazing, dairy cows are able to behave naturally, while giving the landscape added value
11	Use of pesticides	Pesticides are synthetic and application is associated with factory farming
12	Use of new technologies	Use of new technologies is associated by some people with factory farming
13	Use of Genetic Modified Organisms	Use of GMOs is associated with factory farming
14	Use of artificial fertilizer	High use of artificial fertilizer is associated with factory farming
15	Intensity	Intensive agriculture is associated with less environmentally-friendly agriculture
16	Animal Health	The health of dairy cattle is felt to be above average
17	Level of milk production	Increasing milk yields per cow is not judged as natural
18	Farm size	Extremely large farms are associated with factory farming
19	Employment	Dairy farms contribute to employment in urban areas

Appendix 2B

Table 2B.1 Reasons for including attributes pertaining to ecological sustainability

No.	Attribute	Description
1	Use of pesticides	Through leaching and run-off, pesticides negatively affect the quality of ground and surface water
2	Use of antibiotics	Accumulation of antibiotics affects soil biodiversity and soil fertility
3	Global warming	Increased concentrations of greenhouse gases in the atmosphere affects climate
4	Use of ozone depleting gases	Ozone depleting gases allow more UV-radiation to reach the earth
5	Use of heavy metals	Accumulation of heavy metals affects biodiversity and soil fertility
6	Dehydration of the soil	Quality of wildlife is affected by dehydration of the soil
7	Acidification	Emission of acidifying gases is harmful to nature
8	Wastewater disposal	Purifying wastewater increases costs for water boards. It can also affect biodiversity
9	Groundwater pollution	High concentrations of nitrate in groundwater increases costs for water boards
10	Eutrophication	High concentrations of nitrate and phosphate leads to eutrophication
11	Genetic diversity of livestock	By using only a few breeding bulls, the genetic diversity of cattle decreases
12	Use of energy	Energy is a scarce asset and should be used efficiently
13	Use of water	Water is a scarce asset and should be used efficiently
14	Biodiversity	Disappearance of species is irreversible and should be prevented
15	Soil fertility	Good soil fertility is essential for maintaining production levels

References

Barrett, C.B. and Grizzle, R., 1999. A holistic approach to sustainability based on pluralism stewardship. *Environmental Ethics* 21: 23-42.

Barry, P.J., Ellinger, J.A., Hopkin, J.A. and Baker, C.B., 2000. *Financial management in agriculture*. Interstate Publishers, US: Danville.

Bell, S. and Morse, S., 1999. *Sustainability indicators: measuring the immeasurable?* Earthscan, UK: London.

Brundtland, G.H., 1987. *Our common future*. Oxford University Press, UK: Oxford.

Bultena, G.L., Hoiberg, E.O. and Dansingburg, J., 1995. *Impact of sustainable farming on the structure of American agriculture*. In: Bird, E.A.R., Bultena, G.L., Gerdner, J.C. (Eds.), Planting the future. Developing an agriculture that sustains land and community. Iowa State University Press, US: Walthill (Nebraska), pp. 67-82.

Callens, I. and Tyteca, D., 1999. Towards indicators of sustainable development for firms. A productive efficiency perspective. *Ecological Economics* 28: 41-53.

Chandre Gowda, M.J. and Jayaramaiah, K.M., 1998. Comparative evaluation of rice production systems for their sustainability. *Agriculture, Ecosystems and Environment* 69: 1-9.

Churchill, G.A., 1999. *Marketing research: methodological foundations*. Dryden Press, US: Fort Worth.

Cornelissen, A.M.G., van den Berg, J., Koops, W.J., Grossman, M. and Udo, H.M.J., 2001. Assessment of the contribution of sustainability indicators to sustainable development: a novel approach using fuzzy set theory. *Agriculture, Ecosystems & Environment* 86: 173.

De Boer, I.J.M. and Cornelissen, A.M.G., 2002. A method using Sustainability indicators to compare conventional and animal-friendly egg production systems. *Poultry Science* 81: 173-181.

De Graaf, H.J., Musters, C.J.M. and terKeurs, W.J., 1996. Sustainable development: looking for new strategies. *Ecological Economics* 16: 205-216.

De Koeijer, T.J., Wossink, G.A.A., van Ittersum, M.K., Struik, P.C. and Renkema, J.A., 1999. A conceptual model for analysing input-output coefficients in arable farming systems: from diagnosis towards design. *Agricultural Systems* 61: 33-44.

De Wit, J., Oldenbroek, J.K., Vankeulen, H. and Zwart, D., 1995. Criteria for Sustainable Livestock Production - a Proposal for Implementation. *Agriculture Ecosystems & Environment* 53: 219-229.

Douglass, G.K., 1984. *The meanings of agricultural sustainability*. In: Douglass, G.K. (Ed.), Agricultural sustainability in a changing world order. Westview Press, US: Boulder (Colorado), pp. 1-29.

Francis, C.A. and Youngberg, G., 1990. *Sustainable agriculture - an overview*. In: Francis, C.A., Flora, C.B., King, L.D. (Eds.), Sustainable agriculture in temperate zones. John Wiley & Sons, US: New York, pp. 1-23.

Fresco, L.O. and Kroonenberg, S.B., 1992. Time and spatial scales in ecological sustainability. *Land Use Policy* July 1992: 155-168.

Grimble, R. and Wellard, K., 1997. Stakeholder methodologies in natural resource management: A review of principles, contexts, experiences and opportunities. *Agricultural Systems* 55: 173-193.

Hanegraaf, M.C., Biewinga, E.E. and Van der Bijl, G., 1998. Assessing the ecological and economic sustainability of energy crops. *Biomass & Bioenergy* 15: 345-355.

Hansen, J.W., 1996. Is agricultural sustainability a useful concept? *Agricultural Systems* 50: 117-143.

Hansen, J.W. and Jones, J.W., 1996. A systems framework for characterizing farm sustainability. *Agricultural Systems* 51: 185-201.

Hardaker, J.B., 1997. *Guidelines for the integration of sustainable agriculture and rural development into agricultural policies*. FAO, Italy: Rome.

Hardaker, J.B., Huirne, R.B.M. and Anderson, J.R., 1997. *Coping with risk in agriculture*. CAB International, US: New York.

Heinen, J.T., 1994. Emerging, diverging and converging paradigms on sustainble development. *International Journal of Sustainable Development and World Ecology* 1: 22-33.

Jaeger, W.K., 1995. Is Sustainability Optimal - Examining The Differences Between Economists And Environmentalists. *Ecological Economics* 15: 43-57.

Kidd, C.V., 1992. The Evolution Of Sustainability. *Journal of Agricultural & Environmental Ethics* 5: 1-26.

Lowrance, R., Hendrix, P.F. and Odum, E.P., 1986. A hierarchical approach to sustainable agriculture. *American Journal of Alternative Agriculture* 1: 169-173.

Lynam, J.K. and Herdt, R.W., 1989. Sense and Sustainability: Sustainability as an objective in international agricultural research. *Agricultural Economics* 3: 381-398.

Munro, D.A. and Holdgate, M.W., 1991. *Caring for the earth: a strategy for sustainable living*. IUCN, Gland.

Nijkamp, P. and Vreeker, R., 2000. Sustainability assessment of development scenarios: methodology and application to Thailand. *Ecological Economics* 33: 7-27.

Pretty, J.N., 1995. *Regenerating agriculture: policies and practice for sustainability and self-reliance*. Earthscan, UK: London.

Rennings, K. and Wiggering, H., 1997. Steps towards indicators of sustainable development: Linking economic and ecological concepts. *Ecological Economics* 20: 25-36.

Rigby, D. and Caceres, D., 2001. Organic farming and the sustainability of agricultural systems. *Agricultural Systems* 68: 21-40.

Rigby, D., Woodhouse, P., Young, T. and Burton, M., 2001. Constructing a farm level indicator of sustainable agricultural practice. *Ecological Economics* 39: 463-478.

Sands, G.R. and Podmore, T.H., 2000. A generalized environmental sustainability index for agricultural systems. *Agriculture, Ecosystems and Environment* 79: 29-41.

Shearman, R., 1990. The Meaning and Ethics of Sustainability. *Environmental Management* 14: 1-8.

Sulser, T.B., Duryea, M.L., Frolich, L.M. and Guevara-Cuaspud, E., 2001. A field practical approach for assessing biophysical sustainability of alternative agricultural systems. *Agricultural Systems* 68: 113-135.

Thompson, P.B., 1992. The varieties of sustainability. *Agriculture and Human Values* 9: 11-19.

Webster, P., 1999. The challenge of sustainability at the farm level: Presidential address. *Journal of Agricultural Economics* 50: 371-387.

Chapter 3

An LP-model to analyse economic and ecological sustainability on Dutch dairy farms: model presentation and application for experimental farm "de Marke"

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Abstract

Farm level modelling can be used to determine how farm management adjustments and environmental policy affect different sustainability indicators. In this paper indicators were included in a dairy farm LP (linear programming)-model to analyse the effects of environmental policy and management measures on economic and ecological sustainability on Dutch dairy farms. For analysing ecological sustainability, seven indicators were included in the model: eutrophication potential, nitrate concentration in groundwater, water use, acidification potential, global warming potential, terrestrial ecotoxicity and aquatic ecotoxicity. Net farm income was included for measuring economic sustainability. The farm structure of "De Marke" formed the basis for three optimisations: (1) basis situation without environmental policy, (2) situation with Dutch environmental policy for 2004, and (3) situation with farm management measures applied at "De Marke". The Dutch environmental policy was included to comply with the EC nitrate directive. It resulted in lower fertiliser use and consequently in a decrease in sales of maize. This led to a decrease in net farm income of ca. €2500. Including this policy improved most used ecological indicators (except for ecotoxicity) and showed to be an effective tool to reduce the environmental impact of dairy farming. Adapting the model with farm management measures applied at experimental farm "De Marke" resulted in even better ecological performance compared to the situation with environmental policy. Nonetheless this increase in ecological performance led to a considerably lower net farm income (€14,500).

3.1 Introduction

Sustainability in agriculture is an issue that has been popular since the report of the Brundtland Commission (1987). Even though many definitions can be found for sustainable agriculture, it remains difficult to link the concept to practical actions and decisions (Hansen and Jones, 1996). Development of sustainability indicators can be an effective tool to make the concept of agricultural sustainability operational (Rigby et al., 2001) and to assess sustainability in practical policy decisions (Rennings and Wiggering, 1997).

Van de Ven (1996), Van Huylenbroek et al. (2000), Bos (2002) and Berentsen and Tiessink (2003) studied the effect of farm management and/or environmental policy on the environmental impact of dairy farming. Some of these studies (Van Huylenbroek et al., 2000; Berentsen and Tiessink, 2003), however, studied the effect of farm management on policy measures, i.e. nitrogen surplus, rather than the effect of farm management on policy goals (e.g. nitrate concentration in groundwater). Van de Ven (1996) and Bos (2002) studied the effect of farm management on policy goals, i.e. nitrate concentration in groundwater and ammonia emission, but in these studies not all relevant attributes were taken into account (e.g. dehydration of the soil and emission of greenhouse gases). It is important to determine how differences in farm management within and between dairy farming systems (that are often initiated by policy measures) affect a wider range of sustainability attributes.

Farm-level modelling enables simultaneous consideration of production, price and policy information. Modelling at the farm level, for that reason, is suitable to evaluate the effects of farm management and environmental policy on sustainability indicators in dairy farming (Berentsen and Giesen, 1995). Linear programming (LP) is a suitable technique to model economic and ecological sustainability of Dutch dairy farms as it can (Berentsen, 1999):

- incorporate new production techniques by adding new activities
- add environmental policy by including new restrictions in the model or by putting levies on undesired outputs
- add sustainability indicators by including new restrictions to the model

The objectives of this paper are (1) to include economic and ecological indicators into an existing economic-environmental dairy farm model (Berentsen and Giesen, 1995), and (2) to use the model to analyse the experimental farm “De Marke”.

On “De Marke” the potential for profitable dairy farming on sandy soils while meeting strict environmental standards is investigated. The main focus of “De Marke” is reducing harmful nutrient losses to the environment. On “De Marke” several environmental measures are applied. By optimising three situations, the effects of environmental policy and the effects of farm management measures (as applied on “De Marke”) on economic and ecological performance are estimated.

The paper is structured as follows. The existing economic-environmental dairy farm model is described and the selection of sustainability indicators is presented. Then modelling of the ecological indicators is described and technical, economic, and ecological results are presented. The last section contains discussion and concluding comments.

3.2 Method

3.2.1 Description of the economic-environmental model

The basic structure of the economic-environmental LP-model (Berentsen and Giesen, 1995) has the form of a standard linear programming model:

Maximise	$[Z=c'x]$
Subject to	$Ax \leq b$ and $x \geq 0$

where x = vector of activities; c = vector of gross margins per unit of activity; A = matrix of technical coefficients; and b = vector of right hand side values. The constraint set as given by the second equation consists of resource allocation rows, policy constraints and accounting rows. The objective function maximises returns to family labour, own capital, and management. Annualised capital costs are fixed in the model but can be different between situations.

The model contains activities for common production processes on Dutch dairy farms (e.g. grass and silage maize production, and milk production). Technical constraints are included in the model for available fixed assets (e.g. land area and milk quota), as well as feeding requirements and links between different activities. Environmental policy is included as constraint in the model. Nitrogen, phosphorus and potassium balances at the soil, animal and farm levels are included as accounting rows in the model to register nutrient flows. For a more detailed description of the LP-model, see Berentsen and Giesen (1995).

3.2.2 Selection of indicators

Van Calker et al. (2005) divided sustainability into four aspects: economic, internal social, external social and ecological sustainability. Within each aspect of sustainability, one or more attributes were identified and ranked. Attributes can be measured by means of indicators. For example: acidification is an attribute for ecological sustainability (aspect) and is measured by using the acidification potential per ha (indicator). In this paper, the focus is on economic and ecological aspects of sustainability. Van Calker et al. (2005) selected net farm income as the only attribute for measuring economic sustainability. Net farm income is the annual return for family labour, own capital and management.

With respect to ecological sustainability 12 attributes were identified and ranked by experts (Van Calker et al., 2005). Selection of the final set of attributes (see Table 3.1) is based on:

(1) the ability to measure each attribute on the farm by means of an indicator
(2) the ability to represent indicators in the LP-model
(3) the ability of the farmer and the farm system to influence the level of the attribute

Table 3.1 Attributes and indicators for ecological sustainability with respect to Dutch dairy farming

Attributes	Indicator
Eutrophication	Eutrophication Potential per ha
Groundwater pollution	NO_3^- conc. in groundwater (mg NO_3^-/l)
Dehydration of the soil	Water use (m^3/ha)
Acidification	Acidification Potential per ha
Global warming	Global Warming Potential per ha
Ecotoxicity	Aquatic and Terrestrial Ecotoxicity Potential per ha

The ecological indicators that are used in this study are shown in the second column of Table 3.1. These indicators mainly originate from Life Cycle Assessment (LCA) studies (e.g. Cederberg and Mattson, 2000; De Boer, 2003). In the present study, however, the defined indicators are calculated at the farm level. For LCA indicators equivalent factors are used to weight different gases and substances into one indicator. A higher equivalent factor means that the specific substance or gas affects the attributes more than others do.

The Eutrophication Potential (EP) per ha is used as indicator for nutrient enrichment in surface water. In this study EP per ha is expressed in NO_3^--equivalents. Different NO_3^--equivalents factors are used: 1 for nitrate (NO_3^-), 1.35 for nitrogen oxides (NO_x), 3.64 for ammonia (NH_3), and 10.45 for phosphates (PO_4^-) (Weidema et al., 1996).

Nitrate concentration in groundwater is the selected indicator for the quality of groundwater and is calculated by dividing the amount of NO_3^- leaching to the groundwater by the average precipitation surplus (De Vries et al., 2003).

Dehydration of the soil is a topic in the Netherlands because the groundwater level has to increase to preserve natural habitats and furthermore the demand for drinking water is still increasing (Aarts et al., 2000b). Dehydration of the soil is included in the LP-model by calculating water use of cattle, water use during milking and water use of crops.

The Acidification Potential (AP) per ha is used to indicate the emission of acidification gases. Different SO_2-equivalents are used to compute AP per ha of milk production systems: 1 for sulphur dioxide (SO_2), 0.7 for NO_x, and 1.88 for NH_3 (Audsley et al., 1997).

For emission of greenhouse gases different CO_2-equivalent factors are used to estimate the Global Warming Potential (GWP) per ton FPCM: 1 for carbon dioxide (CO_2), 21 for methane (CH_4) and 310 for nitrous oxide (N_2O) (assuming a 100-years time horizon Audsley et al., 1997).

In LCA studies, a toxicity assessment focuses on the effect of exposure to pesticides and heavy metals on ecosystems. Data on aquatic and terrestrial ecotoxicity of pesticides and heavy metals used on the farms are taken from Audsley et al. (1997) and Huijbregts et al. (2000); 1,4 dichlorobenzene is used as reference substance.

Four indicators (EP per ha, NO_3^- concentration in groundwater, AP per ha, and GWP per ton FPCM) are related to the nitrogen (N) cycle. Environmental losses related to the N cycle therefore, are discussed first.

3.2.3 Indicators related to N cycle

The part of the N cycle from excreted N in animal manure to N output in crops is schematically presented in Figure 3.1. The N input to the soil is calculated by using available data on the gross N input of five sources: (1) animal manure excreted in the barn, (2) animal manure excreted during grazing, (3) artificial fertiliser, (4) atmospheric deposition and (5) biological N fixation.

Net N input is calculated by deducting N emission (NH_3, NO_x, N_2O, and N_2) from the five sources of N. The general assumption is made that emission of N_2O-N equals the emission of NO_x-N (Velthof, pers. comm.). The difference between net N input and N output is available for immobilisation/mineralisation, denitrification and nitrification.

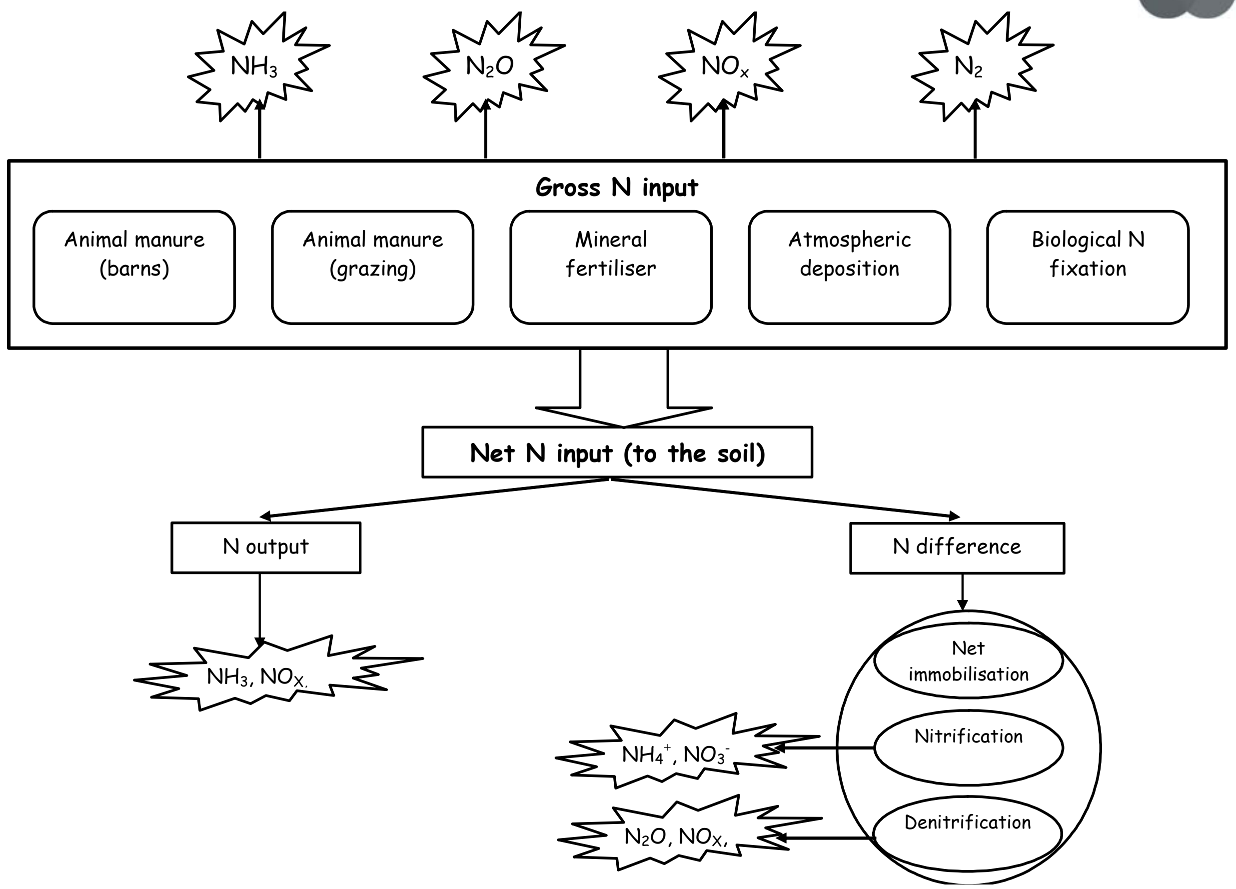

Figure 3.1 Environmental losses related to the N cycle (, N amount; , N losses; , N process)

Animal manure excreted in the barn

Emission of NH_3 from dairy cow manure in barns is calculated by using a combined nutrition-emission model (De Boer et al., 2002; Monteny et al., 2002). Urinary Urea Concentration (UUC) is used as a predictor of NH_3 emission from dairy barns. UUC of a cow is calculated from (1) urine volume, (2) urinary N excretion, and (3) the relationship between UUC and urinary N concentration (see Figure 3.2; De Boer et al., 2002).

(ad 1) Urine volume for each cow is predicted using a regression model based on the feed intake of K, Na and N (Bannink et al., 1999).

(ad 2) The urinary N excretion of a cow is estimated using a regression model based on observed feed characteristics (Van Dongen, 1999). This regression model uses variables of the Dutch protein evaluation system, i.e. diet OEB (rumen digestible protein balance) and DVE (intestinal digestible protein) to predict urinary N excretion by a cow (De Boer et al., 2002).

(ad 3) Urinary N concentration (N excretion divided by urine volume) consists of two parts: a fixed part, mainly allatoin and creatinine and a variable part, mainly urea. A strong relationship was found between measured (UUC) and measured N concentration by de Boer et al. (2002). This relationship is used to determine UUC.

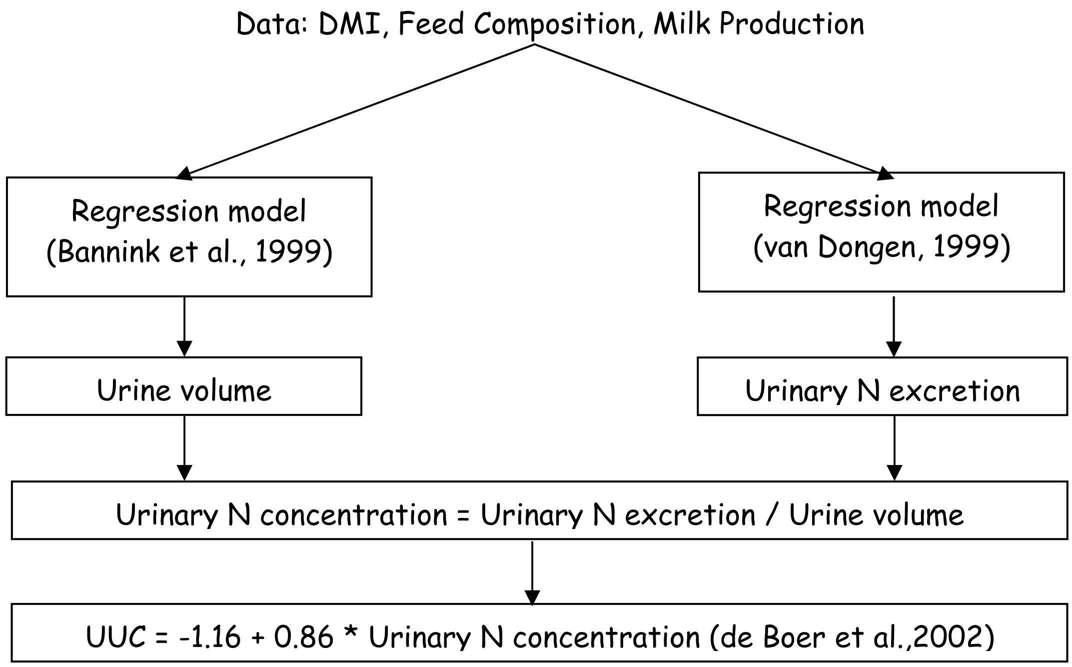

Figure 3.2 Schematic illustration of general modelling strategy used to predict UUC (De Boer et al., 2002)

UUC is used as input in an NH_3 emission model (Monteny and Erisman, 1998). Ammonia emission from the barn is calculated from UUC, type of barn, i.e. conventional housing vs. low-emission housing and temperature, i.e. winter vs. summer (Monteny et al., 2002). Relations derived from the combined nutrition-emission model (De Boer et al., 2002; Monteny et al., 2002) are included in our LP-model.

Young stock is housed separately from dairy cows and, therefore, manure is stored separately. For young stock, a constant volatilisation NH_3-N percentage (in relation to excreted N) for the winter period (10.3%) and the summer period (13.9%) is used (Bruins, 2000).

N_2O-N, NO_x–N and N_2–N volatilisation percentages from manure in barns (for dairy cows and young stock) are respectively 0.1%, 0.1 % and 1% of excreted N and takes place after emission of NH_3 during storage (Oenema et al., 2000).

Manure is subdivided into mineral and organic N for estimating NH_3 emission during manure application. For dairy cows it is assumed that N in urine is mineral and N in faeces is organic (Van Dongen, 1999). For young stock the concentration of organic N is assumed to be fixed at 2.2 g per kg manure (Berentsen and Giesen, 1995). Depending on application technique, different volatilisation percentages (in relation to the mineral N content) are used.

For applying manure on grassland and arable land, the injection technique is used, which corresponds with 10% and 9% NH_3–N emission of mineral N, respectively (Huijsmans, 1999). N_2O-N and NO_x-N volatilisation percentages during application of manure on grassland and maize land are 0.5 % of total N (Velthof and Oenema, 1997). Mineral N that is not emitted is available for the crop, which utilises this N, with the same efficiency as N from artificial fertiliser (Berentsen and Giesen, 1995).

Animal manure excreted during grazing

Ammonia emission during grazing of dairy cows and young stock is calculated assuming that NH_3 emission is dependent on the N content of the feed ration and on the Cation Exchange Capacity (CEC) of the soil (Bussink, 1996). Total NH_3 emission during grazing is also dependent on the grazing system and the length of the grazing season. Heifers and calves graze for 24 hours and all manure is deposited in the paddock.

Emission of N_2O-N and NO_x–N during grazing for both dairy cows and young stock, is 2.5% of excreted N (Velthof and Oenema, 1997).

Artificial fertiliser

Emission of NH_3 from artificial fertiliser (mineral; NH_4NO_3) is assumed to be proportional to the amount of artificial fertiliser applied. A volatilisation factor of 1.6% and 0.8% for the applied N is used, respectively, for grassland and arable land (Pain et al., 1998). Emission of N_2O-N and NO_x–N during application of artificial fertiliser is 2.5% of applied N (Velthof and Oenema, 1997). All remaining N is used as N input to the soil.

Atmospheric deposition

Average atmospheric deposition differs by region. In the region considered in this study a deposition of 49 kilogram of N per hectare per year is assumed (Aarts et al., 2000a). No N gas losses are known from atmospheric deposition, all N is used as N input to the soil.

Biological N fixation

Nitrogen fixation of Dutch dairy farms depends on percentage of clover in the pasture. Emission of N_2O-N and NO_x–N with respect to biological N fixation is 0.5% of fixed N (Velthof and Oenema, 1997). All N is used as input for crop growth. Total N fixation in this study depends on farm management with regard to clover use and therefore differs among farms.

Nitrogen emissions from other sources

In addition to the mentioned sources of N_2O-N and NO_x–N emissions, Velthof and Oenema (1997) discussed emissions from the soil and emissions from the rumen. For sandy soils, emissions of N_2O-N and NO_x–N are 0.9 kg per hectare per year (Velthof and Oenema, 1997). Emissions of N_2O-N and NO_x–N with respect to the rumen are relatively small and therefore neglected. Furthermore, there are background NH_3–N emissions that are related to the use of grassland. These NH_3 emissions have been determined to be 2 kg per hectare per year at “De Marke” (Aarts et al., 2000a).

Nitrogen processes in the soil

The net N input to the soil is calculated as gross N input minus N emissions. This net N input corresponds with an N output (yield of grass, maize or arable crops; Vink and Wolbers, 1997). With respect to the N output, losses occur during conservation of roughage. It is assumed that conservation losses are 9 kg N per hectare per year for “De Marke” (Aarts et al., 2000a). These losses are subdivided in 4 kg N_2-N, 1 kg NO_x–N, and 4 kg NH_3–N emission (Aarts, pers.comm.).

The N difference, i.e. net N input minus N output, is lost to the environment through immobilisation, denitrification and nitrification. In agricultural soils there is no real evidence for an increase in the N pool due to net N immobilisation, i.e. N immobilisation minus N mineralization, and consequently a value of 0 for net N immobilisation is used (De Vries et al., 2003).

Nitrogen transformations via nitrification and denitrification in agricultural soils are estimated as a fraction of the N difference. The nitrification fraction is different for different types of land use, i.e. grassland vs. arable crops/maize, soil type and wetness class, i.e. groundwater table. On dry sandy soils the nitrification fraction however is the same (0.98-1.00) for grassland and arable crops (De Vries et al., 2003). This means that on average 99% of N in the N surplus is oxidised from ammonium (NH_4) via NO_2 to NO_3^-. Environmental pollution as a result of NH_4^+-N is not taken into account as NH_4-N losses are small and hardly contribute to the eutrophication potential and N concentration in groundwater.

Denitrification involves the reduction of NO_3^- to NO_2, N_2O, and dinitrogen gas (N_2). Denitrification activity is strongly related to wetness class (De Vries et al., 2003). On dry sandy soils a denitrification fraction (in % of NO_3^-) of 0.45 is used for grassland and 0.35 for arable land (De Vries et al., 2003). The denitrification fraction consists of NO_x-N, N_2O-N, and N_2-N. Emission of N_2-N is calculated by deducting emissions of NO_x-N and N_2O-N from the denitrified fraction. The remaining NO_3^--N can leach to the groundwater or run-off to the surface water.

Excess rainfall moves into the groundwater (mainly on dry sandy soils with a deep groundwater level) and/or to ditches adjacent to the field (mainly on wet and moist soils). The loss of N from the soil via leaching to groundwater and via lateral transport, i.e. run-off, to ditches equals the excess N input (N_{ex}). This N excess (NH_4^+–N and NO_3^--N) is calculated as net N input minus N output and N emissions during nitrification and denitrification. Leaching fractions and run-off fractions of NH_4^+-N and NO_3^--N are dependent on soil type and wetness class. For dry sandy soils an average run-off fraction of 0.05 is assumed. As a result the average leaching fraction is 0.95 (De Vries et al., 2003). Nitrate concentration in groundwater is calculated by dividing the amount of NO_3^- leaching to the groundwater by the precipitation surplus. The precipitation surplus is calculated based on Aarts et al. (Aarts et al., 2000b).

3.2.4 Additional ecological indicators

Eutrophication potential (EP) per ha

As well as the NO_3^--N, NO_x-N, and NH_3-N losses, the amount of phosphate (P_2O_5) leaching out of the system should be calculated also for EP per ha. This study, like other studies (e.g. De Boer, 2003), assumes that total surplus of P_2O_5 leaches from the system and contributes to EP per ha. This assumption is made as in the Netherlands most sandy soils are phosphate saturated. The surplus of P_2O_5 is calculated by subtracting the output of P_2O_5 at farm level, i.e. milk, animals and sold roughage, from the input of P_2O_5 at farm level, i.e. feed, fertilisers and deposition.

Water use per ha

Water is used as drinking water for livestock, during milking and for crop production. Dairy cows need 31.0 m^3 of drinking water per year. One unit of young stock, which represents one calf and 0.96 heifer, needs 23.4 m^3 of drinking water per year. During the milking procedure 7.7 m^3 water per dairy cow is needed for cleaning the milking machine, the milk barn and the milk tank (Philipsen et al., 2002).

Water use by crops depends on the type of crop. Water consumption of crops is subdivided in water consumption during the growing season, i.e. transpiration, and water consumption outside the growing season, i.e. evaporation. In Table 3.2 the transpiration coefficients and evapotranspiration coefficients are shown (derived from Aarts et al., 2000b).

Table 3.2 Water consumption of crops (Aarts et al., 2000b)

Crops	Transpiration coefficients (kg water/ kg harvestable dm)	Evapotranspiration (m^3 / ha)
Grass	350	750
Maize	175	110
Triticale	238	110

Acidification Potential (AP) per ha

In addition to the calculated NH_3 and NO_x emissions, SO_2 emission at farm level contributes to AP per ha. Sulphur dioxide emissions take place during the use of diesel fuel, during the production of electricity and during the use of gas. Sulphur dioxide emission due to the production of electricity is not taken into account because this emission does not take place at the farm. Gas use on “De Marke” is negligible and therefore not included. At farm level SO_2 emission, therefore, depends on the use of machinery. The use of machinery differs for type of crop (e.g. grass vs. maize). For different operations with respect to land use, diesel fuel use coefficients are assumed (Hageman and Mandersloot, 1994).

Global Warming Potential (GWP) per ton FPCM

Besides the emission of N_2O, the emissions of CO_2 and CH_4 need to be calculated for the GWP. Just like emission of SO_2, emission of CO_2 depends on the use of machinery. Carbon dioxide emission, therefore, is calculated in the same way as emission of SO_2 using coefficients for conversion from kg of diesel to emission of CO_2 (Michaelis, 1998).

Methane, an important greenhouse gas, is a by-product of anaerobic bacterial fermentation of carbohydrates, i.e. mainly cellulose, present in feed and excreta (De Boer, 2003). In animals, CH_4 production depends on animal size and type, feed intake and feed digestibility (Wilkerson et al., 1994). For the purpose of this study we assume that CH_4 loss for a conventional high yielding cow is 118 kg CH_4 per year (Cederberg and Mattson, 2000). Losses per unit of young stock, i.e. calf and heifer, are estimated at 67 kg CH_4 per year and losses during manure storage are 54 kg and 2 kg CH_4 per year for dairy cows and young stock, respectively (IPCC, 1997).

Aquatic and Terrestrial EcoToxicity Potentials (AETP & TETP) per ha

AETP & TETP focus on the effect of pesticides and heavy metals on aquatic and terrestrial ecosystems. The use of pesticides depends on type of crop. For example, maize requires more pesticides in comparison with grass. So at farm level, total pesticide use is related to the cropping plan. The emission of pesticides to air is calculated with a standard emission of 10% per kg of active ingredient applied (Jager and Visser, 1994) and the emission to freshwater is calculated as 1% per kg of active ingredient applied. In this study the assumed emission to the soil is 43 % per kg of active ingredient applied (Woittiez et al., 1996).

The use of heavy metals is determined by calculating balances at farm level. With respect to dairy farming three important heavy metals can be distinguished: cadmium, copper and zinc. The surplus of heavy metals is calculated by subtracting the output of heavy metals, i.e. milk, animals and sold roughage, from the input of heavy metals, i.e. feed, fertilisers and deposition. It is assumed that the total surplus of cadmium, copper and zinc is lost to the soil.

Converting the emissions of pesticides and heavy metals to AETP & TETP standards is done according to Audsley et al. (1997) and Huijbregts et al. (2000) and can be found in Table 3.3.

Table 3.3 Ecotoxicty Potentials for heavy metals and pesticides (Huijbregts et al., 2000)

		Ecotoxicity Potentials	
		Aquatic	Terrestrial
Heavy metals	Cadmium[1]	780	170
	Cupper[1]	590	14
	Zinc[1]	48	25
Pesticides	2,4-D amine[2]	20	0.8
	Glyphosate[2]	17	0.1

[1]Ecotoxicity potential expressed per kg surplus per hectare

[2]Ecotocicity potential expressed per kg used active ingredient per hectare

3.2.5 Further adaptations of the LP-model

Prices in the LP-model have been updated for the year 2002. Furthermore new environmental policies are included in the model.

Since 1995 environmental legislation changed frequently. In 1998 the MINeral Accounting System (MINAS) was introduced to ensure compliance with the EC Nitrate Directive. If an individual farm exceeds the environmentally safe surplus standard, the farmer will be taxed for every kilogram of N or P_2O_5 exceeding this standard (see Table 3.4; Ondersteijn et al., 2002).

Starting from 2002, the Manure Transfer Agreement System (MTAS) was added as an additional regulation to avoid leaching of nutrients from animal manure. MTAS is based on standards for N production in manure and for N application from manure (see Table 3.4; Berentsen and Tiessink, 2003).

Table 3.4 Acceptable nutrient surpluses and levies within MINAS and application standards within MTAS (2004)

	Phosphate	Nitrogen	
		common soils	vulnerable sandy soils
Acceptable surpluses (kg/ha):			
grassland	20[1]	180	140
arable land	25[1]	100	60
Levies €/kg	9	2.30	2.30
Application standards (kg N/ha):			
grassland		250	250
arable land		170	170

[1] P_2O_5 fertiliser is not included as input

The LP-model is adapted to analyse experimental dairy farm “De Marke”. “De Marke” is located in the east of the Netherlands on a well-drained sandy soil with an annual precipitation surplus of 300 mm (Aarts et al., 1992). Groundwater table depth of the soil is 1 to 3 m below soil surface. This location was selected because environmental problems tend to be most severe on drought sensitive sandy soils (Aarts et al., 2000a). The size of “De Marke” is 55 ha, which is slightly larger than the average dairy farm in the Netherlands. The intensity is ca. 12,000 kg milk per ha and somewhat lower than the average in sandy regions but close to the national average (Aarts et al., 2000a).

Table 3.5 Environmental measures applied at “De Marke”.

	Adjustment
Livestock and crop rotation	Less young stock
	Growing and feeding ground maize ear silage
	Growing and feeding triticale
	Crop rotation of grassland with maize and triticale
Fertilisation and feeding	Reduced phosphate fertiliser level
	Reduce nitrogen application (250 kg N/ ha grassland)
	More efficient grazing system
	Catch crop under maize
	Feeding of milking cows according to the standard
	Feeding more maize or trticale in the summer period
	Shortening grazing period of milking cows
Layout of the barn	Low-emission housing

On “De Marke” several environmental measures are applied (see Table 3.5). These environmental measures concern: (1) livestock and crop rotation (2) fertilisation and feeding and (3) layout of the barn. For a more detailed description of the environmental measures see De Haan (2001).

3.2.6 Organisation of the analysis

The general farm structure (milk quota, area of land, soil type) of experimental farm “De Marke” is the basis for the calculations. In the analysis three situations are evaluated:

1. Situation without environmental policy and without measures applied at “De Marke”(“Basis”).
2. Situation with environmental policy and without measures applied at “De Marke” (“Policy 2004”).
3. Situation with environmental policy and with particular measures applied at “De Marke” (“De Marke 2004”).

By choosing this set-up the effect of environmental policy and environmental measures on economic and ecological indicators could be evaluated. In Table 3.6 starting points of the three situations are described. Differences in milk production, fat and protein content between “Basis” and “Policy 2004” on the one hand and “De Marke 2004” on the other hand are mainly a result of the increased average age of dairy cows and are taken from de Haan (2001). The lower replacement rate and grazing hours are environmental measures applied at “De Marke 2004” as well as the higher amount of additional feeding, i.e. triticale or maize, in summer rations. The decreased number of grazing hours per year for dairy cows is a result of less grazing hours per day (cows) and shorter grazing period (cows and young stock). The only difference between “Basis” and “Policy 2004” is the presence of environmental policy.

Table 3.6 Starting points for the calculations

Farm structure	Unit	Basis	Policy 2004	De Marke 2004
Area	(ha)	55	55	55
Milk quota	(* 10^3 kg)	658.5	658.5	658.5
Milk production	(kg per cow)	8760	8760	9080
Fat	(%)	4.36	4.36	4.28
Protein	(%)	3.44	3.44	3.48
Replacement rate	(%)	38.0	38.0	33.0
Grazing cows	hours/year	2196	2196	600
Grazing young stock	hours/year	5832	5832	2880
Min. additional feeding during summer	kgdm/cow/day	4	4	6
Environmental policy		No	Yes	Yes

3.3 Results

3.3.1 Technical results

In “Basis” and “Policy 2004” the number of dairy cows is 75 and the number of young stock is 59. These numbers are determined by the available milk quota, the milk production per cow and the fixed replacement rate. On “De Marke 2004” the number of dairy cows is 74 and the number of young stock is 49. This is the result of the higher milk production and the lower replacement rate.

In general land use and dairy cow rations are determined as follows. The amount of fresh grass in summer is maximised because it is a cheap source of energy and protein, i.e. no harvesting costs. The maximum is determined by the dry matter intake capacity of the cows and by the minimum requirement of 4 kg dm from supplemental feeding, i.e. maize silage and/or triticale, in summer. Supplemental feeding is included as a result of the short grazing period per day. Concentrates and/or ground maize ear silage fulfils the requirement for energy. The amount of grass silage is lower in the winter ration because costs of ensiling are relatively high and because energy production per ha is lower for grass silage in comparison with maize and triticale. Requirements for energy, rumen degradable protein and intestine digestible protein fine tune the composition of the winter ration and influence mineral N, i.e. N_{min}, use on grassland. Higher use of N_{min} results in higher protein concentrations in grass. N_{min} use is also influenced by the required production of grass and together these factors determine the area of grassland (Berentsen and Tiessink, 2003). The rest of the area is used for maize silage, triticale or ground maize ear silage.

Table 3.7 shows the composition of the rations and resulting land use for the three situations. Triticale is included in the summer ration of the “Basis” situation, despite the fact that maize production is cheaper per unit of energy than triticale. As triticale is a winter crop, two cuts of grass silage can be harvested the same year, so the total yield is higher. For “Basis” the maximum of 2 kg dm byproducts, i.e. dried beet pulp, extracted soy meal, undegradable extracted soy meal or extracted rapeseed, is included in the winter ration. Byproducts are a cheap replacement for concentrates. Rations and number of animals determine the area of grassland and the fertilisation level as well as the area of triticale. The remaining land is used for growing maize silage of which 6.9 hectare silage is sold.

Table 3.7 Land use and summer and winter-feed ration for dairy cows for three situations to analyse the effect of environmental policy and management

	Basis	Policy 2004	De Marke 2004
Summer ration (kg dm/day per cow):			
- Grass	13.7	13.0	14.2
- Maize	1.2	2.1	0.0
- Ground maize ear silage	0.0	0.0	1.3
- Triticale	2.8	1.9	6.0
- Concentrates	3.3	4.1	1.8
Winter ration (kg dm/day per cow):			
- Grass silage	5.8	2.8	2.7
- Maize	4.0	6.9	10.0
- Ground maize ear silage	0.0	0.0	2.3
- Triticale	0.0	0.0	0.2
- Byproducts	2.0	2.0	2.0
- Concentrates	9.0	9.0	2.2
Land use:			
- Grassland (ha)	32.7	33.9	22.1
- N application grassland (kg mineral N)	360	199	250
- Maize (ha)	11.5	15.3	20.2
- Maize sold (ha)	6.9	3.1	0.0
- Ground maize ear silage (ha)	0.0	0.0	6.7
- Triticale (ha)	3.9	2.7	5.9
By-products purchased (1000 MJ NEL[1])	171	170	250
Concentrates purchased (1000 MJ NEL[1])	998	1058	354

[1]MJ NEL - Megajoule Net Energy for Lactation

In the situation with environmental policy, i.e. “Policy 2004”, the acceptable surplus of N restricts N input. Decreasing the use of N fertiliser on grassland restricts N input. The resulting shortage of feed is replaced by growing maize for on-farm use instead of selling maize. The lower protein content in the summer ration, as a result of the lower N_{min} use on grassland, is compensated by including more concentrates. Including more soy-products instead of dried beat pulp as feed byproduct compensates for the lower protein content of grass silage in the winter ration. As a result the total amount of purchased feed increases.

One of the farm management measures applied at “De Marke 2004” is to grow concentrates instead of purchasing concentrates. Ground maize ear silage, therefore, is included in the winter and summer ration. Due to the shorter grazing season for dairy cows and young stock, i.e. 120 vs. 183 days, and shorter grazing time per day, i.e. 5 vs. 10 hours, for dairy cows the area of grassland of "De Marke 2004" is considerably lower than in the previous situations.

3.3.2 Economic results

The economic results follow from the technical results. The gross revenues of the farm consist of revenues from milk, animals, maize and subsidy payments for maize and triticale. In the "Basis" situation more maize is sold, consequently gross revenues are higher in this situation in comparison with "Policy 2004" (see Table 3.8).

Table 3.8 Economic results (K€) for three different situations to analyse the effect of environmental policy and management

	Basis	Policy 2004	De Marke 2004
Gross revenues	**257.2**	**253.5**	**249.4**
- milk and meat	242.8	242.8	241.6
- sold maize	6.7	3.0	0
- subsidies	7.7	7.7	7.7
Costs	**221.4**	**220.2**	**230.7**
- purchased feed	29.8	32.4	19.4
- fertilisers	8.9	5.8	3.8
- seed and plant costs	18.0	18.9	20.1
- cattle costs	12.4	12.4	12.9
- contract work	30.1	28.6	46.5
- cost of machinery	19.1	19.1	20.9
- cost of land and buildings	48.3	48.3	51.3
- miscellaneous	54.9	54.6	56.0
Net farm income	**35.8**	**33.3**	**18.6**

Costs that differ between "Policy 2004" and "Basis" are mainly costs of feed, fertilisers and contract work. Costs of feed are higher as soy-products are included in the winter ration and because more concentrates are included in the summer ration. Costs of contract work are lower as a consequence of the lower N level on grassland. This finally results in ±€2,500 lower net farm income for "Policy 2004" compared to the "Basis" situation.

Gross revenue for "De Marke 2004" is lower because no maize is sold. The feed costs are considerably lower, because more farm-produced concentrates are included in the ration, i.e. ground maize ear silage. As a result of the changed crop rotation fertiliser costs on "De Marke 2004" are lower. Higher costs are mainly the result of: (1) more maize in the farm plan and changed crop rotation, i.e. more contract work costs, and (2) low emission housing, i.e. higher costs of buildings. Farm management adjustments applied at “De Marke 2004” lead to a decrease of net farm income of ±€14,700 compared with “Policy 2004” and ±€17,200 versus “Basis”.

3.3.3 Environmental results

Table 3.9 shows the complete N balance and the losses of P_2O_5. Nitrogen enters the farm through concentrates, by-products, purchased roughage, i.e. hay, fertiliser and deposition and leaves the farm through milk, meat and sold maize. All N losses are environmentally harmful except for N_2 emission, which is a harmless loss.

In the “Policy 2004” situation the N losses are 55 kg N/ha lower than the “Basis” situation mainly due to the lower fertilisation level on grassland. The acceptable surplus for N in MINAS restricts the farm plan. As the “Policy 2004” situation is relatively extensive, MTAS does not restrict the farm plan. Phosphate losses did not decrease for “Policy 2004”. The decrease in fertiliser input is compensated by increased input of P_2O_5 through by-products and concentrates and the decreased amount of sold silage.

Farm management measures applied at “De Marke 2004” lead to a decrease of N losses of almost 40 kilogram per ha compared to “Policy 2004”. Despite the higher fixed fertiliser level on grassland (see Table 3.7), the total use of fertilisers is lower for “De Marke 2004” as a result of the applied crop rotation. Feed input is lower as a result of including ground maize ear silage in summer and winter ration. Application of the environmental measures at “De Marke 2004” resulted in ca. 25 % extra reduction of NO_3^- leaching to the groundwater in comparison with “Policy 2004”. Despite the low emission housing, NH_3 emission is only 2 kg lower for “De Marke 2004”. This is a result of the shorter grazing period and consequently the relatively higher amount of NH_3 emission during excretion in the stable, storage and application. The reduction of the P_2O_5 losses (23 kg per ha) is caused by lower purchases of feed and fertiliser.

Table 3.9 Environmental results for three different situations to analyse the effect of environmental policy and management

	Basis	Policy 2004	De Marke 2004
Nitrogen input (kg N/ha)	324	259	212
- concentrates	69	73	25
- byproducts	12	27	51
- roughage	3	3	0
- fertiliser	192	108	82
- fixation	0	0	4
- deposition	49	49	49
Nitrogen output (kg N/ha)	91	81	72
- milk	64	64	65
- meat	8	8	7
- roughage	19	8	0
Nitrogen losses (kg N/ha)	233	178	140
- NH_3 emission	36	31	29
- NO emission	6	5	4
- N_2O emission	5	4	3
- N_2 emission	73	53	41
- NO_3 leaching	105	79	58
- NO_3 run-off	6	4	3
- NH_4 leaching	2	1	1
- NH_4 run-off	0	0	0
Phosphate losses (kg P_2O_5/ha)	24	24	1

3.3.4 Results of ecological indicators

Environmental impact is related to the on-farm area for the EP, NO_3^- concentration in groundwater, water use, AP, and AETP, and TETP. For a global environmental impact category like GWP a product related functional unit, i.e. GWP/ton FPCM, seems appropriate (Haas et al., 2000). In this way both production efficiency and environmental impact are considered (De Boer, 2003). Table 3.10 shows the results for ecological indicators.

Table 3.10 Ecological indicators of three different situations to analyse the effect of environmental policy and management

Indicator	Basis	Policy 2004	De Marke
Eutrophication potential (NO_3^- equivalents/ha)	858	711	421
Nitrate concentration in groundwater(NO_3^- mg/l)	119	79	68
Water use (m^3/ha)	3614	3318	3488
Acidification potential (SO_2 equivalents/ha)	92	79	74
Global warming potential (CO2 equivalents/1000 kg milk)	787	742	684
Aquatic ecotoxicity potential (1,4 dcb equivalents/ha)	159	167	125
Terrestrial ecotoxicity potential (1,4 dcb equivalents/ha)	17	19	14

In the “Basis” situation the level of EP per ha is affected mainly by NO_3^- loss (57%), P_2O_5 surplus (21%), and NH_3 emission (18%). Including environmental policy in the LP-model leads to a 17 % lower EP per ha. The decrease in the “Policy 2004” situation is mainly a result of lower NO_3^- loss. Adding farm management measures in the optimisation results in an extra reduction of 41%. This reduction is predominantly a result of the lower P_2O_5 surplus.

Nitrate concentration in groundwater of “Policy 2004” is 34 % lower in comparison with NO_3^- concentration of “Basis”. The NO_3^- concentration, however, is still higher than the concentration stated in the EC Nitrate Directive policy (50 mg/l). This is a result of the dry sandy soils where the farm is located. Even after applying additional farm management adjustments for “De Marke 2004” NO_3^- concentrations are higher than the EC Nitrate Directive.

Water use per ha on dairy farms is for more than 90 % a result of the chosen crops. The most effective way to prevent dehydration of the soil is to include drought resistant crops in the farm plan. Water use per ha is lower in “Policy 2004” compared to “Basis” as a consequence of the decreased dry matter yield of grassland. Despite the larger area of maize, the water use per ha for “De Marke 2004” is higher in comparison with “Policy 2004”. The higher water use per ha is caused by the water use of the catch crop on maize land.

AP per ha is mainly a result of the emission of NH_3 (±85-90 %). Ammonia emissions are lower in the “Policy 2004” situation as a result of the lower protein content in summer ration. AP per ha for “De Marke 2004” is 7 % lower compared to “Policy 2004” due to feeding cows according to the standard, due to the lower replacement rate, and due to the low emission housing.

Emissions of CH_4 are 63-68% of the GWP per ton FCPM. Methane emission per cow is dependent on the level of production and digestibility of feed. In the model CH_4 emission, however, depends only on the level of production. Differences in GWP per ton FCPM between “Policy 2004” and “Basis”, therefore, mainly are a result of the lower N_2O emission for “Policy 2004”. As a consequence of higher milk production and lower replacement rate,

CH_4 emissions are lower for “De Marke 2004”. This and the decreased N_2O emission result in a lower GWP (8%) in comparison with “Policy 2004”.

The surplus of pesticides causes only 3-4 % of the AETP per ha. For TETP per ha the contribution of pesticides is even smaller. The low contribution of pesticides is due to: (1) the relatively low use of pesticides in “Basis”, and (2) the lack of ecotoxicity potentials for some pesticides. Differences between “Policy 2004” and “Basis” are a result of the lower sale of maize and the higher input of heavy metals by feed. AETP per ha and TETP per ha is ca. 25 % lower for “De Marke” compared to “Policy 2004”. This is due mainly to the lower input of concentrates.

3.4 Discussion and conclusion

This study used an existing economic-environmental LP-model for Dutch dairy farms in which ecological indicators were included. Indicators based on the environmental effects of farmer practices are preferable because the link with the attribute is direct and the choice of means is left to the farmer (Van der Werf and Petit, 2002). Some relations between farm management measures and ecological indicators (e.g. CH_4 emission and NH_3 emission during grazing) are still under study. New and improved relations between farm management measures and ecological indicators can be included in the model later on.

In this study the defined indicators are calculated at farm level. Environmental losses during production of farm inputs are not taken into account because the focus in this research is on direct effects of farm management on environmental impact. Besides, the environmental impact of producing inputs is generally not quantified so dairy farmers do not have control over environmental impacts of different alternatives. This means that in our study to some extent environmental problems could be shifted to other members of the dairy production chain. The chosen indicators mainly originate from Life Cycle Assessment studies. This implies that in further research the effect of other links of the dairy production chain on environmental impact could be considered.

An important part of the data used in the model has a normative character. This pertains to most of the costs, to the feeding standards and to crop production. Besides normative data, the method of linear programming gives the results a normative character. Due to various reasons (like imperfect information, risk aversion, management quality and skills) farmers often do not succeed to manage the farm according to standards. Furthermore, the LP-model maximises net farm income, whereas dairy farmers often maximise more objectives (e.g. Gasson, 1973). Consequently the results should be seen as the optimal attainable performance.

The differences between actual farm performance and model results show the possibilities for dairy farmers to improve both economic and ecological performance.

Included variable relationships and coefficients are only known within some confidence intervals. For example, ammonia volatilisation and nitrate concentrations are highly dependent on weather conditions. As average weather conditions are used, a large uncertainty in estimated model parameters can be expected (Chaubey et al., 1999). Furthermore, uncertainties about the nitrification and denitrification process are considerable and it is essential to put more effort in activities yielding a reduction of these large uncertainties (De Vries et al., 2003). To explore the consequences of uncertainties in model inputs, not accounting explicitly for the probability of these changes a sensitivity analysis could be carried out (Van Groenendaal and Kleijnen, 1997).

Few actual results from "De Marke" can be used to compare the model results with. Mean NO_3^- concentrations in the upper metre of groundwater at “De Marke” were 63 mg l^{-1} (Boumans et al., 2001) and quite consistent with the optimisation. Further, in a study by De Haan (2001) the economic effect of implementation of environmental adaptations on “De Marke” was calculated. De Haan (2001) calculated a difference of €15,000 in labour income between a basis situation and a situation including all adaptations. This difference approximates the results of our study. As far as these results concern it can be concluded that the model performs well.

Results, however, are specific for the farm structure of “De Marke”. To draw more general conclusions concerning the effects of environmental policy and environmental management, optimisations based on different farm structures should be analysed.

The model incorporates ecological and economic indicators of sustainability. Yet, sustainability includes also a social component. The latter will be the focus of further research. The model offers the opportunity to compare different farming systems on their level of economic and ecological sustainability. Furthermore the model can be helpful in evaluation of effectiveness of environmental policy with respect to different economic and ecological attributes.

References

Aarts, H.F.M., Biewinga, E.E. and Van Keulen, H., 1992. Dairy Farming Systems Based on Efficient Nutrient Management. *Netherlands Journal of Agricultural Science* 40: 285-299.

Aarts, H.F.M., Habekotte, B. and van Keulen, H., 2000a. Nitrogen (N) management in the 'De Marke' dairy farming system. *Nutrient Cycling in Agroecosystems* 56: 231-240.

Aarts, H.F.M., Habekotte, B. and van Keulen, H., 2000b. Ground water recharge through optimized intensive dairy farms. *Journal of Environmental Quality* 29: 738-743.

Audsley, E., Alber, S., Clift, R., Cowell, S., Crettaz, P., Gaillard, G., Hausheer, J., Jolliet, O., Kleijn, R., Mortenson, B., Pearce, D., Roger, E., Teulon, H., Weidema, B.P. and Van Zeijts, H., 1997. *Harmonisation of environmental life cycle assessment fro agriculture*. Concerted Action AIR3-CT94-2028 European Commission DG VI, Belgium: Brussels.

Bannink, A., Valk, H. and Van Vuuren, A.M., 1999. Intake and excretion of sodium, potassium, and nitrogen and the effects on urine production by lactating dairy cows. *Journal of Dairy Science* 82: 1008-1018.

Berentsen, P.B.M., 1999. *Economic-environmental modelling of Dutch dairy farms incorporating technical and institutional change*. PhD-thesis, Wageningen University, The Netherlands: Wageningen.

Berentsen, P.B.M. and Giesen, G.W.J., 1995. An Environmental-Economic Model at Farm-Level to Analyze Institutional and Technical Change in Dairy Farming. *Agricultural Systems* 49: 153-175.

Berentsen, P.B.M. and Tiessink, M., 2003. Potential effects of accumulating environmental policies on Dutch dairy farms. *Journal of Dairy Science* 86: 1019-1028.

Bos, J., 2002. *Comparing specialised and mixed farming systems in the clay areas of the Netherlands under future policy scenarios: an optimisation approach*. PhD-thesis, Wageningen University, The Netherlands: Wageningen.

Boumans, L.J.M., Fraters, B. and Van Drecht, G., 2001. Nitrate in the upper groundwater of 'De Marke' and other farms. *Netherlands Journal of Agricultural Science* 49: 163-177.

Bruins, W.J., 2000. *Stikstofvervluchtiging uit mest: berekening op basis van mineralenbalansen*. Plant Research International Report Number 29. The Netherlands: Wageningen.

Brundtland, G.H., 1987. *Our common future*. Oxford University Press, UK: Oxford.

Bussink, D.W., 1996. *Ammonia volatilization from intensively managed dairy pastures*. PhD-thesis, Wageningen University, The Netherlands: Wageningen.

Cederberg, C. and Mattson, B., 2000. Life cycle assessment of milk production - a comparison of conventional and organic farming. *Journal of Cleaner Production* 8: 49-60.

Chaubey, I., Haan, C.T., Grunwald, S. and Salisbury, J.M., 1999. Uncertainty in the model parameters due to spatial variability of rainfall. *Journal of Hydrology* 220: 48-61.

De Boer, I.J.M., 2003. Environmental impact assessment of conventional and organic milk production. *Livestock Production Science* 80: 69-77.

De Boer, I.J.M., Smits, M.C.J., Mollenhorst, H., van Duinkerken, G. and Monteny, G.J., 2002. Prediction of ammonia emission from dairy barns using feed characteristics part 1: Relation between feed characteristics and urinary urea concentration. *Journal of Dairy Science* 85: 3382-3388.

De Haan, M.H.A., 2001. Economics of environmental measures on experimental farm 'De Marke'. *Netherlands Journal of Agricultural Science* 49: 179-194.

De Vries, W., Kros, J., Oenema, O. and De Klein, J., 2003. Uncertainties in the fate of nitrogen II: A quantitative assessment of the uncertainties in major nitrogen fluxes in the Netherlands. *Nutrient Cycling in Agroecosystems* 66: 71-102.

Gasson, R., 1973. Goals and values of farmers. *Journal of Agricultural Economics* 24: 521-537.

Haas, G., Wetterich, F. and Geier, U., 2000. Life cycle assessment framework in agriculture on the farm level. *International Journal of Life Cycle Assessment* 5: 345-348.

Hageman, I. and Mandersloot, F., 1994. *Model energieverbruik melkveebedrijf*. Publicatie 86. Proefstation voor de Rundveehouderij Schapenhouderij en Paardenhouderij, The Netherlands: Lelystad.

Hansen, J.W. and Jones, J.W., 1996. A systems framework for characterizing farm sustainability. *Agricultural Systems* 51: 185-201.

Huijbregts, M.A.J., Thissen, U., Jager, T., van de Meent, D. and Ragas, A.M.J., 2000. Priority assessment of toxic substances in life cycle assessment. Part II: assessing parameter uncertainty and human variability in the calculation of toxicity potentials. *Chemosphere* 41: 575-588.

Huijsmans, J.F.M., 1999. *Mesttoediening*. In: Steenvoorden, J.H.A.M., Bruins, W.J., Van Eerdt, M.M. (Eds.), Monitoring van national emissie uit de landbouw op weg naar een verbeterde rekenmethodiek. DLO-Staring Centrum, Wageningen, pp. 65-75.

IPCC, 1997. *Guidelines for national greenhouse inventories*. Reference Manual Volume 3.

Jager, D.T. and Visser, C.J.M., 1994. *Uniform system for the evaluation of substances (USES), version 1.0*. Ministry of Housing Spatial Planning and the Environment, The Hague.

Michaelis, P., 1998. *Life cycle assessment of energy systems*. PhD-thesis, University of Surrey, UK: Surrey.

Monteny, G.J. and Erisman, J.W., 1998. Ammonia emission from dairy cow buildings: A review of measurement techniques, influencing factors and possibilities for reduction. *Netherlands Journal of Agricultural Science* 46: 225-247.

Monteny, G.J., Smits, M.C.J., van Duinkerken, G., Mollenhorst, H. and de Boer, I.J.M., 2002. Prediction of ammonia emission from dairy barns using feed characteristics part 11: Relation between urinary urea concentration and ammonia emission. *Journal of Dairy Science* 85: 3389-3394.

Oenema, O., Velthof, G.L., Verdoes, N., Groot-Koerkamp, P.W.G., Monteny, G.J., Bannink, A., Van der Meer, H.G. and Van der Hoek, K.W., 2000. *Forfaitaire waarden voor gasvormige stikstofverliezen uit stallen en mestopslagen*. Alterra Report number 107. The Netherlands: Wageningen.

Ondersteijn, C.J.M., Beldman, A.C.G., Daatselaar, C.H.G., Giesen, G.W.J. and Huirne, R.B.M., 2002. The Dutch mineral accounting system and the European nitrate directive: implications for N and P management and farm performance. *Agriculture Ecosystems & Environment* 92: 283-296.

Pain, B.F., Van der Weerden, T.J., Chambers, B.J., Phillips, V.R. and Jarvis, S.C., 1998. A new inventory for ammonia emissions from UK agriculture. *Atmospheric Environment* 32: 309-313.

Philipsen, B., Hemmer, H., Enting, I., Kuunders, K. and Vermeij, I., 2002. *Kwantitatieve Informatie Veehouderij 2001-2002*. Animal Sciences Group, Wageningen UR, The Netherlands: Lelystad.

Rennings, K. and Wiggering, H., 1997. Steps towards indicators of sustainable development: Linking economic and ecological concepts. *Ecological Economics* 20: 25-36.

Rigby, D., Woodhouse, P., Young, T. and Burton, M., 2001. Constructing a farm level indicator of sustainable agricultural practice. *Ecological Economics* 39: 463-478.

Van Calker, K.J., Berentsen, P.B.M., Giesen, G.W.J. and Huirne, R.B.M., 2005. Identifying and ranking attributes that determine sustainability in Dutch dairy farming. *Agriculture and Human Values* 22: 53-63.

Van de Ven, G.W.J., 1996. *Mathematical approach to comparing environmental and economic goals in dairy farming on sandy soils in the Netherlands*. PhD-thesis, Wageningen University, The Netherlands: Wageningen.

Van der Werf, H.M.G. and Petit, J., 2002. Evaluation of the environmental impact of agriculture at the farm level: a comparison and analysis of 12 indicator-based methods. *Agriculture Ecosystems & Environment* 93: 131-145.

Van Dongen, C.F.J., 1999. Dairy cattle feeding and ammonia emission on practical farms. *Meststoffen* (1999): 21-27.

Van Groenendaal, W.J.H. and Kleijnen, J.P.C., 1997. On the assessment of economic risk: factorial design versus Monte Carlo methods. *Journal of Reliability Engineering and System Safety* 57: 91-102.

Van Huylenbroek, G., Jacobs, G. and Vanrolleghem, P., 2000. A simulatiom model to evaluate the impact of environmental programmes on dairy farms. *International Transactions in Operational Research* 7: 171-183.

Velthof, G.L. and Oenema, O., 1997. Nitrous oxide emission from dairy farming systems in the Netherlands. *Netherlands Journal of Agricultural Science* 45: 347-360.

Vink, I. and Wolbers, H., 1997. *Handboek melkveehouderij*. Praktijkonderzoek Rundvee Schapen en Paarden, The Netherlands: Lelystad.

Weidema, B.P., Mortenson, B., Nielsen, P. and Hauschild, M., 1996. *Elements of an impact assessment of wheat production*. Technical University of Denmark, Denmark.

Wilkerson, V.A., Casper, D.P., Mertens, D.R. and Tyrell, H.F., 1994. *Evaluation of several methane producing equations for dairy cows*. In: Aguilera, J.F. (Ed.), Energy metabolism of farm animals. C.S.I.C. Publishing service, Spain: Granada.

Woittiez, R.D., Horeman, G.H., Baas, J., Bekooy, D.A., Buurma, J.S., Van Esch, J.W.J., Huijsmans, J.F.M., Van der Linden, A.M.A., Merkelbach, R.C.M., Peeters, J.M.M., Rotteveel, A.J.W. and Verstappen, G.G.C., 1996. *Meer Jaren Plan Gewasbescherming emissie-evaluatie 1995: einddocument*. Commissie van Deskundigen Emissie-evaluatie MJP-G, The Netherlands: Ede.

Chapter 4

Modelling social sustainability at farm level: an application to conventional and organic dairy farming

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Abstract

Farm level modelling can be used to determine how farming systems and individual farm management measures influence different sustainability indicators. Until now social sustainability is lacking, however, in farm models. In this paper, we first selected attributes for internal social sustainability, i.e. working conditions, and external social sustainability, i.e. food safety, animal welfare, animal health and, landscape quality. Second, possible sustainability indicators for these attributes were identified and selected. Next, the selected indicators were included in an existing dairy farm LP-model that was consequently used to analyse possible differences in social sustainability between a conventional and an organic dairy farming system. Results for internal social and external social sustainability were similar for conventional and organic dairy farming systems in the basis situation and in the situation where additional management measures to improve external social sustainability were included. The only exception is improved animal welfare for the organic farming system due to prescribed grazing in the organic situation and assumed summer feeding in the conventional situation. From this study LP-modelling appeared a suitable methodology to compare farming systems and to determine the effect of management measures on internal and external social sustainability. From the results it was concluded that the level of external social sustainability is determined mainly by applied management measures and that it is hardly related to the particular farming system, i.e. conventional vs. organic.

4.1 Introduction

Sustainability has been an important topic in Dutch dairy farming (see description by Wijffels, 2001). The use of sustainability indicators can be very effective to make the concept of agricultural sustainability operational and to monitor changes in the level of sustainability (Heinen, 1994; Rigby et al., 2001). To improve the level of sustainability of dairy farming, insight has to be gained into the effects of farm management on sustainability indicators. Farm level modelling can be used to determine how changes in farm management affect sustainability indicators (Berentsen and Giesen, 1995).

Consensus exists in research as well as practice that sustainability in Dutch dairy farming deals with economic, social, and ecological sustainability. Several dairy farm models deal with economic and/or ecological sustainability (Berentsen et al., 1998; Kristensen and Kristensen, 1998; Bos and Van De Ven, 1999; Herrero et al., 1999; Rotz et al., 1999; Van Huylenbroek et al., 2000; Pacini et al., 2003; Van Calker et al., 2004). Generally, social sustainability (e.g. animal welfare, food safety and working conditions) is lacking in these dairy farm models. The performance of dairy farming systems on animal health, animal welfare, and food safety have become primarily consumer concerns (Noordhuizen and Metz, 2005). For producers, working conditions are an important issue with respect to sustainability in dairy farming (Hartman et al., 2003).

The objectives of this paper are: (1) to select relevant attributes for social sustainability; (2) to determine indicators to measure selected social attributes; (3) to apply the selected indicators by analysing differences in social sustainability between a conventional and an organic dairy farming system. For this objective, these social indicators have to be included in an existing LP-model (Van Calker et al., 2004).

4.2 Selection of attributes and indicators

In a previous step of this research social sustainability in Dutch dairy farming was subdivided into internal social and external social sustainability (Van Calker et al., 2005). Internal social sustainability relates to qualitative and quantitative working conditions for the farm operator and employees. External social sustainability deals with societal concern about the impact of agriculture on the well being of people and animals (Van Calker et al., 2005). Within internal and external social sustainability attributes (or issues) are selected (see Section 2.1). Attributes are subsequently measured by means of indicators (see Section 2.2).

4.2.1 Selection of attributes

Identification of attributes for internal and external social sustainability is based on Van Calker et al. (2005). By consulting experts and stakeholders, attributes were identified and ranked. Working conditions was selected as the single attribute for internal social sustainability. With respect to external social sustainability 12 attributes were identified (Van Calker et al., 2005). Selection of the final set of attributes within external social sustainability is based on (see Table 4.1):

(1) the relative importance of these attributes, as determined by stakeholders (Van Calker et al., 2004);

(2) the possibility to quantify these attributes in an objective way;

(3) the possibility of farming systems and/or farm management measures to affect the level of these attributes, i.e. sensitivity.

Table 4.1 Sustainability attributes for external social sustainability

Attribute	Selection criteria			
	Relative importance[1,2]		Objectively quantifiable[2]	Sensitivity[2]
Food safety	4.9	✔	✔	✔
Animal welfare	4.6	✔	✔	✔
Animal health	4.4	✔	✔	✔
Landscape quality	4.3	✔	✔	✔
Cattle grazing	4.2	✔	✘	-
Use of GMO	3.5	✔	✘	-
Use of undisputed products	3.3	✔	✘	-
Multi-functionality	3.0	✔	✘	-
Contribution to rural economy	2.7	✘	-	-
Degree of industrialisation	2.4	✘	-	-
Use of by-products	2.4	✘	-	-
Land use in developing countries	2.1	✘	-	-

[1] Relevance scored by experts on a Likert scale from 1 to 5, where 1 = not relevant and 5 = very relevant (Van Calker et al., 2005);
[2] ✔ =selection criteria has been met; ✘=selection criteria has not been met; - =selection criterion has not been considered;

Contribution to rural economy, degree of industrialisation, land use in developing countries and use of by-products are judged less relevant by stakeholders (Van Calker et al., 2005), i.e. a score lower than 3 on a Likert scale from 1 to 5, and are, therefore, not selected. Multi-functionality, use of undisputed products, and use of Genetically Modified Organisms (GMO) are not selected as these attributes cannot be quantified in an objective way, i.e. different opinions exist in assessing the most sustainable level of these attributes. Cattle grazing is an important attribute for social sustainability but is covered by animal welfare and therefore not selected. Food safety, animal welfare, animal health, and landscape quality are selected as they comply with each of the above mentioned selection criteria. In the following sections the selected attributes are defined.

Working conditions

Disability in dairy farming is considered to be caused by insufficient working conditions. Main causes for disability in Dutch agriculture are related to musculo-skeletal disorders (back, neck/upper extremity and lower extremity) and to musculo-skeletal injuries (Hartman et al., 2003). In general risk factors for disability, due to injuries and disorders, can be subdivided into farm characteristics, psychosocial variables, and personal characteristics of the farmer (Hartman, 2004). In this research only farm characteristics are included. Psychosocial variables, i.e. high work pace and workload, and personal characteristics, i.e. increased age, smoking and obesity, are not included as these risk factors are not related to farm management, and therefore cannot explain differences between farming systems.

Food safety

Food safety is defined as the assurance that food will not cause harm to the consumer when it is prepared and/or eaten according to its intended use (Codex-Alimentarius-Commission, 2001). Within food safety three elements can be distinguished (De Groote et al., 2002; Valeeva et al., 2004): (1) chemical food safety, (2) microbiological food safety, and (3) physical food safety. Physical food safety (e.g. glass or metal) is of minor importance (Valeeva et al., 2004) as all milk is filtered on the dairy farm as well as during the processing, and because physical hazards are less likely to affect a large number of people. The most important risk factors are antibiotics and dioxin for chemical food safety and Salmonella, E. coli, S. aureus and M. paratuberculosis for microbiological food safety (Valeeva et al., 2005).

Animal welfare

Animal welfare is an often used, but also much debated concept. During the last 25 years, scientists have engaged in defining animal welfare, but no consensus has been reached (Fraser et al., 1997; Lund and Rocklinsberg, 2001). While the complexities of defining animal welfare and the limitations of any definition are recognised, the ‘five freedoms’ (Webster, 1995) are considered an adequate and appropriate working basis for measuring animal welfare (Winter et al., 1998). The five freedoms (Webster, 1995) are: (1) freedom from thirst, hunger and malnutrition, (2) freedom from discomfort, (3) freedom from pain, injury and disease, (4) freedom to express normal behaviour, and (5) freedom from fear and distress. In this research it is assumed that freedom from thirst, hunger and malnutrition is satisfied due to economic incentives of the farmers. Freedom from pain, injury and disease is captured by animal health (third attribute for external social sustainability). This implies that in this research animal welfare is defined as freedom from discomfort, freedom to express normal behaviour and freedom from fear and distress.

Animal health

In this research, animal health mainly concerns the third freedom: freedom from pain, injury and disease. Diseases can be subdivided into list A-diseases, list B-diseases and production diseases. List A-diseases, e.g. foot-and-mouth disease, are transmissible diseases which have the potential for very serious and rapid spread (Van Schaik, 2000). List A-diseases are not included in this research as the Netherlands is certified free for list A-diseases by the Office International des Epizooties. List B-diseases, e.g. bovine rhinotracheitis and paratuberculosis, are transmissible diseases, which are considered to be of socio-economic and/or public health importance within countries, and which are significant in international trade of animals and animal products (Van Schaik, 2000). The presence of production diseases, e.g. milk fever, ketosis, mastitis and lameness (see for an overview Kelton et al., 1998), is indicated mainly by a decline in production (Wensing, 1999). Mastitis is, together with lameness, recognised as the most important production disease for dairy cows (Webster, 1995).

Landscape quality

Landscape quality of a farm is primarily the result of mutual interaction between natural features of the region, and decisions and attitude of the farmer (Hendriks et al., 2000; Weinstoerffer and Girardin, 2000; Piorr, 2003). This interaction resulted in a wide variety of (agri)cultural landscapes in the Netherlands (Hendriks et al., 2000).

Landscape quality can be evaluated from an objective point of view, i.e. its material substance, made up of forms and actual objects present within a particular physical area, and from a subjective point of view, i.e. the appreciation and interpretation of these concrete forms by different stakeholders (Weinstoerffer and Girardin, 2000). Although the subjective point of view is of considerable importance in the evaluation of landscape quality, only the objective point of view for measuring landscape quality is included in this paper.

In all regions landscapes consists of buildings, fields, trees, bundles, pools, roads, paths, dams, dikes etc. The way these landscape elements are ordered depends on the region (Hendriks and Stobbelaar, 2003; Piorr, 2003). In this research the Netherlands is assumed to be one region with respect to measuring landscape quality.

4.2.2 Selection of indicators

Attributes can be measured by using at least two types of indicators. Animal welfare indicators for example can be categorised into environment-based (indirect) and animal-based (direct) indicators (Johnsen et al., 2001; Main et al., 2003; Mollenhorst et al., 2005). The first category describes features of the environment and management, which can be considered prerequisites for animal welfare (Mollenhorst et al., 2005). The second category records animals' responses to that particular environment and management (Sandoe et al., 1997).

Defining indicators for sustainability attributes is a two-step process (De Boer and Cornelissen, 2002). The first step identifies possible sustainability indicators. The second step selects final sustainability indicators (SI) based on different selection criteria (SC). The SC used in this research are:

- the possible SI can be quantified objectively and can be influenced at farm level (SC1);

  In this study a farm model (Van Calker et al., 2004) is used, which implies that direct indicators, i.e. animal or product based indicators, cannot be included. This means that only indirect indicators based upon farm management measures can be included in the farm model.
- the possible SI has proven to be valid (SC2);

  Indicators should be valid; this can be judged by using output and design validation (Van der Werf and Petit, 2002). Output validation implies the comparison of indicator output with direct measured data. Design validation is based upon submitting the design of the indicators to a panel of experts and can be used when no other method of validation is possible (Bockstaller and Girardin, 2003).
- a utility value can be determined for the possible SI (SC3).

  By determining ideal (utility = 1) and anti-ideal (utility = 0) values for indicators it is possible to benchmark performance of indicators with different units of measurement (De Boer and Cornelissen, 2002). The ideal value represents a maximum value if the indicator is of the type 'more is better' or a minimum value when the indicators is of the type 'less is better'. In line with other research (Hardaker et al., 1997), a linear utility function is assumed for all indicators.

In the next subsection all possible SIs per attribute are listed based on literature, and then all SIs are judged on whether or not they meet the selection criteria. Consideration of a SC for a certain SI is stopped the moment the SI does not comply with an SC. Table 4.2 presents the selection of the indicators for the social attributes.

Table 4.2 Sustainability Indicators (SI) for social attributes

Attribute	Indicator	Reference	Selection criterion[1] (SC)		
			SC1 Quantifiable	SC2 Valid	SC3 Utility
Working conditions	Concise exposure index	Grieco et al. (1998)	✗	-	-
	Physical Load Index	Hartman et al. (2005)	✓	✓	✓
Food safety	HACCP	Noordhuizen and Frankena (1999)	✓	✓/✗[2]	✓
	Food Safety Index	Jorna (2004)	✓	✓/✗[2]	✓
	KKM	Noordhuizen and Metz (2005)	✓	✓/✗[2]	✓
	Chain Food Safety Index	Valeeva et al. (2005)	✓	✓/✗[2]	✓
Animal welfare	TGI200	Sundrum et al. (1994)	✓	✓	✓
	TGI35L	Bartussek (1999)	✓	✓	✓
	Extended Green Label	Van Zeijts et al. (1999)	✓	✓/✗[2]	✓
	Ethical accounting	Sörensen et al. (2001)	✗	-	-
	Italian approach	Tosi et al. (2001)	✗	-	-
Animal health	HACCP	Noordhuizen and Frankena (1999)	✓	✓/✗[2]	✓
	Animal Health Index	Van Zeijts et al. (1999)	✓	✓/✗[2]	✓
Landscape quality	Checklist contribution landscape quality	Kuiper (2000)	✗	-	-
	Checklist for landscape management	Rossi and Nota (2000)	✗	-	-
	Landscape indicator	Weinsoerffer and Girardin (2000)	✗	-	-
	Agricultural Nature Value (ANNA)	Guijt (2002)	✓	✓/✗[2]	✓
	Legibility concept	Hendriks and Stobbelaar (2003)	✗	-	-
	EU landscape indicators	Piorr (2003)	✗	-	-

1 ✓ =selection criterion has been met; ✗=selection criterion has not been met; - =selection criterion has not been considered; [2] the SI is design validated but not output validated

Working conditions

Indicators for working conditions

Not many indicators for working conditions can be found in literature that are suitable for Dutch agriculture (see Table 4.2). In this research the Physical Load Index or 'Agrowerk' (Hartman et al., 2005; Oude Vrielink and Roelofs, 2005) is selected to measure the level of working conditions because the Physical Load Index (PLI) is: (1) the only indicator that is designed to measure working conditions of Dutch dairy farmers, (2) based on farm structure and farm management and can be included in the farm model, and (3) valid, as it was highly associated with sick leave (Hartman et al., 2005).

Physical Load Index

The PLI was developed to explain sick leave due to back disorders and sick leave due to neck, shoulder or upper extremity disorders. The PLI is calculated on the basis of working methods. A working method (e.g. 'milking in a cowshed without automatic removal') is a description of how a particular activity (e.g. milking) is normally carried out (Hartman et al., 2005). The physical load of each working method is based upon eight risk variables for back disorders (e.g. lifting and carrying) and 26 risk variables for neck, shoulder or upper extremity (e.g. highly repetitive neck flexion). For the calculation of the physical load index the relative duration (%) of a risk variable per working method was multiplied by the number of hours per year spent on that working method. A score for low exposure (0), medium exposure (1) and high exposure (2) was obtained for each risk variable within back disorders (derived from Hartman et al., 2005). A score of 0 (for low exposure) or 1 (for high exposure) was obtained for each risk variable within neck, shoulder or upper extremity disorders (Hartman et al., 2005). In this way the PLI can be calculated for back disorders and for neck, shoulder or upper extremity. The 'overall' PLI is calculated by equally weighting the PLI for back disorders and neck, shoulder or upper extremity. Consequently the minimum, i.e. 0 points, is used as ideal value (utility = 1) and the maximum, i.e. 42 points is used as anti-ideal value (utility = 0). A detailed description of the PLI can be found in Hartman et al. (2005).

Food safety

Indicators for food safety

All indicators for food safety equally comply with the selection criteria (see Table 4.2). It would be straightforward to use the existing systems HACCP, i.e. Hazard Analysis and Critical Control Point (Noordhuizen and Frankena, 1999), and KKM, i.e. the Chain Quality Program for Dutch dairy farms (see description by Noordhuizen and Metz, 2005). However, disadvantage of HACCP and KKM is that besides the ideal value, i.e. compliance with requirements for HACCP or KKM, and the anti-ideal value, i.e. no compliance with these requirements, no intermediate values are possible (i.e. the SI is dichotomic). This implies that compensation of less sufficient performance on one specific element of food safety is not possible and that comparisons of the level of food safety between and within farming systems are very limited.

The Food Safety Index is based upon preventive measures that were weighted by consulting experts (Jorna, 2004). In the Chain Food Safety Index (Valeeva et al., 2005) relative importance of preventive measures concerning food safety improvement at dairy chain level are assessed by experts. The methodology of Valeeva et al. (2005) is selected as: (1) this methodology has the potential to be used in the whole dairy chain and (2) this methodology is scientifically founded and is judged design validated.

Chain Food Safety Index

Valeeva et al. (2005) assessed management measures of food safety improvements in all levels of the dairy production chain. The focus in this paper is at farm level and concerns chemical food safety (antibiotics and dioxin) and microbiological food safety (Salmonella, E.coli, M. paratuberculosis, and S.aureus).

The relative importance of 30 preventive measures with respect to chemical and microbiological food safety was assessed by experts (Valeeva et al., 2005). On the basis of these weights an index for chemical and microbiological food safety can be calculated. The most important preventive measures that are included in the farm model are presented in Appendix 4A and can be found in Valeeva et al. (2005). The final Chain Food Safety Index (CFSI) is calculated by equally weighting the index for chemical and microbiological food safety. The ideal value (utility=1) is achieved when all preventive measures for chemical and microbiological food safety are taken and the anti-ideal value (utility=0) for food safety is obtained if no preventive measures are taken at all.

Animal Welfare

Indicators for animal welfare

An extensive number of indicators for animal welfare in dairy farming was found in literature (see Table 4.2). Ethical accounting (Sörensen et al., 2001) and the Italian approach (Tosi et al., 2001) are not selected as these animal welfare indicators are based not only upon indirect variables but also on direct variables. The Extended Green Label indicator for animal welfare (Van Zeijts et al., 1999) is not selected as this indicator, although design validated, is not output validated. Validation of TGI (TierGerechtheitsIndex)-200 (Sundrum et al., 1994) with animal health data gave satisfying results (Alban et al., 2001). TGI(TierGerechtheitsIndex)-35L (Bartussek, 1999) is selected, however, to measure animal welfare as TGI-35L is validated for animal health and animal behaviour (Ofner et al., 2003). Furthermore the TGI-35L (Animal Needs Index in English) is scientifically founded (Bartussek, 1999, 2001).

TierGerechtheitsIndex-35L

TGI-35L was developed in Austria to certify the level of animal welfare on farms. In TGI-35L points are assigned to parameters within five areas of the housing system and management: 1) locomotion, 2) social interaction, 3) flooring, 4) light and air, and 5) craftsmanship (Bartussek, 1999). A detailed description of the TGI-35L can be found in Bartussek (1999) and related management measures can be found in Appendix 4A. The maximum score for TGI-35L is 45.5 points, whereas a score of less than 11 points defines a level of welfare as ‘not suitable’ (Bartussek, 1999). In this research a minimum of 11 points is used as anti-ideal value (utility=0) and the maximum score for TGI-35L (45.5) is used as ideal value (utility=1). The score for TGI-35L is calculated for dairy cows, heifers (1-2 years) and calves (0-1 years). The final score for animal welfare is determined by weighting scores per category according to the numbers of animals per category.

Animal health

Indicators for animal health

Only two indirect animal health indicators were found in literature (see Table 4.2) as most used indicators for animal health are direct indicators (e.g. incidences of several diseases). The HACCP concept is well suited for animal health management at farm level, involving scientifically based risk identification and risk management (Noordhuizen and Frankena, 1999). The HACCP methodology is not selected, however, because of its dichotomic nature.

The Animal Health Index (AHI) is based upon farm management measures and is assessed by experts in the field of animal health in dairy farming (Van Zeijts et al., 1999). No comparison of AHI output with directly measured animal health data is available. The AHI complies, nonetheless, with design validation as the AHI is assessed by experts, and is selected, therefore, for measuring animal health.

Animal Health Index

The AHI is part of extended green label (in Dutch: Verbreed Groen Label), which stimulates individual farmers to produce according to more strict ‘sustainable’ standards (Van Zeijts et al., 1999). The AHI assesses how dairy farmers eradicate and control diseases. Management with respect to eradication of diseases aims at preventing mainly list-B diseases. Management with respect to control of diseases is related to production diseases.

A closed farming system is the basis for eradication of diseases in the AHI as it prevents introduction of for example BHV-1, S. Dublin, BVDV, and L. hardjo (Van Schaik et al., 2001). With respect to control of diseases several management measures are included that maintain the balance between resistance (e.g. feeding and vaccination strategies) and environment of the herd (e.g. hygiene and climate). The most important preventive measures that are included in the farm model are presented in Appendix 4A and can be found in Van Zeijts et al. (1999). The ideal value (utility=1) is achieved when all management measures are taken (100 points). A minimum of 16 points is used as the anti-ideal value (utility=0).

Landscape quality

Indicators for landscape quality

Many indicators for landscape quality can be found in literature (Stobbelaar and Van Mansvelt, 2000; Piorr, 2003). Most of these indicators, however, do not aim to measure landscape quality in an objective way at farm level. Agricultural Nature Norm Analysis (ANNA, Guijt, 2002) is included as it is based upon management measures regarding landscape quality and is already tested in practice. Disadvantage of including ANNA is that output validity is not tested yet. Design validity is guaranteed, however, as ANNA is developed on the basis of scientific literature and by using experts.

Agricultural Nature Norm Analysis

ANNA is developed to list management measures with respect to nature and landscape quality (Guijt, 2002) and is based upon the Farm-Nature Plan as described by Smeding and Joenje (1999). ANNA was developed initially for organic agriculture and was applied on 90 organic farms. ANNA is also suitable for conventional agriculture (pers com. Guijt). Within ANNA management measures with respect to three types of nature, i.e. wet nature, herbaceous nature, and woody nature, and some additional management measures are distinguished (Guijt, 2002). Points are achieved, when these management measures are applied. In Appendix 4A an overview is given of the selected management measures and the corresponding points that can be achieved. For a more detailed description see Guijt (2002). If less than 15 points are achieved then landscape quality is considered low (utility=0). Landscape quality on farms with scores above 36 points is considered high (utility=1) (Guijt, 2002).

4.3 Method

4.3.1 Model description

The basic structure of the economic-environmental LP-model (Berentsen and Giesen, 1995) has the form of a standard linear programming model:

Maximise $[Z=c'x]$

Subject to $Ax \leq b$

and $x \geq 0$

Where x = vector of activities; c = vector of gross margins per unit of activity; A = matrix of technical coefficients; and b = vector of right hand side values. The objective function maximises net farm income. Annualised capital costs are fixed in the model but can be different between situations.

The model contains activities for common production processes on Dutch dairy farms (e.g. grass and silage maize production, and milk production). Constraints are included in the model for available fixed assets (e.g. land area and milk quota), as well as for links between different activities (i.e. feeding requirements versus feed production and feed purchase). Environmental policy is included as a constraint on the basis of the MINeral Accounting System (MINAS; Ondersteijn et al., 2002). Ecological indicators are included as accounting rows in the model. For a more detailed description of the basis LP-model, see Berentsen and Giesen (1995) and Van Calker et al. (2004).

In Appendix 4A the most important coefficients are presented that are included in the LP-model to calculate the internal and external social indicators. For each included management measure effects on costs, internal social and extern social indicators are given.

4.3.2 Organisation of the analyses

The above mentioned model is demonstrated by using farm characteristics of two experimental dairy farms in the Netherlands that can be considered extreme exponents of farming systems (see Table 4.3). Calculations are done for the year 2004.

The main objectives for the High-tech experimental farm are to minimise the cost price per kg of milk and to improve the working conditions. The High-tech farm represents relatively large family farms (800.000 kg milk quota) on fertile clay soil. On the High-tech farm a low cost price per kg milk and improved working conditions are pursued by high production per ha (± 23.000 kg milk per ha), high production per cow (9600 kg milk per cow) and high production per man-hour. High production per man-hour is realised by among others, robot milking, automatic feeding and keeping the herd indoors through the year by means of summer feeding.

Aver Heino converted to organic dairy farming in 1998 and is located on semi-dry sandy soil. Aver Heino is, like most organic dairy farms, characterised by lower intensity of the farm (± 10.000 kg milk per ha) and a lower milk production per cow (7400 kg milk per cow). The most important standards and requirements for organic dairy farming are presented in Table 4.3.

Table 4.3 Farm structure and farm characteristics of High-tech and Aver-Heino

	High-tech	**Aver Heino**
Type	Conventional	Organic
Soil type	Clay	Sand
Area (ha)	35	67.5
Milk quota (* 10^3 kg)	800	682
Milk production (kg per cow)	9600	7400
Fat (%)	4,35	4,65
Protein (%)	3,34	3,38
Replacement rate (%)	34	36
Use chemical fertiliser	Yes	No
Use of chemical-synthetical crop protection	Yes	No
Grazing	Not obliged	Obliged
Purchase of concentrates and roughage	Conventional	Organic
Application of animal manure	No restriction	170 Kg N per ha
Maximum amount of concentrates (kg)	No maximum amount	40% of daily ration
Milk for calves	Artificial milk	Raw milk

To show the possible ranges of social sustainability four situations are analysed:

1. *High-tech*: standard conventional management as applied on the High-tech farm;
2. *Aver Heino*: standard organic management as applied on the Aver Heino farm;
3. *High-tech*$^+$: improved level of external social sustainability by applying additional management measures in the High-tech situation.
4. *Aver Heino*$^+$: improved level of external social sustainability by applying additional management measures in the Aver Heino situation.

Differences between High-tech and High-tech$^+$, and between Aver Heino and Aver Heino$^+$ indicate possibilities for improvement with respect to social sustainability. Table 4.4 presents all applied management measures related to social sustainability for the four situations. No management measures are included that specifically aim to improve working conditions. This implies that performance for working conditions is a result of the model optimisation.

Table 4.4 Management measures applied for the basis situations (High-Tech and Aver-Heino) and for the situation where external social sustainability is improved (High-Tech^{+} and Aver Heino^{+}))*

Measures	High-Tech	Aver Heino	High-Tech^{+}	Aver Heino^{+}
Food safety				
Purchasing not-certified feed	2	2	1	1
Purchasing dairy cows	2	2	1	1
Purchasing animal manure	2	2	1	1
Prevent contact with neighboring cows during grazing	2	2	3	3
Maintenance milking machine	2	2	3	3
Veterinary checks and monitoring animal health	2	2	3	3
Develop treatment plan	2	2	3	3
Housing system dairy cows	Cubicle	Cubicle	Cubicle	Deep litter
Improve water quality for cleaning and drinking	2	2	3	3
Separate calving place	2	2	3	3
Feeding artificial milk	3	1	3	1
Animal welfare				
Grazing cows	1	Day grazing	Day	Day-and-night
Grazing young stock	1	Day-and-night	Day-and-night	Day-and-night
Min. additional roughage during summer (kg dm per cow)	✕	5	5	0
Housing system dairy cows	Cubicle	Cubicle	Cubicle	Deep litter
Housing young stock	Cubicle	Cubicle	Cubicle	Deep litter

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Table 4.4 Continued

Animal health				
Separate housing of dairy cows and young stock	1	1	3	3
Purchasing dairy cows	2	2	1	1
Purchasing animal manure	2	2	1	1
Prevent contact with neighboring cows during grazing	2	2	3	3
Additional housing measures	1	1	3	3
Measures to test health status	2	2	3	3
Artificial milk for calves	3	1	3	1
Landscape quality				
Cleaning ditch	2	2	3	3
Develop additional slope in ditch	2	2	3	3
Develop pool	2	2	3	3
Develop marshland	1	1	2	2
Develop herbaceous grassland	1	1	2	2
Protect meadow birds in grassland	1	1	2	2
Fallow land	1	1	2	2
Improve biodiversity of banks and borders	2	2	3	3
Develop wooded bank and/or thicket	2	2	3	3
Introduce nests for bird, bats and (bumble)bees	2	2	3	3
Develop strategic nature plans	2	2	3	3

*1 = management measure is prohibited in the model, 2 = management measure is optional in the model, 3= management measure is prescribed in the model

4.4 Results

First technical and economic results of the four example situations are presented. Second, the results for internal and external social sustainability are presented.

4.4.1 Technical results

Table 4.5 presents numbers of livestock, land use and purchased feed. The numbers of dairy cows are determined by the available milk quota and the milk production per cow. The number of young stock for High-tech is lower mainly as replacement is partly based on purchased cows. In the High-tech$^+$ situation purchase of dairy cows is not allowed and the number of young stock therefore increased.

Table 4.5 Technical results for the basis situations (High-tech and Aver Heino) and for the situations where external social sustainability is improved (High-tech$^+$ and Aver Heino$^+$)

	High-tech	Aver Heino	High-tech$^+$	Aver Heino$^+$
Livestock				
- # dairy cows	84.8	85.6	84.8	85.6
- # young stock	25.1	32.1	30.0	32.1
- # purchased dairy cows[1]	4.8	0	0	0
Land use				
- Conventional grassland (ha)	7.5	-	16.9	-
- N application grassland (kg mineral N)	315	-	358	-
- Grass / red clover (ha)	0	32.0	0	23.2
- Grass / white clover (ha)	0	23.0		0
- Herbaceous grassland (ha)	0	0	14.3	42.7
- Maize (ha)	27.5	12.6	3.1	0
- Additional nature elements (ha)	0	0	0.6	1.6
Roughage purchased[1] (GJ NEL[2])	0	156	1637	1318
By-products purchased[1] (GJ NEL[2])	419	172	208	172
Concentrates purchased[1] (GJ NEL[2])	1271	790	1235	993

[1] per year; [2] GJ NEL = Giga Joule Net Energy for Lactation

In the High-tech situation no grazing is applied and a constant ration is supplied year-round to the dairy cows and the young stock. The area for maize silage is maximised, as energy production per ha is cheaper for maize in comparison with grassland. MINAS (Ondersteijn et al., 2002) limits the area of maize as phosphate losses per ha are higher for maize in comparison with grassland. Furthermore grass silage is used as protein source for dairy cows and young stock. By-products (beet pulp and undegradable extracted soy meal) and concentrates are included as additional source for energy, rumen degradable protein, and intestine digestible protein.

In the Aver Heino situation no artificial fertiliser is allowed. The two types of legumes that are grown with grass in the Dutch organic dairy farming are red and white clover. Red clover in grass/clover production can bind 200 kg N ha^{-1} on a yearly base whereas white clover can bind 70 kg ha^{-1} (Baars and Van Dongen, 1993), which implies that energy and protein production is higher for grass/red clover. On the other hand, red clover is less persistent especially when grazing takes place. Therefore, costs of renewing grass/red clover are higher than of renewing grass/white clover. The uptake of fresh grass in summer ration by grazing cows is maximised because it is a cheap source of energy and protein (no harvesting costs). The maximum is determined by the dry matter intake capacity of the cows and by the minimum requirement of 5 kg DM from maize silage in summer for day grazing dairy cows. Grass/red clover and grass/white clover are grown in a ratio such that enough grass is available. Own grown maize and purchased maize are included as cheap energy source in winter rations. Shortage of energy and protein is supplemented with by-products (beer pulp) and concentrates.

In the High-tech^{+} situation grazing is applied for dairy cows and young stock to improve external social sustainability. As a consequence the total area of grassland increased. The area of ‘conventional’ grassland is mainly used for grazing and harvesting grass silage for dairy cows, whereas the included herbaceous grassland is used for grazing and harvesting grass silage for young stock and dry cows. Herbaceous grassland and additional nature elements are included in the High-tech^{+} situation to improve landscape quality (see Table 4.4). The nitrogen application for High-tech^{+} on conventional grassland is higher in comparison with High-tech, as the included herbaceous grassland requires less fertiliser. The purchase of maize increased as herbaceous grassland has a lower yield and the area of maize decreased.

In the Aver Heino^{+} situation land use changed due to increased grazing of dairy cows (i.e. day and night grazing instead of day grazing) and including herbaceous grassland and nature elements. Herbaceous grassland yields less energy and protein per ha, which is compensated by agricultural nature subsidies. Grass/red clover is included to fulfil the needs for energy and protein from grassland during grazing of dairy cows and young stock. Grass/red clover is preferred above grass/white clover as it yields more energy and protein. Shortage of food is solved by purchase maize (20.2 ha), by-products (brewers grains), and concentrates.

4.4.2 Economic results

Table 4.6 shows gross revenues, costs and net farm income of the four situations. The economic results follow from the technical results. The gross revenues of the farm consist of revenues from milk, animals, and subsidy payments. Within subsidy payments a distinction can be made between: subsidies for milk production, subsidies for maize production, and subsidies for agricultural nature conservation. Differences in revenues from milk and meat are small between High-tech and Aver Heino, as the lower milk quota (see Table 4.6) of Aver Heino is compensated by the higher price for organic milk. Subsidies for High-tech and Aver Heino are mainly based on the milk quota and the area of maize.

Gross revenues are higher for High-tech$^+$ in comparison with High-tech, due to subsidies for including herbaceous grassland and other nature elements. Improvement of external social sustainability leads also for Aver Heino$^+$ to higher gross revenues as a result of subsidies for herbaceous grassland and subsidies for other nature elements.

Table 4.6 Economic results (€) for the basis situations (High-tech and Aver Heino) and for the situations where external social sustainability is improved (High-tech$^+$ and Aver Heino$^+$)

	High-tech	Aver Heino	High-tech$^+$	Aver Heino$^+$
Gross revenues	***264178***	***255787***	***278674***	***299880***
- Milk and meat	249569	242817	249164	242817
- Subsidies	14609	12970	29510	57063
Costs	***240493***	***236832***	***250609***	***289426***
- Purchased feed	47540	37407	73474	73919
- Fertilisers	2060	2572	2602	1640
- Seed and plants costs	11322	16373	6087	13330
- Cattle costs	31669	22227	26824	41289
- Contract work	29223	30730	12381	16048
- Cost of machinery	49694	49758	49694	52967
- Cost of land and buildings	67307	77765	67045	80495
- Food safety & animal health costs	0	0	4958	6308
- Landscape costs	0	0	1904	3430
- Additional costs	1678	0	5614	
Net farm income	***23684***	***18955***	***28064***	***10454***

Costs that differ between High-tech and Aver Heino are mainly cost of feed, cattle costs and costs of land and buildings. Despite the lower price of conventional concentrates and roughages, costs for feed are higher for High-tech in comparison with Aver Heino. This is a result of the higher intensity (kg milk/ha) of High-tech. Cattle cost are higher for High-tech as conventional dairy cows and young stock use more veterinary drugs (e.g. antibiotics) in comparison with organic dairy farming. Due to the larger area, cost of land and buildings are higher for Aver Heino. In contrast to N fertiliser, some types of phosphate and potassium fertiliser are used by Aver Heino as they are not artificially produced. As the ratio of nitrogen and phosphate in manure does not fit the requirements for maize and grassland additional phosphate fertiliser has to be purchased. Additional cost for High-tech are the result of taxes for exceeding the environmentally safe surplus standard in MINAS (Ondersteijn et al., 2002). This finally results in ±€4700 higher net farm income for High-tech compared to Aver Heino.

The higher costs for High-tech^{+} in comparison with High-tech are mainly the result of including herbaceous grassland. Due to the low productivity of herbaceous grassland costs for feed increased. Manure has to be disposed as hardly any manure can be applied at herbaceous grassland, which leads to higher additional costs. The decreased area of maize leads to lower costs for contract work and seed and plant costs. Finally the net farm income is ±€4,400 higher for High-tech^{+} compared to High-tech, which seems that the higher costs are compensated by the agricultural nature conservation subsidies. The change of income is, however, mainly the result of the change from summer feeding to day grazing, as grass for grazing is the cheapest energy and protein source. This implies that if no grazing was applied for High-tech^{+}, then the net farm income would have been ±€3,400 lower in comparison with High-tech.

Effects that explain differences in net farm income between High-tech and High-tech^{+} also explain differences in net farm income between Aver Heino and Aver Heino^{+}. The change of housing system is nonetheless the main explanation for the lower net farm income (±€8,500) for Aver Heino^{+} in comparison with Aver Heino. Costs for cattle are higher through the higher input for straw for deep litter systems. If external social sustainability (see Table 4.4) was increased without a deep litter system, then net farm income of Aver Heino^{+} would have been ±12,000 higher in comparison with Aver Heino mainly due to the received agricultural nature subsidies.

4.4.3 Results for internal social sustainability

Table 4.7 presents the results for internal social sustainability for the four situations. The larger area of agricultural land and the manual pest control result in a higher need for labour with respect to grassland and maize for Aver Heino. For dairy cows grazing, however, does not lead to savings for labour as dairy cows have to be brought into the barn for milking. This finally results in a working week of 70 hours for High-tech and a working week of 82 hours for Aver Heino.

A lower score for the Physical Load Index is related to worse working conditions. Surprisingly the translation of the working weeks into the PLI does not result in differences between High-tech and Aver Heino. The reason for the equal score on the PLI is that in the High-tech situation exposure to the most relevant risk factors for dairy farming is already exceeded. For example the limit of exposure to lifting, i.e. risk variable for back disorders, is set at 300 hours per year. In the High-tech situation this limit is exceeded already. For Aver Heino this limit is exceeded even more, which, nonetheless, does not result into a worse score for PLI.

Table 4.7 Results for internal social sustainability for the basis situations (High-tech and Aver Heino) and for the situations where external social sustainability is improved (High-tech$^+$ and Aver Heino$^+$)

Tasks		High-tech	Aver Heino	High-tech$^+$	Aver Heino$^+$
Work load (hours per year)					
Dairy cows	- Milking	527	643	641	757
	- Feeding	428	277	279	271
	- Care	787	772	765	1087
Heifers (10d-2y)		753	692	673	801
Calves (0-10d)		272	274	272	274
Grassland		135	706	349	792
Maize		85	227	9	0
Food safety & animal welfare		5	0	76	151
Landscape		0	0	17	32
General		650	678	669	668
Total		***3640***	***4269***	***3750***	***4834***
Physical load index (0-1)		***0.39***	***0.39***	***0.42***	***0.41***
- back disorders		0.25	0.25	0.30	0.20
- neck, shoulder and upper extremity disorders		0.54	0.54	0.54	0.62

The increased work load for High-tech+ (3540 hours per year and 72 hours per week) in comparison with High-tech (3750 hours per year and 70 hours per week) is mainly the result of the higher need for labour for management measures to improve external social sustainability. The increased workload does not result in a worse score for PLI. Instead the

PLI score for High-tech$^+$ is improved in comparison with High-tech. The improved physical load for back disorders for High-tech$^+$ is a result of the applied grazing, which results into a lower exposure to risk variables.

In the Aver Heino$^+$ situation working weeks are longer (93 hours) in comparison with Aver Heino (82 hours). These changes are mainly the result of: (1) deep litter housing system, (2) day-and-night grazing for dairy cows and, (3) additional management measures to improve external social sustainability. The deep litter housing system increases labour need for care of dairy cows, heifers and animal welfare, as spreading straw and cleaning out the barn request more labour in comparison with conventional cubicle systems. Day-and-night grazing increases the need for labour during milking as the cows have to be brought into the barn for milking twice a day. Again, the increased working hours, do not lead to a worse score for PLI. Instead an improved score is obtained for Aver Heino$^+$. The spreading of straw in the barn has, in comparison with spreading of sawdust in cubicles, a negative influence on back disorders, but a positive influence on neck, shoulder and upper extremity disorders.

4.4.4 *Results for external social sustainability*

Table 4.8 presents external social results for the four situations. Differences in the Chain Food Safety Index (CFSI) are relatively small between High-tech and Aver Heino. Purchase of roughage by Aver Heino (see Table 4.5) explains the difference for chemical food safety. Differences for microbiological food safety between High-tech and Aver Heino are the result of: (1) purchase of roughage by Aver Heino, (2) purchase of animal manure by Aver Heino, (3) feeding of raw milk to calves on Aver Heino, (4) possible contacts with other herds during grazing for Aver Heino and, (5) purchase of cattle by High-tech. This finally results in a slightly improved score for High-tech with respect to microbiological food safety and total food safety.

Grazing has a positive influence on locomotion, social interaction, quality of flooring and availability of fresh air and light. As a consequence the score for TGI-35L, i.e. animal welfare, is higher for Aver Heino in comparison with High-tech as in this situation grazing is applied for dairy cows and young stock.

Performance for the Animal Health Index is higher for High-tech as: (1) no raw milk is fed to calves (part of basic requirements), (2) contacts with other herds are prevented by keeping the herd indoors through out the year, and (3) no animal manure is purchased (part of farm management). This means that despite the purchase of dairy cows, which brings the risk of disease introduction, ‘High-tech achieves a higher score for the Animal Health Index in comparison with Aver Heino. It is obvious that most management measures affecting food safety also affect animal health and vice versa.

The minimum level of 15 points for ANNA is not achieved and subsequently no scores for landscape quality are achieved in the basis situations (High-tech and Aver Heino).

Table 4.8 Results for external social sustainability for the basis situations (High-tech and Aver Heino) and for the situations where external social sustainability is improved (High-tech$^+$ and Aver Heino$^+$)

	High-tech	Aver Heino	High-tech$^+$	Aver Heino$^+$
CFSI (food safety)				
- Chemical food safety	0.55	0.50	0.93	0.93
- Microbiological food safety	0.61	0.58	0.92	0.87
Relative score (0-1)	***0.58***	***0.53***	***0.92***	***0.90***
TGI-35L (animal welfare)				
- Locomotion	0.5	3.5	3.5	9
- Social interaction	1	4	4.5	7.5
- Flooring	3	4.5	4.5	7
- Light and air	5	7.5	7.5	7.8
- Craftsmanship	8	8	8	8
Total score	17.5	27.5	28	39.3
Relative score (0-1)	***0.19***	***0.49***	***0.50***	***0.84***
Animal Health Index				
- Basis requirements	3	6	16	13
- Housing and grazing	14	6	34	34
- Farm management	22	21	35	35
- Testing health status	0	0	8	8
Total score	39	33	93	90
Relative score (0-1)	***0.27***	***0.20***	***0.92***	***0.88***
ANNA (landscape quality)				
- wet nature	0	0	7	7
- herbaceous nature	1	1	11	9
- woody nature	0	0	6	6
- additional measures	2	4	9	10
Total score	3	5	34	34
Relative score (0-1)	***0***	***0***	***0.90***	***0.90***

The included management measures to improve external social sustainability (see Table 4.4) for High-tech$^+$ results in a higher score for CFSI in comparison with High-tech. By applying grazing the conventional dairy farm (High-tech$^+$) achieves a score for TGI-35L that is similar to the organic dairy farm (Aver Heino). For High-tech$^+$: (1) no dairy cows are purchased, (2) dairy cows, heifers and calves are housed separate, (3) animal health status is monitored, and (4) additional measures with respect to preventing introduction of list B- diseases and control of production diseases are applied (see Table 4.4). This results in a higher score for the Animal Health Index for High-tech$^+$ in comparison with High-tech. Included management measures with respect to landscape quality, e.g. herbaceous land an improving biodiversity of banks and borders, results in a higher score for ANNA. Maximum score for ANNA can be achieved easily by just including more management measures, e.g. planting pollard willows or solitary trees.

Inclusion of management measures to improve external social sustainability results in higher scores for all external social indicators with respect to Aver Heino$^+$ in comparison with Aver Heino. In general the resulting performance for CSFI, Animal Health Index, and ANNA as a result of improving external social sustainability is equal for the conventional (High-tech$^+$) and the organic dairy farm (Aver Heino$^+$). Aver Heino$^+$ achieves only for TGI-35L, i.e. animal welfare, a higher score in comparison with High-tech$^+$.

4.5 Discussion and conclusions

In this paper we successfully included social indicators in a dairy farm LP-model. The model offers the opportunity to compare different dairy farming systems on their level of economic, internal social, and external social sustainability. This means that the model can be helpful to analyse trade-offs of different farm management measures between economic and social sustainability. The selected indicators are the most suitable indicators to measure social sustainability at this moment of time. Improved indicators for social sustainability that comply with selection criteria can be included easily later on in the farm model.

Two experimental farms, a conventional dairy farm and an organic dairy farm, with an optimal level of farm management are used as examples to demonstrate the farm model. Differences in PLI score are relatively small between the conventional and organic dairy farming system. Differences in work load, i.e. working hours per week, are explained mainly by the lower intensity (i.e. larger area) and the manual pest control of the organic dairy farming system. These conclusions regarding work load are consistent with a study that discussed the sustainability of organic Dutch dairy farms (Spruijt-Verkerke et al., 2004). The PLI, however, is not very sensitive as it is designed for different agricultural sectors. Still, the

PLI gives additional information about the work load and the corresponding physical load for back disorders and for neck, shoulder and upper extremity disorders. The limits of exposure of the risk variables are reconsidered in new version of PLI (Oude Vrielink and Roelofs, 2005), which probably will increase the sensitivity of the PLI. When available, this new version of the PLI will be included in the farm model.

In this study only small differences exist in performance of a conventional and organic dairy farming system for food safety, animal health, and landscape quality in the basis situation, i.e. High-tech and Aver Heino, as well as in the situation for improved external social sustainability, i.e. High-tech$^+$ and Aver Heino$^+$. For conventional as well as organic dairy farming systems performance on external social sustainability can be improved by applying additional management measures.

For microbiological food safety no evidence was found to support the assertion that organic products are more safe than conventional products (Kouba, 2003). For chemical food safety it was concluded that organic products might be safer than conventional products as no pesticides and less veterinary drugs are used (Kouba, 2003). In this study we assumed an optimal level of management, which minimises the risk of residues in animal products for conventional products. As a consequence the similar level for conventional and organic dairy farming systems with respect to food safety is consistent with the mentioned literature.

Prevalence of specific production diseases (e.g. mastitis, parasite related diseases and metabolic disorders) can be different between organic and conventional dairy farming (Hardeng and Edge, 2001). Several studies (Sundrum, 2001; Hovi et al., 2003; Lund and Algers, 2003) concluded, however, that no differences exist in *overall* animal health regarding production diseases between dairy farming systems, i.e. conventional vs. organic. This implies that the similar performance for the conventional dairy farm (High-tech and High-tech $^+$) and for the organic dairy farm (Aver Heino and Aver Heino$^+$) is consistent with literature.

In empirical research of Hendriks and Stobbelaar (2003) it was concluded that organic dairy farms in general achieved a better score for landscape quality. The organic farms contribute more than average to landscape quality due to among others contracts with nature conservation organisations. Apparently organic dairy farming systems and organic dairy farmers are more amendable to management measures to improve landscape quality. Variation in their results of both conventional and organic farms was considerable, however, and indicated that conventional dairy farms can achieve scores similar to organic dairy farms as shown in our study.

If dairy cows and young stock are housed in deep litter barns, then the score for animal welfare is higher for organic dairy farms (Aver Heino$^+$) in comparison with conventional dairy farms (High-tech$^+$). Deep litter barns, however, are not commonly applied (18%) on organic dairy farms (De Jong and Van Zoest, 2001). The obligation of grazing for organic dairy farms guarantees, nonetheless, a minimum level of animal welfare. But so far 90% of all Dutch dairy farms applies grazing (De Bont and Van Everdingen, 2004).

From these results it is concluded that the level of external social sustainability is determined mainly by applied management measures and that this level is hardly related to the particular farming system, i.e. conventional vs. organic. This means that higher performance for external social sustainability is mainly dependent on cost-effectiveness of management measures that help to improve external social sustainability and the attitude of the dairy farmer.

Appendix 4A

Table 4A.1 Technical coefficients that are included in the LP-model to calculate the internal and external social indicators

Measures	Costs (€)	Working conditions (hours)	Chemical food safety (points)	Microbiological food safety (points)	Animal welfare (points)	Animal health (points)	Landscape quality (points)
Purchasing non-certified roughage	-1 % per kg	-	-7.92	-3.10	-	-	-
Purchasing non-certified concentrates	-1 % per kg	-	-18.39	-7.11	-	-	-
Purchasing dairy cows (health status is unknown)	€1050 per cow	-	-	-4.47	-	-9	-
Purchasing dairy cows (health status is known)	€1250 per cow	-	-	-1.04	-	-3	-
Quarantine for purchased dairy cows	€560 + €43 per cow	1/cow	-	3.29	-	-	-
Purchase of animal manure	variable	-	-	-4.06	-	-4	-
Prevent contact with neighbouring cows during grazing	€40/ha	2.6/ha	-	3.62	-	4	-
Maintenance milking machine	€1000	-	7.67	3.88	-	-	-
Veterinary checks	€189.68	1.5		4.10	-	5	-
Participation in monitoring programs (salmonella and Johne's disease)	€164.8	4	-	3.95	-	5	-
Develop treatment plan for diseased cattle	€105.83	1	6.30	-	-	-	-
Cubicle housing (dairy cows)	€4100 per cow	variable	-	2.90	9.5	-	-
Deep litter (dairy cows)	€3750 per cow	variable	-	2.66	20.5	-	-
Reuse of water	€461,18	-	-7.17	-3.51	-	-	-
Cleaning water trough	-	52	-	2.71	-	-	-
Outdoor drinking of tap water	€1176	-	7.44	3.81	-	4	-
Use of tap water only	€0.48/m^3	-	7.81	3.44	-	-	-

Table 4A.1 Continued

Separate calving place	€560	-	-	4.26	-	6	-
Feeding artificial milk	€50,29	-	-	3.79	-	3	-
Grazing of dairy cows	variable	variable	-	-	11-12	-	-
Grazing of young stock	variable	variable	-	-	9.5	-	-
Cubicle housing (young stock)	€1650-€1850 per unit of young stock	variable	-	-	9.5	-	-
Deep litter (young stock)	€1510-€1690 per unit of young stock	variable	-	-	20.5	-	-
Separate housing of dairy cows and young stock	€100-€200 per unit of young stock	-	-	-	-	13	-
Participation in monitoring program (Bovine Virus Diarrhoea)	€97.85	2	-	-	-	3	-
Cleaning ditch	€260.00	-	-	-	-	-	4
Develop additional slope in ditch	€100.21	1.50	-	-	-	-	3
Develop pool	€50.85	0.33	-	-	-	-	1
Develop marshland	-€584.40	9.2	-	-	-	-	1
Develop herbaceous grassland	-€854.40	9.2	-	-	-	-	2
Protect meadow birds in grassland	-€403.40	9.2	-	-	-	-	1
Fallow land	-€361.00	6.9	-	-	-	-	1
Improve biodiversity of banks and borders	-€3.70	3	-	-	-	-	6
Develop wooded bank and/or thicket	€34.24	8	-	-	-	-	6
Introduce nests for bird, bats and (bumble)bees	€20.80	1	-	-	-	-	4
Develop strategic nature plans	€350.00	8	-	-	-	-	3
General practices	-	-	27.23	33.18	8	24	3

References

Alban, L., Ersboll, A.K., Bennedsgaard, T.W. and Johnsen, P.F., 2001. Validation of welfare assessment methods at herd level: An example. *Acta Agriculturae Scandinavica A* 51: 99-102.

Baars, T. and Van Dongen, M., 1993. *Mogelijkheden van rode klaver in de weidebouw: een literatuurstudie*. Louis Bolk Instituut, The Netherlands: Driebergen.

Bartussek, H., 1999. A review of the animal needs index (ANI) for the assessment of animals' well-being in the housing systems for Austrian proprietary products and legislation. *Livestock Production Science* 61: 179-192.

Bartussek, H., 2001. An historical account of the development of the animal needs index ANI-35L as part of the attempt to promote and regulate farm animal welfare in Austria: An example of the interaction between animal welfare science and society. *Acta Agriculturae Scandinavica Section a-Animal Science* A 51: 34-41.

Berentsen, P.B.M. and Giesen, G.W.J., 1995. An Environmental-Economic Model at Farm-Level to Analyze Institutional and Technical Change in Dairy Farming. *Agricultural Systems* 49: 153-175.

Berentsen, P.B.M., Giesen, G.W.J. and Schneiders, M., 1998. Conversion from conventional to biological dairy farming: Economic and environmental consequences at farm level. *Biological Agriculture & Horticulture* 16: 311-328.

Bockstaller, C. and Girardin, P., 2003. How to validate environmental indicators. *Agricultural Systems* 76: 639-653.

Bos, J.F.F.P. and Van De Ven, G.W.J., 1999. Mixing specialized farming systems in Flevoland (The Netherlands): agronomic, environmental and socio-economic effects. *Netherlands Journal of Agricultural Science* 47: 185-200.

Codex-Alimentarius-Commission, 2001. *Codex alimentarius: food hygiene basic texts*. FAO, Italy: Rome.

De Boer, I.J.M. and Cornelissen, A.M.G., 2002. A method using Sustainability indicators to compare conventional and animal-friendly egg production systems. *Poultry Science* 81: 173-181.

De Bont, K. and Van Everdingen, W., 2004. Koeien in de wei? Het worden er steeds minder. *Agri-Monitor* September 2004:

De Groote, Y.G.M., Wijtzes, T., Arts, C.J.M. and Deen, H.M.M., 2002. *Elsevier praktijkhandboek voedselveiligheid*. Reed Business Information, The Netherlands: Arnhem.

Chapter 4

De Jong, H. and Van Zoest, Y., 2001. *De biologische melkveehouderijsector in kaart gebracht: studie naar de ontwikkeling van de biologische melkveehouderijsector in Nederland*. BSc-thesis, Christelijke Agrarische Hogeschool, The Netherlands: Dronten.

Fraser, D., Weary, D.M., Pajor, E.A. and Milligan, B.N., 1997. A scientific conception of animal welfare that reflects ethical concerns. *Animal Welfare* 6: 187-205.

Guijt, J., 2002. *ANNA (Agrarische NatuurNorm Analyse) en agrarische natuur op uw biologisch bedrijf*. Platform Biologica, The Netherlands: Utrecht.

Hardaker, J.B., Huirne, R.B.M. and Anderson, J.R., 1997. *Coping with risk in agriculture*. CAB International, US: New York.

Hardeng, F. and Edge, V.L., 2001. Mastitis, ketosis, and milk fever in 31 organic and 93 conventional Norwegian dairy herds. *Journal of Dairy Science* 84: 2673-2679.

Hartman, E., 2004. *Risk analysis of sick leave among Dutch farmers*. PhD-thesis, Wageningen University, The Netherlands: Wageningen.

Hartman, E., Oude Vrielink, H.H.E., Huirne, R.B.M. and Metz, J.H.M., 2003. Sick leave analysis among self-employed Dutch farmers. *Occupational Medicine* 53: 461-468.

Hartman, E., Oude Vrielink, H.H.E., Huirne, R.B.M. and Metz, J.H.M., 2005. Exposure to physical risk factors in Dutch agriculture: effect on sick leave due to musculoskeletal disorders. *International Journal of Industrial Ergonomics* In press:

Heinen, J.T., 1994. Emerging, diverging and converging paradigms on sustainable development. *International Journal of Sustainable Development and World Ecology* 1: 22-33.

Hendriks, K. and Stobbelaar, D.J., 2003. *Landbouw in een leesbaar landschap: hoe gangbare en biologische landbouwbedrijven bijdragen aan landschapskwaliteit*. PhD-thesis, Wageningen University, The Netherlands: Wageningen.

Hendriks, K., Stobbelaar, D.J. and Van Mansvelt, J.D., 2000. The appearance of agriculture. An assessment of the quality of landscape of both organic and conventional horticultural farms in West Friesland. *Agriculture, Ecosystems and Environment* 77: 157-175.

Herrero, M., Fawcett, R.H. and Dent, J.B., 1999. Bio-economic evaluation of dairy farm management scenarios using integrated simulation and multiple-criteria models. *Agricultural Systems* 62: 169-188.

Hovi, M., Sundrum, A. and Thamsborg, S.M., 2003. Animal health and welfare in organic livestock production in Europe: current state and future challenges. *Livestock Production Science* 80: 41-53.

Johnsen, P.F., Johannesson, T. and Sandoe, P., 2001. Assessment of farm animal welfare at herd level: Many goals, many methods. *Acta Agriculturae Scandinavica A* 51: 26-33.

Jorna, I., 2004. *Vergelijking van de directe en indirecte bepaling van de voedselveiligheid op het Nederlandse melkveebedrijf*. MSc-thesis, Wageningen University, Wageningen.

Kelton, D.F., Lissemore, K.D. and Martin, R.E., 1998. Recommendations for recording and calculating the incidence of selected clinical diseases of dairy cattle. *Journal of Dairy Science* 81: 2502-2509.

Kouba, M., 2003. Quality of organic animal products. *Livestock Production Science* 80: 33-40.

Kristensen, T. and Kristensen, E.S., 1998. Analysis and simulation modelling of the production in Danish organic and conventional dairy herds. *Livestock Production Science* 54: 55-65.

Lund, V. and Rocklinsberg, H., 2001. Outlining a conception of animal welfare for organic farming systems. *Journal of Agricultural & Environmental Ethics* 14: 391-424.

Lund, V. and Algers, B., 2003. Research on animal health and welfare in organic farming - a literature review. *Livestock Production Science* 80: 55-68.

Main, D.C.J., Kent, J.P., Wemelsfelder, F., Ofner, E. and Tuyttens, F.A.M., 2003. Applications for methods of on-farm welfare assessment. *Animal Welfare* 12: 523-528.

Mollenhorst, H., Rodenburg, T.B., Bokkers, E.A.M., Koene, P. and de Boer, I.J.M., 2005. On-farm assessment of laying hen welfare: a comparison of one environment-based and two animal-based methods. *Applied Animal Behaviour Science* 90: 277-291.

Noordhuizen, J. and Frankena, K., 1999. Epidemiology and quality assurance: applications at farm level. *Preventive Veterinary Medicine* 39: 93-110.

Noordhuizen, J.P.T.M. and Metz, J.H.M., 2005. Quality control on dairy farms with emphasis on public health, food safety, animal health and welfare. *Livestock Production Science* 94: 51.

Ofner, E., Amon, T., Lins, M. and Amon, B., 2003. Correlations between the results of animal welfare assessments by the TGI 35 L Austrian animal needs index and health and behavioural parameters of cattle. *Animal Welfare* 12: 571-578.

Ondersteijn, C.J.M., Beldman, A.C.G., Daatselaar, C.H.G., Giesen, G.W.J. and Huirne, R.B.M., 2002. The Dutch mineral accounting system and the European nitrate directive: implications for N and P management and farm performance. *Agriculture Ecosystems & Environment* 92: 283-296.

Oude Vrielink, H.H.E. and Roelofs, P.F.M.M., 2005. Description Physical Load Index (upcoming 2005).

Pacini, C., Wossink, A., Giesen, G., Vazzana, C. and Huirne, R., 2003. Evaluation of sustainability of organic, integrated and conventional farming systems: a farm and field-scale analysis. *Agriculture Ecosystems & Environment* 95: 273-288.

Piorr, H.P., 2003. Environmental policy, agri-environmental indicators and landscape indicators. *Agriculture Ecosystems & Environment* 98: 17-33.

Rigby, D., Woodhouse, P., Young, T. and Burton, M., 2001. Constructing a farm level indicator of sustainable agricultural practice. *Ecological Economics* 39: 463-478.

Rotz, C.A., Mertens, D.R., Buckmaster, D.R., Allen, M.S. and Harrison, J.H., 1999. A dairy herd model for use in whole farm simulations. *Journal of Dairy Science* 82: 2826-2840.

Sandoe, P., Munksgaard, L., Badsgard, N.P. and Jensen, K.H., 1997. How to manage the management factor - assessing animal welfare at the farm level. In: Sorensen, J.T. (Ed.), Livestock Farming Systems: More than food production. Proceedings of the Fourth International Symposium on Livestock Farming Systems. Wageningen Pers, Foulum, Denmark, pp. 221-230.

Smeding, F.W. and Joenje, W., 1999. Farm-Nature Plan: landscape ecology based farm planning. *Landscape and Urban Planning* 46: 109-115.

Sörensen, J.T., Sandoe, P. and Halberg, N., 2001. Animal welfare as one among several values to be considered at farm level: The idea of an ethical account for livestock farming. *Acta Agriculturae Scandinavica A* 51: 11-16.

Spruijt-Verkerke, J., Schoorlemmer, H., Woerden, S.v., Peppelman, G., Visser, M.d. and Vermeij, I., 2004. *Duurzaamheid van de biologische landbouw: prestaties op milieu, dierenwelzijn en arbeidsomstandigheden*. Praktijkonderzoek Plant en Omgeving Business-unit Akkerbouw Groente en ruimte en Vollegrondsgroente, Wageningen.

Stobbelaar, D.J. and Van Mansvelt, J.D., 2000. The process of landscape evaluation. Introduction to the 2nd special AGEE issue of the concerted action: "The landscape and nature production capacity of organic/sustainable types of agriculture". *Agriculture, Ecosystems and Environment* 77: 1-15.

Sundrum, A., 2001. Organic livestock farming - A critical review. *Livestock Production Science* 67: 207-215.

Sundrum, A., Andersson, R. and Postler, G., 1994. *Tiergerechtheitsindex - 200, 1994: ein Leitfaden zur Beurteilung von Haltungssystemen*. Koellen, Bonn.

Tosi, M.V., Canali, E., Gregoretti, L., Ferrante, V., Rusconi, C., Verga, M. and Carenzi, C., 2001. A descriptive analysis of welfare indicators measured on Italian dairy farms: Preliminary results. *Acta Agriculturae Scandinavica A* 51: 69-72.

Valeeva, N.I., Meuwissen, M.P.M. and Huirne, R.B.M., 2004. Economics of food safety in chains: a review of general principles. *Njas-Wageningen Journal of Life Sciences* 51: 369-390.

Valeeva, N.I., Meuwissen, M.P.M., Oude Lansink, A.G.M.J. and Huirne, R.B.M., 2005. Improving food safety within the dairy chain: an application of conjoint analysis. *Journal of Dairy Science* 88: 1601-1612.

Van Calker, K.J., Berentsen, P.B.M., Giesen, G.W.J. and Huirne, R.B.M., 2005. Identifying and ranking attributes that determine sustainability in Dutch dairy farming. *Agriculture and Human Values* 22: 53-63.

Van Calker, K.J., Berentsen, P.B.M., De Boer, I.J.M., Giesen, G.W.J. and Huirne, R.B.M., 2004. An LP-model to analyse economic and ecological sustainability on Dutch dairy farms: model presentation and application for experimental farm "de Marke". *Agricultural Systems* 82: 139-160.

Van der Werf, H.M.G. and Petit, J., 2002. Evaluation of the environmental impact of agriculture at the farm level: a comparison and analysis of 12 indicator-based methods. *Agriculture Ecosystems & Environment* 93: 131-145.

Van Huylenbroek, G., Jacobs, G. and Vanrolleghem, P., 2000. A simulation model to evaluate the impact of environmental programmes on dairy farms. *International Transactions in Operational Research* 7: 171-183.

Van Schaik, G., 2000. *Risk and economics of disease introduction into dairy farms*. Wageningen University, Wageningen.

Van Schaik, G., Nielen, M. and Dijkhuizen, A.A., 2001. An economic model for on-farm decision support of management to prevent infectious disease introduction into dairy farms. *Preventive Veterinary Medicine* 51: 289-305.

Van Zeijts, H., Kool, A., Rougoor, C.W. and Van der Schans, F.C., 1999. *Systemen om de duurzaamheid van veebedrijven te waarderen*. 431-1999. Centrum voor Landbouw en Milieu, Utrecht.

Webster, J., 1995. *Animal welfare: a cool eye towards Eden: a constructive approach to the problem of man's dominion over the animals*. Blackwell Science, Oxford.

Weinstoerffer, J. and Girardin, P., 2000. Assessment of the contribution of land use pattern and intensity to landscape quality: use of a landscape indicator. *Ecological Modelling* 130: 95-109.

Wensing, T., 1999. *Production diseases in farm animals: 10th international conference 1998*. Wageningen Pers, Wageningen.

Wijffels, H.H.F., 2001. *Toekomst voor de veehouderij: agenda voor een herontwerp van de sector*. Ministry of Agriculture, Nature and Food Quality, The Netherlands: The Hague.

Winter, M., Fry, C. and Carruthers, S.P., 1998. European agricultural policy and farm animal welfare. *Food Policy* 23: 305-323.

Chapter 5

Development and application of a multi-attribute sustainability function for Dutch dairy farming systems

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Abstract

Sustainability in dairy farming is determined by using aspects (economic, social and ecological). Per aspect a number of measurable attributes is selected. Difficulty for determining the sustainability of farming systems is the combination of the different attribute measures into a sustainability function, which measures the overall sustainability. Furthermore, stakeholder groups often evaluate sustainability different and should be consulted to determine sustainability. In this research the Multi-Attribute Utility Theory (MAUT) is used to develop an overall sustainability function for Dutch dairy farming systems. This approach consists of four steps: (1) determination of attribute utility functions; (2) assessing attribute weights to determine utility functions per aspect; (3) assessing aspect weights to determine the overall sustainability function per stakeholder group; and (4) determination of the overall sustainability function for society by aggregating preferences of stakeholders and experts using a goal programming approach . Depending on the possibility for objective evaluation of each aspect, either experts or stakeholders were consulted to determine attribute utility functions and the utility functions of the particular aspect. In this study experts determined (attribute) utility functions for economic and ecological sustainability. Stakeholders (producers, consumers, industrial producers and policy makers) determined their own utility function for external social sustainability and their own aspect weights. The developed overall sustainability function is applied to different Dutch dairy farming systems represented by four experimental farms. MAUT proves to be a suitable method to determine an overall sustainability function. Sustainability rankings for the dairy farming systems appear to be relatively insensitive to changes in attribute and aspect weights. Based on these results it is concluded that the developed sustainability function based on stakeholder and expert perceptions can be used with reasonable confidence to determine the sustainability of different dairy farming systems.

5.1 Introduction

Recent developments in agriculture have stirred up interest in the concept of "sustainable" farming. Some farming systems (e.g. integrated farming and organic farming) are often equated with sustainable agriculture (based on Hansen, 1996). Nonetheless, appropriate methods to objectively determine the sustainability of different farming systems are still lacking.

Development of sustainability attribute measures, i.e. indicators, can be an effective way to make the concept of agricultural sustainability operational (Rigby et al., 2001). Although many studies have developed attribute measures for sustainability (Callens and Tyteca, 1999; Rigby et al., 2001; De Boer and Cornelissen, 2002; Pacini et al., 2003; Van Calker et al., 2004a) it still remains difficult to determine the extent to which farming systems can be considered sustainable (Rigby and Caceres, 2001). A crucial and complex problem for determining the sustainability of farming systems is the amalgamation of the different attribute measures into a sustainability function, which measures the overall sustainability (Hanley et al., 1999). Several examples exist in which a sustainability function (i.e. sustainability index) was developed (Taylor et al., 1993; Rigby et al., 2001; Diaz-Balteiro and Romero, 2004a). Most of these studies focused on certain aspects of sustainability, but did not include the whole range of key aspects of sustainability, i.e. economic, social and ecological sustainability.

As evaluation of sustainability of farming systems can differ among stakeholders (Lowrance et al., 1986; Shearman, 1990; Heinen, 1994; Hardaker et al., 1997; Rigby and Caceres, 2001), it is important to include a representative set of stakeholders in the assessment. But, if certain aspects of sustainability can be evaluated objectively, then experts should be included in the assessment. In published studies, occasionally a very limited number of stakeholders is consulted to assess the sustainability function. Usually, however, no distinction is made between aspects of sustainability that *can* be evaluated objectively and aspects of sustainability that *cannot* be evaluated objectively.

The first objective of this paper is to develop a method to determine the overall sustainability function for Dutch dairy farms by using data at the attribute level and using stakeholders and experts for assessment of subjective and objective attributes respectively. Goal programming is used to aggregate assessments of the experts and/or stakeholders. The second objective is to apply the developed sustainability function to different Dutch dairy farming systems in order to rank these farming systems according to sustainability.

5.2 Material and methods

5.2.1 Basic concepts

Based upon Van Calker et al. (2005) sustainability is subdivided into the following aspects: (a) economic; (b) internal social; (c) external social; (d) ecological sustainability. Within these aspects attributes were selected by experts and stakeholders. In Figure 5.1, decomposition of overall sustainability into aspects and attributes is shown. Only one attribute was selected for economic and internal social sustainability. External and ecological sustainability, nonetheless, can not be measured by one attribute alone. This means that 'profitability' is equivalent to economic sustainability and 'working conditions' is equivalent to internal social sustainability. This decomposition and the corresponding attribute measures (Van Calker et al., 2004a; Van Calker et al., 2004b) are used as the starting point in this paper.

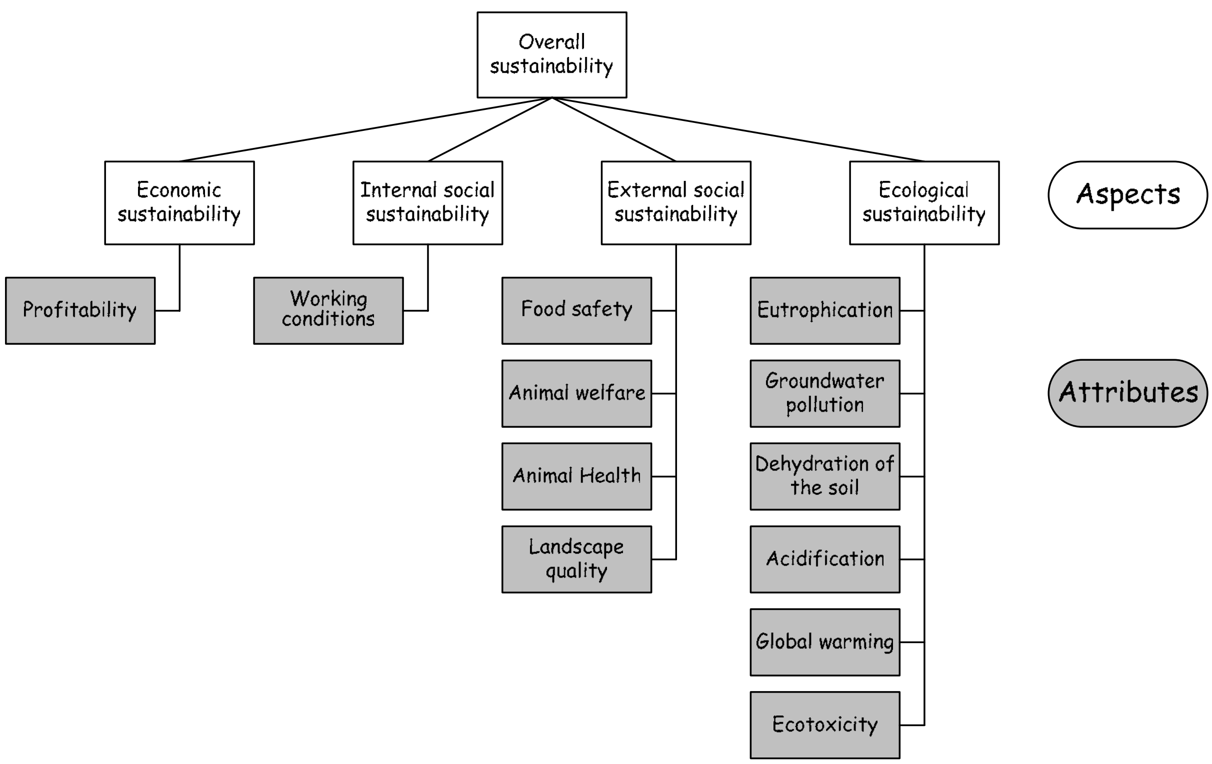

Figure 5.1 Decomposition of overall sustainability of dairy farms into aspects and attributes (Van Calker et al., 2005)

Formulation of the overall sustainability function requires the individual attribute measures to be comparable. By expressing attributes in a homogenous unit of measurement, i.e. utility, all attributes can be amalgamated into one sustainability function.

Overall evaluation of sustainability of farming systems based on multiple attributes as shown in Figure 5.1, can be supported by multi-attribute utility models (Keeney and Raiffa, 1976; Anderson et al., 1977; Hardaker et al., 1997). Multi-attribute utility models are part of the Multiple Criteria Decision Making (MCDM) paradigm which allows to include several partly conflicting attributes (Romero and Rehman, 2003). By using Multi-Attribute Utility Theory (MAUT) a multi-attribute function, in this case the overall sustainability function, can be designed that is amalgamated of the individual attribute utility functions (Clemen, 1991).

To justify the decomposition of overall sustainability into aspects and attributes assumptions about the structure of respondents preferences have to be made (Keeney and Raiffa, 1976; Clemen, 1991; Hardaker et al., 1997). These assumptions refer to preferential independence, utility independence and additive independence. Additive independence is the strongest assumption (Keeney and Raiffa, 1976). If attributes are close to additively independent, then the simple additive utility function can be applied. Additive independence was captured by taking into account independence conditions in the identification and selection process of aspects and attributes of sustainability (Van Calker et al., 2005). Moreover, the additive utility function gives consistent and reliable results, if non-linearities in the utility functions are adequately captured (Stewart, 1996). From this perspective, a mutually additive-independent condition seems acceptable, what leads to an approach based upon additive utility functions. For measuring each aspect of sustainability the following multi-attribute utility function is used:

$$U_j\,(x_1, x_2, \ldots, x_n) = \sum_{i=1}^{n} w_i u_i(x_i) \qquad j \in \{1,2,3,4\} \qquad (1)$$

where U_j is the multi-attribute utility function for the j-th aspect (economic, internal social, external social and ecological sustainability), $u_i(x_i)$ is the utility corresponding to the i-th attribute and the w_i represent the weight for the i-th ***attribute*** ($w_i \geq 0$ and $\sum_{i=1}^{n} w_i = 1$). The sustainability function (S) is described as follows:

$$S\,(U_1, U_2, U_3, U_4) = \sum_{j=1}^{4} W_j U_j \qquad (2)$$

where W_j represent the weight for the j-th ***aspect*** of sustainability ($W_j \geq 0$ and $\sum_{j=1}^{4} W_j = 1$). By using this two-step procedure hierarchical weighting is assumed. This hierarchical weighting procedure is preferred as splitting biases occur in non-hierarchical weighting (Weber et al., 1988; Pöyhönen and Hämäläinen, 1998). Splitting biases refers to the phenomenon that a decision maker implicitly increases the weight of an aspect when it is divided into more than one attribute and when the attributes are weighted non-hierarchically (Pöhyhönen and Hämäläinen, 1998). A consequence of the number of attributes per aspect is that it can be expected that ‘final’ weights (i.e. aspect weight multiplied by attribute weight) for ‘profitability’ and ’working conditions’ are higher than ‘final’ weights of the attributes within external social and ecological sustainability.

Table 5.1 Summary of the four steps to determine the sustainability function

Type of respondent	Step 1 Attribute utility function (u_x)	Step 2 Aspect utility function (U_j)	Step 3 Sustainability function per stakeholder group (S_l)	Step 4 Sustainability function for society (S)
Experts	$u_{Profitability}$ (u_{11})	$U_{Economic\ sustainability}$		
Experts	$u_{Working\ condition}$ (u_{21})	$U_{Internal\ social\ sustainability}$		
Stakeholders	$u_{Food\ safety}$ (u_{31})	$U_{External\ social,\ producers}$		
-Producers	$u_{Animal\ Welfare}$ (u_{32})	$U_{External\ social,\ consumers}$		
-Consumers	$u_{Animal\ health}$ (u_{33})	$U_{External\ social,\ industrial\ producers}$	$S_{producers}$	
-Industrial producers	$u_{Landscape\ quality}$ (u_{34})	$U_{External\ social,\ policy\ makers}$	$S_{consumers}$	$S_{society}$
-Policy makers			$S_{industrial\ producers}$	
			$S_{policy\ makers}$	
Experts	$u_{Eutrophication}$ (u_{41})			
	$u_{Groundwater\ pollution}$ (u_{42})			
	$u_{Dehydration}$ (u_{43})			
	$u_{Acidification}$ (u_{44})	$U_{Ecological\ sustainability}$		
	$u_{Global\ warming}$ (u_{45})			
	$u_{Aquatic\ ecotoxicity}$ (u_{46})			
	$u_{Terrestrial\ ecotoxicity}$ (u_{47})			

5.2.2 Steps in the assessment of the overall sustainability function

To determine the overall sustainability function four steps are involved:

- Step 1: determination of the attribute utility functions; u_x;
- Step 2: determination of the aspect utility functions; U_j;
- Step 3: determination of the sustainability functions per stakeholder group; S_l;
- Step 4: determination of the sustainability function for society; S;

The procedure to aggregate preferences of respondents, which is used in a similar manner for all functions, is described in step 4. The involved steps in the assessment of the overall sustainability functions are schematically presented in Table 5.1.

Step 1: Determination of the attribute utility functions

The general form of the attribute utility function is shown in Figure 5.2, in which utility is scaled from 0 to 1. The functional form of the curve is a negative exponential. This means that a constant degree of curvature is assumed (Huirne and Hardaker, 1998). This implies that diminishing marginal utility is used for ‘goods’ (more is better) and increasing marginal disutility is used for ‘bads’ (less is better).

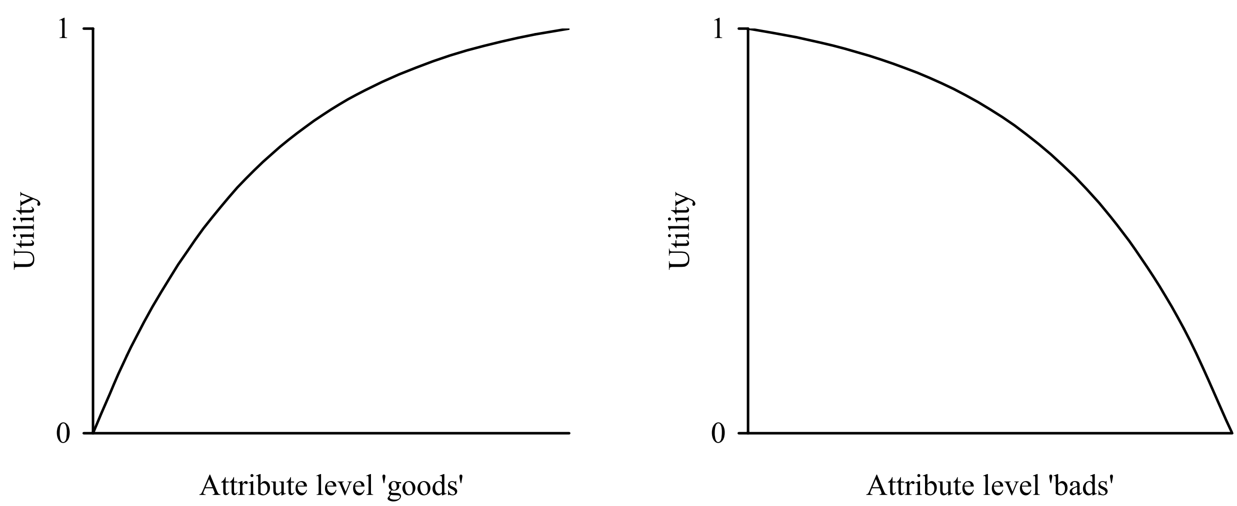

Figure 5.2 Attribute utility functions for ‘goods’ and ‘bads’

To determine an attribute utility function, the starting point, end point and curvature have to be determined. First, the starting point and the end point are identified and assigned values of 0 and 1 respectively. This procedure is according to the conjunctive non-compensatory model (Hogarth, 1987). This model implies that if the value of an attribute measure is worse than the starting point, then the specific alternative is considered to be not sustainable in that attribute and will not receive a score on the sustainability function. On the other hand, if a specific alternative attains a better score than the endpoint of an attribute measure, it is assumed that this better score has no added value with respect to sustainability and will receive a value of 1. The previous pertains to 'goods'. For 'bads' the reverse is true.

The curvature of the utility function is determined by identifying an intermediate point. The intermediate point is proposed to be located halfway between the starting point and the endpoint. In this way assessment of the curvature of the utility function is straightforward for respondents. The negative exponential utility function is then fitted on the basis of three points (the starting, intermediate and end point). Three points are considered sufficient to fit an attribute utility function (Stewart, 1996; Huirne and Hardaker, 1998). The constant degree of curvature equals the parameter c in the attribute utility function $u(x) = a[1-exp\{-c(x+b)\}]$ (Huirne and Hardaker, 1998). The parameters of the negative exponential utility function are obtained using standard curve-fitting software.

Attribute utility functions usually are assumed to be non-linear as linear attribute utility functions are unlikely to be realistic over a wide range of attribute measures (Hardaker et al., 1997). Assessing attribute utility functions for composite attribute measures based upon several qualitative variables is however rather complex. Moreover these qualitative variables are weighted already in the concerning composite indicator. For these kinds of attribute measures a linear utility function is assumed. This implies that attribute utility functions for internal and external social sustainability are assumed linear. The starting and end points of attribute utility functions for internal and external social sustainability are described in Van Calker et al. (2004b)

Experts are consulted to assess the shape of the attribute utility functions for economic and ecological sustainability, as attribute utility functions for these aspects can be assessed objectively (Van Calker et al., 2005). Experts are selected on the basis of written scientific or popular papers and on the basis of experiences in the concerned aspect of sustainability. Table 5.2 shows the number of respondents, background of respondents and way of collecting data that are used to assess the attribute utility functions for economic and ecological sustainability.

Table 5.2 Type of respondents, number of respondents, background of respondents and way of collecting data per aspect of sustainability

Aspect	Type	N	Background	Way of collection data[1]
Economic	Experts	9	- Universities - research institutes - banks - accounting agencies	Questionnaire
External social	Producers	119	- conventional farmers - organic farmers	Questionnaire
	Consumers	8	- animal welfare organisations - nature organisations - consumer organisations	Questionnaire
	Industrial producers	10	- dairy co-operatives - dairy processing companies - retail	Questionnaire
	Policy makers	10	- ministry of agriculture - ministry of environment - regional policy makers	Questionnaire
Ecological	Experts	9	- Universities - research institutes - governmental organisations	Group decision room [2]

[1]Information on questionnaires and the Group Decision room can be obtained from the author

[2] A Group Decision Room (GDR) is an electronically supported meeting room designed to be used to aid members of a meeting to solve complex problems where these members (i.e. experts) can be expected to hold different opinions.

Step 2: Determination of the utility functions per aspect

To determine the utility functions per aspect the attribute utility functions have to be amalgamated. Therefore, attribute weights have to be derived. Weight elicitation methods that do not incorporate ranges into the procedure might lead to biased weights (Von Nitzsch and Weber, 1993; Fischer, 1995). Pöhyhönen and Hämäläinen (2001), however, did not find significant differences in weights between methods that incorporate ranges (e.g. swing weighting) and methods that do not incorporate ranges (e.g. direct rating). Therefore they concluded that practitioners can choose a method dependent on the context of the judgment problem and following their personal preferences (Pöyhönen and Hämäläinen, 2001). In this paper Direct Point Allocation (DIRECT, Bottomley and Doyle, 2001) is applied to determine the weights *per attribute*. In this method attribute ranges are included implicitly by giving a description of attribute ranges in the questionnaire. Moreover, this method is highly transparent and easy to understand, which is recommended when dealing with large groups of respondents. In DIRECT the expert or stakeholder allocates numbers to describe the attribute weights directly.

Within economic and internal social sustainability one attribute was selected (see Figure 5.1). Hence attribute weights are determined only for external social and ecological sustainability. Assessment of attribute weights for external social sustainability depends strongly on preferences of stakeholder groups, as societal concerns differ between stakeholder groups. In this research four stakeholder or interest groups were therefore included to determine the attribute weights: producers, consumers, industrial producers and policy makers (Van Calker et al., 2005). The number of respondents, background of respondents and way of collecting data that were used to assess the utility function for external social sustainability is described in Table 5.2. The same group of experts that determined the ecological attribute utility functions also determined ecological attribute weights (see Table 5.2).

Step 3: Determination of the overall sustainability function per stakeholder group

The overall sustainability function is determined per stakeholder group as assessment can be dependent on professional and cultural backgrounds. Aspect weights have to be determined to amalgamate the aspect utility functions into the overall sustainability function per stakeholder group. DIRECT was used to determine weights *per aspect*. This straightforward method is favorable as comparisons between multi-dimensional aspects can be difficult for stakeholders. Finally the overall sustainability function per stakeholder group is determined by using the utility functions for external social sustainability per stakeholder group, and the three other utility functions per aspect (economic, internal social and ecological) combined with the aspect weights per stakeholder group (see Figure 5.1).

Step 4: Determination of the overall sustainability function for society

Society attribute weights for external social sustainability and society aspect weights are calculated to determine the sustainability function for society. The society attribute weights for external social sustainability and society aspect weights are calculated by aggregating the attribute and aspect weights per stakeholder. In this study the aggregated preferences of stakeholder groups are weighted equally into the overall sustainability function for society. After the assessment of the sustainability function for society, different dairy farming systems can be compared with respect to sustainability.

Aggregation procedure

For all functions in step 1 through step 4 preferences of experts and stakeholders have to be aggregated. Arrow (1963), however, showed that aggregation of preferences cannot exist without violating the ‘impossibility theorem’, stating that interpersonal comparison of utility is not possible. Despite this ‘impossibility theorem’ aggregation of preferences is probably the rule rather than the exception (Hardaker et al., 1997). Anderson et al. (1977, pp. 139-140) list some possible approaches like 'under the boardroom' method and a majority rule to aggregate preferences.

In this paper the preferences of the different respondents, i.e. experts and stakeholders, are aggregated by optimising the consensus of the group. For this, an Extended Goal Programming (EGP) model is used (Gonzalez-Pachon and Romero, 1999; Linares and Romero, 2002). This 'under the boardroom' approach offers the possibility to maximise agreement and to minimise disagreement. Since the aggregation procedures for all utility functions (i.e. attribute utility function, aspect utility function, overall sustainability function per stakeholder group, and overall sustainability function for society) are similar, only the aggregation procedure for the attribute utility function is presented.

To obtain the attribute utility function per expert group or stakeholder group, individual attribute utility functions have to be aggregated. To do so the following notation will be used throughout the paper:

k = number of observed coefficient of the attribute utility function (1 = starting point, 2 = endpoint, 3 = intermediate point and 4 = utility value of intermediate point);

r = number of members per group (experts or stakeholders);

a_k^{ml} = value attached to the kth observed coefficient by the mth member of the lth group;

A_k^l = the lth group preference value for the kth observed utility value

The EGP model is used in which a Weighted Goal Programming (WGP) model and a MINIMAX or Chebyshev model are combined in a convex way. The WGP model provides a solution that maximises the average agreement between respondents, i.e. *maximum average agreement solution*, whereas the MINIMAX solution provides the solution for which the disagreement of the most displaced respondent is minimised, i.e. *most balanced solution*. The first solution represents the "best" consensus from an aggregated point of view, but it can be biased against the preferences shown by the minority. Whereas, the second solution represents the "best" consensus from the point of view of the minority, but it can provide a poor aggregated performance. A way to solve this dilemma consists in resorting to the following EGP model that permits to determine compromises between the above mentioned solutions (Linares and Romero, 2002):

Achievement function:

$$\text{Min } (1 - \lambda)\text{D} + \lambda \sum_{k=1}^{4} \sum_{m=1}^{r} (\overline{n}_{km} + \overline{p}_{km})$$

Subject to:

Goals:

$$\sum_{k=1}^{4} (\overline{n}_{k1} + \overline{p}_{k1}) - D \leq 0,$$

$$\vdots$$

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$$\sum_{i=1}^{4}(\overline{n}_{kr} + \overline{p}_{kr}) - D \leq 0, \qquad (3)$$

$$A_k^l + n_{km} - p_{km} = a_k^{ml} \qquad k \in \{1,\ldots,4\}, \quad m \in \{1,\ldots,r\}.$$

Accounting rows:

$$\sum_{k=1}^{4}(\overline{n}_{k1} + \overline{p}_{k1}) - D_1 = 0$$

$$\vdots$$

$$\sum_{k=1}^{4}(\overline{n}_{kr} + \overline{p}_{kr}) - D_r = 0$$

$$\sum_{k=1}^{4}\sum_{m=1}^{r}(\overline{n}_{km} + \overline{p}_{km}) - Z = 0$$

where D represents the maximum disagreement of individual experts or stakeholders with respect to the obtained solution. The variables $D_1, \ldots, D_r$ represent the disagreement for each expert or stakeholder with respect to the obtained solution. The deviation variables n_{km} (negative deviation) and p_{km} (positive deviation) are normalised by using the summation normalisation system. This procedure is especially suitable when some of the right hand side values have a value of zero (Tamiz et al., 1998). The last row of the EGP model is an accounting row measuring total disagreement (Z) corresponding to each solution (Linares and Romero, 2002).

The model is used to determine the group preference (A_k^l) given the individual preferences (a_k^{ml}) and the target to minimise deviations (D and/or $n_{kr}+p_{kr}$). The control parameter λ determines which solution is selected. For $\lambda = 0$, i.e. the MINIMAX model, this EGP model defines the *most balanced solution* by minimising the disagreement of the most displaced expert. For $\lambda = 1$, i.e. the WGP-model, the model defines the *maximum average agreement solution* by minimising the sum of individual disagreements. Thus, as λ decreases, more importance is given to the largest deviation or more importance is attached to the minority or outlier expert. For intermediate values of parameter λ compromises between these two solutions are obtained. The λ range for different solutions is found by a trial and error procedure (Linares and Romero, 2002).

5.3 Results

The derivation of the utility functions for economic and ecological attributes is presented in Section 5.3.1. In Section 5.3.2 the aspect utility functions and in Section 5.3.3 the sustainability function per stakeholder group are presented. Results on the sustainability function for society are presented in Section 5.3.4*. Finally in Section 5.3.5 the assessed attribute utility functions, the attribute weights, and the aspect weights are applied for different Dutch dairy farming systems.

5.3.1 Attribute utility functions

Economic attribute utility function

Profitability was measured by using the net farm income. In the questionnaire a starting point for net farm income of €18,000 was suggested. This starting point was based upon social security payments and an employer's share (e.g. insurance payments) as a minimum acceptable income for living. The suggested endpoint (€ 74,000) was based upon the net farm income of the five percent highest net farm incomes in the Netherlands. The intermediate point (€46,000) was suggested to be located halfway between the starting point and the end point.

The EGP model (3) was used to aggregate the preferences of the economic experts. This model was solved for different values of parameter λ. The results obtained are shown in Table 5.3.

Table 5.3 Aggregated utility values for profitability for different values of parameter λ[1]

	λ	Starting point	Intermediate point	End point	Utility value intermediate	Z	D
I	[1-0.16)	18,000	46,000	74,000	0,80	0.43	0.15
П	[0.16-0)	18,000	46,000	74,000	0,85	0.61	0.12
Ш	0	19,800	46,000	74,000	0,84	0.90	0.12

[1] I=maximum average agreement solution, П=most balanced solution, Ш=non-efficient solution

The *maximum average agreement solution* (I) is obtained for values of parameter λ larger than 0.16. These aggregated utility values for profitability correspond to the median values. The total disagreement, also known as the indicator of aggregate consensus (Linares and Romero, 2002), is Z = 0.43 units (a low Z value implies more agreement). This solution is biased for one respondent with a maximum disagreement (D) of 0.15 units. This represents 35.8 % ($\frac{0.15}{0.43}*100\%$) of the total disagreement. The MINIMAX solution (Ш), i.e. when λ = 0, is non-efficient as total disagreement (Z) increases while the maximum disagreement of one respondent (D) remains unchanged. This implies that the *most balanced solution* (П), being efficient at the same time, corresponds to values of parameter λ lower than 0.16 and larger than 0.

* For text saving reasons result from the aggregation procedure is presented only for the attribute utility function for economic sustainability and for the sustainability function for society.

Only the value of the intermediate point is different between the *maximum average agreement solution* (I) and the *most balanced solution* (Π; see Table 5.3). This implies that economic experts agreed on most coefficients of the utility function. The *maximum average agreement solution* seems suitable since in this case, the possible minorities are members of the same group, i.e. economic experts. In fact, the possible biased character of the different points of view or perceptions are not between groups but among members of the same group with likely similar perceptions. From this it can be concluded that for all experts the *maximum average agreement solution* is a reasonable choice with respect to the coefficients of a utility function for profitability.

A negative exponential function is fitted through the starting point (worst), end point (best) and intermediate point of the *maximum average agreement solution* (I). The fitted attribute utility function for profitability is: $u_{11}(x_{11})$ = 1.067[1-exp{-0.000050(x_{11}-18000)}]. As expected the experts assume diminishing marginal utility to assess the shape of the utility function for profitability.

Ecological attribute utility functions

Reference points for ecological attribute measures based upon the results of experimental farms and upon calculations for environmental policy targets (Verhagen, 2003; Van Calker et al., 2004a) are used to assess the starting point and end point of the attribute utility functions. All experts agreed that the intermediate points for all attributes are located halfway between the concerning starting point and end point. Again, the EGP model (3) is used to aggregate the preferences of ecological experts. Results for different λ's are reported in Appendix 5A (Table 5A.1). In Table 5.4 the results for the *maximum average agreement solution* (I) are presented only as this solution is a reasonable choice to aggregate perceptions of ecological experts.

Table 5.4 The assessed attribute utility functions with respect to ecological sustainability[1]

Attribute x_I	Unit	Attribute measure x_i			Assessed utility functions $u_i(x_i)$
		Worst	Best	Utility value intermediate	
x_{41} = Eutrophication	NO_3 eq. per ha	500	100	0.75	$1.125[1-\exp\{0.00549(x_{41}-500)\}]$
x_{42} = Groundwater quality	mg NO_3 per l	70	10	0.80	$1.067[1-\exp\{0.046210(x_{42}-70)\}]$
x_{43} = Dehydration	m^3 per ha	5500	3000	0.80	$1.067[1-\exp\{0.001109(x_{43}-5500)\}]$
x_{44} = Acidification	SO_2 eq. per ha	100	50	0.50	$-0.02x_{44} + 2$
x_{45} = Global warming	CO2 eq. per 1000 kg milk	1000	400	0.50	$-0.0017x_{45} + 1.667$
x_{46} = Aquatic ecotoxicity	1,4 DCB eq. per ha	200	50	0.83	$1.042[1-\exp\{0.021459(x_{46}-200)\}]$
x_{47} = Terrestrial ecotoxicity	1,4 DCB eq. per ha	20	0	0.88	$1.021[1-\exp\{0.194591(x_{47}-20)\}]$

[1] maximum average agreement solution

Since ecological attributes are ‘bads’, the starting points in Table 5.4 correspond to ‘worst’ and the endpoint correspond to ‘best’. The experts assessed that all ecological attributes with a local impact (e.g. eutrophication) have to be presented by non-linear utility functions. As expected for ecological attributes, the non-linear utility functions show increasing marginal disutility. For ecological attributes with a global or national impact (global warming and acidification) the experts assessed a linear utility function. This difference in curvature of the utility function is obvious. The contributions of a dairy farm to an ecological attribute with a local impact can really improve the local environmental quality. For example, experimental dairy farm “De Marke” improved the nitrate concentration in groundwater from more than 100 mg/l before 1992 to 49 mg/l in 2002 (Verhagen, 2003). This implies that the phenomenon of increasing marginal disutility concerns ecological attributes with a local impact. Contributions of a single dairy farm to an ecological attribute with a global or national impact however are negligible with respect to the environmental quality. This implies that each local improvement has an equal contribution to the total environmental quality. As a consequence utility functions for ecological attributes with a global or national impact are linear.

5.3.2 Aspect utility functions

Within economic and internal social sustainability one attribute is selected. The aspect utility functions for these aspects, therefore, correspond to the attribute utility function (see Table 5.1).

External social utility function

The corresponding EGP model is solved per stakeholder group for different values of parameter λ to calculate the aspect utility functions for external social sustainability (see Appendix 5A; Table 5A.2). In Table 5.5 the external social utility functions (*U*) for different stakeholders, including the weights per attribute, are presented using the *maximum average agreement solution* (I) as the minorities are members of the same stakeholder group.

Table 5.5 Aspect utility function for external social sustainability for different stakeholders[1,2]

Stakeholder	$U_{External\ social}$
Producers	$0.37u_{food\ safety} + 0.26u_{animal\ welfare} + 0.26u_{animal\ health} + 0.11u_{landscape\ quality}$
Consumers	$0.11u_{food\ safety} + 0.43u_{animal\ welfare} + 0.34u_{animal\ health} + 0.11u_{landscape\ quality}$
Industrial producers	$0.55u_{food\ safety} + 0.15u_{animal\ welfare} + 0.20u_{animal\ health} + 0.10u_{landscape\ quality}$
Policy makers	$0.33u_{food\ safety} + 0.28u_{animal\ welfare} + 0.22u_{animal\ health} + 0.17u_{landscape\ quality}$

[1] *maximum average agreement solution*

[2] *u=attribute utility function*

It is obvious that attribute weights and thus the external social utility function are different between stakeholders groups in the Netherlands. Table 5.5 shows that policy makers and producers allocate the weights more evenly for external social attributes than consumers and industrial producers. Industrial producers attach the highest weight to food safety (0.55), whereas consumers attach the lowest weight to food safety (0.11). Apparently, Dutch consumers consider animal welfare and animal health more relevant for external social sustainability, despite the concern for food safety of the past five years (e.g. dioxin and BSE). The low weight attached to food safety can be related also to the selected representatives of consumers. In this research mainly nature and animal welfare organisations are included as representatives of consumers. Industrial producers are highly dependent on food safety of dairy products and it is likely that they for that reason attach highest weight to food safety. All stakeholder groups regard landscape quality as less important than all other attributes within external social sustainability. This is surprising since nowadays landscape quality is one of the focal points regarding license to produce and regarding additional income of dairy farmers, both in the Netherlands and the European Union.

Ecological utility function

The corresponding EGP model is solved for different values of parameter λ to determine the ecological utility function (see Appendix 5A; Table 5A.3).

Including the attribute weights of the *maximum average agreement solution* (I) into the additive utility function for ecological sustainability results in the following formulation of the ecological utility function:

$$U_{ecological\ sutainability} = 0.32u_{eutrophication} + 0.21u_{groundwater\ pollution} + 0.05u_{dehydration} + 0.21u_{acidification} + 0.05u_{global\ warming} + 0.11u_{aquatic\ ecotoxicity} + 0.05u_{terrestrial\ ecotoxicity}$$

where U=aspect utility function and u=attribute utility function.

As mentioned, the choice of the *maximum average agreement solution* is reasonable as ecological experts are assumed to be members of the same group. Eutrophication is by far the most important attribute within the ecological utility function for Dutch dairy farming systems. Moreover eutrophication, groundwater pollution, and acidification together determine the performance with respect to ecological sustainability for 74%.

5.3.3 Overall sustainability function per stakeholder group

To assess the overall sustainability function per stakeholder group aspect weights are aggregated. The corresponding EGP model is solved for different values of parameter λ (see Appendix 5A; Table 5A.4) to determine the overall sustainability function per stakeholder group. In Table 5.6 sustainability functions for Dutch dairy farming systems are presented for different stakeholders using the *maximum average agreement solution* (I). It should be noted that $U_{external\ social}$ is different between stakeholders.

Table 5.6 Sustainability function (S) for different stakeholders[1]

Stakeholder	*S*
Producers	$0.42U_{Economic} + 0.26U_{Internal\ social} + 0.16U_{External\ social} + 0.16U_{Ecological}$
Consumers	$0.13U_{Economic} + 0.13U_{Internal\ social} + 0.38U_{External\ social} + 0.38U_{Ecological}$
Industrial producers	$0.33U_{Economic} + 0.17U_{Internal\ social} + 0.28U_{External\ social} + 0.22U_{Ecological}$
Policy makers	$0.32U_{Economic} + 0.11U_{Internal\ social} + 0.26U_{External\ social} + 0.32U_{Ecological}$

[1] *maximum average agreement solution*; [2] *U*=Utility function per aspect of sustainability

It is obvious that aspect weights and thus the overall sustainability functions are different between stakeholders groups in the Netherlands. This corresponds with literature concluding that people with different professional and cultural backgrounds view sustainability often quite different (Lowrance et al., 1986; Shearman, 1990; Heinen, 1994; Hardaker et al., 1997; Rigby and Caceres, 2001). Economically dependent stakeholders, i.e. producers and industrial producers, view economic sustainability as most important within the sustainability function. In comparison with policy makers and consumers the economically dependent stakeholders also attach more weight to internal social sustainability. Consumers attach highest weights to external social and ecological sustainability, whereas policy makers attach proportional weights to economic, external social and ecological aspects of sustainability.

5.3.4 Overall sustainability function for society

Stakeholder preferences have to be aggregated to assess the overall sustainability function for society. The corresponding EGP model is solved for different values of parameter λ to calculate the society weights for external social attributes and aspects (see Table 5.1). The input for the EGP model is derived from Table 5.5 and 5.6. It is assumed that stakeholder groups are equally important.

With respect to society weights for external social attributes only two efficient solutions are found (see Table 5.7a). No more efficient solutions are found as preferences of the outliers (i.e. consumers and industrial producers) are scattered around the *maximum average agreement solution* (I) and the *most balanced solution* (Π). Disagreement of consumers (D_2) and industrial producers (D_3) for these solutions is considerable, whereas disagreement of producers (D_1) and policy makers (D_4) is relatively small. This implies that the 'well-being' of consumers and industrial producers is unsatisfactorily treated in comparison with the 'well-being' of producers and policy makers when the presented 'society' solutions are used to express their preferences.

Table 5.7a Society weights for external social attributes for different values of λ[1]

	Λ	Food safety	Animal welfare	Animal health	Landscape quality	Z	D_1 (producers)	D_2 (consumers)	D_3 (industrial producers)	D_4 (policy makers)
Ш	[1-0.99)	0.38	0.29	0.23	0.11	1.02	0.06	0.53	0.33	0.10
I	[0.99-0.33)	0.34	0.28	0.27	0.12	1.02	0.06	0.45	0.42	0.09
П	[0.33-0)	0.33	0.29	0.26	0.11	1.05	0.07	0.43	0.43	0.11
Ш	0	0.34	0.38	0.19	0.09	1.73	0.43	0.43	0.43	0.43

[1] I=maximum average agreement solution, П=most balanced solution, Ш =non-efficient solution; Z=total disagreement of all stakeholders; D=disagreement per stakeholder

Table 5.7b Society weights for aspects for different values of λ[1]

	λ	Economic sustainability	Internal social sustainability	External social sustainability	Ecological sustainability	Z	D_1 (producers)	D_2 (consumers)	D_3 (industrial producers)	D_4 (policy makers)
I, П	[1-0)	0.33	0.13	0.29	0.24	1.06	0.43	0.43	0.12	0.07
Ш	0	0.36	0.11	0.23	0.30	1.46	0.43	0.43	0.12	0.43

[1] I=maximum average agreement solution, П=most balanced solution, Ш=non-efficient solution; Z = total disagreement of all stakeholders; D = disagreement per stakeholder

With respect to society weights for sustainability aspects only one efficient solution can be found (see Table 5.7b). This means that this solution is the *most balanced solution* and the *maximum average agreement solution* at the same time. In comparison with policy makers (D_4) and industrial producers (D_3) disagreement of producers (D_1) and consumers (D_2) is considerable. This implies that no sustainability function for society can be used without harming preferences of individual stakeholders.

5.3.5 Application for different Dutch dairy farming systems

The sustainability function is applied to four experimental farms that can be considered representatives of different dairy farming systems. Characteristics of the experimental dairy farms are presented in Table 5.8.

Table 5.8 Characteristics of experimental dairy farms representing dairy farming systems

	De Marke	**High-tech**	**Low cost**	**Aver Heino**
Type	Conventional	Conventional	Conventional	Organic
Soil type	Clay	Clay	Sand	Sand
Area (ha)	54.9	35	32	67.5
- Grassland (ha)	31.9	22	25.5	57
- Maize (ha)	14.6	13	6.5	1.5
- Arable (ha)	8.4	-	-	9
Milk quota (* 10^3 kg)	658	800	400	682
Milk production (kg per cow)	8780	9619	8220	7410
Fat (%)	4,32	4,35	4,51	4,65
Protein (%)	3,38	3,34	3,36	3,38
Replacement rate (%)	34	35	28	41
Grazing cows (hours per year)	600	0	4290	1290
Grazing young stock (hours per year)	2880	0	4020	3550
Fertiliser (N per ha)	49	143	120	0
Fertiliser (P_2O_5 per ha)	0	47	31	0
Type of housing	Cubicles with slatted floor	Cubicles with slatted floor	Cubicles with slatted floor	Deep litter

The objective of “De Marke” is to design, test and further develop a farming system that can serve as a starting point for the development of dairy farms on dry sandy soils with average intensity (± 12.000 kg per ha). ‘De Marke’ especially aims at reducing environmental problems by focusing on the question to what extent technological options can improve nutrient management on dairy farms offer while maintaining milk production per hectare (Van Keulen et al., 2000). The main objective for the "High-tech" and the "Low-cost" experimental farm is to reduce the cost price per kg of milk on clay soil. Their second objective is to improve the working conditions. The "High-tech" farm represents relatively big family farms (800.000 kg milk quota) on fertile clay soil. On the "High-tech" farm a low cost price per kg milk and improved working conditions are achieved through high productivity per ha (± 23.000 kg milk per ha), high productivity per cow (9619 kg milk per cow) and high productivity per man-hour. High productivity per man-hour is realised by among others, robot milking, automatic feeding and keeping the stock indoors. The "Low-cost" experimental farm represents relatively small family farms (400.000 kg milk quota) on fertile clay soil and focuses on saving costs by reducing inputs, e.g. concentrates and fertiliser, and on saving costs for housing of the cattle. "Aver Heino" converted to organic dairy farming in 1998 and is located on semi-dry sandy soil. The main objective of "Aver Heino" is to focus on conversion problems for farms on sandy soils and on future organic farming systems. Specific research themes are housing systems, maintenance of nitrogen in the system, uptake and efficiency of organic feed and the working of slurry and manure during conversion. The most important standards and requirements for organic dairy farming concern prohibition of the use of artificial fertiliser and chemical-synthetical crop protection; limits to the amount and origin of purchased feed and the obligation for grazing.

Table 5.9 presents the results for the experimental farms on all attribute measures and the corresponding performance for the overall sustainability function. The *maximum average agreement solutions* (I) for society weights (see Table 5.7a and 5.7b) are used to calculate the performance of the experimental dairy farms for the overall sustainability function. The assumption of the conjunctive non-compensatory model, meaning that an insufficient score for one attribute cannot be compensated by high scores for other attributes, implies that only the "Low-cost farm" attains a score for overall sustainability (0.69). If compensation would be allowed the overall sustainability scores would be 0.44 for "De Marke", 0.52 for "High-tech", and 0.48 for "Aver Heino". Still the "Low-cost farm" attains the highest score with respect to overall sustainability.

Table 5.9 Results of experimental farms on sustainability attributes and the corresponding performance for the attribute, aspect and overall Sustainability function

		Sustainability attributes				Sustainability function			
Attribute/aspect	Unit	De Marke	High-tech	Low-cost	Aver Heino	De Marke	High-tech	Low-cost	Aver Heino
Profitability	€ per year	-8,167	31,218	47,537	12,356	—	0.51	0.82	—
Economic sustainability						**—**	**0.51**	**0.82**	**—**
Working conditions	Index score (0-1)	0.35	0.37	0.40	0.37	0.35	0.37	0.40	0.37
Internal social sustainability						**0.35**	**0.37**	**0.40**	**0.37**
Food safety	Index score (0-1)	0.94	0.96	0.88	0.92	0.94	0.96	0.88	0.92
Animal welfare	Index score (0-100)	30.5	25.5	34	35	0.57	0.42	0.67	0.70
Animal health	Index score(0-100)	92	86	87	91	0.90	0.83	0.85	0.89
Landscape quality	Index score (0->35)	63	11	16	45	1.00	—	0.05	1.00
External social sustainability						**0.83**	**—**	**0.71**	**0.86**
Eutrophication	NO_3 eq. per ha	379	984	486	360	0.55	—	0.08	0.60
Groundwater pollution	mg NO_3 per l	61	35	11	33	0.35	0.86	0.99	0.87
Dehydration	m^3 per ha	4010	4948	4749	4215	0.86	0.49	0.60	0.81
Acidification	SO_2 eq. per ha	73	144	65	85	0.53	—	0.69	0.30
Global warming	CO_2 eq. per 1000 kg milk	696	664	771	1030	0.77	0.82	0.68	0.35
Aquatic ecotoxicity	1,4 DCB eq. per ha	126	186	156	122	0.83	0.26	0.64	0.85
Terrestrial ecotoxicity	1,4 DCB eq. per ha	13	20	16	13	0.75	0.08	0.52	0.76
Ecological sustainability						**0.60**		**0.63**	**0.74**
Overall sustainability (non-compensatory approach)						**—**	**—**	**0.69**	**—**
Overall sustainability (compensatory approach)						**0.44**	**0.52**	**0.69**	**0.48**

"De Marke" and "Aver Heino" do not attain a score with respect to economic sustainability. Their insufficient net farm incomes are among others related to: (1) the productivity of the soil type, i.e. sandy soils are less productive and harder to use in an environmental friendly way than clay soils; and (2) the objectives of the experimental farms, i.e. the "High-tech" and "Low-cost" aim mainly for economic sustainability whereas "De Marke" and "Aver Heino" aim for external social and/or ecological sustainability. Differences for internal social sustainability are relatively small as experimental farms have employees whose working conditions, i.e. quantity and quality, are part of their collective employment agreement. "Aver Heino", i.e. the organic dairy farm, attains the highest score for external social sustainability. The High Tech" farm attains no score for external social sustainability as performance for landscape quality is insufficient. Differences between the organic and conventional experimental dairy farms are however relatively small as all experimental farms have to comply with the strictest requirements for external social attributes. The "High-tech" farm attains no score for ecological sustainability, as performances for eutrophication and acidification are insufficient. These insufficient performances are due to the high intensity, i.e. kg milk per hectare, which results in high nitrogen and phosphate surpluses per hectare and high ammonia emissions. Differences for ecological sustainability between the three other experimental farms are small. "De Marke" and "Aver Heino" are located on dry sandy soils, which results in relatively high losses to the environment. "De Marke" and "Aver Heino", especially aiming for a good performance on environmental impact, achieve therefore a relative low score for ecological sustainability. The "Low-cost" farm mainly achieves a good performance for ecological sustainability through low inputs, which results in low surpluses of nitrogen, phosphate and heavy metals.

To identify critical model inputs that may affect the ranking of the experimental farms, several sensitivity analyses are conducted. The sensitivity analyses focuses on the aspect weights and attribute weights. The results are presented in Table 5.10. The base situation, based on society weights (see Table 5.9), is given in the first column of Table 5.10. The ranking of the experimental farms is presented between brackets. In the sensitivity analyses compensation of insufficient scores is allowed (i.e. compensatory approach).

Table 5.10 Effect of sensitivity analysis on the overall sustainability and ranking of experimental dairy farms

Farming system	Solution	De Marke	High-tech	Low-cost	Aver Heino
Base situation	I	0.44 (4)	0.52 (2)	0.69 (1)	0.48 (3)
Producers	I	0.32 (4)	0.49 (2)	0.66 (1)	0.35 (3)
Consumers	I	0.56 (3)	0.50 (4)	0.64 (1)	0.63 (2)
Industrial producers	I	0.44 (4)	0.54 (2)	0.69 (1)	0.47 (3)
Policy makers	I	0.45 (4)	0.51 (2)	0.67 (1)	0.50 (3)
Society	II	0.43 (4)	0.52 (2)	0.69 (1)	0.48 (3)
Producers	II	0.25 (4)	0.50 (2)	0.71 (1)	0.27 (3)
Consumers	II	0.57 (3)	0.50 (4)	0.65 (2)	0.65 (1)
Industrial producers	II	0.53 (4)	0.60 (2)	0.74 (1)	0.57 (3)
Policy makers	II	0.44 (4)	0.53 (2)	0.71 (1)	0.50 (3)

1 I=maximum average agreement solution, Π=most balanced solution

First part of the sensitivity analysis focuses on the effect of stakeholder perceptions on the ranking of different dairy farming systems with respect to sustainability. Stakeholders assessed different aspect weights (see Table 5.6) and attribute weights for external social sustainability (see Table 5.5). Ranking of the experimental farms based on sustainability remains unchanged for producers, industrial producers and policy makers. Differences in sustainability score between experimental farms are larger for producers due to the higher weight for economic sustainability. As expected (see Section 5.3.4), differences between the base situation and the aggregated solutions for policy makers and industrial producers are small. The ranking of the four experimental farms is different for consumers. "Aver Heino" and "De Marke" received a higher sustainability score and ranking as consumers attach more weight to external social and ecological sustainability.

Second part of the sensitivity analysis focuses on the effect of the selected aggregation solution. In the second part the most balanced solution (Π) is used to rank the four experimental dairy farms (see Table 5.7a and 5.7b and Appendix 5A Table 5A.2 and 5A.4). In comparison with the base situation only the ranking of consumers was different. The organic dairy farm "Aver Heino" is ranked highest by the consumers. Difference with the low-cost farm is, however, small.

5.4 Discussion and conclusion

In this research the Multi-Attribute Utility Theory (MAUT), which is part of the Multiple Criteria Decision Making (MCDM) paradigm, is used to construct the sustainability function. The MCDM paradigm is conceptually superior to single criterion methods because they avoid some of the ethical, theoretical and practical shortcomings of conventional economic approaches as this procedure does not require assigning monetary values to non-marketed goods and services (Prato, 1999). Within MCDM approaches MAUT is often referred to as a theoretically sound approach (Keeney and Raiffa, 1976). MAUT is, due to the strong assumptions about the structure of the decision makers preferences, often replaced by other MCDM approaches supported by weaker behavioral assumptions (Cornelissen et al., 2001; Strassert and Prato, 2002; Diaz-Balteiro and Romero, 2004b). Main problem is that preferential assumptions for applying MAUT are not generally easy to test empirically (Diaz-Balteiro and Romero, 2004b). Even without testing these assumptions, MAUT can give satisfactory results and in any event is likely to be less in error than any other practical alternative (Hardaker et al., 1997).

The optimisation of the group consensus through an EGP model seems an attractive method to aggregate assessments of experts and stakeholders as: (1) the procedure can generate solutions with respect to the interests of the majority or the minority, as well as sound compromises between the interests of both groups, (2) different solutions of the EGP model increase the understanding of variation in preferences of respondents, and (3) different solutions can generate useful input for sensitivity analysis. In general the sensitivity analysis shows that within stakeholder groups rankings of the experimental dairy farms are independent of the selected solution, i.e. the *maximum average agreement solution* vs. the *most balanced solution*. This confirms the conclusion (Linares and Romero, 2002) that the *maximum average agreement solution* is appropriate when utility functions or weights are assessed by members of the same social group. Rankings for experimental dairy farms with respect to different stakeholders and society are different only for consumers. This implies that the EGP solution for society gives unsatisfactory results for consumers. This confirms once more that some stakeholders evaluate sustainability of dairy farming systems quite different.

It is difficult to find a representative group of consumers that can be expected to be capable to judge sustainability of dairy farming systems. In this research consumers are represented by animal protection organisations, nature organisations and consumer organisations. These groups represent themselves as consumers in the public debate about sustainable dairy farming in the Netherlands. These organisations however focus on specific aspects of sustainability, i.e. external social and ecological, and hold a strong view on these aspects. It can be expected that 'average' consumers hold a less strong view and allocate less weight to these aspects of sustainability.

The presented method is applied to four experimental dairy farms. Although these experimental dairy farms can be considered as representative for different farming systems it is difficult to draw conclusions regarding the sustainability of these farming systems as non farming systems related factors, e.g. soil type, significantly affect the sustainability of these experimental farms. A justified comparison for sustainability between these farming systems can be done by using a multiple goal programming model in which non farming systems related factors can be kept constant.

Despite the simplifications made, the sustainability function based on MAUT showed to be a suitable method to compare and rank different dairy farming systems. Furthermore the model is found to produce very stable rankings, which are relatively insensitive to changes in attribute and aspect weights. Based on these results it is concluded that the method based on stakeholder and expert perceptions can be used with reasonable confidence to determine the sustainability of different dairy farming systems. Although the developed overall sustainability function is applied to Dutch dairy farming, it can be used for other agricultural sectors and for other countries as well.

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Appendix 5A

In the Tables in Appendix 5A the following notations will be used: Z = indicator of consensus; D = maximum disagreement of one respondent; I=*maximum average agreement solution*; П=*most balanced solution*; Ш=*non-efficient solution*; IV=*compromise solution*

Table 5A.1 Utility values for ecological attributes for different values of parameter λ[1]

Attribute measure		λ	k = 1	k = 2	k = 4	Z	D
Eutrophication Potential	I	[1-0,49)	500	100	0.75	0.81	0.35
(NO_3 eq. per ha)	IV	[0,49-0,24)	600	100	0.80	0.86	0.30
	П	[0,16-0)	600	200	0.82	1.17	0.20
Nitrate concentration in groundwater	I	[1-0,5)	70	10	0.80	0.86	0.29
(mg/l)	IV	[0,5-0,25)	70	15	0.80	0.90	0.25
	П	[0,24-0)	70	20	0.83	1.08	0.19
Water use (m^3 per ha)	I	[1-0,24)	5500	3000	0.80	0.61	0.19
	П	[0,24-0)	5500	3000	0.87	0.79	0.13
Acidification Potential	I	[1-0,49)	100	50	0.50	0.70	0.26
(SO_2 eq. per ha)	IV	[0,49-0,24)	100	50	0.67	0.76	0.20
	П	[0,24-0)	100	50	0.73	0.88	0.16
Global Warming Potential	I	[1-0,49)	1000	400	0.50	0.54	0.18
(CO_2 eq. per 1000 kg milk)	IV	[0,49-0,24)	1100	500	0.50	0.58	0.15
	П	[0,16-0)	1200	600	0.52	0.77	0.10
Aquatic EcoToxicity Potential	I	[1-0,50)	200	50	0.83	1.44	0.31
(1,4 DCB eq. per ha)	П	[0,50-0)	200	36	0.80	1.52	0.24
Terrestrial EcoToxicity Potential	I	[1-0,49)	20	0	0.88	1.56	1.14
(1,4 DCB eq. per ha)	IV	[0,49-0,24)	20	0	0.89	1.62	1.08
	П	[0,12-0)	30	4.4	0.91	4.82	0.60

[1] k=1=starting point, k=2=end point, and k=4=utility value intermediate point

Chapter 5

Table 5A.2 Weights (w_i) attached to each external social attribute by different stakeholders for different values of parameter λ [1]

Stakeholder		λ	w_{31}	w_{32}	w_{33}	w_{34}	Z	D
Producers	I	[1-0.16)	0.37	0.26	0.26	0.11	35.23	0.95
	IV	[0.09-0.04)	0.33	0.28	0.28	0.11	36.64	0.90
	Π	[0.01-0)	0.38	0.25	0.31	0.06	41.31	0.80
Consumers	I	[1-0.33)	0.11	0.43	0.34	0.11	3.45	0.68
	Π	[0.33-0)	0.12	0.45	0.30	0.12	3.55	0.63
Industrial producers	I	[1-0.33)	0.55	0.15	0.20	0.10	2.75	0.71
	Π	[0.33-0)	0.60	0.10	0.20	0.09	2.96	0.60
Policy makers	I	[1-0.33)	0.33	0.28	0.22	0.17	3.63	1.10
	IV	[0.20-0.14)	0.35	0.29	0.18	0.18	3.77	1.05
	Π	[0.11-0)	0.55	0.45	0.00	0.00	5.97	0.75

[1] w_{31} = food safety, w_{32} = animal welfare, w_{33} = animal health, and w_{34} = landscape quality

Table 5A.3 Normalised weights (w_i)[1] attached to each ecological attribute for different values of parameter λ

λ		w_{41}	w_{42}	w_{43}	w_{44}	w_{45}	w_{46}	w_{47}	Z	D
[1-0.5)	I	0.32	0.21	0.05	0.21	0.05	0.11	0.05	4.09	0.85
[0.5-0.25)	IV	0.33	0.17	0.06	0.22	0.06	0.11	0.06	4.14	0.80
[0.16-0)	Π	0.33	0.16	0.00	0.22	0.11	0.11	0.06	4.48	0.70

[1] w_{41}=eutrophication, w_{42}=groundwater pollution, w_{43}=dehydration, w_{44}=acidification, w_{45}=global warming, w_{46}=aquatic ecotoxicity and, w_{47}=terrestrial ecotoxicity

Table 5A.4 Normalised weights attached to each aspect of sustainability by different stakeholders for different values of parameter λ [1]

Stakeholder		λ	W_1	W_2	W_3	W_4	Z	D
Producers	I	[1-0.04)	0.42	0.26	0.16	0.16	34.15	1.15
	Π	[0.02-0.01)	0.53	0.24	0.12	0.12	40.55	0.95
Consumers	I	[1-0.33)	0.13	0.13	0.38	0.38	3.70	0.80
	Π	[0.33-0)	0.13	0.06	0.38	0.44	3.90	0.70
Industrial producers	I	[1-0.33)	0.33	0.17	0.28	0.22	3.80	1.00
	IV	[0.19-0.14)	0.32	0.11	0.32	0.26	4.30	0.85
	Π	[0.11-0)	0.31	0.00	0.37	0.31	5.30	0.70
Policy makers	I	[1-0.33)	0.32	0.11	0.26	0.32	1.59	0.35
	IV	[0.33-0.2)	0.31	0.10	0.25	0.34	1.65	0.32
	Π	[0.2-0)	0.31	0.09	0.26	0.34	1.72	0.30

[1] W_1=economic sustainability, W_2=internal social sustainability, W_3=external social sustainability, and W_4=ecological sustainability

References

Anderson, J.R., Dillon, J.L. and Hardaker, J.B., 1977. *Agricultural decision analysis*. The Iowa State University Press, US: Iowa.

Arrow, K.J., 1963. *Social choice and individual values*. John Wiley & Sons, US: New York.

Bottomley, P.A. and Doyle, J.R., 2001. A comparison of three weight elicitation methods: good, better, and best. *Omega-International Journal of Management Science* 29: 553-560.

Callens, I. and Tyteca, D., 1999. Towards indicators of sustainable development for firms. A productive efficiency perspective. *Ecological Economics* 28: 41-53.

Clemen, R.T., 1991. *Making hard decisions: an introduction to decision analysis*. PWS-Kent Publishing Company, US: Boston.

Cornelissen, A.M.G., Van den Berg, J., Koops, W.J., Grossman, M. and Udo, H.M.J., 2001. Assessment of the contribution of sustainability indicators to sustainable development: anovel approach using fuzzy set theory. *Agriculture, Ecosystems and Environment* 86: 173-185.

De Boer, I.J.M. and Cornelissen, A.M.G., 2002. A method using Sustainability indicators to compare conventional and animal-friendly egg production systems. *Poultry Science* 81: 173-181.

Diaz-Balteiro, L. and Romero, C., 2004a. In search of a natural systems sustainability index. *Ecological Economics* 49: 401-405.

Diaz-Balteiro, L. and Romero, C., 2004b. Sustainability of forest management plans: a discrete goal programming approach. *Journal of Environmental Management* 71: 351-359.

Fischer, G.W., 1995. Range Sensitivity of Attribute Weight in Multiattribute Value Models. *Organizational Behavior and Human Decision Processes* 62: 252-266.

Gonzalez-Pachon, J. and Romero, C., 1999. Distance-based consensus methods: a goal programming approach. *Omega-International Journal of Management Science* 27: 341-347.

Hanley, N., Moffatt, I., Faichney, R. and Wilson, M., 1999. Measuring sustainability: a time series of alternative indicators for Scotland. *Ecological Economics* 28: 55-73.

Hansen, J.W., 1996. Is agricultural sustainability a useful concept? *Agricultural Systems* 50: 117-143.

Hardaker, J.B., Huirne, R.B.M. and Anderson, J.R., 1997. *Coping with risk in agriculture*. CAB International, US: New York.

Heinen, J.T., 1994. Emerging, diverging and converging paradigms on sustainable development. *International Journal of Sustainable Development and World Ecology* 1: 22-33.

Hogarth, R.M., 1987. *Judgement and choice: the psychology of decision*. Wiley, UK: Chichester.

Huirne, R.B.M. and Hardaker, J.B., 1998. A multi-attribute utility model to optimise sow replacement decisions. *European Review of Agricultural Economics* 25: 488-505.

Keeney, R.L. and Raiffa, H., 1976. *Decisions with multiple objectives: preferences and value tradeoffs*. John Wiley & Sons, US: New York.

Linares, P. and Romero, C., 2002. Aggregation of preferences in an environmental economics context: a goal-programming approach. *Omega-International Journal of Management Science* 30: 89-95.

Lowrance, R., Hendrix, P.F. and Odum, E.P., 1986. A hierarchical approach to sustainable agriculture. *American Journal of Alternative Agriculture* 1: 169-173.

Pacini, C., Wossink, A., Giesen, G., Vazzana, C. and Huirne, R., 2003. Evaluation of sustainability of organic, integrated and conventional farming systems: a farm and field-scale analysis. *Agriculture Ecosystems & Environment* 95: 273-288.

Pöyhönen, M. and Hämäläinen, R.P., 1998. Notes on the weighting biases in value trees. *Journal of Behavioral Decision Making* 11: 139-150.

Pöyhönen, M. and Hämäläinen, R.P., 2001. On the convergence of multiattribute weighting methods. *European Journal of Operational Research* 129: 569-585.

Prato, T., 1999. Multiple attribute decision analysis for ecosystem management. *Ecological Economics* 30: 207-222.

Rigby, D. and Caceres, D., 2001. Organic farming and the sustainability of agricultural systems. *Agricultural Systems* 68: 21-40.

Rigby, D., Woodhouse, P., Young, T. and Burton, M., 2001. Constructing a farm level indicator of sustainable agricultural practice. *Ecological Economics* 39: 463-478.

Romero, C. and Rehman, T., 2003. *Multiple criteria analysis for agricultural decisions*. Elsevier, The Netherlands: Amsterdam.

Shearman, R., 1990. The Meaning and Ethics of Sustainability. *Environmental Management* 14: 1-8.

Stewart, T.J., 1996. Robustness of additive value function methods in MCDM. *Journal of Multi-Criteria Decision Analysis* 5: 301-310.

Strassert, G. and Prato, T., 2002. Selecting farming systems using a new multiple criteria decision model: the balancing and ranking method. *Ecological Economics* 40: 269-277.

Tamiz, M., Jones, D. and Romero, C., 1998. Goal programming for decision making: an overview of the current state of the art. *European Journal of Operational Research* 111: 569-581.

Taylor, D., Mohamed, Z., Mohayidin, M. and Chiew, E., 1993. Creating a Farmer Sustainability Index: A Malaysian Case Study. *American Journal of Alternative Agriculture* 8: 175-184.

Van Calker, K.J., Berentsen, P.B.M., Giesen, G.W.J. and Huirne, R.B.M., 2005. Identifying and ranking attributes that determine sustainability in Dutch dairy farming. *Agriculture and Human Values* 22: 53-63.

Van Calker, K.J., Berentsen, P.B.M., De Boer, I.J.M., Giesen, G.W.J. and Huirne, R.B.M., 2004a. An LP-model to analyse economic and ecological sustainability on Dutch dairy farms: model presentation and application for experimental farm "de Marke". *Agricultural Systems* 82: 139-160.

Van Calker, K.J., Berentsen, P.B.M., De Boer, I.J.M., Giesen, G.W.J. and Huirne, R.B.M., 2004b. Modeling social sustainability at farm level: model presentation and application for a conventional and organic dairy farming system. *Submitted*

Van Keulen, H., Aarts, H.F.M., Habekotte, B., van der Meer, H.G. and Spiertz, J.H.J., 2000. Soil-plant-animal relations in nutrient cycling: the case of dairy farming system 'De Marke'. *European Journal of Agronomy* 13: 245-261.

Verhagen, C., 2003. *Sustainability of Dutch dairy farming: comparison of four experimental farms*. MSc-thesis, Wageningen University, Wageningen.

Von Nitzsch, R. and Weber, M., 1993. The effect of attribute ranges on weights in multiattribute utility measurements. *Management Science* 39: 937-943.

Weber, M., Eisenfuhr, F. and Vonwinterfeldt, D., 1988. The Effects of Splitting Attributes on Weights in Multiattribute Utility Measurement. *Management Science* 34: 431-445.

Chapter 6

Maximising sustainability of Dutch dairy farming systems for different stakeholders by means of modelling

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Abstract

By means of Weighted Goal Programming a multi-attribute sustainability function is integrated into a dairy farm LP-model to create a Weighted Linear Goal Programming (WLGP)-model that maximises sustainability of different farming systems. The WLGP-model is used to analyse the impact of: (1) maximisation of individual sustainability aspects and (2) maximisation of overall sustainability using stakeholder preferences. Showing the maximum possible scores per sustainability aspect appears to be more informative than showing the 'aggregated' overall sustainability scores per stakeholder. It is concluded that the WLGP model is a suitable tool to analyse the sustainability of different dairy farming systems.

6.1 Introduction

Developments in modern agriculture have led to doubts regarding the sustainability of conventional farming systems (Rigby et al., 2001). At the same time society increasingly values alternative farming systems for their potential to enhance wildlife and landscape, to decrease environmental harm caused by farming practices and to improve animal health, animal welfare and food safety (Pacini et al., 2003). As a result, the market share of alternative farming systems with emphasis on these aspects of sustainability, i.e. ecological and social sustainability, is growing (Rigby and Caceres, 2001).

To analyse sustainability of agricultural systems, the concept of sustainability has to be made operational and appropriate methods need to be designed for its measurement (Heinen, 1994). Reaching agreement on a more precise, operational definition of sustainable agriculture is extremely problematic, partly because there are different stakeholders (e.g. consumers and producers) involved in the debate (Rigby and Caceres, 2001). Especially the importance attached to each of the sustainability aspects, i.e. economic, social and ecological sustainability, is often different between stakeholders (Heinen, 1994; Rossing et al., 1997; Ten Berge et al., 2000; Rigby and Caceres, 2001; Van Calker et al., 2005c). In the current paper a methodology for assessing sustainability of Dutch dairy farming systems is used as starting point (Van Calker et al., 2005c). In this methodology, different stakeholders and experts assessed utility functions per attribute and assigned weights to sustainability attributes and aspects. Building on this, an overall sustainability score per stakeholder for different dairy farming systems can be calculated.

Farm modelling gives the opportunity to evaluate current and future farming systems by including the perceptions of different stakeholders, i.e. including different weights for sustainability aspects. Furthermore, farm modelling can be a way to analyse differences in sustainability between dairy farming systems as exogenous factors (e.g. soil type), independent of a particular farming system, can be excluded. Although several dairy farm models (Herrero et al., 1999; Ten Berge et al., 2000; Pacini et al., 2004) are developed to determine sustainability aspects, i.e. economic, social and ecological, none of these models included sustainability in an aggregated way for different stakeholders.

The objective of this paper is to present and apply a model that maximises 'aggregated' overall sustainability of dairy farming systems. The presented model builds upon a dairy farm model in which economic, social and ecological attributes are included (Van Calker et al., 2004; Van Calker et al., 2005b). The new feature of the presented model is the integration of the sustainability assessment methodology (i.e. utility function per attribute, attribute weights, and aspect weights) into the dairy farm model. In this way sustainability can be maximised per aspect or in an aggregated way by using preferences of stakeholders. The model is used to simulate a conventional and an organic dairy farming system to analyse the impact of: (1) maximisation of individual sustainability aspects and (2) maximisation of 'aggregated' overall sustainability using stakeholder preferences. In this way the potential of different dairy farming systems concerning all aspects of sustainability is analysed and the effects of stakeholder preferences on overall sustainability are shown.

6.2 Material and methods

6.2.1 Assessment of sustainability for Dutch dairy farming systems

A sustainability assessment system, referred to as the overall sustainability function (also called 'Dairy Farm Sustainability' Index; in Dutch 'BedrijfsDuurzaamheidsScore'), is used as starting point. The overall sustainability function is based on Van Calker et al. (2004; 2005b; 2005a; 2005c) and includes economic, internal social, external social and ecological aspects of sustainability. Economic sustainability is defined as the ability of the dairy farmer to continue his farming business (economic viability). Internal social sustainability relates to qualitative and quantitative working conditions for the farm operator and employees. External social sustainability deals with societal concern about the impact of agriculture on the well being of people and animals. Ecological sustainability concerns threats or benefits to flora, fauna, soil, water and climate (Van Calker et al., 2005a).

Within each aspect of sustainability, experts and/or stakeholders were consulted to assess relevant attributes (Van Calker et al., 2005a). The final set of attributes was selected on the basis of relative importance, possibility for quantification and sensitivity towards differences within and between farming systems. Subsequently indicators for these sustainability attributes were identified and selected (Van Calker et al., 2004; Van Calker et al., 2005b). The aspects, attributes and corresponding indicators of the overall sustainability function are listed in the first and second column of Table 6.1.

Table 6.1 Utility functions and stakeholder weights for all aspects and indicators of sustainability in dairy farming[1]

Aspect *- Attribute 1* *- Attribute 2* *- Attribute n*	*Indicator (unit)*	*Utility function*	$W_{producers}$	$W_{consumers}$	$W_{indus.\ prod.}$	$W_{policy\ makers}$	$W_{society}$
Economic			**0.42**	**0.13**	**0.33**	**0.32**	**0.33**
- Profitability	Net farm income (€)	$1.067[1-\exp(-0.000050(x_{11}-18000))]$	1	1	1	1	1
Internal social			**0.26**	**0.13**	**0.17**	**0.11**	**0.13**
- Working conditions	Physical Load Index[2]	$0.5x_{21a} + 0.5x_{21b}$	1	1	1	1	1
External social			**0.16**	**0.38**	**0.28**	**0.26**	**0.29**
- Food safety	Chain Food Safety Index	$0.5x_{31a} + 0.5x_{31b}$	0.37	0.11	0.55	0.33	0.34
- Animal welfare	Animal Need Index (TGI-35L)	$0.029x_{32}-0.319$	0.26	0.43	0.15	0.28	0.28
- Animal health	Animal Health index	$0.012x_{33} - 0.190$	0.26	0.34	0.20	0.22	0.27
- Landscape quality	Agricultural Nature Norm Analysis	$0.0476x_{34} - 0.714$	0.11	0.11	0.10	0.17	0.12
Ecological			**0.16**	**0.38**	**0.22**	**0.32**	**0.24**
- Eutrophication	Eutrophication Potential (NO_3^- equiv./ha)	$1.125[1-\exp(0.00549(x_{41}-500))]$	0.32	0.32	0.32	0.32	0.32
- Groundwater quality	Nitrate conc. in groundwater (NO_3^- mg/l)	$1.067[1-\exp(0.046210(x_{42}-70))]$	0.21	0.21	0.21	0.21	0.21
- Dehydration of the soil	Water use (m^3/ha)	$1.067[1-\exp(0.001109(x_{43}-5500))]$	0.05	0.05	0.05	0.05	0.05
- Acidification	Acidification Potential (SO_2 equiv./ha)	$-0.02x_{44} + 2$	0.21	0.21	0.21	0.21	0.21
- Global Warming	Global Warming Potential (CO_2 equiv./1000 kg milk)	$-0.0017x_{45} + 1.667$	0.05	0.05	0.05	0.05	0.05
- Terrestrial ecotoxicity	Terrestrial Ecotoxicity Potential (1,4 dicholorobenzene equiv./ha)	$1.042[1-\exp(0.021459(x_{46}-200))]$	0.05	0.05	0.05	0.05	0.05
- Aquatic ecotoxicity	Aquatic Ecotoxicity Potential (1,4 dicholorobenzene equiv./ha)	$1.021[1-\exp(0.194591(x_{47}-20))]$	0.11	0.11	0.11	0.11	0.11

[1] x_{ki} = performance of farming system on the *i*th indicator of the *k*th aspect (where 1 = economic sustainability, 2= internal social sustainability, 3 = external social sustainability, 4 = ecological sustainability) and W= weight; [2] x_{21a} = Physical Load index for back disorders and x_{21b} =Physical Load Index for upper extremity; [3] x_{31a} = Chemical food safety and x_{31b} = microbiological food safety

In the overall sustainability function, all indicators for sustainability are integrated into one index that reveals the sustainability of a particular farming system. The development of the overall sustainability function consisted of four steps (Van Calker et al., 2005c): (1) determination of a utility function per indicator; (2) assessment indicator weights to determine a utility function for each aspect of sustainability per stakeholder group; (3) assessment of aspect weights to determine the overall sustainability function per stakeholder group; and (4) aggregation of preferences of all stakeholder groups to determine the overall sustainability function for society. Experts were involved if assessments could be made objectively. Stakeholders, i.e. primary producers, consumers, industrial producers, and policy makers, were involved if assessments were expected to depend strongly on preferences. A detailed description of the overall sustainability function can be found in Van Calker et al. (2005c).

Table 6.1 presents the utility functions in the third column and the assessed weights for all aspects and indicators per stakeholder in the next columns. The bold weights give the weights of the aspects per stakeholder group. The other weights are the weights assigned to the attributes within the particular aspect that sum up to one. Within economic and internal social sustainability only one attribute was selected meaning that the weight of the concerning attribute is 1.

The score for the overall sustainability function is determined as follows: (1) for each indicator the utility score, where 1 equals the ideal value and 0 equals the anti-ideal value, is determined by inserting the performance, i.e. x_{ki}, of the farming system on the indicator into the utility function, (2) all utility scores are multiplied by the weight per indicator and summed per aspect, and (3) these sums are multiplied by the weight per aspect and summed again. The ideal and anti-ideal values for all sustainability indicators are presented in Appendix 6A. The weights for society as a whole are based upon the aggregation of the weights per stakeholder group (clarification can be found in Van Calker et al., 2005c).

In principle a non-compensatory approach is assumed in the sustainability assessment system. This implies that if a farming system achieves a performance worse than the anti-ideal value, then the specific farming system is considered unsustainable with respect to the concerning attribute and it will not receive a score for the overall sustainability function. Farming systems that perform at least at the anti-ideal value for all indicators receive a score for overall sustainability that is between 0, i.e. minimum level of sustainability and 1, i.e. maximum level of sustainability.

6.2.2 Model description

Linear Programming (LP) is well suited for maximisation of 'aggregated' overall sustainability as LP-models provide an optimum seeking procedure. In this research an existing dairy farm LP-model is used as starting point. The sustainability function is included in the objective function of the adapted model to maximise the overall sustainability of different farming systems per stakeholder.

Dairy farm LP-model

The basic structure of the existing dairy farm LP-model (Berentsen and Giesen, 1995) has the form of a standard linear programming model:

Maximise $[Z=c'x]$

Subject to $Ax \leq b$

and $x \geq 0$

where x = vector of activities; c = vector of gross margins per unit of activity; A = matrix of technical coefficients; and b = vector of right hand side values. The objective function maximises net farm income, i.e. economic sustainability. Annualised capital costs are fixed in the model but can be different between situations.

The model contains activities for common production processes on Dutch dairy farms (e.g. grass and silage maize production, and milk production). Constraints are included in the model for available fixed assets (e.g. land area and milk quota). Links between different activities (i.e. feeding requirements versus feed production and feed purchase) form another type of constraints in the model. Environmental policy is included as a constraint on the basis of the MINeral Accounting System (MINAS; Ondersteijn et al., 2002). Van Calker et al. (2004) describe how the economic and ecological indicators are included in the dairy farm LP-model and Van Calker et al. (2005b) describe how internal social and external social indicators are included.

Weighted Linear Goal Programming model

Goal Programming is a technique that aims to optimise several goals simultaneously. In Weighted Goal Programming (WGP) or Archimedean Goal Programming all goals are considered simultaneously and the relative importance of the individual goals is part of the objective function (Romero and Rehman, 2003). The overall sustainability function can be included in the objective function of a WGP model as WGP models can maximise a separable and additive sustainability function (Tamiz et al., 1998). For this reason this paper integrates the multi-attribute sustainability function, by means of WGP, into the dairy farm LP-model to create a Weighted Linear Goal Programming (WLGP)-model that maximises sustainability of different farming systems.

In general, WGP considers all the goals, i.e. indicators, simultaneously in a composite objective function, which minimises the sum of all the deviations of the individual goals from their target levels. The goals are included in the objective function by converting the accounting row for each indicator to equalities through the addition of positive and negative deviation variables that allow for under- and over-achievement of the target level of each indicator (Romero and Rehman, 2003). The ideal value for each indicator is used as target level in the model. Negative deviation variables are included in the objective function for indicators that are of the type ‘more is better’ (e.g. net farm income) and positive deviation variables are included in the objective function for indicators that are of the type ‘less is better’ (e.g. Eutrophication Potential).

The deviation variables of the sustainability indicators, measured in different units, have to be normalised to include the overall sustainability function correctly in the WLGP-model. Deviation variables are normalised, therefore, using an adapted percentage normalisation technique (Tamiz et al., 1998). In this research the normalisation constant is the ideal value minus the anti-ideal value (see Appendix 6A) divided by hundred. In this way the relevant ranges of indicator values are taken into account and the deviation variable is expressed as percentage under- or overachievement of the ideal value. As a result the objective function minimises the total percentage sum of deviations from all indicators.

By including the deviation variables in this manner a deviational variable is penalised according to a constant marginal penalty; in other words, any marginal change is of equal importance no matter how distant it is from the ideal value (Romero, 1991; Tamiz et al., 1998). This assumption holds for indicators with linear utility functions but is inaccurate for indicators with non-linear utility functions. For non-linear utility functions the improvement from the anti-ideal value to the intermediate value is more important than the improvement from the intermediate value to the ideal value. These kind of non-linear utility functions can be included by using a piecewise linear approximation (Williams, 1990; Jones and Tamiz, 1995). This implies that non-linear utility functions need to be separated into two straight-line segments. These additional straight-line segments are included as constraints in the WLGP-model. The intermediate value is then used as target value for the new constraint. For net farm income for example, the increase from €18,000, i.e. anti-ideal value, to €46,000, i.e. intermediate value, is according to economic experts 4 times more important than the increase from €46,000 to €74,000, i.e. ideal value (Van Calker et al., 2005c). This means that a ‘penalty’ weight of 0.75, i.e. $\frac{(4-1)}{4}$, is attached to the deviation variable that measures the underachievement related to the intermediate value and a ‘penalty’ weight of 0.25 is attached to the deviation variable that measures the underachievement related to the ideal value. Appendix 6A presents the ‘penalty’ weights and the intermediate values for the non-linear utility functions.

To maximise overall sustainability, aspect and indicator weights have to be attached to the deviations in the objective function. The attached weights per indicator can be calculated from Table 6.1. The society weight for Eutrophication Potential, for example, is calculated by

multiplying the individual indicator weight by the aspect weight, i.e. *0.32 * 0.24 = 0.08*. By including the indicator weights (w_{ij}) of the separate stakeholders, sustainability can be maximised per stakeholder.
The WLGP formulation of the overall sustainability problem for stakeholder *j* under the compensatory approach is:

Objective function

$$Minimise\ z = \left[\sum_{i=1}^{q} (w_{ij} \times (\frac{\alpha_{i1} n_{i1} + \beta_{i1} p_{i1}}{[f_{i1} - f_{i3}]}) \times 100 + \sum_{i=1}^{q} (w_{ij} \times (\frac{\alpha_{i2} n_{i2} + \beta_{i2} p_{i2}}{[f_{i1} - f_{i3}]}) \times 100 \right]$$

Goals and constraints

$$f_i(x_{ki}) + n_{i1} - p_{i1} = f_{i1}\ ,\ i \in \{1,....., q\}$$

$$f_i(x_{ki}) + n_{i2} - p_{i2} = f_{i2}$$

$$x_{ki} \geq 0,\ j \in \{1,..5\},\ n \geq 0,\ p \geq 0\ .$$

x_{ki} is the contribution of a decision variable to the *i*th indicator of the *k*th aspect, f_{i1} is the ideal value for the *i*th indicator, n_{i1} and p_{i1} are negative and positive deviations from the ideal value of the *i*th indicator, f_{i2} is the intermediate value for the *i*th indicator, n_{i2} and p_{i2} are negative and positive deviations from the intermediate value of the *i*th indicator, f_{i3} is the anti-ideal value for the *i*th indicator, α_{i1} is the ‘penalty’ weight for the *under*achievement related to the ideal value, β_{i1} is the ‘penalty’ weight for the *over*achievement related to the ideal value, α_{i2} is the ‘penalty’ weight for the *under*achievement related to the intermediate value, β_{i2} is the ‘penalty’ weight for the *over*achievement related to the intermediate value, w_{ij} is the indicator weight for the *i*th indicator concerning the *j*th stakeholder (where 1 = society, 2 = consumers, 3 = producers, 4 = industrial producers and 5 = policy makers).

For linear utility functions the ‘penalty’ weight for the overachievement or underachievement with respect to the intermediate value (α_{i2} and β_{i2}) equals 0, meaning that the second term of the objective function is not included for these indicators. The ‘penalty weights’ of linear utility functions in the first term logically equal 1. By using the above-formulated model a solution is obtained that provides the maximum overall sustainability per stakeholder (Romero, 2004).

6.2.3 Organisation of the analysis

The model is used to maximise 'aggregated' overall sustainability and to maximise sustainability per aspect for two different dairy farming systems, i.e. conventional vs. organic dairy farming, located on sandy soil. The average structure of a conventional dairy farm in the Netherlands in 2002 (see Table 6.2) is used as starting point and originates from the Farm Accountancy Data Network (Poppe, 2004).

Table 6.2 Farm structure and farm characteristics of a Dutch conventional and organic dairy farm

	Conventional	Organic
Area (ha)	37	37
Milk quota (*10^3 kg)	465	465
Milk production (kg/year)	7,500	6,500
Fat (%)	4.45	4.45
Protein (%)	3.47	3.47
Replacement rate (%)	34	30
Use chemical fertiliser	Yes	No
Use of chemical crop protection	Yes	No
Grazing	Optional	Mandatory
Purchase of feed	Conventional	Organic
Application of manure (Kg N per ha)	No maximum	Max. of170
Amount of concentrates in ration (%)	No maximum	Maximum of 40%
Milk for calves	Artificial milk	Raw milk

In contrast to conventional livestock production, organic livestock production is defined by basic guidelines (Sundrum, 2001). In general these guidelines provide that (SKAL, 2002): (1) application of artificial fertiliser is not allowed, (2) chemical-synthetic crop protection is not allowed, (3) inputs are organically produced, (4) feeding calves with artificial milk is not allowed, (5) maximum application of animal manure is 170 kg N per hectare, (6) under sufficient weather conditions dairy cows and young stock should be given access to outdoors, fresh air and sunlight, (7) in the daily ration a minimum amount of 60% of dry matter intake should be originating from roughage, (8) preventive use of allopathic medicine and antibiotics is not allowed. Milk production per cow in organic farming is assumed to be 1000 kg lower than milk production per cow in conventional farming. The lower milk production is a result of the lower amount of concentrates in the ration for organic dairy cows and the differences in breeding goals between organic and conventional dairy farming (Berentsen et al., 1998). The replacement rate is lower for organic dairy farming as the average age of organic dairy cows is higher than the average age of conventional dairy cows (Reksen et al., 1999; Evers and De

Haan, 2004). In this research it is assumed that the conventional as well as the organic dairy farm apply restricted grazing, i.e. 10 hours per day, during spring and summer. This is a reasonable approach as still 85% of all Dutch dairy farms applies grazing (Luesink et al., 2005). Furthermore, it is assumed that conventional dairy farms apply a minimum of 170 kg nitrogen from animal manure per hectare.

First, the maximum score for individual sustainability aspects is analysed. This is done by adapting the weights attached to the negative and positive deviation variables in the objective function. Three situations will be analysed[1]: (1) maximisation of economic sustainability, i.e. all weight is set on economic sustainability, (2) maximisation of external social sustainability, i.e. all weight is set on external social sustainability, and (3) maximisation of ecological sustainability, i.e. all weight is set on ecological sustainability. Second, consumer, producer and society weights are used in the WLGP model to analyse the maximum sustainability of the organic and conventional dairy farming system. The compensatory and the non-compensatory approach are used for all situations. In this way the effect of stakeholder perception on the maximum sustainability of both farming systems and the robustness of the solutions can be analysed. Moreover, individual stakeholder analysis shows how the scores per sustainability aspect deviate from the maximum achievable scores for these aspects. Results of calculations with weights of policy makers and industrial producers are not included in this paper as these weights are almost similar with society (Van Calker et al., 2005c).

6.3 Results

First, the technical and overall sustainability results are presented for the conventional dairy farm. Second, the technical and overall sustainability results are presented briefly for the organic dairy farm. Results are presented for the compensatory approach extensively as this approach gives more insight into the maximum sustainability per aspect and into the maximum overall sustainability. The results for the non-compensatory approach are discussed briefly at the end of the conventional and organic section.

6.3.1 Conventional dairy farming system

Technical results

Table 6.3 presents the technical, economic and environmental results from the maximisation per aspect of sustainability (column 2 through 4) and the maximisation using the preferences

[1] The maximisation of internal social sustainability is not included as these results show insufficient change in the Physical Load Index

of consumers, producers and the society as a whole (column 5 through 7). For all solutions the number of dairy cows for the conventional dairy farming system is 62 and the number of young stock is 43. These numbers are determined by the available milk quota, the milk production per cow and the replacement rate.

Table 6.3 Technical results for maximisation of sustainability under the *compensatory* approach for a Dutch *conventional* dairy farm using different weights

Used weights	Aspect of sustainability[1]			Stakeholder[2]		
	Economic	External social	Ecological	Consumers	Producers	Society
Land use (ha)						
- conventional grassland	15.7	17.7	13.6	15.2	17.5	16.2
- N application grassland (kg mineral N)	369	384	300	286	295	314
- herbaceous grassland	21.3	17.8	0	1	14.1	19.1
- meadow bird grassland	0	1	19.6	19.1	0	1
- maize	0	0	0	0	4.8	0
- ground maize ear silage	0	0	1.1	0.6	0	0
- triticale	0	0	2.1	0.4	0	0
- nature elements	0	0.5	0.6	0.6	0.6	0.7
Purchase of feed (per year)						
- roughage (GJ NEL[2])	1113	1409	1094	1133	893	1218
- byproducts (GJ NEL[2])	149	156	157	157	157	157
- concentrates (GJ NEL[2])	590	208	388	401	478	497
Environmental results						
- manure disposal (m^3)	0	198	385	383	0	368
- purchase of artificial fertiliser (kg N per ha)	85.3	123.8	76.5	72.4	92.6	89.0
- N surplus (kg/ha)	205.2	202.0	133.8	133.1	196.9	165.4
- P_2O_5 surplus (kg/ha)	22.0	8.6	0	1.4	14.0	7.3
Economic results (K€)						
- gross revenues	195.3	193.2	185.0	186.3	189.1	194.8
- costs	164.8	173.7	165.4	171.6	163.1	171.5
- net farm income	30.5	19.4	19.6	14.8	26.0	23.3

[1] The concerning aspect of sustainability is maximised;

[2] Weights per stakeholder (see Table 6.2) are used to maximise overall sustainability

For economic maximisation the area of herbaceous grassland is maximised as the subsidies for nature conservation compensate the purchase of additional roughage, byproducts or concentrates which is a result of a lower energy and protein production of herbaceous grassland. This lower feed quantity and quality is a result of the limited amount of manure that can be applied on herbaceous grassland and the exclusion of the use of pesticides and artificial fertilisers. Herbaceous grassland is, due to the low feed quality, available only for young stock, i.e. fresh grass and grass silage, and dry cows, i.e. grass silage. Conventional grassland is required in the cropping plan to comply with the feeding requirements of the dairy cows during grazing and in the winter ration. The applied amount of mineral nitrogen on conventional grassland is restricted by high taxes within the Dutch MINeral Accounting System (MINAS; Ondersteijn et al., 2002). In the economic maximisation all manure is applied on the farm and high costs of manure disposal, i.e. €10,- per m^3, are saved. This finally results in a net farm income of €30,500.

For external social maximisation nature elements and meadow bird grassland are included to further increase the landscape quality of the conventional farm. For meadow bird grassland mowing is allowed only after the 15th of June, i.e. to protect sitting birds, resulting in less efficient grassland use. The nature conservation subsidy is lower for meadow bird grassland in comparison with herbaceous grassland as decrease of energy and protein production is lower for meadow bird grassland. Only one hectare of meadow bird grassland is included as by including a minimum of one hectare meadow bird grassland additional landscape quality points are obtained. Artificial fertiliser replaces manure that is disposed from the farm. The higher effectiveness of artificial fertiliser makes it easier to comply with MINAS. This results, however, in higher costs for artificial fertiliser and manure disposal. Moreover costs are higher because of increased performance on food safety, animal health and landscape quality (Appendix 6B; Table 6B.2). As a consequence net farm income is €11,050 lower for external social maximisation in comparison with economic maximisation.

For ecological maximisation the area of conventional grassland is decreased to the minimum feeding requirements for dairy cows. The mineral nitrogen application for grassland is decreased to save purchase of artificial fertiliser. Triticale and ground maize ear silage (in combination with a catch crop) are included in the cropping plan as losses to the environment, i.e. nitrogen, phosphate, and heavy metals, are relatively low. Meadow bird grassland replaces herbaceous grassland as nitrogen and phosphate losses per hectare are lower for meadow bird grassland. A maximum amount of manure is disposed as losses from artificial fertilisers are lower than losses from organic manure. Maximising ecological sustainability leads to lower nitrogen and phosphate losses in comparison with economic and external social maximisation. Net farm income is €10,850 lower in comparison with economic maximisation.

Consumers attach most weight, i.e. 76%, to external social and ecological sustainability (see Table 6.1). As a consequence the land use for the consumers' solution is in between land use of external social and ecological maximisation. Net farm income (€14,800), nonetheless, is lower in comparison with both external social and ecological maximisation and lower than the anti-ideal value for net farm income. Environmental results are similar to ecological maximisation.

Producers attach most weight, i.e. 68%, to economic and internal social sustainability (see Table 6.1). In comparison with economic maximisation, maize (without catch crop) is included instead of herbaceous grassland due to the higher energy production, which avoids additional purchase of roughage and concentrates. The lower nitrogen application on grassland results in lower nitrogen and phosphate surpluses in comparison with economic maximisation. Lower revenues from nature conservation subsidies together with higher costs for increased performance on food safety, animal health and landscape quality (see Appendix 6B; Table 6B.2) finally result in a lower net farm income (€4,500) for the producers' solution in comparison with economic maximisation.

For the solution in which sustainability is maximised for society a more balanced distribution of the aspect weights is included in the model (see Table 6.1). This leads to a solution that is, with respect to economic and environmental results, in between the consumers' and the producers' optimal solution.

Overall sustainability results

Table 6.4 follows from Table 6.3 and presents the performance on sustainability per aspect and the performance on overall sustainability. Appendix 6B (Table 6B.1 and 6B.2) presents the underlying results for internal social, external social and ecological indicators.

The maximum score for economic sustainability of the selected conventional farming system is 0.50. For economic maximisation the scores for landscape quality and eutrophication are below the anti-ideal values. External social maximisation shows the maximum score for external social sustainability for the concerning farming system, (0.79). For external social maximisation only the score for eutrophication is below the anti-ideal value. The highest score for ecological sustainability for the conventional farming system is 0.64. Internal social sustainability is equal for all solutions. This confirms the conclusion of a previous study (Van Calker et al., 2005b) that the current version of the Physical Load Index is not very discriminating between farming systems.

Table 6.4 Results for overall sustainability after maximisation of sustainability under the *compensatory* approach for a Dutch *conventional* dairy farm using different weights

Used weights	*Aspect of sustainability*[1]			*Stakeholders*[2]		
	Economic	External social	Ecological	Consumers	Producers	Society
Economic sust.	**<u>0.50</u>**	**0.07**	**0.08**	**-**	**0.35**	**0.25**
Internal social sust.	**0.38**	**0.38**	**0.38**	**0.38**	**0.38**	**0.38**
External social sust.	**0.42**	**<u>0.79</u>**	**0.41**	**0.71**	**0.69**	**0.73**
- food safety	0.62	0.98	0.59	0.96	0.82	0.89
- animal welfare	0.49	0.49	0.49	0.49	0.49	0.49
- animal health	0.29	0.80	0.29	0.80	0.62	0.67
- landscape quality	-	1.00	-	1.00	0.90	1.00
Ecological sust.	**0.24**	**0.31**	**<u>0.64</u>**	**0.63**	**0.31**	**0.46**
- eutrophication	-	-	0.66	0.63	-	0.25
- groundwater quality	0.38	0.41	0.86	0.86	0.50	0.71
- dehydration	1.00	0.99	0.98	0.98	0.99	1.00
- acidification	0.04	0.13	0.28	0.25	0.17	0.23
- global warming	0.48	0.46	0.50	0.50	0.48	0.50
- aquatic ecotoxicity	0.61	0.83	0.84	0.83	0.65	0.79
- terrestrial ecotoxicity	0.13	0.55	0.60	0.58	0.44	0.42
Overall sustainability				**<u>0.55</u>**	**<u>0.40</u>**	**<u>0.46</u>**

[1] The concerning aspect of sustainability is maximised

[2] Weights per stakeholder (see Table 6.2) are used to maximise overall sustainability

Despite the insufficient score for economic sustainability, an overall sustainability score of 0.55 is achieved for the consumers' solution. The scores for external social and ecological sustainability approach the maximum scores of the conventional farming system. In the producers' solution a more evenly distributed score for the different aspects is achieved which leads to an overall sustainability score of 0.40. The overall sustainability score is lower in comparison with the consumers' solution due to the relatively low maximum score for economic sustainability in combination with the higher weight for economic sustainability. The score for external social sustainability (0.69) comes relatively close to the maximum score of this aspect (0.79). The score for ecological sustainability (0.31), however, is less than half the maximum score for ecological sustainability (0.64). This means that management measures that improve external social sustainability can be included more easily, i.e. have less impact on other sustainability aspects, than management measures that improve ecological sustainability. In the society solution the lowest utility value of an individual indicator is 0.23 (i.e. acidification). The resulting score for overall sustainability (0.46) is in between the overall sustainability score of the consumers' and producers' solution.

For animal welfare, dehydration, and global warming hardly any differences are found between the different solutions. Animal welfare scores are highly dependent on the used housing and grazing system. The housing and grazing system are used, however, as input for the model and cannot be changed during maximisation. The scores for dehydration are mainly dependent on water use by crops. In all solutions a substantial area is used for nature conservation. This leads to high scores for dehydration as water use is lower for less productive grassland (Aarts et al., 2000). The score for global warming is mainly dependent on methane production (De Boer, 2003; Van Calker et al., 2004). The methane production is dependent on the farming system, i.e. conventional vs. organic, and the number of animals (Cederberg and Mattson, 2000). Consequently, an equal number of animals for all solutions leads to small differences in scores for global warming.

Non-compensatory approach

The results for the non-compensatory approach are presented in Appendix 6C (Table 6C.1). The non-compensatory approach is equal to the compensatory approach for the society solution as all indicators achieved a score higher than the anti-ideal value (see Table 6.4). For the other solutions improvements had to be made for net farm income (consumers), landscape quality (economic and ecological) and eutrophication (economic, external social, and producers). Complying with the anti-ideal value for eutrophication, in general results in a decrease of net farm income. In the three solutions the anti-ideal value for Eutrophication Potential, i.e. 500 NO_3^- equivalents per ha, is exactly achieved, leading to a score of 0.00. Improvement for eutrophication results also in improvements for groundwater quality and acidification. The improvement for net farm income in the consumers' solution results in a decreased level of eutrophication and groundwater quality. Improvements for landscape quality result in a small decrease of net farm income. In general, the non-compensatory approach results in lower or equal overall sustainability scores.

6.3.2 Organic dairy farming system

Technical results

Table 6.5 presents the technical, economic and environmental results for the organic dairy farm solutions. For all solutions the number of dairy cows is 73 and the number of young stock is 45.

Table 6.5 Technical results for maximisation of sustainability under the *compensatory* approach for a Dutch *organic* dairy farm using different weights

Used weights	Aspect of sustainability[1]			Stakeholder[2]		
	Economic	External social	Ecological	Consumers	Producers	Society
Land use (ha)						
- grass / red clover	24.8	24.8	21.7	18.2	24.6	22.2
- grass / white clover	0	0	0	5.2	0	0
- herbaceous grassland	12.2	11.6	0	0	10.8	1.0
- meadow bird grassland	0	0	15.3	13.0	1	13.2
- nature elements	0	0.6	0	0.6	0.6	0.6
Purchase of feed (per year)						
- roughage (GJ NEL[2])	1491	1500	1210	1476	1495	1437
- concentrates (GJ NEL[2])	452	452	657	443	452	452
Environmental results						
- manure disposal (m^3)	548	550	674	587	576	650
- N surplus (kg/ha)	183.9	184.2	146.8	152.6	179.6	152.7
- P_2O_5 surplus (kg/ha)	7.2	7.4	3.2	4.8	7.2	4.2
Economic results (K€)						
- gross revenues	214.0	214.3	210.2	209.8	214.0	210.9
- costs	187.2	194.5	186.8	192.4	189.8	189.0
- net farm income	26.8	19.7	23.4	17.4	24.2	21.8

[1] The concerning aspect of sustainability is maximised
[2] Weights per stakeholder (see Table 6.2) are used to maximise overall sustainability

Red clover is included in all solutions where one aspect of sustainability is maximised. Red clover in grass/clover production can bind 200 kg nitrogen per ha on a yearly base whereas white clover can bind 70 kg nitrogen per ha (Baars and Van Dongen, 1993), which implies that energy and protein production is higher for grass/red clover. The higher productivity of red clover compensates the higher costs, which are a result of the lower persistency of red clover. Meadow bird grassland is included instead of herbaceous grassland for ecological maximisation because nitrogen and phosphate losses per hectare are lower and because the higher productivity requires less purchase of roughage or concentrates.

The highest possible net farm income for the organic dairy farm is €26,800 and lower in comparison with the conventional dairy farm. This is mainly the result of the higher prices for organic concentrates. This study assumes prices that are higher than current organic concentrate prices as all components of concentrates have to be produced organically starting from August 2005. This leads to approximately 20% higher prices for organic concentrates (Ter Veer, 2005). Maximising external social sustainability results in a lower net farm income in comparison with maximising ecological sustainability. This is in contrast with the conventional dairy farming system, where the decrease of net farm income is equal for both solutions. Apparently, improvement for ecological sustainability comes more at the cost of economic sustainability for conventional dairy farms in comparison with organic dairy farms, given the farm structure and farm characteristics. For economic and external social maximisation, manure disposal is equal to the minimum manure disposal, i.e. nitrogen production in manure exceeding the maximum animal manure production of 170 kg N per ha. The manure disposal is higher for the ecological solution to avoid environmental losses. The N surpluses for economic, external social and ecological maximisation are similar with the N surpluses for the conventional farm of these three maximisations as nitrogen fixation is included in the N surplus. This, nonetheless, does not lead to higher MINAS-surpluses as nitrogen fixation is not included in the Dutch MINAS (Ondersteijn et al., 2002). The results of the maximisations using stakeholder weight can be explained from the solutions per aspect of sustainability.

Overall sustainability results

Table 6.6 presents the performance on the overall sustainability and the performance on the sustainability per aspect of the organic dairy farm.

All solutions achieve at least the anti-ideal value for all ecological indicators. In economic and ecological maximisation only for landscape quality a score lower than the anti-ideal value is achieved. The net farm income for the consumer’s solution is lower than the anti-ideal value. The maximum achievable score for external social sustainability is almost similar for the conventional dairy farming system (0.79) and the organic dairy farming system (0.78). The lower score for the organic dairy farm is a result of feeding cow milk to calves, which is related to transfer of Johne’s disease (Groenendaal et al., 2002). Surprisingly, the maximum achievable score for ecological sustainability is higher for the conventional dairy farm (0.64) in comparison with the organic dairy farm (0.56). The lower score for ecological sustainability, i.e. mainly for eutrophication, groundwater quality and global warming, on the organic dairy farm is related to including nitrogen fixation in the N-surplus and the higher number of dairy cows per hectare due to a lower milk production per cow.

Table 6.6 Results for overall sustainability after maximisation of sustainability under the *compensatory* approach for a Dutch *organic* dairy farm using different weights

Used weights	*Aspect of sustainability*[1]			*Stakeholders*[2]		
	Economic	External social	Ecological	Consumers	Producers	Society
Economic sust.	**<u>0.38</u>**	**0.09**	**0.25**	**-**	**0.29**	**0.19**
Internal social sust.	**0.38**	**0.38**	**0.38**	**0.38**	**0.38**	**0.38**
External social sust.	**0.41**	**<u>0.78</u>**	**0.39**	**0.69**	**0.68**	**0.71**
- food safety	0.60	0.96	0.56	0.95	0.80	0.87
- animal welfare	0.49	0.49	0.49	0.49	0.49	0.49
- animal health	0.25	0.76	0.25	0.76	0.58	0.63
- landscape quality	-	1.00	-	1.00	0.95	0.00
Ecological sust.	**0.36**	**0.36**	**<u>0.56</u>**	**0.54**	**0.39**	**0.54**
- eutrophication	0.07	0.06	0.52	0.45	0.12	0.46
- groundwater quality	0.56	0.57	0.80	0.77	0.61	0.78
- dehydration	0.97	0.97	0.96	0.97	0.97	0.96
- acidification	0.21	0.21	0.25	0.28	0.22	0.26
- global warming	0.27	0.27	0.29	0.29	0.27	0.28
- aquatic ecotoxicity	0.80	0.80	0.82	0.82	0.81	0.83
- terrestrial ecotoxicity	0.44	0.44	0.45	0.48	0.45	0.52
Overall sustainability				**<u>0.51</u>**	**<u>0.39</u>**	**<u>0.45</u>**

[1] The concerning aspect of sustainability is maximised

[2] Weights per stakeholder (see Table 6.2) are used to maximise overall sustainability

Non-compensatory approach

The results for the non-compensatory approach are presented in Appendix 6C (Table 6C.2). The non-compensatory approach is equal to the compensatory approach using the weights of producers and society and when external social sustainability is maximised (see Table 6.6). For the other solutions improvements had to be made for net farm income (consumers) and landscape quality (economic and ecological). Improvements to comply with the anti-ideal value for landscape quality result in a small decrease of net farm income. The improvement for net farm income in the consumers' solution results in a small decrease in the performance of food safety. This decrease, nonetheless, does not result in a lower overall sustainability score. In general, the non-compensatory approach hardly affects the overall sustainability results.

6.4 Discussion and conclusion

In this study a WLGP-model for Dutch dairy farming in which sustainability can be maximised for different stakeholders is presented. Maximisation of sustainability aspects shows the maximum possible score for the concerning aspect of a farming system. Maximisation of sustainability according to the aspect and attribute weights of consumer, producer and society shows the maximum possible score for overall sustainability per stakeholder. In this research the spread of the overall sustainability scores for the conventional farm and the organic farm is small between stakeholders. The spread of the sustainability scores for economic and ecological sustainability is more evident between stakeholders. Apparently, differences in scores for sustainability aspects are cancelled out in the overall sustainability score due the aspect weights of stakeholders. For this reason showing the maximum possible scores for the sustainability aspects, is more informative with respect to sustainability performance. Maximisations per aspect of sustainability show the sustainability 'boundaries' of the concerning farming system.

In this paper the anti-ideal values of profitability, landscape quality and eutrophication are most restrictive for the non-compensatory approach. This implies that these attributes are least sustainable of all attributes for the specific dairy farming system. Nonetheless, differences in overall-sustainability results between the compensatory and non-compensatory approach is small, which means that the restrictiveness of the anti-ideal values is small for this particular farming system. Still, the non-compensatory and the compensatory approach are useful for analysing maximum sustainability of dairy farming systems as anti-ideal values, i.e. thresholds, might be more restrictive for other farming systems.

In this study we assumed a certain farm structure and a certain technical state-of-the-art (e.g. milk and crop production). For the conventional and the organic dairy farm these assumptions result in maximum possible scores for the sustainability aspects that are below the ideal value. Economic sustainability can be improved, for example, by an increase of scale, higher milk production and lower replacement rates. External social sustainability can be improved mainly by changes in housing system, i.e. cubicle vs. deep litter, and grazing system, i.e. unrestricted grazing vs. restricted grazing. Ecological sustainability can be improved, for example, by increasing the area of land resulting in a lower intensity (Halberg et al., 2005) and a higher crop production. Improvements for internal social sustainability, although small due to the low sensitivity of the Physical Load Index, can be achieved by mechanisation and computerisation.

Maximisation of sustainability for the farming systems results in higher overall sustainability scores for consumers in comparison with producers. This logically results from the higher weights for economic and internal social sustainability of producers in combination with lower maximum sustainability scores for these aspects.

Surprisingly, the conventional dairy farm achieves a slightly higher score for overall sustainability than the organic dairy farm for all stakeholders. No general conclusions can be drawn from this result as: (1) average organic dairy farms (±8800 kg per hectare; based on numbers of accounting agency Alfa) are less intensive than the intensity of the farm used in the WLGP-model; (2) a large area of nature conservation area is included for organic and conventional dairy farming. In general this is less common practice for conventional dairy farming; (3) perceptions regarding sustainability can be different between conventional and organic dairy farmers. Organic dairy farmers have, for example, environmental, animal welfare and financial motives to convert from conventional towards organic dairy farming (Berentsen et al., 1998).

It can be concluded that the WLGP-model is very suitable to explore the possible sustainability of dairy farming systems. Furthermore, the model can be helpful to analyse the effects of alternative policy measures and future developments on individual sustainability attributes, sustainability aspects, and overall sustainability. Finally, the model shows that it is possible for conventional dairy farms to achieve similar overall sustainability scores in comparison with organic dairy farms.

Appendix 6A

Table 6A.1 Ideal values, anti-ideal values, intermediate values, and 'penalty' weights for all sustainability indicators [1,2]

Indicators	*Anti-ideal*	*Ideal*	*Inter-mediate*	*Penalty weight*
Economic sustainability				
Net Farm income (€)	18,000	74,000	46,000	0.80
Internal social sustainability				
Physical Load Index	0	1	-	-
External social sustainability				
Chain Food Safety Index	0	1	-	-
Animal Need Index (TGI-35L)	11	45.5	-	-
Animal Health index	16	100	-	-
Agricultural Nature Norm Analysis	15	36	-	-
Ecological sustainability				
Eutrophication Potential (NO_3^- equiv./ha)	500	100	300	0.75
Nitrate conc. in groundwater (NO_3^- mg/l)	70	10	40	0.80
Water use (m^3/ha)	5500	3000	4250	0.80
Acidification Potential (SO_2 equiv./ha)	100	50	-	-
Global Warming Potential (CO_2 equiv./1000 kg milk)	1000	400	-	-
Terrestrial Ecotoxicity Potential (1,4 dcb equiv./ha)	20	0	10	0.88
Aquatic Ecotoxicity Potential (1,4 dcb equiv./ha)	200	50	125	0.83

[1] For linear utility functions no intermediate values and penalty weights are shown;

[2] Penalty weight with respect to under- or overachievement of intermediate value

Chapter 6

Appendix 6B

Table 6B.1 Results for ecological sustainability after maximisation of sustainability under the *compensatory* approach for a Dutch *conventional* dairy farm using different weights

	Unit	Aspects of sustainability			Stakeholders		
		Economic	External social	Ecological	Consumers	Producers	Society.
Eutrophication Potential	**NO_3^- equivalents/ha**	**649**	**523**	**341**	**350**	**575**	**454**
- NO_x emission	kg N / ha	5.6	5.8	5.3	5.3	5.6	5.4
- NH_3 emission	kg N / ha	38.7	36.2	33.7	34.3	35.8	34.8
- NO_3 leaching and run-off	kg N / ha	62.6	59.1	37.4	36.4	62.6	48.5
- NH_4 leaching and run-off	kg N / ha	4.0	3.8	2.3	2.3	3.9	3.1
- P_2O_5 losses	kg P_2O_5 / ha	22.0	8.8	0.0	1.4	14.0	7.2
Nitrate concentration	**NO_3^- mg/l**	**61**	**57**	**34**	**34**	**56**	**46**
Water use	**m^3/ha**	**3007**	**3087**	**3285**	**3242**	**3116**	**2972**
Acidification	**SO_2 equivalents/ha**	**98**	**92**	**86**	**87**	**91**	**89**
- NH_3 emission	kg N / ha	38.7	36.2	33.7	34.3	35.8	34.8
- NO_x emission	kg N / ha	5.6	5.8	5.3	5.3	5.6	5.4
- SO_2 emission	kg SO_2 / ha	1.0	1.0	1.0	1.0	1.0	1.0
Global Warming Potential	**CO_2 equivalents per 1000 kg milk**	**700**	**706**	**684**	**684**	**697**	**688**
-CH_4 emission	kg CH_4 / 1000 kg milk	22.8	22.8	22.8	22.8	22.8	22.8
- N_2O emission	kg N / 1000 kg milk	0.4	0.4	0.3	0.3	0.4	0.4
- CO2 emission	kg CO_2 / 1000 kg milk	42.3	41.0	40.1	40.1	41.2	39.9
Aquatic ecotoxicity	**1,4 dicholorobenzene equivalents/ha**	**159**	**125**	**124**	**125**	**154**	**134**
Terrestrial ecotoxicity	**1,4 dicholorobenzene equivalents/ha**	**19.3**	**16.1**	**15.5**	**15.7**	**17.1**	**17.3**
- Cadmium surplus	g/ha	1.1	1.0	0.8	0.8	1.0	0.9
- Cupper surplus	g/ha	210	160	159	162	197	174
- Zinc surplus	g/ha	646	546	517	531	564	587
- Pesticide use	kg active ingredient / ha	0.22	0.26	0.24	0.20	0.33	0.20

Table 6B.2 Results for external social sustainability after maximisation of sustainability under the *compensatory* approach for a Dutch *conventional* dairy farm using different weights

	Aspects of sustainability			Stakeholders		
	Economic	External social	Ecological	Consumers	Producers	Society
Work load (hours per year)	**4495**	**4572**	**4456**	**4527**	**4354**	**4517**
Physical load index	**0.38**	**0.38**	**0.38**	**0.38**	**0.38**	**0.38**
- back disorders	0.25	0.25	0.25	0.25	0.25	0.25
- neck, shoulder and upper extremity	0.50	0.50	0.50	0.50	0.50	0.50
CFSI (food safety)	**0.62**	**0.98**	**0.59**	**0.96**	**0.82**	**0.89**
- chemical food safety	0.57	1.00	0.54	1.00	0.85	0.92
- microbiological food safety	0.66	0.95	0.64	0.93	0.79	0.85
TGI-35L (animal welfare)	**28.5**	**28.5**	**28.5**	**28.5**	**28.5**	**28.5**
Animal Health Index	**40**	**83**	**40**	**83**	**68**	**72**
- basis requirements	9	9	9	9	9	9
- housing and grazing	6	31	6	31	16	20
- farm management	25	35	25	35	35	35
- testing health status	0	8	0	8	8	8
ANNA (landscape quality)	**3**	**36**	**4**	**36**	**34**	**36**
- wet nature	0	13	0	12	11	11
- herbaceous nature	1	9	2	9	9	10
- woody nature	0	6	0	6	6	6
- additional measures	2	8	2	9	8	9

Appendix 6C

Table 6C.1 Results for overall sustainability after maximisation of sustainability under the *non-compensatory* approach for a Dutch *conventional* dairy farm using different weights

Used weights	*Aspect of sustainability*[1]			*Stakeholders*[2]		
	Economic	External social	Ecological	Consumers	Producers	Society
Economic sust.	**<u>0.40</u>**	**0.03**	**0.08**	**0.00**	**0.32**	**0.25**
Internal social sust.	**0.38**	**0.38**	**0.38**	**0.38**	**0.38**	**0.38**
External social sust.	**0.42**	**<u>0.79</u>**	**0.42**	**0.70**	**0.69**	**0.73**
- food safety	0.62	0.98	0.59	0.91	0.82	0.89
- animal welfare	0.49	0.49	0.49	0.49	0.49	0.49
- animal health	0.29	0.80	0.29	0.80	0.62	0.67
- landscape quality	0.00	1.00	0.05	1.00	0.90	1.00
Ecological sust.	**0.35**	**0.36**	**<u>0.64</u>**	**0.57**	**0.36**	**0.46**
- eutrophication	0.00	0.00	0.66	0.51	0.00	0.25
- groundwater quality	0.61	0.59	0.86	0.80	0.63	0.71
- dehydration	1.00	0.99	0.98	0.99	1.00	1.00
- acidification	0.18	0.20	0.28	0.25	0.21	0.23
- global warming	0.49	0.48	0.50	0.50	0.49	0.50
- aquatic ecotoxicity	0.78	0.83	0.84	0.82	0.77	0.49
- terrestrial ecotoxicity	0.41	0.55	0.60	0.52	0.44	0.42
Overall sustainability				**<u>0.52</u>**	**<u>0.40</u>**	**<u>0.46</u>**

[1] The concerning aspect of sustainability is maximised

[2] Weights per stakeholder (see Table 6.2) are used to maximise overall sustainability

Chapter 6

Table 6C.2 Results for overall sustainability after maximisation of sustainability under the *non-compensatory* approach for a Dutch *organic* dairy farm using different weights

Used weights	*Aspect of sustainability*[1]			*Stakeholders*[2]		
	Economic	External social	Ecological	Consumers	Producers	Society.
Economic sust.	**<u>0.37</u>**	**0.09**	**0.23**	**0.02**	**0.29**	**0.19**
Internal social sust.	**0.38**	**0.38**	**0.38**	**0.38**	**0.38**	**0.38**
External social sust.	**0.41**	**<u>0.78</u>**	**0.39**	**0.69**	**0.68**	**0.71**
- food safety	0.60	0.96	0.56	0.89	0.80	0.87
- animal welfare	0.49	0.49	0.49	0.49	0.49	0.49
- animal health	0.25	0.76	0.25	0.76	0.58	0.63
- landscape quality	0.00	1.00	0.00	1.00	0.95	1.00
Ecological sust.	**0.36**	**0.36**	**<u>0.56</u>**	**0.54**	**0.39**	**0.54**
- eutrophication	0.07	0.06	0.52	0.45	0.12	0.46
- groundwater quality	0.57	0.57	0.80	0.77	0.61	0.78
- dehydration	0.97	0.97	0.96	0.97	0.97	0.96
- acidification	0.21	0.21	0.25	0.28	0.22	0.26
- global warming	0.27	0.27	0.29	0.29	0.27	0.28
- aquatic ecotoxicity	0.80	0.80	0.82	0.82	0.81	0.83
- terrestrial ecotoxicity	0.44	0.44	0.45	0.48	0.45	0.52
Overall sustainability				**<u>0.51</u>**	**<u>0.39</u>**	**<u>0.45</u>**

[1] The concerning aspect of sustainability is maximised

[2] Weights per stakeholder (see Table 6.2) are used to maximise overall sustainability

References

Aarts, H.F.M., Habekotte, B. and van Keulen, H., 2000. Ground water recharge through optimized intensive dairy farms. *Journal of Environmental Quality* 29: 738-743.

Baars, T. and Van Dongen, M., 1993. *Mogelijkheden van rode klaver in de weidebouw: een literatuurstudie*. Louis Bolk Instituut, The Netherlands: Driebergen.

Berentsen, P.B.M. and Giesen, G.W.J., 1995. An Environmental-Economic Model at Farm-Level to Analyze Institutional and Technical Change in Dairy Farming. *Agricultural Systems* 49: 153-175.

Berentsen, P.B.M., Giesen, G.W.J. and Schneiders, M., 1998. Conversion from conventional to biological dairy farming: Economic and environmental consequences at farm level. *Biological Agriculture & Horticulture* 16: 311-328.

Cederberg, C. and Mattson, B., 2000. Life cycle assessment of milk production - a comparison of conventional and organic farming. *Journal of Cleaner Production* 8: 49-60.

De Boer, I.J.M., 2003. Environmental impact assessment of conventional and organic milk production. *Livestock Production Science* 80: 69-77.

Evers, A.G. and De Haan, M.H.A., 2004. *Kostprijsverschil tussen biologisch en gangbaar geproduceerde melk = Comparison of cost price of organic and regular milk*. Animal Sciences Group, Praktijkonderzoek, The Netherlands: Lelystad.

Groenendaal, H., Nielen, M., Jalvingh, A.W., Horst, S.H., Galligan, D.T. and Hesselink, J.W., 2002. A simulation of Johne's disease control. *Preventive Veterinary Medicine* 54: 225-245.

Halberg, N., van der Werf, H.M.G., Basset-Mens, C., Dalgaard, R. and de Boer, I.J.M., 2005. Environmental assessment tools for the evaluation and improvement of European livestock production systems. *Livestock Production Science* in press.

Heinen, J.T., 1994. Emerging, diverging and converging paradigms on sustainable development. *International Journal of Sustainable Development and World Ecology* 1: 22-33.

Herrero, M., Fawcett, R.H. and Dent, J.B., 1999. Bio-economic evaluation of dairy farm management scenarios using integrated simulation and multiple-criteria models. *Agricultural Systems* 62: 169-188.

Jones, D. and Tamiz, M., 1995. Expanding the flexibility of goal programming via preference modelling techniques. *Omega* 23: 41-48.

Luesink, H.H., Van Everdingen, W. and De Haan, M.H.A., 2005. Nieuw mestbeleid: Koe kan in de wei blijven. *Agri-Monitor* maart 2005: 1-2.

Ondersteijn, C.J.M., Beldman, A.C.G., Daatselaar, C.H.G., Giesen, G.W.J. and Huirne, R.B.M., 2002. The Dutch mineral accounting system and the European nitrate directive:

implications for N and P management and farm performance. *Agriculture Ecosystems & Environment* 92: 283-296.

Pacini, C., Wossink, A., Giesen, G., Vazzana, C. and Huirne, R., 2003. Evaluation of sustainability of organic, integrated and conventional farming systems: a farm and field-scale analysis. *Agriculture Ecosystems & Environment* 95: 273-288.

Pacini, C., Giesen, G., Wossink, A., Omodei-Zorini, L. and Huirne, R., 2004. The EU's Agenda 2000 reform and the sustainability of organic farming in Tuscany: ecological-economic modelling at field and farm level. *Agricultural Systems* 80: 171-197.

Poppe, K.J., 2004. *Bedrijven-Informatienet van A tot Z*. report number 1.03.06. Landbouw Economisch Instituut, The Netherlands: Den Haag.

Reksen, O., Tverdal, A. and Ropstad, E., 1999. A comparative study of reproductive performance in organic and conventional dairy husbandry. *Journal of Dairy Science* 82: 2605-2610.

Rigby, D. and Caceres, D., 2001. Organic farming and the sustainability of agricultural systems. *Agricultural Systems* 68: 21-40.

Rigby, D., Woodhouse, P., Young, T. and Burton, M., 2001. Constructing a farm level indicator of sustainable agricultural practice. *Ecological Economics* 39: 463-478.

Romero, C., 1991. *Handbook of critical issues in goal programming*. Pergamon Press, UK: Oxford.

Romero, C., 2004. A general structure of achievement function for a goal programming model. *European Journal of Operational Research* 153: 675-686.

Romero, C. and Rehman, T., 2003. *Multiple criteria analysis for agricultural decisions*. Elsevier, The Netherlands: Amsterdam.

Rossing, W.A.H., Meynard, J.M. and van Ittersum, M.K., 1997. Model-based explorations to support development of sustainable farming systems: case studies from France and the Netherlands. *European Journal of Agronomy* 7: 271.

SKAL, 2002. Informatie over de biologische productiemethode = Information on organic way of producing. SKAL- Certificatie Biologische Productie.

Sundrum, A., 2001. Organic livestock farming - A critical review. *Livestock Production Science* 67: 207-215.

Tamiz, M., Jones, D. and Romero, C., 1998. Goal programming for decision making: An overview of the current state-of-the-art. *European Journal of Operational Research* 111: 569-581.

Ten Berge, H.F.M., Van Ittersum, M.K., Rossing, W.A.H., Van de Ven, G.W.J., Schans, J. and Van de Sanden, P.A.C.M., 2000. Farming options for The Netherlands explored by multi-objective modelling. *European Journal of Agronomy* 13: 263-277.

Ter Veer, D.F., 2005. *Scenariostudie 100% biologisch voeren melkvee*. Animal Sciences Group, The Netherlands: Wageningen.

Van Calker, K.J., Berentsen, P.B.M., Giesen, G.W.J. and Huirne, R.B.M., 2005a. Identifying and ranking attributes that determine sustainability in Dutch dairy farming. *Agriculture and Human Values* 22: 53-63.

Van Calker, K.J., Berentsen, P.B.M., De Boer, I.J.M., Giesen, G.W.J. and Huirne, R.B.M., 2004. An LP-model to analyse economic and ecological sustainability on Dutch dairy farms: model presentation and application for experimental farm "de Marke". *Agricultural Systems* 82: 139-160.

Van Calker, K.J., Berentsen, P.B.M., De Boer, I.J.M., Giesen, G.W.J. and Huirne, R.B.M., 2005b. Modelling social sustainability at farm level: an application to conventional and organic dairy farming. *Submitted to Agricultural Systems*

Van Calker, K.J., Berentsen, P.B.M., Romero, C., Giesen, G. and Huirne, R.B.M., 2005c. Development and application of a multi-attribute sustainability function for Dutch dairy farming systems. *Ecological Economics* in press.

Williams, H.P., 1990. *Model building in mathematical programming*. Wiley, UK: Chichester.

Chapter 7

General discussion

7.1 Introduction

The main objective of the research presented in this thesis was to quantify sustainability for Dutch dairy farming and to gain insight into the effects of management measures and farming systems on all aspects of sustainability by using farm-level modelling. Five questions were identified in the research project:

1. Which attributes are relevant with respect to economic, social, and ecological sustainability of Dutch dairy farming?
2. Which indicators are suitable to quantify economic, social, and ecological sustainability and can be included in the dairy farm model?
3. What are the effects of farm management measures and farming systems on economic, social, and ecological sustainability indicators?
4. How can the selected indicators for economic, social, and ecological sustainability be amalgamated into one overall sustainability function by using the preferences of different stakeholders and expert knowledge?
5. What is the effect of maximising overall sustainability on the sustainability performance (i.e. overall sustainability, aspect sustainability, and attribute sustainability) of different dairy farming systems for different stakeholder groups?

The developed sustainability assessment methodology to quantify sustainability was applied to 4 experimental dairy farms. Furthermore, the sustainability assessment methodology was integrated into a dairy farm LP-model by using Weighted Goal Programming (WGP). By using this Weighted Linear Goal Programming (WLGP) model the effect of management measures and farming systems on all aspects of sustainability was analysed.

This chapter discusses research issues and draws the main conclusions. Sections 7.2-7.5 deal with research issues. In section 7.2 conceptual issues related to sustainability like Corporate Social Responsibility, license to produce, Triple P bottom line, and sustainable entrepreneurship are discussed. In section 7.3 methodological issues with respect to the farm-level approach, the use of Linear Programming, the selection of attributes and indicators, and the amalgamation and aggregation procedure are discussed. Section 7.4 discusses the effects of farm management measures and farming systems on sustainability performance, i.e. overall sustainability, aspect sustainability and attribute sustainability. Section 7.5 addresses future possibilities of the sustainability assessment methodology and future possibilities of the WLGP-model. Finally, section 7.6 presents the main conclusions on methodology and results achieved within this study.

7.2 Conceptual issues

In this thesis a sustainability assessment methodology is described which can be helpful to monitor and support the transition towards more sustainable dairy farming. With respect to a transition to a more ‘sustainable world’ several other concepts are used like corporate social responsibility, sustainable entrepreneurship and licenses to operate and to produce. The relationship between the sustainability assessment methodology as described in this thesis and these other concepts is shown in Figure 7.1. The grey coloured elements in Figure 7.1 are directly related to the sustainability assessment methodology developed in this research.

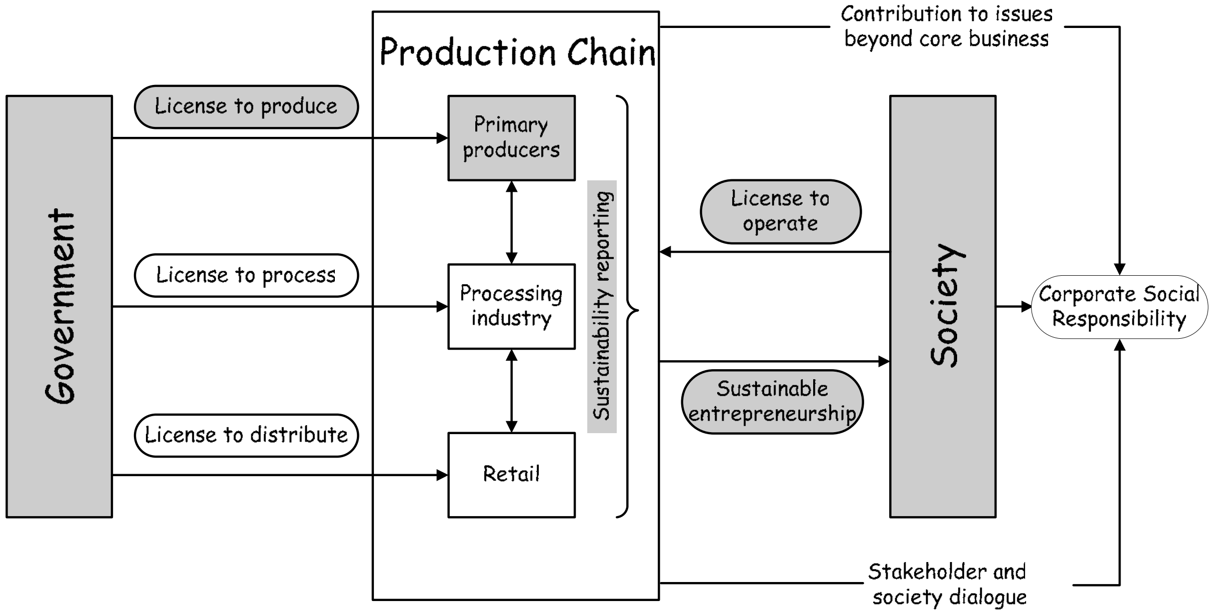


Figure 7.1 Relationship between sustainability concepts in agriculture (based on SER, 2003)

Starting point in Figure 7.1 is the government, i.e. EU, national, and regional government. The government defines prerequisites for primary producers, processing industry, and retail. These prerequisites are related to minimum standards like complying with manure and animal welfare policy (i.e. primary producers), complying with regulations of the Food and Consumer Product Safety Authority (i.e. processing industry), and complying with policy with respect to the hours of trading (i.e. retail). Production chain members complying with these prerequisites receive a license to produce, to process, or to distribute. Besides the prerequisites from governments also mutual agreements between production chain members, governmental institutions and societal organisations can be part of these licenses (SER, 2003). The sustainability assessment methodology presented in this thesis focuses on the sustainability performance of primary producers only and the license to produce is a basic condition for using this assessment methodology.

Society more and more expects additional efforts from chain members to sustain their production leading to public prosperity in the longer run. This public prosperity can be achieved by long term value creation that is not only related to economic value, but also concerns environmental quality and social acceptance. The long term value creation in these three dimensions refers to the Triple P bottom line meaning that chain members should not only strive for a bottom line with respect to economic performance (Profit) but also strive for a bottom line with respect to environmental quality (Planet) and social acceptance (People; Elkington, 1998). These three dimensions, i.e. people, planet, and profit, are considered equivalents of the sustainability aspects used in the sustainability assessment methodology of this thesis. Commitment to these aspects of sustainability can be shown in sustainability reports in which the principles and the results for these aspects of sustainability are presented. Chain members who produce in a sustainable way that can be judged from public available sustainability reports, can be classified as sustainable entrepreneurs and ideally ‘receive’ a license to operate as a reward from society (see Figure 7.1; SER, 2003). For dairy production it is makes sense to develop sustainability reports in cooperation with other chain members as it is not likely that individual dairy farmers will do this themselves.

Form Figure 7.1 it can be seen that Corporate Social Responsibility (CSR) exceeds sustainable entrepreneurship as CSR incorporates, according to the Dutch Social Economic Council (SER), two additional elements (SER, 2000): (1) contribution of chain members to issues that go beyond the firms’ core business, and (2) active dialogue of chain members with chain related stakeholders and society at large. SCR and sustainable entrepreneurship, however, have in common that the progress/performance on important sustainability issues should be assessed and reported. The sustainability assessment methodology as described in this thesis can be considered as a first step to support sustainable entrepreneurship and CSR.

7.3 Methodological issues

7.3.1 Approach at farm level

In this research we used the farm level approach to quantify sustainability. Sustainability is particularly relevant at farm level (De Koeijer et al., 1995; Hansen and Jones, 1996) because the major decision making unit to affect sustainability in reality is at farm level. Effects on ecological sustainability, for example, are caused mainly at farm level (Iepema and Pijnenburg, 2001). Furthermore, societal concerns with respect to sustainability in dairy farming mainly are associated with issues at farm level, e.g. animal welfare and landscape quality. Disadvantage of the approach at farm level is that sustainability effects caused by other supply chain members, i.e. suppliers of primary producers, processing industry, distributors, and re-tail, are not taken into account. This implies that in our study increasing sustainability performance at farm level can take place at the expense of decreasing sustainability performance of other chain members.

The spatial level of sustainability assessment, i.e. field, farm, region, country, and world, is important in particular for ecological sustainability. At farm level, extensive systems show in general a lower environmental impact per hectare (Halberg et al., 2005; Nevens et al., 2005). If, nonetheless, the lower milk production per hectare of these extensive farming systems is compensated by more intensive milk production in other areas or with production in former nature areas, then the total environmental impact on a global scale may be the same or even higher in comparison with more intensive farming systems. Therefore some kind of productivity indicator should be developed in addition to the selected indicators to compare the sustainability performance of individual dairy farming systems on a global scale.

7.3.2 The use of an LP-model

Sustainability of dairy farming systems can be analysed by applying statistical modelling based on data of commercial farms or by using a mathematical modelling approach. In this research we used a mathematical modelling approach to analyse sustainability as: (1) recent and future developments (e.g. environmental policy and technical change) can be included, (2) it provides insight in the effect of individual management measures on sustainability, (3) it provides insight on the potential sustainability of different dairy farming systems, and (4) insufficient detailed sustainability data is available for statistical modelling.

In this study we used an LP-model to model the dairy farm because an optimum seeking procedure is provided and sustainability, therefore, can be maximised for different situations. An LP-model, however, does not take into account all the objectives and constraints that are important for dairy farmers (Berentsen, 1999; Bos, 2002), which implies that the modelling approach can lead to results that differ from reality. Besides, due to various reasons (like imperfect information, risk aversion, management quality and skills) farmers often do not succeed to manage the farm like an LP-model does. Consequently the results should be seen as the optimal attainable performance or benchmark with respect to the particular farming system and the used constraints and objectives.

7.3.3 Selection of attributes and indicators

Experts were consulted to identify and rank attributes for aspects of sustainability that can be determined objectively (i.e. for economic, internal social, and ecological sustainability) and stakeholders were consulted to identify and rank attributes for aspects of sustainability that cannot be determined objectively (i.e. for external social sustainability). By including primary producers and industrial producers, i.e. processing industry and retail, all relevant members of the dairy production chain were included. Policy makers were included as stakeholder group because policy affects the sustainability of Dutch dairy farming. Consumers were included as stakeholder group because they have the possibility to affect the sustainability of dairy farming by participation in the public debate. By using an interactive stakeholder approach, i.e. consultative participation, all relevant attributes were selected. Note that in this research, representatives of suppliers of primary producers (e.g. concentrate producers) are not included as stakeholder group because it is assumed that these chain suppliers are not expected to add to the knowledge of primary producers with respect to sustainability at farm level.

7.3.4 Amalgamation and aggregation procedure

The judgement which dairy farming system is most sustainable can be seen as a decision making problem. The traditional framework for analysing decision-making presupposes the existence of three elements: a decision maker, several alternatives, and a well defined criterion of choice (Romero and Rehman, 2003). In this research the decision makers or judges are the included stakeholders, the alternatives are the different dairy farming systems and the criterion of choice is the overall sustainability function. Most complicated element is the development of the overall sustainability function. In this thesis (see Chapter 5) we used the Multi-Attribute Utility Theory (MAUT), which is part of multiple criteria decision making (MCDM) paradigm, to develop an overall sustainability function for Dutch dairy farming. MCDM methodologies amalgamate economic, social and ecological sustainability indicators using a dimensionless scale. Besides MCDM methodologies, also monetary based methodologies like (societal) Cost Benefit Analysis are used to evaluate the sustainability of alternatives (Reinhard et al., 2003; Van der Wielen, 2005). Subjective elements based on stakeholder preferences can be included easily in MCDM approaches. MCDM approaches, therefore, are attractive methodologies in the quantification of sustainability. Several other MCDM methodologies, different from the multi-attribute overall sustainability function, are used in literature to amalgamate sustainability indicators and aspects into an overall sustainability function like the balancing and (out)ranking method (Strassert and Prato, 2002), the weighted arithmetic mean (De Boer and Cornelissen, 2002; Zinck et al., 2004), fuzzy set theory (Cornelissen et al., 2001), and the Analytical Hierarchic Process (Mendoza and Prabhu, 2000). The multi-attribute overall sustainability function is used in this thesis because: (1) it is theoretically sound (Keeney and Raiffa, 1976; Hardaker et al., 2004), (2) it allows to include objective as well as subjective elements of sustainability, (3) it can be used to evaluate the sustainability of a unrestricted number of alternatives, (4) it is simple to use, and (5) it is transparent.

By using the multi-attribute overall sustainability function the sustainability performance of farming systems can be calculated per stakeholder group. In this thesis, we aggregated sustainability functions of individual stakeholders into a sustainability function per stakeholder group by using Extended Goal Programming. This method is valid for aggregating preferences of members of the same social group. Aggregating sustainability functions of stakeholder groups into a sustainability function for society that gives satisfactorily results for all stakeholders is not possible (see Chapter 5). Other possibilities to develop a sustainability function for society are collective choice rules and group decision support systems (Bose et al., 1997). Although communication and feedback on the overall sustainability function will narrow the gap between stakeholder groups, it is not likely that all stakeholder groups reach consensus with respect to an overall sustainability function. For this reason and because performance on sustainability aspects is cancelled out in the overall sustainability score it is more informative to show the performance per sustainability aspect.

7.4 Sustainability results for Dutch dairy farming systems

In Chapters 3 through 6 the effects of management measures and farming systems on economic, social, ecological and/or overall sustainability are analysed. In Chapter 3 it is concluded that the Dutch manure policy (MINAS) is an effective tool to reduce environmental impact of dairy farming and that measures applied on experimental farm “De Marke” reduce environmental impact even more. Nevertheless, improvements of ecological sustainability are often at the expense of economic sustainability. The same holds for improvements with respect to external social sustainability (see Chapter 4 & 6). The “Low cost” experimental dairy farm showed, however, that sufficient performance for economic, social, and ecological sustainability can go hand in hand (see Chapter 5). This is in line with findings of a Dutch dairy farming project called ‘Farm Data in Practice’ (Project Praktijkcijfers in Dutch). In that project it appeared that improvements of nutrient management (either through efficiency or technology improvements) led to an increase of ecological as well as economic sustainability (Ondersteijn et al., 2003). The negative trade-off between ecological and (external) social sustainability at the one hand and economic sustainability at the other hand (see Chapter 3, 4 & 6) is a result of the optimum seeking procedure of the dairy farm model. This procedure leads to the optimal attainable performance of a dairy farming system with respect to the objective function and improvements of one aspect are consequently at the expense of another aspect. Furthermore, the current model shows hardly any efficiency and productivity improvements as the model uses standards for feeding and fertilising that include a good level of productivity. For the model there is no reason to feed and fertilise above the standards (i.e. normative approach). These efficiency and productivity improvements, nonetheless, partly explain the simultaneous improvement of economic and ecological sustainability in the project ‘Farm Data in Practice’.

In Chapter 4, 5 and 6 it is concluded that conventional dairy farming systems in comparison with organic dairy farming systems have the potential to achieve similar scores for sustainability. To draw more general conclusions on the sustainability of conventional and organic commercial dairy farms, data should be collected on a substantial number of conventional and organic dairy farms to determine scores for the selected sustainability attributes. Data for these attributes should be collected during a few consecutive years to take into account weather and year effects. By using aspect and attribute (for external social sustainability) weights it can be determined per stakeholder group which farming system is judged most sustainable.

7.5 Outlook

The sustainability assessment methodology presented in this thesis can be used to evaluate the progress in sustainability performance of individual dairy farms and therefore can be used to support the transition towards more sustainable dairy farming systems. By assessing attribute sustainability scores of a large group of farms benchmarks can be set for sustainability attributes and sustainability aspects. Benchmarking can be used to analyse causes for differences between farms. To facilitate the benchmarking process a Sustainability Accounting System can be developed. This accounting system can been seen as an extension of existing financial accounting systems with social and ecological sustainability aspects. This Sustainability Accounting System can be the basis of a sustainability report with respect to Corporate Social Responsibility and sustainable entrepreneurship (see Figure 7.1).

Most important for the transition towards a sustainable dairy sector in the Netherlands is the support for dairy farmers to make this transition. Several initiatives in the Netherlands aim to support this transition (e.g. Oenema et al., 2001; Stuiver et al., 2003; Grin et al., 2004; Van Calker et al., 2005). Ideally, the transition towards more sustainable dairy farming systems is supported and initiated by an increased consumer demand for sustainable dairy products. Consumers, however, only have the possibility to choose between organic and conventional dairy products that are produced on the basis of prescribed practices and do not guarantee a certain level of sustainability. The introduction of a sustainability label for both conventional and organic dairy products is a possibility to stimulate sustainable dairy farming. The integrated methodology for sustainability quantification as presented in this thesis can be a starting point to develop such a certification system. By using this integrated methodology a certain level of economic, social, and ecological sustainability is guaranteed to consumers.

The successful implementation of such a certification system is dependent on the transparency and the simplicity of the used sustainability indicators and on the acceptation of such a certification system by consumers, primary producers and industrial producers.

Beside the responsibility of the supply chain members, the government also has responsibilities to stimulate the transition towards more sustainable dairy farming practices. This transition can be supported by developing policy measures that are effective on several aspects of sustainability. Constant changes of policies with respect to nutrients, pesticides, animal health, and animal welfare, however, are a serious risk for the sustainability results of dairy farmers (Huirne, 1999). For these reasons it would be desirable to develop policies that take account of all sustainability aspects in an integrated way and which are intended to be used for a long-term period. In addition, new policy should be performance-oriented instead of measures-oriented as performance-oriented policies give farmers maximal opportunities and responsibility to find a pathway to sustainable dairy production according to their particular farm structure, farm characteristics, individual ambitions and, individual competences. The WLGP-model (see Chapter 6) provides a framework to evaluate the effectiveness of new developed policy on different sustainability aspects.

7.6 Main conclusions

The following general conclusions can be drawn from the methodologies used in this thesis:

- ❖ Extended Goal Programming model is an attractive method to aggregate preferences per stakeholder group;
- ❖ The developed multi-attribute sustainability function based on stakeholder perceptions and expert knowledge can be used to quantify the sustainability of different dairy farming systems per stakeholder group;
- ❖ Weighted Linear Goal Programming model is suitable to analyse the sustainability of different dairy farming systems and improves insight in the effects of policy and future developments on sustainability performance;

The following general conclusions can be drawn from the results of this thesis:

- ❖ Quantification of sustainability is dependent on time, place, and perception. This implies that studies that quantify sustainability: (1) should be repeated regularly, (2) are valid only for a certain region and agricultural sector, and (3) should include stakeholder consultation;
- ❖ At Dutch dairy farm level, economic and internal social sustainability can be described sufficiently by one attribute, while external social and ecological need multiple attributes to be measured adequately;
- ❖ The use of one 'societal' overall sustainability function that satisfactorily includes preferences of all stakeholder groups is limited as stakeholder groups evaluate sustainability of dairy farming systems considerably different;
- ❖ For farm and policy decision making it is more relevant to show the performance per sustainability aspect than to show the overall sustainability score;
- ❖ Analysis with the Weighted Linear Goal Programming model shows that conventional dairy farms potentially are able to achieve similar sustainability scores in comparison with organic dairy farms (and vice versa).

References

Berentsen, P.B.M., 1999. *Economic-environmental modelling of Dutch dairy farms incorporating technical and institutional change*. PhD-thesis, Wageningen University, The Netherlands: Wageningen.

Bos, J., 2002. *Comparing specialised and mixed farming systems in the clay areas of the Netherlands under future policy scenarios: an optimisation approach*. PhD-thesis, Wageningen University, The Netherlands: Wageningen.

Bose, U., Davey, A.M. and Olson, D.L., 1997. Multi-attribute utility methods in group decision making: Past applications and potential for inclusion in GDSS. *Omega-International Journal of Management Science* 25: 691-706.

Cornelissen, A.M.G., van den Berg, J., Koops, W.J., Grossman, M. and Udo, H.M.J., 2001. Assessment of the contribution of sustainability indicators to sustainable development: a novel approach using fuzzy set theory. *Agriculture, Ecosystems & Environment* 86: 173.

De Boer, I.J.M. and Cornelissen, A.M.G., 2002. A method using Sustainability indicators to compare conventional and animal-friendly egg production systems. *Poultry Science* 81: 173-181.

De Koeijer, T.J., Renkema, J.A. and Van Mensvoort, J.J.M., 1995. Environmental-Economic Analysis of Mixed Crop-Livestock Farming. *Agricultural Systems* 48: 515-530.

Elkington, J., 1998. *Cannibals with forks: the triple bottom line of 21st century business*. New Society Publishers, US: Gabriola Island, BC.

Grin, J., Felix, F., Bos, B. and Spoelstra, S., 2004. Practices for reflexive design: lessons from A Dutch programme on sustainable agriculture. *International Journal of Foresight and Innovation Policy* 1: 126-149.

Halberg, N., van der Werf, H.M.G., Basset-Mens, C., Dalgaard, R. and de Boer, I.J.M., 2005. Environmental assessment tools for the evaluation and improvement of European livestock production systems. *Livestock Production Science* in press:

Hansen, J.W. and Jones, J.W., 1996. A systems framework for characterizing farm sustainability. *Agricultural Systems* 51: 185-201.

Hardaker, J.B., Anderson, J.R., Huirne, R.B.M. and Lien, G., 2004. *Coping with risk in agriculture*. Cabi, UK: Wallingford.

Huirne, R., 1999. *Strategie en risico*. Speech for inauguration, Wageningen University, The Netherlands: Wageningen.

Iepema, G. and Pijnenburg, J., 2001. *Conventional versus organic dairy farming. A comparison of three experimental farms on environmental impact, animal health and animal welfare*. MSC-thesis, Wageningen University, The Netherlands: Wageningen.

Keeney, R.L. and Raiffa, H., 1976. *Decisions with multiple objectives: preferences and value tradeoffs*. John Wiley & Sons, US: New York.

Mendoza, G.A. and Prabhu, R., 2000. Multiple criteria decision making approaches to assessing forest sustainability using criteria and indicators: a case study. *Forest Ecology and Management* 131: 107-126.

Nevens, F., Verbruggen, I., Reheul, D. and Hofman, G., 2005. Farm gate nitrogen surpluses and nitrogen use efficiency of specialized dairy farms in Flanders: Evolution and future goals. *Agricultural Systems* In Press:

Oenema, J., Koskamp, G.J. and Galama, P.J., 2001. Guiding commercial pilot farms to bridge the gap between experimental and commercial dairy farms; the project 'Cows & Opportunities'. *Netherlands Journal of Agricultural Science* 49: 277-296.

Ondersteijn, C.J.M., Beldman, A.C.G., Daatselaar, C.H.G., Giesen, G.W.J. and Huirne, R.B.M., 2003. Farm structure or farm management: effective ways to reduce nutrient surpluses on dairy farms and their financial impacts. *Livestock Production Science* 84: 171.

Reinhard, S., Vreke, J., Wijnen, W., Gaaff, A. and Hoogstra, M., 2003. *Integrale afweging van ruimtegebruik. Ontwikkeling van een instrumentarium voor het beoordelen van veranderingen in aanwending van ruimte*. 4.03.03. Agricultural Economics Research Institute (LEI), The Netherlands: The Hague.

Romero, C. and Rehman, T., 2003. *Multiple criteria analysis for agricultural decisions*. Elsevier, The Netherlands: Amsterdam.

SER, 2000. *Winst van waarden: advies over maatschappelijk ondernemen*. Social Economische Raad, Den Haag.

SER, 2003. *Duurzaamheid vraagt om openheid: op weg naar een duurzame consumptie*. SER Sociaal-Economische Raad, Den Haag.

Strassert, G. and Prato, T., 2002. Selecting farming systems using a new multiple criteria decision model: the balancing and ranking method. *Ecological Economics* 40: 269-277.

Stuiver, M., Van Der Ploeg, J.D. and Leeuwis, C., 2003. The VEL and VANLA environmental co-operatives as field laboratories. *Netherlands Journal of Agricultural Science* 51: 27-39.

Van Calker, K.J., Hooch Antink, R.H.J., Beldman, A.C.G. and Mauser, A., 2005. Caring Dairy: a sustainable dairy farming initiative in Europe, In: Developing Entrepreneurship Abilities to Feed the World in a Sustainable Way; proceedings of the 15th International Farm Management Congress 2005, Brazil: Campinas.

Van der Wielen, P., 2005. *De onbetaalde rekening van de Nederlandse veeteelt. Een verkenning naar de maatschappelijke kosten van de veeteeltsector*. CE, The Netherlands: Delft.

Zinck, J.A., Berroteran, J.L., Farshad, A., Moameni, A., Wokabi, S. and Van Ranst, E., 2004. Approaches to assessing sustainable agriculture. *Journal of Sustainable Agriculture* 23: 87-109.

Summary

Introduction

The current conventional way of Dutch dairy farming is under debate. Conventional Dutch dairy farming is highly productive through a high level of farm management (e.g. high milk and crop production) and high intensity, i.e. kg milk per hectare. Side-effects of the intensification of dairy farming became evident from the end of the 1970s and beginning of the 1980s onwards. Ecological sustainability is under pressure mainly due to decreased quality of surface water and groundwater and contribution to global warming and acidification. The debate on social sustainability issues like food safety and animal welfare has started more recently. Nevertheless, this sustainability aspect is very important for the image of Dutch dairy farming. Last but not least, economic sustainability of Dutch dairy farms is under pressure mainly due to decreasing milk prices and increasing production costs. According to policy makers, agricultural organisations, societal organisations and scientists sustainability can be a basis to address future developments for dairy farming. The transition towards more sustainable, i.e. economic, social and ecological, farming systems is a central element of the Dutch agenda for the reconstruction of the livestock production sector. The concept of sustainability needs to be quantified to evaluate the effectiveness of a transition towards more sustainable farming systems and to measure the sustainability of farming systems. Furthermore, the transition process can be supported with improved insight into the effects of management measures and farming systems on individual sustainability aspects and overall sustainability. The general objective of this research presented in this thesis was to quantify sustainability at farm level and to gain insight into the effects of management measures and farming systems on all aspects of sustainability in dairy farming by using farm-level modelling. The perceptions of different societal groups should be taken into account when quantifying subjective elements of sustainability in dairy farming as different stakeholders, like politicians, consumers, and producers, can view sustainability quite differently. Expert knowledge should be included to quantify objective elements of sustainability in dairy farming. This results in the following questions for this research:

1. Which attributes are relevant with respect to economic, social, and ecological sustainability of Dutch dairy farming?
2. Which indicators are suitable to quantify economic, social, and ecological sustainability and can be included in the dairy farm model?
3. What are the effects of farm management measures and farming systems on economic, social, and ecological sustainability indicators?
4. How can the selected indicators for economic, social and ecological sustainability be amalgamated into one overall function system by using the preferences of different stakeholders and expert knowledge?

5. What is the effect of maximising overall sustainability on the sustainability performance (i.e. overall sustainability, aspect sustainability and attribute sustainability) of different dairy farming systems for different stakeholder groups?

Which attributes are relevant with respect to economic, social and ecological sustainability of Dutch dairy farming?

This thesis focuses on four aspects of sustainability: economic, internal social, external social, and ecological sustainability (see Chapter 2). Economic sustainability is defined as the ability of the dairy farmer to continue his farming business, i.e. economic viability. Social sustainability is subdivided into internal and external social sustainability. Internal social sustainability relates to working conditions for the farm operator and employees. External social sustainability has to do with societal concern regarding the impact of agriculture on the well being of people and animals. Ecological sustainability concerns threats or benefits to the flora, fauna, soil, water, and climate. For each aspect, one or more attributes are selected that are defined as a particular feature of an aspect of sustainability.

Scientific experts were consulted to compile a list of attributes for economic, internal social and ecological sustainability, as the assessment of attributes with respect to these aspects of sustainability is a matter of expert knowledge. Identification of external social sustainability attributes depends strongly on the preferences of stakeholders, as societal concerns differ between stakeholders. The list of attributes for external social sustainability, therefore, was assessed by representatives of stakeholder groups, i.e. consumer and farmer organisations, industrial producers, and policy makers. For economic and internal social sustainability only one attribute was selected: profitability and working conditions, respectively. The list for external social sustainability contained 19 attributes and the list for ecological sustainability contained 15 attributes. To assess their relative importance, the same experts and stakeholders ranked the attributes for external social and ecological sustainability by using a questionnaire. A final selection (see Figure 1) of attributes was based upon: (1) the relative importance, (2) the possibility to quantify these attributes in an objective way, and (3) the possibility of farming systems to affect the level of these attributes.

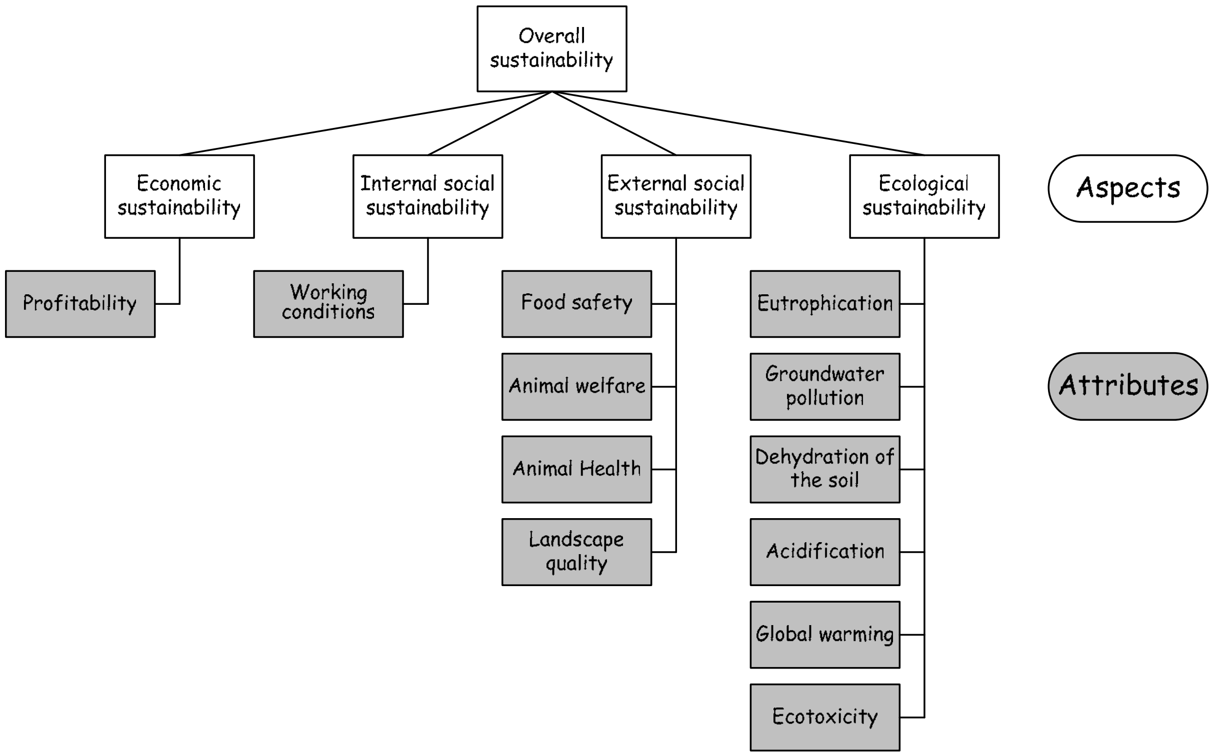


Figure 1 Decomposition of overall sustainability of Dutch dairy farms into aspects and attributes

Which indicators are suitable to quantify economic, social, and ecological sustainability and can be included in the dairy farm model?

The indicators that are used to measure the attributes were selected on the basis of the following selection criteria: (1) it should be possible to include the indicators in a dairy farm LP (Linear Programming)-model, (2) the indicators should be valid, and (3) an ideal (utility = 1) and an anti-ideal value (utility = 0) can be determined for the indicators. The implication of including the indicators in an LP-model was that only indirect indicators based upon farm management measures were selected.

Net farm income was selected as indicator for measuring economic sustainability. The Physical Load Index was selected to measure the level of working conditions within internal social sustainability. This is the only indicator that is developed to explain sick leave as a result of insufficient working conditions in different Dutch agricultural sectors. For external social sustainability, indicators were selected that are based upon features of the environment and management which can be considered prerequisites for ‘sustainable’ performance on the external social attributes. The Chain Food Safety Index, TGI(TierGerechtheitsIndex)-35L, Animal Health Index, and Agricultural Nature Norm Analysis were included to measure food safety, animal welfare, animal health, and landscape quality respectively. For ecological sustainability, indicators were selected that originate from Life Cycle Assessment. In the present study, however, the defined indicators are calculated at the farm level. The selected ecological indicators are: eutrophication potential, nitrate concentration in groundwater, water use, acidification potential, global warming potential, terrestrial ecotoxicity and aquatic ecotoxicity.

What are the effects of farm management measures and farming systems on economic, social, and ecological sustainability indicators?

Farm level modelling was used to determine how farm management measures and farming systems affect different sustainability indicators. In this thesis economic, social and ecological indicators were included in a dairy farm LP (Linear Programming)-model. Linear programming (LP) is a suitable technique to model sustainability of Dutch dairy farms as it can: (1) incorporate recent and future developments (e.g. environmental policy and technical change) and (2) add sustainability indicators by including new restrictions to the model.

In Chapter 3 the LP-model was used to analyse the effects of environmental policy and management measures on economic and ecological sustainability. The farm structure of experimental farm “De Marke” formed the basis for three optimisations: (1) basis situation without environmental policy, (2) situation with Dutch environmental policy for 2004, and (3) situation with farm management measures applied at “De Marke”. The environmental policy resulted in lower fertiliser use and consequently in lower feed production which ended up in a decrease in sales of surplus roughage. This led to a decrease in net farm income of ca. €2,500. Including this policy improved the performance of the used ecological indicators (except for ecotoxicity) and showed to be an effective tool to reduce the environmental impact of dairy farming. Adapting the model with farm management measures applied at experimental farm “De Marke” resulted in even better ecological performance compared to the situation with environmental policy. Nonetheless, this increase in ecological performance led to a considerably lower net farm income (ca. €14,500) in comparison with the basis situation without environmental policy.

In Chapter 4 the dairy farm LP-model was used to analyse possible differences in social sustainability between a conventional and an organic dairy farming system. Results for internal social and external social sustainability were similar for conventional and organic dairy farming systems in the basis situation and in the situation where additional management measures to improve external social sustainability were included. The only exception was improved animal welfare for the organic farming system due to prescribed grazing in the organic situation and assumed summer feeding in the conventional situation. From these results it is concluded that the level of external social sustainability is determined mainly by applied management measures and that it is hardly related to the particular farming system, i.e. conventional vs. organic.

How can the selected indicators for economic, social and ecological sustainability be amalgamated into one overall function system by using the preferences of different stakeholders and expert knowledge?

In Chapter 5 the Multi-Attribute Utility Theory was used to develop an overall sustainability function for Dutch dairy farming systems. This approach consists of four steps: (1) determination of attribute utility functions; (2) assessing attribute weights to determine utility functions per aspect; (3) assessing aspect weights to determine the overall sustainability function per stakeholder group; and (4) determination of the overall sustainability function per stakeholder group and for society as a whole by aggregating preferences of stakeholders and stakeholder groups using an extended goal programming approach. Depending on the possibility for objective evaluation of each aspect, either experts or stakeholders were consulted to determine attribute utility functions and the attribute weights per aspect. In this study experts determined (attribute) utility functions for economic and ecological sustainability. Stakeholder groups (producers, consumers, industrial producers and policy makers) determined their own utility function for external social sustainability and their own aspect weights. Assessments of stakeholders and experts were aggregated by optimising the consensus within the group. For this, an Extended Goal Programming (EGP) model was used. As final step the EGP-model was used to aggregate stakeholder group assessments into the overall sustainability function for society. The EGP model appeared to be an attractive methodology to aggregate assessment of members of the same group. The aggregation of stakeholder group assessments, however, can give unsatisfactory results for one or more stakeholder groups as stakeholder groups evaluate sustainability of dairy farming systems considerably different. The developed overall sustainability function was applied per stakeholder to different Dutch dairy farming systems represented by four experimental farms. The “Low cost” experimental dairy farm attained the highest score for overall sustainability due to economical management of inputs. Sustainability rankings for the dairy farming systems per stakeholder group were relatively insensitive to minor changes in attribute and aspect weights. Based on these results it is concluded that the developed sustainability function based on stakeholder perceptions and expert knowledge can be used with reasonable confidence to determine the sustainability of different dairy farming systems per stakeholder group.

What is the effect of maximising overall sustainability on the sustainability performance of different dairy farming systems for different stakeholder groups?

In Chapter 6 a model that maximises overall sustainability of dairy farming systems is presented and applied. The presented model builds upon the dairy farm model in which economic, social and ecological attributes were included (see Chapter 3 & 4). By means of Weighted Goal Programming the overall sustainability function (see Chapter 5) was integrated into a dairy farm LP-model to create a Weighted Linear Goal Programming (WLGP)-model. In this way sustainability can be maximised per aspect or in an aggregated way by using preferences of stakeholders. The model was used to simulate an average Dutch conventional and an organic dairy farming system. Maximisation of individual sustainability aspects showed the maximum possible score for the concerning aspect of a farming system and showed the sustainability ‘boundaries’ of the concerning farming system. Maximisation of sustainability according to the aspect and attribute weights of the different stakeholders and of society as a whole showed the maximum possible score for overall sustainability per stakeholder group and for society as a whole. Differences in the overall sustainability scores for the conventional farm and the organic farm were small between the stakeholder groups and society. The differences in the sustainability scores for economic and ecological sustainability were more evident between stakeholders. Economic sustainability, for example, was considerably higher in the solution where overall sustainability was maximised according the preferences of producers in comparison with the consumers’ solution. Apparently, differences in scores for sustainability aspects were cancelled out in the overall sustainability score. For this reason showing the maximum possible scores for the sustainability aspects, is more informative with respect to sustainability performance. Analysis with the WLGP-model showed that conventional dairy farms have the potential to achieve similar sustainability scores in comparison with organic dairy farms (and vice versa). It is concluded that the WLGP model is a suitable tool to analyse the sustainability of different dairy farming systems.

Conclusions

The following general conclusions can be drawn from the methodologies used in this thesis:

- ❖ Extended Goal Programming model is an attractive method to aggregate preferences per stakeholder group;
- ❖ The developed multi-attribute sustainability function based on stakeholder perceptions and expert knowledge can be used to quantify the sustainability of different dairy farming systems per stakeholder group;
- ❖ Weighted Linear Goal Programming model is suitable to analyse the sustainability of different dairy farming systems and improves insight in the effects of policy and future developments on sustainability performance;

The following general conclusions can be drawn from the results of this thesis:

- ❖ Quantification of sustainability is dependent on time, place, and perception. This implies that studies that quantify sustainability should be repeated regularly, are valid only for a certain region and agricultural sector and should include stakeholder consultation;
- ❖ At Dutch dairy farm level, economic and internal social sustainability can be described sufficiently by one attribute, while external social and ecological need multiple attributes to be measured adequately;
- ❖ The use of one ‘societal’ overall sustainability function that satisfactorily includes preferences of all stakeholder groups is limited as stakeholder groups evaluate sustainability of dairy farming systems considerably different;
- ❖ For farm and policy decision making it gives more insight to show the performance per sustainability aspect than to show the overall sustainability score;
- ❖ Analysis with the Weighted Linear Goal Programming model shows that conventional dairy farms potentially are able to achieve similar sustainability scores in comparison with organic dairy farms (and vice versa).

Samenvatting

Achtergrond

De conventionele productiewijze in de Nederlandse melkveehouderij staat ter discussie. De Nederlandse melkveehouderij onderscheidt zich door een hoge productiviteit welke wordt mogelijk gemaakt door een hoog managementniveau (bijv. hoge melk- en grasproductie) en een hoge intensiteit (kilogram melk per hectare). Neveneffecten van de intensivering kwamen met name naar voren aan het eind van de jaren zeventig en het begin van de jaren tachtig. De milieukwaliteit staat onder druk wat blijkt uit onvoldoende kwaliteit van verschillende oppervlaktewateren en omdat in teveel gebieden de WHO-limiet van 50 mg nitraat per liter grondwater wordt overschreden. Dit wordt grotendeels veroorzaakt door overschotten van fosfaat en stikstof vanuit de landbouw. Ook draagt de landbouw bij aan de emissie van broeikasgassen (methaan, lachgas en koolstofdioxide) en aan de emissie van verzurende gassen (vooral ammoniak). Naast de milieuproblematiek hebben recente crises met betrekking tot BSE, MKZ en dioxine het imago van de melkveehouderij negatief beïnvloed. Ook de discussie rondom de weidegang van melkkoeien en jongvee is indicatief voor de bezorgdheid van verschillende belangengroepen over de productiewijze in de melkveehouderij. De economische positie van melkveebedrijven staat de afgelopen jaren onder druk door stijgende productiekosten en een dalende melkprijs. In het nieuwe gemeenschappelijke landbouwbeleid wordt het marktondersteunende beleid stapsgewijs veranderd in een inkomensondersteunend beleid. Voor het verkrijgen van deze inkomenssteun moeten melkveehouders voldoen aan verschillende eisen m.b.t. tot milieu en dierenwelzijn en bovendien is het budget en de termijn van deze inkomenssteun onzeker. Deze veranderingen veroorzaken een verdere druk op de inkomens van melkveebedrijven.

Duurzaamheid is het kernbegrip in discussies over de toekomst van de Nederlandse melkveehouderij. De transitie naar een duurzame melkveehouderij is dan ook het centrale element in beleidsplannen voor de Nederlandse veehouderij. Om de effectiviteit van een transitie naar duurzaamheid te kunnen evalueren is het noodzakelijk dat duurzaamheid meetbaar wordt gemaakt. De transitie naar duurzaamheid kan verder worden ondersteund door een verbeterd inzicht in de duurzaamheidseffecten van verschillende managementmaatregelen en bedrijfssystemen.

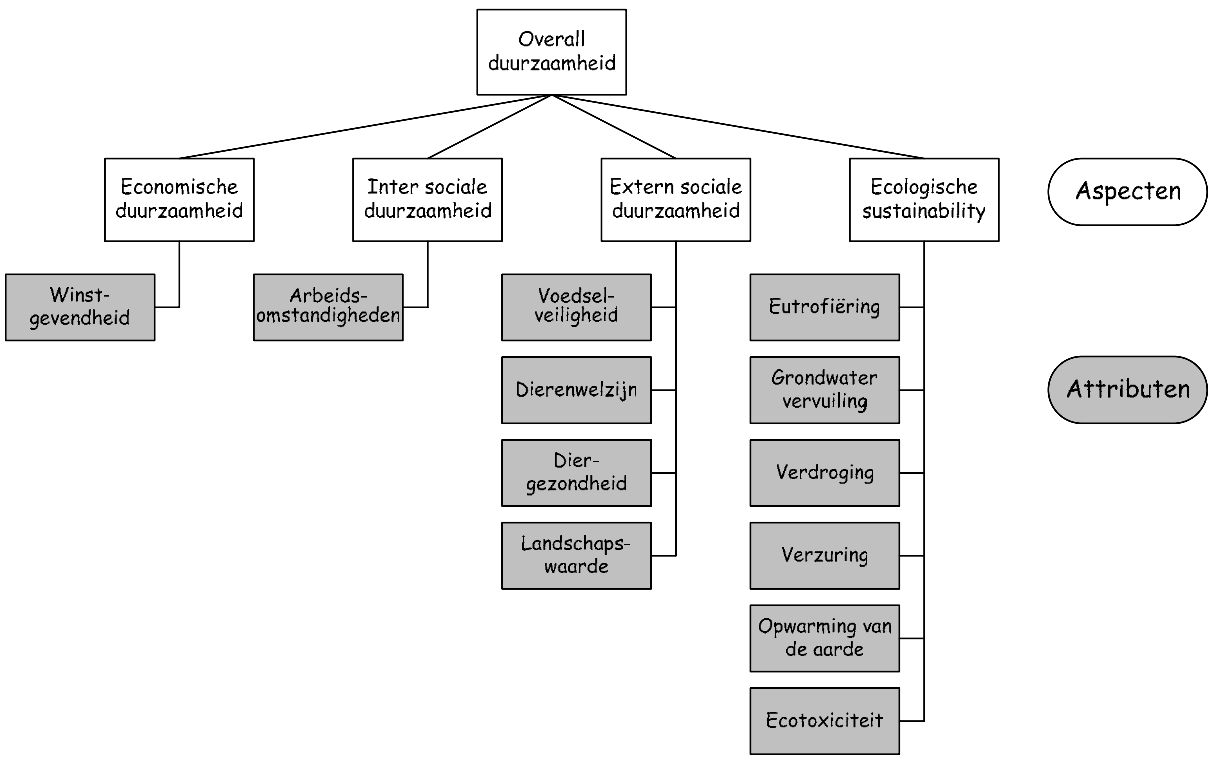
De doelstelling van dit proefschrift is het kwantificeren van duurzaamheid op bedrijfsniveau en het verkrijgen van inzicht in de effecten van managementmaatregelen en bedrijfssystemen op duurzaamheid in de melkveehouderij door middel van modellering. De beoordeling of een bepaald systeem duurzaam genoemd kan worden is onder andere afhankelijk van de perceptie van de betrokken belanghebbenden. Zo kan een melkveehouder een andere perceptie van duurzaamheid hebben dan een consument. Dit betekent dat de perceptie van belanghebbenden meegenomen moet worden wanneer subjectieve elementen van duurzaamheid worden gekwantificeerd. Experts moeten worden geraadpleegd wanneer objectieve elementen van duurzaamheid worden gekwantificeerd. De doelstelling van het onderzoek valt uiteen in de volgende onderzoeksvragen:

1. Welke attributen zijn belangrijk voor economische, sociale, en ecologische duurzaamheid van de Nederlandse melkveehouderij?
2. Welke indicatoren zijn geschikt voor het meetbaar maken van economische, sociale en ecologische attributen van duurzaamheid en kunnen tevens worden opgenomen in een bedrijfsmodel voor de melkveehouderij?
3. Wat zijn de effecten van managementmaatregelen en bedrijfssystemen op het niveau van economische, sociale en ecologische indicatoren?
4. Hoe kunnen op basis van percepties van belanghebbenden en expertkennis de verschillende indicatoren worden geïntegreerd in één overall functie voor duurzaamheid voor melkveebedrijven?
5. Wat is voor verschillende bedrijfssystemen de score voor duurzaamheid wanneer duurzaamheid zowel per aspect als overall wordt gemaximaliseerd?

Welke attributen zijn belangrijk voor economische, sociale, en ecologische duurzaamheid van de Nederlandse melkveehouderij?

In Hoofdstuk 2 zijn vier aspecten van duurzaamheid onderscheiden: economische, intern sociale, extern sociale en ecologische duurzaamheid. Economische duurzaamheid heeft betrekking op de winstgevendheid van het melkveebedrijf. Intern sociale duurzaamheid betreft de arbeidsomstandigheden van de meewerkende gezinsleden. Extern sociale duurzaamheid heeft betrekking op de bezorgdheid van de maatschappij over de wijze van produceren. Ecologische duurzaamheid, tenslotte, heeft te maken met de gevolgen voor flora, fauna, bodem, water en klimaat.

De aspecten van duurzaamheid kunnen worden beschreven door één of meerdere attributen (of onderwerpen). Omdat attributen voor economische, intern sociale en ecologische duurzaamheid objectief vastgesteld kunnen worden, zijn voor het samenstellen van een groslijst met attributen voor deze aspecten experts benaderd. Het vaststellen van attributen voor extern sociale duurzaamheid is duidelijk meer afhankelijk van de perceptie van belanghebbenden. Om die reden zijn in dit onderzoek consumenten, melkveehouders, industriële producenten (verwerkende industrie en retail) en beleidsmakers geraadpleegd als belanghebbenden voor het vaststellen van een groslijst met attributen voor extern sociale duurzaamheid. In dit onderzoek bleek het met betrekking tot economische en intern sociale duurzaamheid voldoende om één attribuut te selecteren, respectievelijk winstgevendheid en arbeidsomstandigheden. Extern sociale en ecologische kunnen echter niet op basis van één attribuut worden beschreven. Voor extern sociale duurzaamheid zijn 19 attributen vastgesteld en voor ecologische duurzaamheid is een lijst met 15 attributen vastgesteld. Om te inventariseren welke attributen het meest relevant zijn is in een schriftelijke enquête aan belanghebbenden (extern sociale duurzaamheid) en experts (ecologische duurzaamheid) gevraagd om de verschillende attributen te rangschikken naar belangrijkheid. De definitieve selectie van de attributen is gebaseerd op: (1) de relevantie voor duurzaamheid, (2) de objectieve meetbaarheid van de attributen, en (3) de mogelijkheid om met veranderingen in het bedrijfssysteem het niveau van de attributen te beïnvloeden. In Figuur 1 zijn de geselecteerde attributen weergegeven.



Figuur 1 Geselecteerde aspecten en attributen voor het kwantificeren van duurzaamheid in de melkveehouderij

Welke indicatoren zijn geschikt voor het meetbaar maken van economische, sociale en ecologische attributen van duurzaamheid en kunnen tevens worden opgenomen in een bedrijfsmodel voor de melkveehouderij?

De indicatoren die zijn gebruikt om het niveau van de verschillende attributen te meten zijn geselecteerd op basis van (zie Hoofdstuk 3 & 4): (1) de mogelijkheid om indicatoren op te

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nemen in een model van een melkveebedrijf, (2) de validiteit van de indicatoren, en (3) de mogelijkheid tot het vaststellen van minimum en maximum waarden voor duurzaamheid.

Het gezinsinkomen uit het melkveebedrijf (per ondernemer) is geselecteerd als indicator voor het economische attribuut winstgevendheid (zie Figuur 1). Voor het meten van de intern sociale duurzaamheid is de "Physical Load Index" (PLI) geselecteerd. Dit is de enige beschikbare indicator die op basis van bedrijfsstructuur en bedrijfskarakteristieken een inschatting maakt van de kwantitatieve en kwalitatieve arbeidsomstandigheden. Voor extern sociale duurzaamheid zijn indicatoren geselecteerd die zijn gebaseerd op bedrijfsstructuur, bedrijfskarakteristieken en bedrijfsmanagement: "Chain Food Safety Index" (voedselveiligheid), "TierGerechtheitsIndex" (dierenwelzijn), "Index voor diergezondheid" (diergezondheid) en "Agrarische Natuur Norm Analyse" (landschapwaarde). Voor ecologische duurzaamheid is zoveel mogelijk gebruik gemaakt van zogenaamde "Levens Cyclus Analyse" (LCA) indicatoren. Deze indicatoren geven een beeld van de totale milieubelasting tijdens de productie van één kilogram product (bijv. melk). In dit onderzoek is echter alleen gekeken naar de bijdrage van het primaire bedrijf m.b.t. de milieubelasting. De milieubelasting door de productie van grondstoffen (vb krachtvoer) of door het verwerken van de melk is dus niet meegenomen. De geselecteerde indicatoren voor het meten van de attributen voor ecologische duurzaamheid zijn: eutrofieringspotentieel, nitraatconcentratie in grondwater, gebruik van water, verzuringspotentieel, broeikasgaspotentieel, terrestische ecotoxiciteit en aquatische ecotoxiciteit.

Wat zijn de effecten van managementmaatregelen en bedrijfssystemen op het niveau van economische, sociale en ecologische indicatoren?

Modellering op bedrijfsniveau kan worden gebruikt om de effecten van managementmaatregelen en bedrijfssystemen op de verschillende duurzaamheidsindicatoren te berekenen. In dit onderzoek zijn de geselecteerde indicatoren voor economische, sociale (intern en extern) en ecologische duurzaamheid in een Lineair Programmerings (LP)-model van een melkveebedrijf opgenomen. Lineaire Programmering is een geschikte methodiek om de duurzaamheid van melkveebedrijven te modelleren omdat: (1) recente en toekomstige ontwikkelingen (bijv. technische en beleidsmatige veranderingen) eenvoudig in het model kunnen worden opgenomen en (2) indicatoren voor duurzaamheid door middel van beperkingen in het model kunnen worden opgenomen.

In Hoofdstuk 3 is het LP-model gebruikt om te analyseren wat de effecten zijn van het milieubeleid (MINAS; MINeralen Aangifte Systeem) en managementmaatregelen op de economische en ecologische duurzaamheid. MINAS is in 1998 geïntroduceerd om te voldoen aan de zogenaamde Nitraatrichtlijn die de Europese Unie heeft uitgevaardigd om te voldoen aan de WHO-limiet van 50 mg nitraat per liter grondwater. De bedrijfsstructuur en -karakteristieken van proefbedrijf "De Marke" zijn in de berekeningen als uitgangspunt genomen. Drie verschillende situaties zijn geoptimaliseerd: (1) een basissituatie zonder milieubeleid, (2) een basissituatie met milieubeleid, (3) een situatie met extra managementmaatregelen t.a.v. het milieu zoals deze op proefbedrijf "De Marke" worden genomen. Opname van MINAS in het LP-model leidde tot een verminderd verbruik van kunstmest in vergelijking met de situatie zonder milieubeleid. Dit leidde tot een lagere ruwvoerproductie, waardoor de mogelijkheden om het overschot aan ruwvoer te verkopen beperkt waren. Uiteindelijk resulteerde de opname van MINAS voor het geoptimaliseerde bedrijf tot een daling van het gezinsinkomen van €2,500 in vergelijking met de situatie zonder milieubeleid. MINAS bleek een effectieve beleidsmaatregel te zijn om de milieu-impact van "De Marke" op alle indicatoren (behalve ecotoxiciteit) te verminderen. Aanpassing van het LP-model met de extra milieumaatregelen zoals deze op proefbedrijf "De Marke" worden genomen resulteerde in een nog betere score voor ecologische duurzaamheid. De verbetering van ecologische duurzaamheid ging echter wel ten koste van het gezinsinkomen (daling van €14,500 in vergelijking met basissituatie zonder milieubeleid).

In Hoofdstuk 4 is het LP-model gebruikt om de verschillen in sociale duurzaamheid tussen verschillende bedrijfssystemen te analyseren. Het gangbare "Hightechbedrijf" en het biologische "Aver Heino" vormden hierbij de basis. De scores voor extern sociale duurzaamheid voor het gangbare en biologische melkveebedrijf waren vergelijkbaar in zowel de basissituatie als in de situatie waarbij extra maatregelen zijn genomen om de extern sociale duurzaamheid te verbeteren. Uitzondering hierop was de score voor dierenwelzijn, omdat in de basissituatie voor het gangbare bedrijf is aangenomen dat de melkkoeien het hele jaar op stal staan terwijl de melkkoeien in de biologische situatie verplicht weidegang kregen. Op basis van deze resultaten is geconcludeerd dat het niveau van extern sociale duurzaamheid met name wordt bepaald door de toegepaste managementmaatregelen en dat het niveau van extern sociale duurzaamheid nauwelijks gerelateerd is aan het betreffende bedrijfssysteem (d.w.z. gangbaar vs. biologisch).

Hoe kunnen op basis van percepties van belanghebbenden en expertkennis de verschillende indicatoren worden geïntegreerd in één overall functie voor duurzaamheid voor melkveebedrijven?

Verschillende belangengroepen kijken verschillend tegen duurzaamheid aan en wegen het relatieve belang van bepaalde onderdelen van duurzaamheid anders. Dit betekent dat de perceptie van verschillende belangengroepen moet worden meegenomen bij het bepalen van de overall duurzaamheid van melkveebedrijven. In Hoofdstuk 5 is de Multi-Attribute Utility Theory (MAUT) gebruikt voor het ontwikkelen van de overall functie voor duurzaamheid in de melkveehouderij. Deze benadering bestaat uit vier stappen: (1) vaststellen van nutsfuncties per attribuut, (2) bepalen van relatieve gewichten per attribuut voor het vaststellen van nutsfuncties per aspect, (3) bepalen van relatieve gewichten per aspect voor het vaststellen van de overall functie voor duurzaamheid per belangengroep en (4) bepalen van de overall functie voor duurzaamheid per belangengroep en voor de 'maatschappij' door aggregatie van percepties van experts, belanghebbenden en belangengroepen d.m.v. Extended Goal Programming (EGP). Afhankelijk van de mogelijkheid om een aspect objectief te beoordelen zijn experts of belanghebbenden geraadpleegd om de nutsfunctie per attribuut en het gewicht per attribuut te kwantificeren. In deze studie zijn experts geraadpleegd voor het kwantificeren van nutsfuncties voor economische, intern sociale en ecologische duurzaamheid terwijl belangengroepen (d.w.z. consumenten, melkveehouders, industriële producenten en beleidsmakers) zijn geraadpleegd voor het kwantificeren van nutsfuncties voor externe sociale duurzaamheid. Belangengroepen zijn ook gevraagd voor het bepalen van de relatieve gewichten per aspect van duurzaamheid.

Voor het vaststellen van de nutsfuncties per attribuut is een minimumwaarde (duurzaamheidscore van 0) en maximumwaarde (duurzaamheidscore van 1) bepaald. De minimumwaarde is het minimum waaraan een bepaald bedrijfssysteem moet voldoen om als duurzaam beoordeeld te kunnen worden. Zo is door experts voor het attribuut winstgevendheid een minimumwaarde van €18,000 gezinsinkomen (per melkveehouder per jaar) vastgesteld. Bedrijfssystemen die een gezinsinkomen halen lager dan €18,000 worden dus niet als economisch duurzaam beoordeeld. Een gezinsinkomen van €74,000 per jaar is door experts vastgesteld als maximumwaarde voor het attribuut winstgevendheid wat betekent dat het deel hoger dan €74,000 geen toegevoegde waarde heeft met betrekking tot de economische duurzaamheid van het betreffende bedrijfssysteem. Afhankelijk van het attribuut is gekozen voor een lineair of een niet-lineaire nutsfunctie.

Het EGP-model minimaliseert de afwijkingen van individuele percepties tot de groepsperceptie en is gebruikt om de percepties van experts en belanghebbenden te aggregeren per groep van experts of belanghebbenden. Dit resulteerde uiteindelijk in een overall functie voor duurzaamheid per belangengroep. Daarna is het EGP-model gebruikt om de overall functies voor duurzaamheid van de vier belangengroepen te aggregeren tot een 'maatschappelijke' overall functie voor duurzaamheid. Het EGP-model bleek een aantrekkelijke methode te zijn om percepties binnen groepen experts of belanghebbenden te aggregeren. De aggregatie van overall functies voor duurzaamheid van de vier belangengroepen in een 'maatschappelijke' overall functie voor duurzaamheid kan echter onbevredigende resultaten geven voor één of meerdere belangengroepen. Dit wordt vooral veroorzaakt door verschillen tussen belangengroepen met betrekking tot het toegekende relatieve gewicht per aspect van duurzaamheid. De vertegenwoordigers van consumenten kennen bijvoorbeeld 76% van het relatieve gewicht toe aan extern sociale en ecologische duurzaamheid, terwijl vertegenwoordigers van melkveehouders 68% van het relatieve gewicht toekennen aan economische en intern sociale duurzaamheid. Industriële producenten en beleidmakers hebben een meer evenwichtige verdeling van de gewichten per aspect van duurzaamheid.

De ontwikkelde overall functie voor duurzaamheid is voor de periode 2000-2002 per belangengroep toegepast op vier proefbedrijven: “Aver Heino”, “De Marke”, het “Hightechbedrijf” en het “Lagekostenbedrijf”. Het “Lagekostenbedrijf” was het enige bedrijf dat voldeed aan de minimumwaarde voor alle attributen en haalde de hoogste score voor overall duurzaamheid, namelijk 0.69 (op een schaal van 0 tot 1). De hoge score voor het “Lagekostenbedrijf” wordt vooral veroorzaakt door een efficiënt management m.b.t. verschillende inputs (bijv. kunstmest en krachtvoer) in combinatie met een zeer goede bodemvruchtbaarheid. De rangschikking van deze bedrijven op basis van de score voor overall duurzaamheid bleek per belangengroep relatief ongevoelig voor variatie in gewichten van attributen en aspecten. Op basis van deze resultaten is geconcludeerd dat de ontwikkelde overall functie voor duurzaamheid met voldoende vertrouwen gebruikt kan worden om per belangengroep de duurzaamheid van verschillende bedrijfssystemen in de melkveehouderij te bepalen.

Wat is voor verschillende bedrijfssystemen de score voor duurzaamheid wanneer duurzaamheid zowel per aspect als overall wordt gemaximaliseerd?

Hoofdstuk 6 presenteert een model dat de overall functie voor duurzaamheid van bedrijfssystemen in de melkveehouderij maximaliseert. Het gepresenteerde model bouwt voort op het LP-model waarin de ecologische, sociale en ecologische indicatoren zijn opgenomen (zie Hoofdstuk 3 & 4). De functie voor overall duurzaamheid is in het LP-model opgenomen als doelfunctie zodat het model is omgevormd tot een Weighted Linear Goal Programming model. Door dit model te gebruiken kan duurzaamheid per aspect en voor overall duurzaamheid worden gemaximaliseerd. Het model is toegepast voor een gemiddeld Nederlands gangbaar en biologisch bedrijfssysteem. Maximalisatie per aspect van duurzaamheid geeft de maximum score van het betreffende bedrijfssysteem voor deze aspecten en geeft dus de ‘grenzen van duurzaamheid’ van het betreffende systeem. Maximalisatie van economische duurzaamheid resulteerde in een gezinsinkomen van €30,500 (economische duurzaamheidscore van 0.50) voor het gangbare bedrijfssysteem en in een gezinsinkomen van €26,800 (economische duurzaamheidscore van 0.38) voor het biologische bedrijfssysteem. De intern sociale duurzaamheidscore was voor beide bedrijfssystemen 0.38 en varieerde nauwelijks tussen de verschillende systemen. Maximalisatie van extern sociale duurzaamheid resulteerde in een extern sociale duurzaamheidscore van 0.79 voor het gangbare bedrijfssysteem en in een extern sociale duurzaamheidscore van 0.78 voor het biologische bedrijfssysteem. Maximalisatie van ecologische duurzaamheid resulteerde in een ecologische duurzaamheidscore van 0.64 voor het gangbare bedrijfssysteem en in een ecologische duurzaamheidscore van 0.56 voor het biologische bedrijfssysteem. De lagere score voor het biologisch bedrijfssysteem wordt vooral veroorzaakt doordat op dit bedrijf meer melkkoeien worden gehouden in verband met de lagere melkproductie per koe. Op basis van deze resultaten is geconcludeerd dat gangbare bedrijfssystemen in potentie dezelfde scores voor duurzaamheid kunnen halen in vergelijking met biologische bedrijfssystemen (en vice versa).

Maximalisatie van duurzaamheid met gebruik van de overall functie voor duurzaamheid geeft de maximaal haalbare duurzaamheid van het betreffende bedrijfssysteem per belangengroep. Het verschil in onderliggende scores voor overall duurzaamheid van het gangbare en biologische bedrijfssysteem was relatief klein tussen belangengroepen in vergelijking met de verschillen tussen duurzaamheidscores per aspect. Zo haalde het gangbare bedrijfssysteem een score voor overall duurzaamheid van 0.55 wanneer werd geoptimaliseerd met de overall functie voor duurzaamheid van consumenten. Optimalisatie met de overall functie voor duurzaamheid van melkveehouders resulteerde in een overall duurzaamheidscore van 0.40. Het verschil in scores voor economische en ecologische aspecten van duurzaamheid was echter veel groter tussen belangengroepen. Zo is de economische duurzaamheidscore van het gangbare bedrijfssysteem 0 voor consumenten en 0.35 voor melkveehouders. Blijkbaar werden verschillen in duurzaamheidscores per aspect uitgemiddeld in de overall score voor duurzaamheid. Om deze reden is het waardevoller om de maximale scores per aspect te laten zien i.p.v. de overall score voor duurzaamheid.

Discussie en conclusies

In Hoofdstuk 7 zijn verschillende discussiepunten en de voornaamste conclusies van het proefschrift besproken. Bovendien is ingegaan op de toekomstige mogelijkheden van de overall functie voor duurzaamheid voor melkveebedrijven en het WLGP-model.

De gepresenteerde functie voor overall duurzaamheid voor melkveebedrijven is geschikt om de transitie naar een duurzamere melkveehouderij te monitoren. Door langdurige monitoring van duurzaamheid op een grote groep melkveebedrijven kunnen benchmarks worden vastgesteld voor alle indicatoren van duurzaamheid. Dit proces kan worden ondersteund door het uitbreiden van de bedrijfseconomische boekhouding met sociale en ecologische aspecten. Deze te ontwikkelen duurzaamheidsboekhouding kan de basis vormen voor een duurzaamheidsrapportage m.b.t. Maatschappelijk Verantwoord Ondernemen en Duurzaam Ondernemen. Na certificatie van dit systeem kan, wanneer hiervoor bij de verschillende belanghebbenden (o.a. consumenten, melkveehouders en industriële producenten) draagvlak is gecreëerd, een duurzaamheidslabel worden geïntroduceerd waarmee het niveau van duurzaamheid wordt aangegeven. Het WLGP-model kan hierbij als ondersteuning dienen en is bovendien een geschikte basis om de effectiviteit van bestaand en nieuw beleid ten aanzien van verschillende aspecten van duurzaamheid te evalueren.

De volgende conclusies kunnen worden getrokken op basis van de gebruikte methodes in dit proefschrift:

❖ Extended Goal Programming is een aantrekkelijke methodiek om percepties per belangengroep te aggregeren;
❖ De ontwikkelde functie voor overall duurzaamheid welke is gebaseerd op percepties van belanghebbenden en expertkennis is geschikt om per belangengroep duurzaamheid van verschillende bedrijfssystemen te kwantificeren;
❖ Weighted Linear Goal Programming is geschikt voor het analyseren van de overall duurzaamheid van verschillende bedrijfssystemen en verbetert de kennis over effecten van beleid en toekomstige ontwikkelingen op de score voor duurzaamheid.

De volgende conclusies kunnen worden getrokken op basis van de resultaten van dit proefschrift:

❖ Het kwantificeren van duurzaamheid is afhankelijk van tijd, plaats en perceptie. Dit betekent dat studies die duurzaamheid kwantificeren regelmatig moeten worden herhaald, alleen geldig zijn voor een betreffende regio en sector en dat belangengroepen in het onderzoek betrokken moeten worden;
❖ Economische en intern sociale duurzaamheid kan voor Nederlandse melkveebedrijven worden beschreven door slechts één attribuut. Voor het verantwoord bepalen van extern sociale en ecologische duurzaamheid zijn meerdere attributen nodig;
❖ Één ‘maatschappelijke’ overall functie voor duurzaamheid komt onvoldoende tegemoet aan de verschillen in perceptie van de verschillende belangengroepen;
❖ Voor het nemen van politieke en bedrijfsbeslissingen is het waardevoller de score per aspect van duurzaamheid te presenteren dan de overall score voor duurzaamheid;
❖ Analyse met het Weighted Linear Goal Programming-model laat zien dat gangbare bedrijven in potentie vergelijkbare scores halen voor de overall functie voor duurzaamheid in vergelijking met biologische melkveebedrijven (en vice versa).

Publications

Refereed scientific papers

Van Calker, K.J., Berentsen, P.B.M., Giesen, G.W.J. and Huirne, R.B.M., 2005. Identifying and ranking attributes that determine sustainability in Dutch dairy farming. *Agriculture and Human Values* 22: 53-63.

Van Calker, K.J., Berentsen, P.B.M., De Boer, I.J.M., Giesen, G.W.J. and Huirne, R.B.M., 2004. An LP-model to analyse economic and ecological sustainability on Dutch dairy farms: model presentation and application for experimental farm "de Marke". *Agricultural Systems* 82: 139-160.

Van Calker, K.J., Berentsen, P.B.M., De Boer, I.J.M., Giesen, G.W.J. and Huirne, R.B.M., 2005. Modelling social sustainability at farm level: an application to conventional and organic dairy farming. Submitted to *Agricultural Systems*.

Van Calker, K.J., Berentsen, P.B.M., Romero, C., Giesen, G. and Huirne, R.B.M., 2005. Development and application of a multi-attribute sustainability function for Dutch dairy farming systems. *Ecological Economics* (in press).

Van Calker, K.J., Berentsen, P.B.M., Giesen, G.W.J. and Huirne, R.B.M., 2005. Maximising sustainability of Dutch dairy farming systems for different stakeholders by means of modelling. Submitted to *European Review of Agricultural Economics*.

Conferences papers

Van Calker, K.J., Hooch Antink, R.H.J., Beldman, A.C.G. and Mauser, A., 2005. Caring Dairy: a sustainable dairy farming initiative in Europe. In: Developing Entrepreneurship Abilities to Feed the World in a Sustainable Way; proceedings of the 15th International Farm Management Congress 2005, Brazil: Campinas.

Van Calker, K.J., Berentsen, P.B.M., De Boer, I.J.M., Giesen, G.W.J. and Huirne, R.B.M., 2003. An LP-model to analyse economic and ecological sustainability in Dutch dairy farming. In: Farming at the edge; proceedings of the 14th International Farm Management Congress 2003, Australia: Perth, pp. 991-1000.

Van Calker, K.J., Berentsen, P.B.M., Giesen, G.W.J. and Huirne, R.B.M., 2001. Measuring sustainability in dairy farming by using preferences of experts. In: Van der Honing, Y. (Ed.), Book of Abstracts No. 7: Book of Abstracts of the 52nd Annual Meeting of the European Association for Animal Production, Hungary: Budapest, pp. 219.

Van Calker, K.J., Berentsen, P.B.M., Giesen, G.W.J. and Huirne, R.B.M., 2001. Method for measuring sustainability in dairy farming. In: Villacampa, Y., Brebbia, C.A. and Usó, J.L. (Eds.), Proceedings of the 3rd International Conference on Ecosystems and Sustainable Development. WITPress, Southampton, Spain: Alicante, pp. 824-831.

Van Calker, K.J., 2000. Framework for measuring sustainability in dairy farming. In: Van der Fels-Klerx, H.J. and Mourits, M.C.M. (Eds.), Proceedings of the Symposium on Economic Modelling of Animal Health and Farm Management, The Netherlands: Wageningen, pp. 29-36.

Other publications

Wolleswinkel, A.P., Roep, D., Van Calker, K.J., De Rooij, S.J.G. and Verhoeven, F.P.M., 2004. *Atlas van innoverende melkveehouders; Veelbelovende vertrekpunten bij het verduurzamen van de melkveehouderij.* Wageningen UR, The Netherlands: Wageningen.

Van Calker, K.J. and Verhagen, C.A., 2004. Bedrijfsduurzaamheidindex hoog op het lagekostenbedrijf. *Praktijkkompas Rundvee* 18 (1): 24-25.

Van Calker, K.J., 2003. Duurzaamheid meetbaar! *Praktijkkompas. Rundvee* 17 (6): 4-6.

Van Calker, K.J., 2003. Krachtvoerprijs bepaalt economische duurzaamheid biologisch bedrijf. *Praktijkkompas Rundvee* 17 (6): 30.

Van Calker, K.J., 2003. Melkveehouderij in Australië. *Praktijkkompas Rundvee* 17 (5): 16-17.

Van Calker, K.J. and Galama, P., 2001. Zoektocht naar meten van duurzaamheid. *Praktijkonderzoek Rundvee, Schapen en Paarden* 15 (6): 16-18.

Thesis related articles in professional journals

Booij, A., 2004. "Mijn melk zit in dat ijsje": twaalf melkveehouders gaan extra duurzame melk leveren voor Ben & Jerry's-ijs. *Veeteelt* 21 (21): 54-55.

Booij, A., 2004. Ben & Jerry's maakt keten sluitend. *Zuivelzicht* 96 (17): 10-12.

Booij, A., 2004. Duurzaamheid in cijfers uitgedrukt. *Zuivelzicht* 96 (1): 15-17.

Booij, A., 2003. Een cijfer voor duurzaamheid: nieuwe index BDI biedt houvast voor bepaling duurzaamheid van melkveebedrijven. *Veeteelt* 20 (20): 46-47.

Kort, K., 2002. Duurzaamheid langs de meetlat: gemiddeld bedrijf voldoet nu aan meerderheid van aspecten 'duurzaamheidschecklist'. *Boerderij, Veehouderij supplement* 87: 4VE-7VE.

Curriculum Vitae

Klaas Jan van Calker werd op 10 augustus 1976 geboren te Ruinerwold (Drenthe). In 1994 behaalde hij het Atheneum diploma aan het toenmalige Reestdalcollege te Meppel. In september van dat jaar startte hij met de studie Zoötechniek aan de toenmalige Landbouwuniversiteit Wageningen. Hij studeerde in september 1999 af met als afstudeervakken Veevoeding en Agrarische Bedrijfseconomie. In november van dat jaar startte hij als toegevoegd onderzoeker bij de leerstoelgroep Agrarische Bedrijfseconomie met een onderzoek naar de kosteneffectiviteit van een graslandhoogtemeter. In januari 2000 is hij gestart met dit proefschrift, financieel en inhoudelijk mede mogelijk gemaakt door Praktijkonderzoek (Veehouderij) van de Animal Sciences Group. In januari 2002 trad hij in dienst bij Praktijkonderzoek Veehouderij, waar naast het promotieonderzoek onder andere gewerkt is aan de “Atlas van innoverende melkveehouders” en een ketenproject m.b.t. duurzame melkveehouderij (“Caring Dairy”). Een deel van het promotieonderzoek is in 2004 verricht bij het Departemento de Economia y Gestion Forestal, Universidad Politechnica de Madrid. Per 1 januari 2006 start hij als wetenschappelijk onderzoeker bij de afdeling Dier van het Landbouw Economisch Instituut met als aandachtsgebied monitoring van duurzaam ondernemen.

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