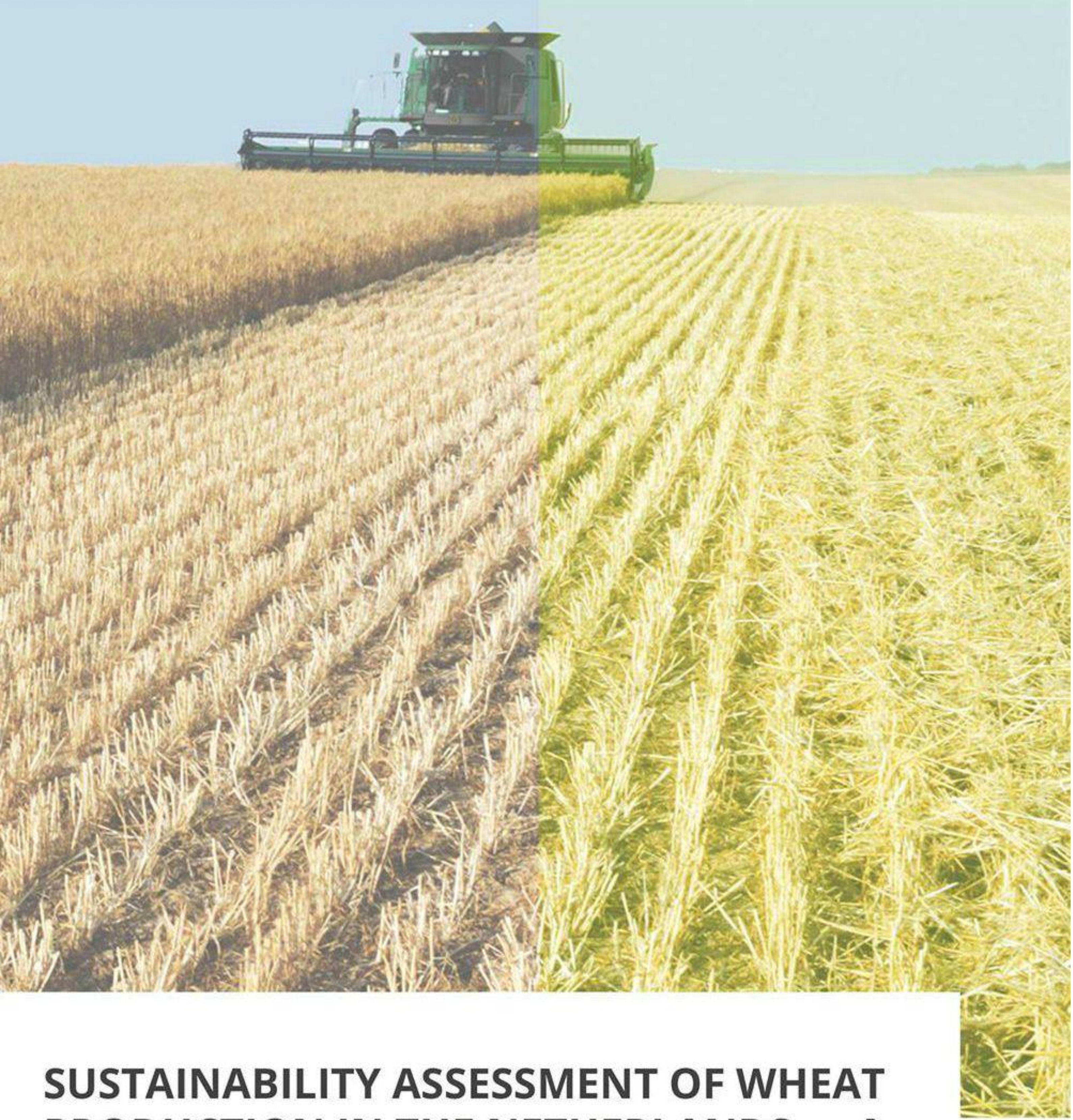

SUSTAINABILITY ASSESSMENT OF WHEAT PRODUCTION IN THE NETHERLANDS – A COMPARISON BETWEEN ORGANIC AND CONVENTIONAL PRODUCTION.

ALMA ZOILA KAEGI TREJO

AUGUST, 2015
WAGENINGEN UNIVERSITY, WAGENINGEN

WAGENINGEN UNIVERSITY
WAGENINGEN UR

Sustainability assessment of wheat production in the Netherlands - A comparison between organic and conventional production

By Alma Zoila Kaegi Trejo

Student Number: 880704416020

Wageningen University and Research Center

Department of Social Sciences

MSc Thesis Business Economics

Course Code: BEC-80436

Supervised by: Dr.ir. HJ (Ine) van der Fels

August, 2015

Acknowledgements

I dedicate this achievement to my family; their love, support, and understanding have helped me to build a strong foundation which I take with me wherever I go.

Alma Kaegi
August, 2015

Abbreviations and acronyms

A.I – Active Ingredient

BOA – Balance of Acceptability

C - Conventional

CAP – Common Agricultural Policy

DON – Deoxynivalenol

EC – European Commission

EU – European Union

FADN – Farm Accountancy Data Network

FAO – Food and Agriculture Organization of the United Nations

FiBL - Forschungsinstitut für biologischen Landbau (Research Institute of Organic Agriculture)

GE – Genetically Engineered

IFOAM – International Federation of Organic Agriculture Movements

LCA – Life Cycle Assessment

LOD – Limit of Detection

O – Organic

OECD – Organization for Economic Co-operation and Development

SAI platform – Sustainable Agriculture Initiative Platform

UAA – Utilized Agricultural Area

Abstract

Sustainability is increasingly gaining relevance in the agricultural sector and organic agriculture has become one of the most representative sustainable production systems, due to the restrictions and requirements set on the system i.e. absence of synthetic fertilizers, pesticides, growth regulators, genetically engineered (GE) organisms, and additives in livestock feed. In this research project, a sustainability assessment was conducted to compare organic and conventional wheat production in the Netherlands. Furthermore, it was investigated if the specific requirements and policy support make organic production more sustainable. This study incorporated the three dimensions of sustainability: people, planet and profit. It was conducted following a protocol developed for evaluating the sustainability of food production systems and by incorporating data into the Balance of Acceptability (BOA) software. The results from the assessment showed that organic wheat production in the Netherlands is more sustainable when compared to a conventional scenario. Conventional production scored reasonably in the assessment, this is a positive result compared to the expected low score. It was concluded that agriculture in the Netherlands is shifting to a more sustainable version of conventional farming. Organic agriculture is a good sustainable alternative to conventional farming. Conventional agriculture's reasonable score is a positive result and it reflects the sustainable agenda in the Dutch agricultural policy, particularly regarding chemical pesticide use. It is recommended to extend research by quantifying the actual impact in emissions caused by intensive fertilization, e.g. by conducting an LCA study for wheat production in the Netherlands. Another topic for investigation can be to analyze the impact of the Common Agricultural Policy's reforms, especially the subsidies, and their impact on the income and productivity of Dutch farmers. Furthermore, there should be focus in increasing breeding research for Dutch wheat varieties, for both organic and conventional agriculture.

Key words: wheat; sustainability assessment; sustainable; organic; conventional; agriculture; farming; Netherlands

Table of Contents

1 Introduction

1.1 Background

Sustainability is increasingly gaining interest, especially as a result of the rising global consciousness regarding the effects that human activities have on natural resources. According to statistics, human population is expected to increase to 9 billion people by 2050 (Godfray *et al.*, 2010). In addition, the increase in wealth and purchasing power leads to an increase in consumption and demand of food products. Producers are faced with the responsibility of meeting food demand, as well as doing so in a sustainable way. In the European Union, organic farming is recognized as a favorable alternative to conventional farming. It is considered a possibility to improve the sustainability of agriculture (Brentrup *et al.* (2004); Acs *et al.* (2007); Nemecek *et al.* (2011); Tuomisto *et al.* (2012b)).

The utilized agricultural area (UAA) in the Netherlands is approximately 2 million hectares (ha); this represents over half of the total territory. According to data from public sources (Eurostat, IFOAM, and FiBL) cereals represent around 12% of total UAA and common wheat represents 7%. Due to its high yield capacity, wheat is the most cultivated grain followed by maize and barley (Pol, 2007). In terms of land use, wheat is Europe’s dominant crop (Boogaard *et al.*, 2013) it is used for human and animal consumption, as well as in the production of other by-products (e.g. starch and bio-ethanol).

Organic agricultural area covers around 48,038 ha which represents around 2.5% of total UAA. Organic cereals represent the second biggest share of organic land in the EU, after permanent grasslands (European Commission, 2013a). In the Netherlands, Approximately 1.2 million tons of wheat are produced each year, this represents around 1% of EU production. Of this production, 55% becomes animal feed, 20% of the wheat is milled into flour, 20% goes to the starch industry, and 5% for bio-ethanol production. Milling companies pay a higher price than the other industries, so the milling market is the primary interest for farmers. The quality of the grain determines its functionality (Pol, 2007).

1.2 Problem description

In Europe, post-world war II efforts focused on large-scale intensification and mechanization of agricultural production. The increase of farm productivity and efficiency was essential in order to increase self-sufficiency, food security, and prevent food shortages. In the Netherlands, in addition to technical efforts, the government also invested in agricultural research (Meerburg *et al.*, 2009). These efforts resulted in a constant yield growth, which led to over production and environmental pollution.

Modern agriculture has had a significant impact on biodiversity loss, climate change, and man-induced changes to the natural nitrogen cycle (Meier *et al.*, 2015). After the mid-1970s food security was no longer considered an immediate priority and environmental impacts took center stage when environmental organizations started shedding light on intensive use of resources in agriculture. Rural labor force declined due to an increase in mechanization and this resulted in a social gap between the rural and the increasing urban population. This marked an important milestone, when sustainability became a dominating factor in European and Dutch policy, especially regarding agricultural activity.

Sustainable agriculture represents farming systems that produce good quality food, maintaining productivity through an efficient utilization of resources, while reducing application of chemicals and the depletion of non-renewable resources, as much as possible; using biological control and other sustainable alternatives instead. These goals lead to an increase in the expected sustainability of production systems. By nature, organic agriculture is an alternative to conventional agriculture for reducing the environmental impacts caused by intensive farming activities.

Organic agriculture is a production system that applies careful management of agricultural activities and proper control of their impact on the environment, reducing as much as possible the dependence on external inputs and utilizing efficiently internal inputs e.g. water, air, soil, energy, and biodiversity (de Ponti *et al.*, 2012); (David *et al.*, 2012). It differs from conventional farming, primarily, because there are restrictions on the use of: synthetic fertilizers, pesticides, growth regulators, genetically engineered (GE) organisms, and additives in livestock feed. Furthermore, organic agriculture includes agricultural practices like multiannual crop rotations (6 years) and reduced tillage (Jansen, 2000). It has a theoretical foundation based on the four principles developed by IFOAM (Luttikholt, 2007): the principles of health, ecology, fairness, and care.

Dutch agricultural policies are very supportive of organic agriculture; furthermore conventional agriculture is increasingly being pressured and regulated by agricultural policies which support a shift towards sustainable production. In addition to national policies, the Netherlands follows the Common Agricultural Policy (CAP), which is a common policy for all European Union member states. Through this policy farmers receive support to adopt sustainable farming methods (European Commission, 2012). In addition to environmental concerns, policy goals include food security to EU citizens and ensuring a reasonable standard of living for EU farmers. Reforms to the CAP support sustainable agriculture, and as challenges increase, policies become more focused on climate change, sustainable management of resources, the health of the rural economy, and the competitiveness of farms.

1.3 Research objectives

The aim of this study was to conduct a comparative sustainability assessment between organic and conventional wheat production in the Netherlands. We wanted to determine if the restrictions set on organic farming, in addition to governmental control and policy support, make organic agriculture more sustainable when compared to a conventional scenario. Wheat production was chosen for the assessment due to its importance as a staple food and core ingredient in multiple products for human and animal consumption, in addition to being an important factor for crop rotation.

To reach this objective the following specific objectives were considered:

1. Describe the case study representing a typical wheat producing Dutch farm.
2. Selection of indicators for each of the three dimensions of sustainability: people, planet, and profit.
3. Selection of sustainability limits for the selected indicators.
4. Asses the values for the selected indicators and their relative contribution.
5. Evaluate and compare overall sustainability of conventional and organic wheat production.

1.4 Theoretical Framework

To fulfill the objectives, this study applies the 3 dimension framework of sustainability: people, planet, and profit; also called the three pillars of sustainability. In agriculture, the people dimension focuses on social sustainability; it represents producing healthy and good quality food, as well as offering good working conditions. The planet dimension represents the impact the production systems have on the environment, and the profit dimension represents the economic viability of the farming systems. This multi-dimensional characteristic of sustainability makes the concept complex to measure, reason being that different criteria have to be considered and weighed for their relevance and influence on determining levels of sustainability. One approach to measuring sustainability is the use of sustainability indicators; in complex situations, indicators compress information into a more comprehensible form. They can be classified into each of the dimensions of sustainability.

The Balance of Acceptability (BOA) software, developed by van der Voet *et al.* (2014), is a decision support tool for conducting sustainability assessments, moreover it helps compare different scenarios. The tool allows (1) grouping indicators into a hierarchical system, (2) defining sustainability limits based on acceptable and unacceptable values, (3) defining the relative importance of dimensions, themes, and indicators, and (4) combining the results into a final score for each scenario. This study used this tool to assess and compare overall sustainability of organic production and conventional production. The BOA software enables the decision maker to make a sensitivity analysis by changing weights and compensability factors between the dimensions. A protocol explaining the use of the BOA tool was developed by van Asselt *et al.* (2014). This protocol was followed to conduct the sustainability assessment and comparison of organic and conventional wheat production.

1.5 Outline of the report

The following chapter (2) describes the main scientific literature that was consulted regarding sustainability assessments; forming the foundation of this study. Chapter (3) is a description and explanation of the materials and methods used for the assessment and comparison of the scenarios. Chapter (4) describes the results obtained by following the methods and using the BOA software for final sustainability scores. Chapter (5) is an interpretation and discussion of the main results concerning individual indicators, dimensions, and overall sustainability scores. Finally, Chapter (6) outlines the main conclusions of this study.

2 Literature Review

Different methods are used to conduct sustainability assessments. Indicators and assessment tools have been developed by organizations like SAI Platform, FAO, and OECD to set a framework for farmers and other decision makers. Indicators can be classified into any of the three dimensions: people, planet, or profit. In agricultural topics the majority of assessments focus on environmental factors. Moreover, studies can focus on a specific topic like energy use and global warming potential ((Tuomisto *et al.*, 2012a); (Meul *et al.*, 2007); (Bos *et al.*, 2014)), and they can focus on a product, e.g. like milk ((van Asselt *et al.*, 2015); (Cederberg & Mattsson, 2000); (Eide, 2002)) or arable crops ((van Asselt *et al.*, 2014); (Charles *et al.*, 2006); (Williams *et al.*, 2010). Multi-criteria decision-making methods have been applied to analyze data which has to be weighed and organized in a predetermined hierarchy. Tools like the Balance of Acceptability (BOA) (Van der Voet *et al.,* 2014) allow a holistic and transparent approach in a final sustainability assessment, including the three dimensions.

Life Cycle Assessment (LCA) is one of the methods used to conduct sustainability assessments of agricultural production. LCA takes into account all relevant impacts occurring throughout the entire production system. Brentrup *et al.* (2004) designed an LCA study tailored specifically for crop production. In the UK, they tested the impact of different rates of nitrogen fertilization on resource use, product yield, and emissions; applied to a winter wheat case study. The LCA method can also be used in comparison studies, Williams *et al.* (2010) used life cycle analysis and system modelling to compare the environmental impacts of organic and non-organic production of bread wheat, oilseed rape, and potatoes in England and Wales. They analyzed land occupation, emissions, and energy, fertilizer, and pesticide use. They found that organic agriculture on average makes more extensive use of resources represented with higher land use, but lower pesticide, fertilizer, and energy use.

Researchers have conducted different studies to determine whether organic farming does reduce negative impacts caused by intensive agriculture on the environment. Tuomisto *et al.* (2012b) conducted a meta-analysis in which they analyzed published studies that compared environmental impacts of organic and conventional farming in Europe. They found that organic farming generally scored better than conventional per unit of area, but this was not the same if compared per unit of product, this was due to lower yields experienced in organic farming.

Acs *et al.* (2007) compared conventional and organic arable farming systems in the Netherlands using bio-economic modelling with results from economic, environmental, and technical nature. They analyzed the growing environmental concern in society and governmental incentives as important factors influencing farmer decisions for switching to organic farming. After comparing both systems they concluded that organic agriculture made less intensive use of land and had overall better environmental results.

In contrast to the environmental results, higher hired labor use may result in increased variable costs. Acs *et al.* (2009) studied the effect of yield and price risk farms faced when converting from conventional to organic farming. Nemes (2009) compiled a list of profitability studies and found that the majority of cases showed farms with higher economic performance, despite lower yields. Most of the times better results were due to higher prices for organic products; equally important were the farmer's management skills.

The social dimension is less represented in the comparative analyses. It is mostly considered indirectly or merged into the other dimensions (i.e. socio-economic, socio-environmental). Different aspects of agriculture affect the social dimension like: emissions, land use, labor opportunities, animal welfare, food safety, landscape quality, and leisure for the urban population. Van Calker *et al.* (2007) compared social sustainability in conventional and organic milk production in the Netherlands considering indicators for physical working conditions of farmers, animal welfare, landscape quality, and food safety. Both systems had similar results for physical working conditions, but organic farming had better results for animal welfare due to grazing and friendlier treatment of the animals. Other studies can be linked indirectly to the social sustainability comparison of both systems, e.g. Hoogenboom *et al.* (2008) compared contaminants and microorganisms in Dutch food products, they measured the presence of heavy metals and *Fusarium* toxins in organic and conventional products. The presence of these contaminants affects human and animal health; therefore this topic involves food safety. There is still room for research in this subject.

Other methods apply multi-criteria decision making methods to make a holistic assessment which includes the three dimensions framework. van Asselt *et al.* (2014) developed a protocol for assessing the sustainability of agro-food production systems using the Balance of Acceptability (BOA) software, it allows a comparison between overall sustainability scores, but furthermore, between the different dimensions of the systems studied. They applied the protocol to a case study of potato production in peri-urban agriculture in the Netherlands. They compared conventional, organic, and peri-urban farms; the overall results favor peri-urban agriculture, but the scores are close to each other.

On the same line, van Asselt *et al.* (2015) conducted a sustainability assessment of milk production in the Netherlands comparing organic and conventional milk. They found that raw organic milk scored highest in the overall sustainability score which they attributed to a better environmental as a result of the omission of pasteurization. No scientific literature was found for sustainability assessments of wheat production or for comparisons of organic and conventional wheat production, in the Netherlands. This study assesses and compares the sustainability of organic and conventional wheat production in the Netherlands.

3 Materials and methods

The sustainability assessment was conducted following the protocol developed by van Asselt et al. (2014). This protocol includes the application of the Balance of Application (BOA) support tool for the sustainability assessment. With this tool indicators from the three dimensions were weighed, compared, and evaluated (van der Voet *et al.*, 2014). The protocol consists of 6 steps: (1) definition of the case study, (2) selection of sustainability indicators that are specific for the case study, (3) selection of sustainability limits for the chosen indicators, (4) data collection for parameters of chose indicators, (5) entering limit and parameter data into weighing tool, and (6) analyse final overall sustainability score. These phases are explained in more detail in the following sections.

A literature review was conducted in search of articles and information regarding Dutch and European agriculture, focusing on those articles which compared organic and conventional agriculture, specifically cereal production, i.e. wheat production.

3.1 Definition of case study

The case study is a description of both scenarios: organic wheat production (O) and conventional wheat production (C) in the Netherlands. Animal production was not taken into consideration, only crop production was studied with focus on wheat production.

3.1.1 Organic wheat production (Scenario O):

In Europe, organic wheat is produced in certified organic arable farms that follow the guidelines defined by the European Commission (EC) of the European Union in Regulation No. 834/2007, and are certified in the Netherlands by Skal Biocontrole. This regulation sets the guidelines for organic production and labelling of organic products for the European Union (Council Regulation, 2007). Organic agriculture is the only form of sustainable agriculture and food production that is specified by law (LEI Wageningen UR, 2013).

3.1.2 Conventional or intensive wheat production (Scenario C):

In contrast, conventional farming was described and considered in this study as intensive and specialized farming systems that rely on heavy use of inputs and mechanization (Jansen, 2000); (de Ponti *et al.*, 2012). In the Netherlands, fertilizer use in conventional farming is not as severely restricted as in organic farming, but sustainable crop protection is demanded by government policy; pesticides use is highly regulated. Another important characteristic are the shorter crop rotations (3-4 years) (Acs *et al.*, 2007), which don’t normally include legumes, and focus lies primarily on market crops, particularly cereals.

3.1.3 Typical arable farm in the Netherlands

In the Netherlands, the average size of an organic farm is approximately 26 ha and for a conventional farm it is 18 ha. To make both scenarios comparable, and as the available land area for production per farm is a limiting factor for the farmers, in this study, the size of a typical arable farm was considered to be 48 ha [analogous to (Acs *et al.*, 2007); (Acs *et al.*, 2009); (Bos *et al.*, 2014)]. In the Netherlands a large part of the farms are family farms, therefore the labor force is composed primarily of family members. Typically, only one or two people work on a farm (Pol, 2007). According to FADN data, family labor accounts for 77% of the total labor force in EU27.

The production of wheat is the first step in the Dutch bread chain (Bunte *et al.*, 2009). The Dutch wheat grower typically has a relatively small company compared to the other actors in the chain. Wheat is produced in farms that grow a number of arable farming products; it is grown for profit from yield and for incorporation in a crop rotation in order to avoid the build-up of pathogens and pests that can often occur when one species is cropped continuously (Pol, 2007). Crop rotations in the Netherlands include potato, sugar beet, onion, barley, carrot, green pea, and wheat; the crops in rotation vary between organic and conventional farming.

Most farms whether organic or conventional are specialized farms, producing either milk, arable crops or vegetable crops (Bos *et al.*, 2014). Average conventional wheat yield is approximately 8.5 t/ha and according to a meta-analysis conducted by de Ponti *et al.* (2012) organic yield is on average 80% of conventional yield, this varies depending on the analyzed crop; in the case of wheat, yields are on average 74% that of its conventional counterpart, approximately 6.3 t/ha (Hoogenboom *et al.*, 2008). This study assumed these values to calculate indicator values in the following sections of the report.

3.2 Selection of indicators

11 core indicators were chosen, categorized into each of the three sustainability dimensions. They were gathered based on a literature review from published articles and reports (e.g. Pacini *et al.* (2003); Brentrup *et al.* (2004); Charles *et al.* (2006); Meul *et al.* (2007); Pol (2007); Nemes (2009); Gafsi and Favreau (2010); Nemecek *et al.* (2011); Halberg (2012); Tuomisto *et al.* (2012c); van Asselt *et al.* (2015); Meier *et al.* (2015)). The indicators were measurable, sensitive to variations, relevant to the case study, and related directly to the themes. The differences between conventional and organic production systems (expressed mainly as the restrictions on the use of synthetic fertilizers, pesticides, genetically engineered organisms, and additives in livestock feed) were represented, as much as possible, in the different themes and indicators. Table 1 details the final list of core indicators and the functional units used for this study.

Table 1. List of chosen indicators

Dimension	Theme	Subtheme	Indicator
Social (people)	Food quality	---------------	1. Protein content *(%)*
	Food Safety	-Chemical contamination	2. Level of heavy metals (cadmium & Lead content) *(mg/kg)*
		-Microbiological contamination	3. *Fusarium* contamination (DON content) *(µg /kg)*
	Farmer welfare	-----------------	4. Labor *(hrs/yr)*
Environment (planet)	Environmental factors	-Biodiversity	5. Number of species *(relative to 100%)*
		-Soil quality	6. Soil organic matter (SOM) content *(relative to 100%)*
		-Emissions	7. Pesticide use (*kg a.i/ha)*
		-----------------	8. Acidification potential *(kg SO_2-eq./ ha)*
		-----------------	9. Eutrophication potential *(kg PO_4 -eq ./ ha)*
	Use of natural resources	-----------------	10. Total energy use *(MJ /ha)*
Economic (profit)	Economic performance	-Profitability	11. Farm income *(Euros)*

Within the social dimension, the relevant themes chosen for this study were food quality, food safety, and farmer welfare. Food quality was represented by the protein content indicator; protein content is an important factor in the bread-making quality of wheat. Food quality standards depend on the final use given to wheat. Protein content determines what the commercial use of the wheat will be, considering that wheat is also grown as part of the rotation and for incorporation as green manure (Ponti et al 2012).

In the Netherlands, the highest added value is achieved with wheat that is suitable for bread production; millers pay the highest price for wheat with protein content ideally higher than 13%. Dutch millers and collectors accept a minimum protein content of 11.5% (Osman *et al.*, 2015); wheat growers can supply the wheat that doesn't meet milling quality standards to the feed industry for a slightly lower price ((G. Van der Burgt & Timmermans, 2009); Timmermans, BGH, 2009). Soft flour for pastries and hard flour for bread making require different percentages of protein content (below 10% and higher than 13% respectively); Dutch wheat varieties are more suitable for bread making (Pol 2007), therefore those standards were assumed as limits.

The theme food safety contains two subthemes: chemical contamination and microbiological contamination. They were represented by the indicators cadmium and lead content, and DON content, respectively. The use of animal manure, synthetic fertilizers, and pesticides may lead to high levels of cadmium and lead content which are a health threat. Deoxynivalenol (DON) is a mycotoxin produced by the *Fusarium* genus and it is one of the most frequently found mycotoxins at field level, in Europe. Even though it does not have an effect in baking qualities, it can be toxic to human and animal health if ingested in high concentrations (Franz *et al.*, 2009). DON contamination starts in the field as a consequence of *Fusarium culmorum* and *Fusarium graminearum*. Wet weather conditions are known to increase contamination *(*Harcz *et al.,* 2007*)*. The theme farmer welfare is represented by the indicator labor requirement which was measured in labor hours per year, and assessed against the limited available family labor.

Environmental factors were compared using biodiversity, soil quality, and emissions indicators. These indicators were chosen because they capture the environmental impact caused by organic and conventional agricultural production. Using these indicators we were able to assess if the restrictions set on organic production make the scenario more environmentally sustainable, e.g. they measure the impact caused by the use of synthetic fertilizers, pesticides, and animal manure.

We chose energy use as the indicator to represent the theme: use of natural resources. Energy use is influenced by activities such as fertilization and machinery use. Water use was not considered because wheat is mostly irrigated with rain water. The economic dimension is assessed by considering the indicator farm income; this indicator is influenced by factors such as revenues, costs, and prices.

3.3 Assessing indicator values for each scenario

Data was gathered, for each indicator and scenario, from the scientific sources outlined in Table 2. Values pertain to wheat production in the Netherlands, as much as possible; otherwise values from comparable countries were used.

Table 2 Parameter values for the chosen indicators

Number	Indicator	O	C	Source
1	Protein content *(%)*	10.6	11	O: Franz *et al.* (2009); C: Pol (2007)
2	Cadmium content *(mg/kg)*	0.077	0.077	Hoogenboom *et al.* (2008)
2	Lead content *(mg/kg)*	0.001	0.001	Hoogenboom *et al.* (2008)
3	DON content *(µg /kg)*	670	830	Hoogenboom *et al.* (2008)
4	Labor *(hrs/yr)*	6277	2604	Acs *et al.* (2007)
5	Number of species *(relative to 100%)*	100%	70%	Tuomisto *et al.* (2012c)
6	Soil organic matter (SOM) content *(relative to 100%)*	100%	93%	Tuomisto *et al.* (2012c)
7	Pesticide use (*kg a.i/ha)*	0	2.8	Acs *et al.* (2007)
8	Acidification potential *(kg SO_2-eq/ ha)*	22.68	28.05	Williams *et al.* (2010)
9	Eutrophication potential *(kg PO_4 -eq / ha)*	58.59	25.5	Williams *et al.* (2010)
10	Total energy use *(MJ /ha)*	8000	19000	Tuomisto *et al.* (2012a)
11	Farm income *(Euros)*	64045	24530	Acs *et al.* (2007)

The value for protein content (indicator 1), for the organic scenario, was obtained from an article by Osman *et al.* (2015) who studied quality traits in organic wheat varieties (i.e. *Lavett)* in the Netherlands. The value for the conventional scenario was obtained from a study conducted by Pol (2007) where she studied the Dutch wheat supply chain composed by the breeders, producers, collectors, millers, bakers, retailers. The values for cadmium & lead content, as well as for DON content (indicators 2 & 3), for both scenarios, were obtained from a study conducted by Hoogenboom *et al.* (2008), where organic and conventional products were compared based on the presence of contaminants and microorganisms.

For both scenarios, the values for labor requirement, pesticide use, and farm income (indicators 4, 7 & 11) were obtained from a study conducted by Acs *et al.* (2007) where they compared organic and conventional arable farms using technical, economic, and environmental factors. Farm income was assumed as a total of all farming activities, meaning that it was not limited to wheat production activities, but included the margins for the crops in rotation, i.e. potato, sugar beet, onion, barley, carrot, and green pea.

The values for biodiversity and SOM content (indicators 5 & 6), for both scenarios, were derived from a meta-analysis conducted by Tuomisto *et al.* (2012) where they analyzed published studies that compared the environmental impacts of organic and conventional agriculture in Europe. For the emissions theme, there were no data available from LCA studies focusing on Dutch wheat production; most environmental studies focus on milk, potato, or greenhouse production.

Acidification potential and eutrophication potential (indicators 8 & 9) were obtained from an LCA study conducted by Williams *et al.* (2010) in which they compared the environmental impacts of producing bread wheat in the UK. The values were reported in per ton units, but for this study the values were converted to per ha units using the organic and conventional yield values (6.3 t/ha and 8.5 t/ha respectively), as defined in section 3.1.3 of this report; this enables a uniform unit of measurement for the assessment. Total energy use (indicator 10) was obtained from a study conducted by Tuomisto *et al.* (2012), also in the UK, in which they compared environmental impacts caused by energy use and the global warming potential of organic and conventional wheat production.

3.4 Assessing sustainability limits for each indicator

As detailed in Table 3, values for sustainability limits (undesirable, reasonable, and desirable) for each indicator were derived based on quality standards, legal regulations or best practices as considered in the scientific articles. The BOA software was used to compare both scenarios; the weighing tool calculated a final score by assessing the indicator values against these limits.

The desirable (D) limit for protein content was assumed to be 13% analogous to Charles *et al.* 2006; this value is a standard bakery and milling requirement. The undesirable (U) limit was assumed to be 11% analogous to Osman *et al.* (2015), where this level is considered low protein content for good bread-making quality.

Limits for indicators 2 & 3 in the food safety theme were derived from legal regulations. High values are undesirable therefore U was set as the legal maximum accepted limit and D was set as the limit of detection (LOD), which is the lowest identifiable quantity of a substance, taken from Hoogenboom *et al.* (2008). The reasonable limit was set to be the average between U and D. The desirable limit for labor was assumed to be the available family labor per year (in hours), analogous to Acs *et al.* 2007; U and R were assumed to be 85% and 70% of D, respectively, analogous to van Asselt *et al.* 2015; this indicates that values greater than the available labor are undesirable.

Table 3 Sustainability limits for the core indicators

Number	Indicator	U	R	D	Source
1	Protein content *(%)*	11%	12%	13%	U: Franz *et al.* (2009) D: Charles *et al.* (2006) R: Geometric mean between U&D
2	Cadmium content *(mg/kg)*	0.2	0.04	0.01	U: maximum level of heavy metals as regulated by Commission Regulation (EC) No 1881/2006. D: LOD Hoogenboom *et al.* (2008) R: Geometric mean between U&D
2	Lead content *(mg/kg)*	0.2	0.04	0.01	U: maximum level of heavy metals as regulated by Commission Regulation (EC) No 1881/2006. D: LOD (analogous to Hoogenboom *et al.* (2008)) R: Geometric mean between U&D
3	DON content *(µg /kg)*	1250	675	100	U: maximum level of heavy metals as regulated by Commission Regulation (EC) No 1881/2006. D: LOD Hoogenboom *et al.* (2008) R: Geometric mean between U&D
4	Labor *(hrs/yr)*	3221	2653	2255	D: Labor availability (Acs *et al.*, 2007) U: D/85% R: D/70% (U & D as used in van Asselt *et al.* (2015))
5	Number of species *(relative to 100%)*	70%	85%	100%	D: 100% U: 70% R: 85% (As used in van Asselt *et al.* (2015))
6	Soil organic matter (SOM) content *(relative to 100%)*	70%	85%	100%	D: 100% U: 70% R: 85% (As used in van Asselt *et al.* (2015))
7	Pesticide use *(kg a.i/ha)*	14	6.75	0	D: 0 U: Intensive pesticide use mentioned in Nuijten and van Bueren (2013) R: Average between U & D
8	Acidification potential *(kg SO_2-eq/ ha)*	25.4	20.9	17.78	D: Charles et al. 2006 U: D/85% R: D/70% (U & D as used in van Asselt *et al.* (2015))
9	Eutrophication potential *(kg PO_4 -eq / ha)*	5	4.1	3.47	D: Charles et al. 2006 U: D/85% R: D/70% (U & D as used in van Asselt *et al.* (2015))
10	Total energy use *(MJ /ha)*	27614	22741	19330	D: Meul *et al.* (2007) U: D/85% R: D/70% (U & D as used in van Asselt *et al.* (2015))
11	Farm income *(Euros)*	0	10700	21400	U: 0 D: As much as possible; at least net farm income specialized cereal farms in EU (EU Cereal farms report 2010-2013) R: Average between U & D

The limits for indicators 5 & 6 were assumed to be relative to 100%, therefore D was set to 100%, and U and R were set to 70% and 85% respectively. The desirable limits for indicators 7-10 were set to the best performing scenario found in the scientific sources outlined in Table 3, U and R were assumed to be 85% and 70% of D, respectively, indicating that lower values were desirable. The average yield values described in section 3.1.3 (Scenario C yield: 8.5 ton/ ha and scenario O yield: 6.3 ton/ha) were used to convert values expressed in "per ton" units to "per ha units".

D was set to 0 due to the chemical pesticide ban on organic agriculture and the reduction of pesticide-use as a goal for sustainable production. The U limit for pesticide use was assumed to be the intensive pesticide use referred to in Table 4 (14 kg a.i. /ha) and R was the average between U and D. Farm income (indicator 11) should be as much as possible, however for this study it should be at least the value recorded for cereal farms in the EU (21400 euros), U was set to 0 because it is undesirable to have no profit or economic loss.

3.5 Weighting the indicators

The Balance of acceptability (BOA) weighing tool, used to perform the final assessment, converts sustainability scores to unit-free scores that are rated on a scale from 0-100. This applies to indicators, themes, and overall sustainability scores enabling a comparison between scenarios at each of these levels. Linear weighting was set for all the indicators except for the food safety indicators; following the description detailed in van der Voet *et al.* (2014). Compensability was set to 0.5; this means that low values of one indicator could be compensated by higher values in other indicators within the same theme and dimension. The compensability for food safety was set to 0 because the indicator values within the theme had to comply with legal limits.

The three main dimensions (people, planet, and profit) were considered equally important for the overall sustainability score, therefore they were assigned equal weights (people=33, planet=34, profit=33 equaling the final score to 100). The same assumption was made within the sub themes where indicators were weighed equally. In their study, van Asselt *et al.* (2015) additionally consulted with policy makers to include their input in the weighing process.

3.6 Sensitivity Analyses

Two sensitivity analyses were conducted to test the impact that changes in the assumptions have on the final score. The first sustainability analysis was conducted by making the sustainability limits 10% stricter and 10% less strict, while keeping all other factors the same. The second sensitivity analysis was conducted by calculating the final score by giving different relative weights than the ones previously assumed; one dimension was weighed higher than the other two (w=50) while keeping the two remaining dimensions weighed equally (w=25), e.g. set the weight of the people dimension to 50 and the weight for planet and profit to 25. The overall sustainability score was recorded each time and the results can be seen in the following section.

4 Results

4.1 Sustainability assessment results

The indicator values and sustainability limits (Tables 2 and 3) were inserted into the weighing tool for a final sustainability assessment. Figure 3.1 illustrates the overall sustainability score and the individual scores per dimension. Scenario O scored a little higher for overall sustainability (64%) compared to the scenario C (56%), implying that Dutch organic wheat production is more sustainable when compared to a conventional scenario, although scenario C is close behind.

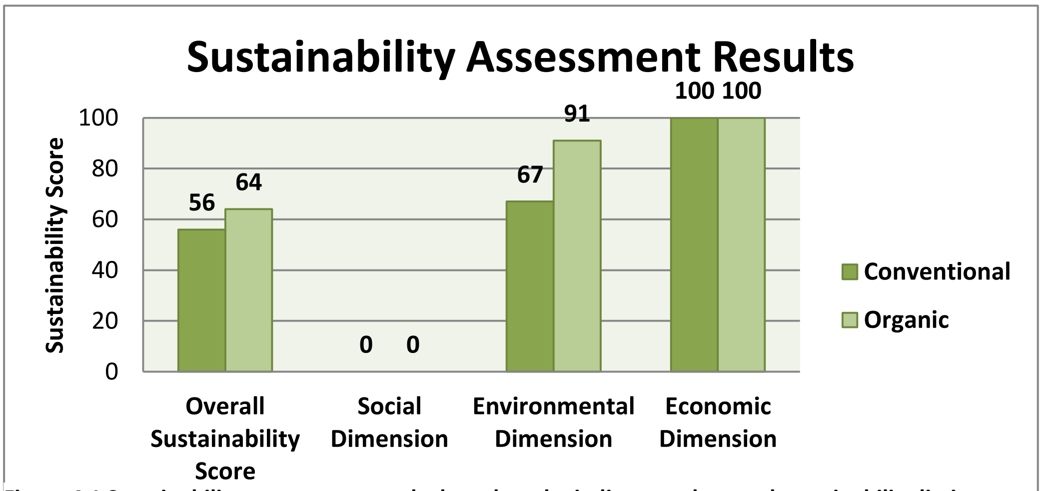

Figure 4.1 Sustainability assessment results based on the indicator values and sustainability limits.

When analyzed individually, both scenarios scored poorly for the social dimension (0%). This is primarily because of the non-compensability feature of the social dimension. The values for the food safety indicators were within the reasonable sustainability limit for both scenarios, but this subtheme punished the social dimension score due to the non-compensability characteristic of indicators 2 & 3, whose values had to comply with legal standards. This means that the indicators within the social dimension cannot compensate for or replace each other. The indicator value of protein content did not meet the desirable limit in the food quality theme; in addition, in scenario O, labor requirement exceeded labor availability. These values reduced the sustainability score within the social dimension, but the food safety indicators, which are important to human and animal health, scored within reasonable limits.

We hypothesized that DON content (mycotoxin contamination) would be higher in scenario O due to the ban on fungicides and the use of reduced tillage, which could enable the proliferation of mycotoxins. Nevertheless, the results indicated that scenario C had a higher occurrence of mycotoxin contamination; however both values fell within EC legal limits for maximum acceptable DON content in unprocessed wheat. The values for indicators cadmium and lead content were equal in both scenarios. Lead content was higher than cadmium content, with cadmium content under the limit of detection.

Scenario O scored higher in the environmental dimension (91%) compared to scenario C (67%), nevertheless scenario C scored within the reasonable sustainability limit. Scenario O scored better in all environmental indicators, except for eutrophication potential (indicator 9) in the emissions subtheme (Table 2 of Section 2.3), value which exceeded the unsustainability limit. Scenario O scored better for biodiversity and soil quality (indicators 5 & 6), these results were expected because maintaining and improving these indicators are part of the sustainability goals of organic agriculture.

Scenario O scored better for acidification potential, but the value was roughly lower than the unsustainability limit. This indicator is linked to pesticide use. Comparative studies made clear assumption of zero pesticide use for organic farming (Acs *et al.*, 2007; Williams *et al.*, 2010) therefore this study assumed 0 pesticide use in scenario O. We expected the value for pesticide use to be higher for scenario C, but it scored within the reasonable limit and much lower than the value set for the unsustainability limit, making this a very positive indicator for scenario C.

Both scenarios scored equally high for the economic dimension (100%). Scenario O scored higher for farm income, despite scenario C's lower production costs and higher yields. It was hypothesized that farm income would be lower in scenario O due to lower yields and higher labour costs, but the results showed that higher prices for organic produce can compensate for these factors. The higher labor requirement in the organic scenario offset the cost reduction expected from reduced procurement and application of synthetic fertilizers.

These results are dependent on the assumptions made throughout the study and the outcome may be different by applying different indicators, themes, values, limits, and weights. There are different factors that make a sustainability assessment subjective and the choice of sustainability limits is one of them.

When legal limits and policy targets were unavailable for particular indicators the limits were taken from published sources, but assuming different limits lead to different results. Other subjective factors were the weights and compensations assumed; this study considered the three dimensions equally important therefore they were weighed equally. If one dimension (e.g. environmental) were to be considered more important and weighed higher, consequently this influences the final results.

4.2 Sensitivity Analysis

4.2.1 10% change in the sustainability limits

The first sensitivity analysis was conducted by making the sustainability limits first 10% stricter and then 10% less strict, while keeping all other factors the same. This was applied to the indicators for which legal limits or policy targets were unavailable. Figures 3.2 and 3.3 illustrate the results for both scenarios for the overall sustainability score and for each individual score per dimension.

The environmental dimension appears to be the most sensitive to these changes in the limits, and the changes applied have a stronger effect on the individual dimensions' scores, than on the overall sustainability score. Figure 3.2 illustrates the effects on the scores when 10% stricter limits were applied. Scenario O remained unchanged with a 64% overall sustainability score, but the score of scenario C reduces from 56% to 51%. This is not a big reduction, but it demonstrated that stricter limits made it more difficult to reach the desirable level. The value for the environmental dimension dropped for both scenarios, from 67% - 54% in scenario C and 91% - 90% in scenario O. Both scenarios remained scoring poorly in the social dimension (0%), still attributed to the legal standards that had to be complied with. The economic dimension was still the highest scoring for both scenarios (100%).

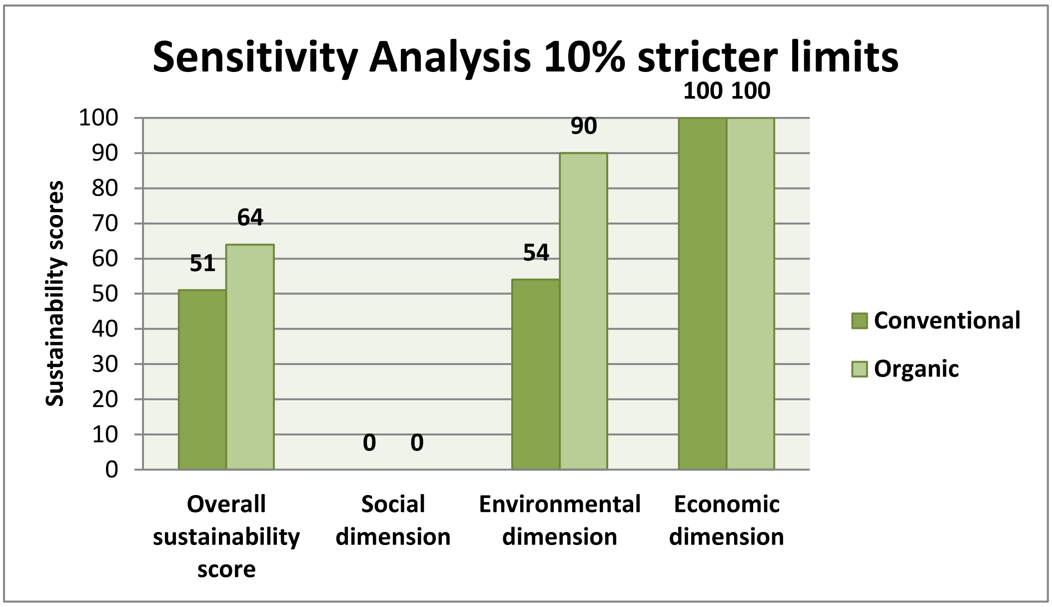

Figure 4.2 Sensitivity analysis including 10% stricter limits

In contrast, when 10% less strict limits were applied the value of the overall sustainability score for scenario C increased from 56% to 57%. The value of the overall sustainability score for scenario O remained the same, this also happened for the score of both scenarios for the social dimensions. Figure 3.3 illustrates how the environmental dimension scores for both scenarios increased. Scenario O increased from 91% to 92% and scenario C increased from 67% to 70%. The economic dimension for both scenarios continued scoring 100%. This sensitivity analysis demonstrated that 10% less strict limits allow the indicators to score better and closer to the desirable limit.

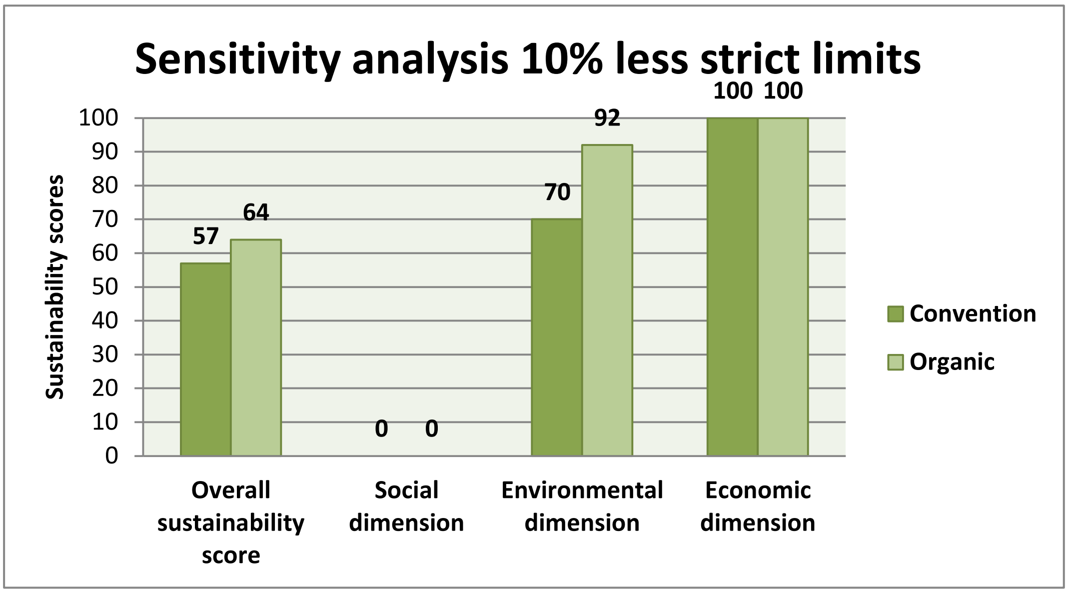

Figure 4.3 Sensitivity analysis including 10% less strict limits

4.2.2 Change of the relative weights of the three sustainability dimensions

The second sensitivity analysis was conducted by changing the relative weights of the three dimensions. One dimension was weighed higher than the other two (w=50) while keeping the two remaining dimensions weighed equally (w=25), e.g. set the weight of the people dimension to 50 and the weight for planet and profit to 25.

Figures 4.4, 4.5, and 4.6 illustrate how this change impacted overall sustainability scores for both scenarios. The biggest impact on the overall sustainability score was noted when the social dimension was weighed higher than the other two dimensions. In scenario O, the overall score decreased from 64% to 48% and scenario C decreased from 56% to 42%. This was especially attributed to the non-compensability characteristic of the indicators within the dimension.

On the other hand, changing the relative weights of the environmental and economic dimensions improved the overall sustainability results for both scenarios. When weighing the environmental dimension higher, the overall scores for both scenarios increased (scenario O increased to 70% and scenario C to 59%). The same happened when weighing the economic dimension higher, but with a higher increase in the overall scores, scenario O increased to 73% and scenario C increased to 67%.

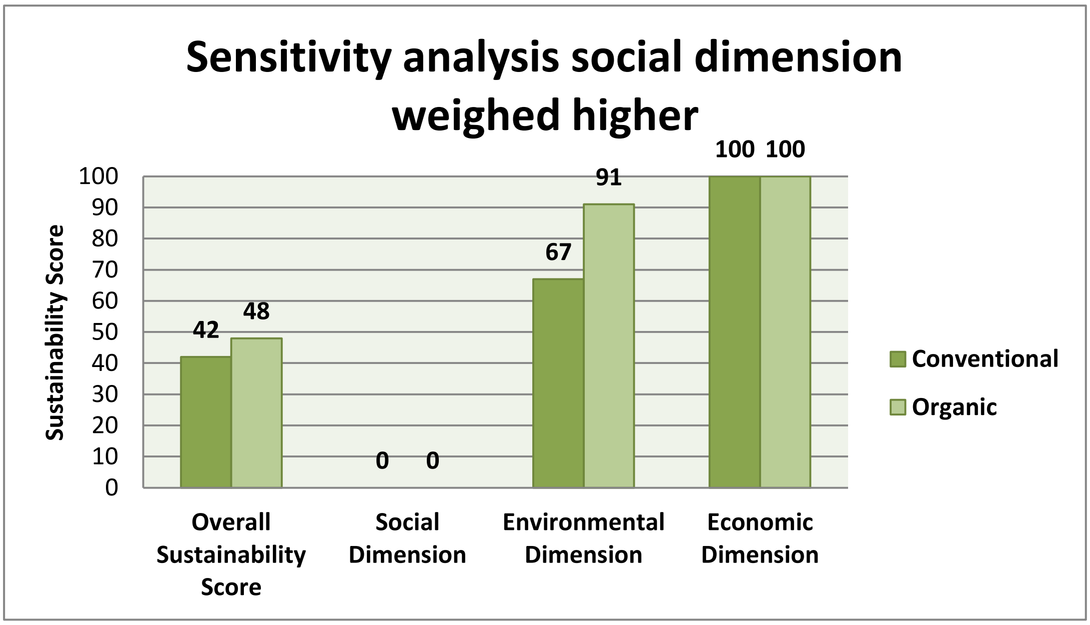

Figure 4.4 Results of the sensitivity analysis with social dimension weighed higher

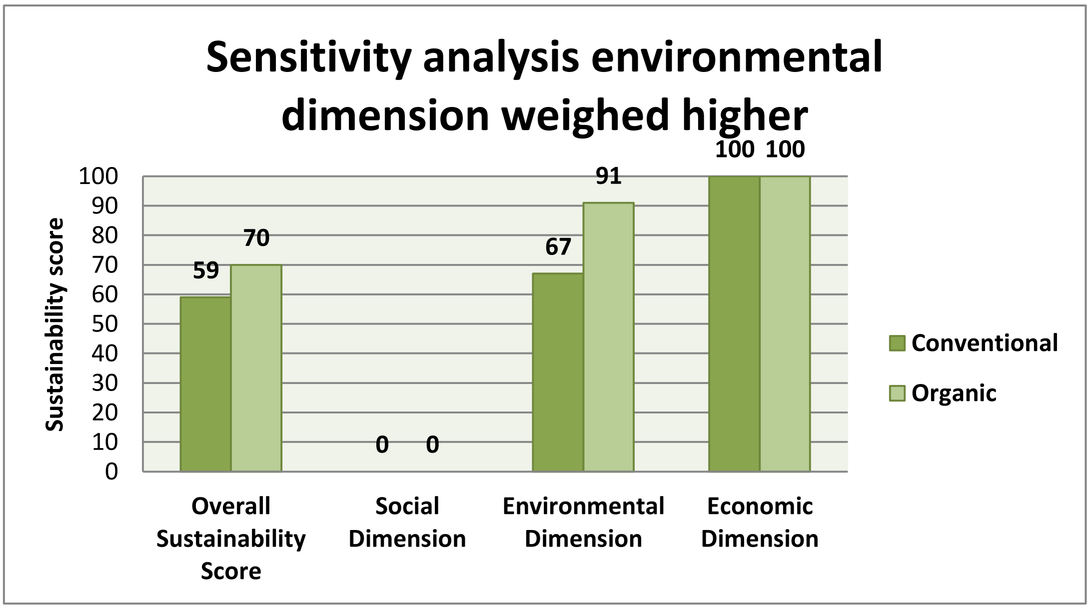

Figure 4.5 Results of the sensitivity analysis with environmental dimension weighed higher

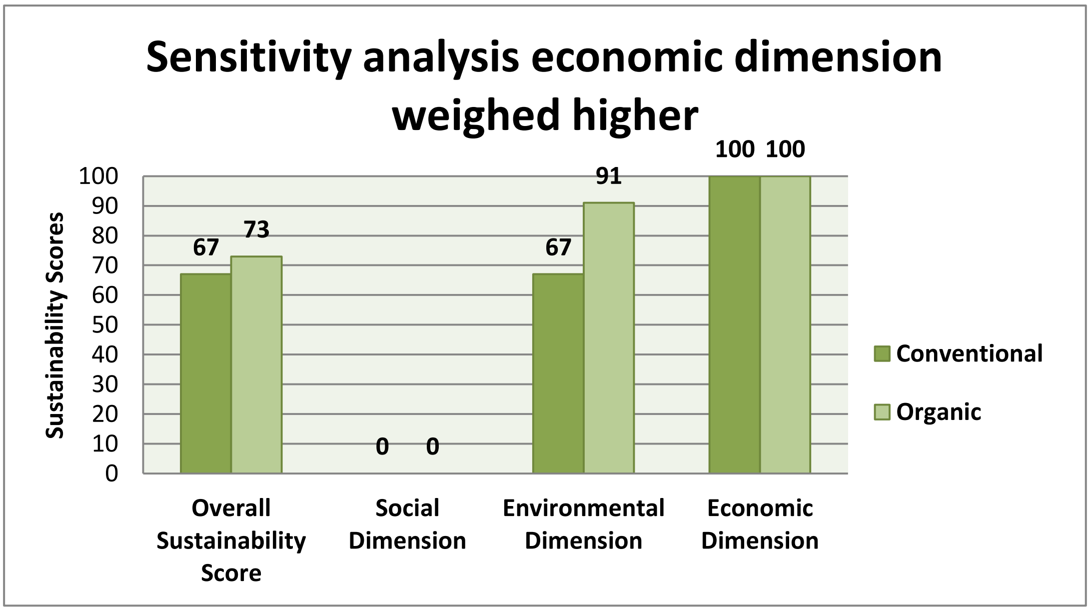

Figure 4.6 Results of the sensitivity analysis with economic dimension weighed higher

Overall, as expected, scenario O scored better in the sustainability assessment when compared to scenario C, but results were mixed when the individual dimensions were analyzed. The BOA tool allows a holistic and transparent decision; these characteristics were tested in the sensitivity analysis and can be seen in the changes of the results. The results presented in this section are discussed in the following section.

5 Discussion

This study aimed to investigate if organic wheat production is more sustainable than conventional production taking into consideration the restrictions set on the system to make it more sustainable, in addition to governmental control and policy support. These restrictions often resulted in higher labor and operating costs, nutrient deficiency in soil, reduced yields, and increased land requirement to compensate for less yields (European Commission, 2013b).

As an overall final result, organic wheat production in the Netherlands appears to be more sustainable when compared to conventional production. The conventional scenario in this study scored lower than the organic scenario, but the score was within reasonable sustainability limits. Despite organic production scoring overall higher than conventional production, it scored worse in protein content and labor requirement in the social dimension, and in eutrophication potential in the environmental dimension.

5.1 Social sustainability

Both scenarios scored low in protein content, but scenario O scored lower than scenario C, this agrees with the results of L-Baeckström *et al.* (2004); (Osman *et al.*, 2015); and (Casagrande *et al.*, 2009) who found lower levels of protein content in organic wheat. They attributed the variation to factors such as: crop cultivar, crop nitrogen status and weed density at flowering. According to Pol (2007), Dutch wheat is suitable as milling wheat to a limited extent; milling companies receive only 20% of national production to produce meal and flour for bread, 55% is used in the production of animal feed, and the rest is destined for the starch and bio-ethanol industry. Therefore, the Netherlands is a net importer of grain; almost 80% is obtained from other countries, mainly Germany and France. According to FAO, in 2007 the Netherlands was one of the countries with higher wheat imports.

Equally important was the fact that Dutch weather is unfavourable for producing a high quality product; this influences the baking quality of wheat. Varieties used in the Netherlands are not suitable for making soft flour (used in mainly in pastries), which require protein content less than 10%; but neither do they reach the protein content requirements for bread making. Pol (2007) argued that one of the reasons for low protein content in Dutch wheat is the low availability of wheat varieties that are bred specifically for Dutch conditions, for both conventional and organic agriculture. It is estimated that at least 95% of the varieties used in organic agriculture were bred for high-input conventional conditions (van Bueren et al 2013). Since 1992 farmers rely on a wheat variety developed in Sweden called *Lavett* (Hoogenboom *et al.*, 2008); (Osman *et al.*, 2015). Nevertheless, policy support for the organic sector is increasing with higher percentage of public investments being destined for research and development (Sukkel & Hommes, 2009). The use of genetically engineered (GE) organisms for commercial use is not allowed in the Netherlands; therefore this is not an option any time in the near future.

Scientist from Wageningen University and Research Center (UR) and the Louis Bolk Institute cooperate closely in research breeding programs for organic agriculture. Previously, research efforts were dedicated towards improving cultivation methods for organic agriculture (while still relying on conventional crop varieties); now the efforts can be focused on increasing the number and the use of organic crop varieties. Still, the Netherlands represents 1% of EU wheat production, therefore due to low production (compared to bigger EU members) there is minimum investment in plant breeding for organic wheat varieties (Pol & Visscher, 2010; van Bueren *et al.*, 2011). There are no organic wheat breeders in the Netherlands; the organic area is too small to attract professional breeders. Nevertheless, growers, bakers, and millers have organized and communicated with breeding companies as a first step in setting up a breeding programme (Sukkel & Hommes, 2009).

In their different studies (van Bueren *et al.*, 2011) and (Osman *et al.*, 2015) emphasized the importance of breeding varieties suitable for organic agriculture, and even though breeding goals are similar for both organic and conventional production systems, it is important to express them for low-input conditions like those experienced in organic agriculture. Farmers team up with research institutes in a “bottom up” approach searching for solutions to improve efficiency in organic agriculture (Van der Ploeg & van Dijk, 1995) because farmers have the valuable experience and knowledge in the field.

According to Mäder *et al.* (2007), in addition to crop variety, protein content is influenced by the level of nitrogen available in the soil (i.e. fertilization). In conventional production it is easier to compensate for soil nutrient deficiencies by fertilizing with synthetic fertilizers than it is in organic production (van Bueren *et al.*, 2011), enabling conventional wheat to have higher protein content level. An increase in N fertilizer can increase yield and protein content, but Charles *et al.* (2006) found that wheat varieties express an inverse relationship between yield and quality (i.e. protein content).

Dutch millers recommend N application for increasing protein content (Pol, 2007), this increase is applied in conventional production, nevertheless organic farmers have also increased nitrogen fertilization (G. J. H. M. van der Burgt *et al.*, 2011). In their study Gauer *et al.* (1992) found the same positive relationship between crop nitrogen and protein content. In addition, they found that increased moisture lowered protein content.

The food safety indicators for both scenarios scored within the reasonable limits. Scenario O scored better than scenario C, although the difference was not big. No difference was found in heavy metal content between both scenarios and the values were below maximum legal limits. This indicator is linked to chemical use, e.g. pesticide application. For this reason it was expected that scenario O would score better than scenario C, due to the ban on pesticides in organic agriculture. This ban has direct impact in the sustainability assessment because there should be considerable reduction or no traces of chemical contamination in the organic scenario (Mäder *et al.*, 2007). Levels of pesticides and contaminants found in organic crops may be related to previous land use or stray chemical sprays from neighboring conventional fields (Köpke, 2003). Harcz *et al.* (2007) found higher levels of lead concentrations in organic cereals, but they attributed this to airborne origins.

Moreover, it was expected that the ban on fungicides (in addition to Dutch weather conditions) would promote an increase in *Fusarium* contamination in scenario O. The results were contrary to expected with scenario C scoring a higher value in DON content than scenario O. In contrast, during the years studied (Hoogenboom *et al.*, 2008) found no significant difference in the heavy metal content and DON content between organic and conventional crops in the Netherlands. DON content was under maximum legal limits most of the time, though always present; similar results were found by (Edwards, 2009) in the UK.

DON content is influenced by factors like crop nitrogen, crop rotation, crop variety, and weather conditions. When high contents were recorded, it correlated with years that experienced heavy rain fall, this agrees with the study of (Franz *et al.*, 2009) who found that DON level increased with higher temperature, increased precipitation, and higher relative humidity. In contrast, Bernhoft *et al.* (2010); Pussemier *et al.* (2006); Rossi *et al.* (2006) found lower average levels in organic wheat. Studies have found a positive relationship between DON content and grain nitrogen ((Bernhoft *et al.*, 2010); (Lemmens *et al.*, 2004); (CuiLin *et al.*, 2001); (G. J. H. M. van der Burgt *et al.*, 2011); (Vanova *et al.*, 2008)). This is the same relationship found between protein content and grain nitrogen; the additional application of nitrogen for increasing protein content can result in an increase of mycotoxin contamination (expressed in DON content).

In addition to crop nitrogen, crop rotation is important because residues stay in the soil after harvesting, especially if reduced tillage is used because cereals are a major source of infection. Therefore it is recommended to design the crop rotation in order that different cereals are not cultivated in sequence. This can benefit organic production due to the more diverse and longer crop rotations compared to conventional production where one crop may take 100% of the rotation, increasing risk of contamination. In addition, wet weather conditions as those found in the Netherlands also increase risk of contamination. These factors helped explain higher DON content and protein content found in scenario C. (Timmermans *et al.*, 2009) argued that crop variety has a bigger influence over DON content than cultivation measures and that wheat varieties bred for Dutch conditions could reduce contamination risk.

Scenario O had a higher labor requirement than scenario C, this agrees with studies that reported higher labor requirement after switching from conventional to organic agriculture (European Commission (2013b); Acs *et al.* (2007); Nemes (2009)). This can be explained by an increase in manual labor for certain activities, like weeding and harvesting. Dutch agriculture is characterized by family labor where 2-3 family members work full time on the farm, which can be a limitation regarding higher labor requirements. Nevertheless, Acs *et al.* (2007) considered there is no limit for the extra labor that can be hired in high requirement season. This implies higher variable costs for organic farms, however (Jansen, 2000) argued that as farmers gain more experience in the organic production system labor requirement may reduce.

5.2 Environmental sustainability

The organic scenario scored better than the conventional in most of the environmental indicators. It scored better for soil quality and biodiversity indicators. These indicators are influenced by factors like the use of synthetic fertilizers, pesticides, reduced tillage, and organic matter application. All of these factors are closely managed in organic agriculture, reason for which these results were expected. As the conventional scenario did not score as low as expected, this may be attributed to government support for sustainable agriculture and the increasing environmental concern and involvement of consumers and the population.

In their study, de Ponti *et al.* (2012) mentioned that it is important to consider the potential of "greening" conventional agriculture to meet the demands being met by organic products. Sustainable approaches used in organic agriculture can be useful in conventional agriculture. (Tuomisto et al 2012) mentioned in their study that an increase in organic matter application in conventional agriculture, for example with manure application, may improve results by approaching or exceeding the results found for organic agriculture.

Pesticide use is one of the factors that have most impact on the environment; accordingly it is one of the most influential comparative factors. Historically, Dutch agriculture has relied on intensive use of farm resources, including land and heavy pesticide use. Agricultural policies in the Netherlands are increasingly supporting production systems that apply sustainable management. Pesticide use is banned in organic agriculture, and in conventional agriculture it is strictly controlled, with preference falling on biological control agents as first option and chemical applications as a last resort (Acs *et al.*, 2007). The results in this study reflect a positive impact of more sustainable policies. In recent years the Dutch parliament has banned certain pesticides and herbicides (e.g. Monsanto's glyphosate based herbicides); nevertheless farmers argue that a certain amount of pesticide use is necessary in conventional agriculture, particularly due to weather conditions and the lack of proper crop varieties that grow efficiently in these conditions.

Both scenarios scored poorly in eutrophication potential, but scenario O scored worse than scenario C. This indicator is influenced by fertilizer use and this result was not expected for the organic scenario, because fertilizer use should be strictly controlled in organic agriculture. As previously mentioned, these results are subjective to the assumptions made and the values assumed for this indicator exceeded the unsustainability limit. This may be linked with the fact that both production systems make intensive use of resources, especially fertilizers, be it in organic or synthetic form (Bos *et al.* (2014); de Ponti et al. 2012). Meier *et al.* (2015) found similar results in their comparative study where they highlight that organic farming may result in worse scores in categories like potential emissions due to improper soil fertility management of manure fertilization and crop N fixation.

De Wit and Verhoog (2007) debate that Dutch organic agriculture shows sign of "conventionalization". Organic farming is a growing market and most of the organic farms have recently (10 years ago) switched to organic practices (Hoogenboom *et al.*, 2008). Dutch organic production's high intensity level is expressed in crop rotations with a large share of high value crops, high fertilizer inputs, and frequent field operations related to weeding (Bos *et al.*, 2014). The Netherlands is one of the most densely populated countries in the world; issues like population growth have influenced a shift in landscape from agriculture to urbanized areas (Meerburg *et al.*, 2009). Land allocation is an important subject due to limited land availability and the different demands on this land (e.g. infrastructure, agriculture, nature conservation, etc...).

Scenario O scored better than scenario C in energy use, this result was expected because this indicator is influenced by synthetic fertilizer use, pesticide applications, and machinery use. Due to synthetic fertilizer and pesticide bans in organic agriculture, energy use tends to be lower than in conventional agriculture. Bos *et al.* (2014) found higher energy use in organic crop production, but the results were higher when compared per unit of product instead of per area, due to lower yields perceived under organic management. Higher energy use in organic crop production could be explained by higher use of machinery for mechanical weeding and manure application (Nemecek *et al.*, 2011), this may be a contradicting result given that less machinery use is a sustainability goal.

5.3 Economic sustainability

Both scenarios scored high on the profit dimension, however scenario O had a higher farm income value than scenario C. Wheat is grown for profit and it is also valuable as part of the rotation, though it doesn't contribute a high gross margin to the farm. Farm income included the income share from the different crops produced at the farm. In this regard, potatoes contributed a higher margin to farm income than wheat production (Acs *et al.*, 2009). According to van Leeuwen and Dekkers (2013) income obtained from agricultural production in the Netherlands is relatively high, on average a farmer's income is composed 80% from production activities, meaning less percentage is off-farm income.

Studies have shown that higher prices for organic products and lower production costs can compensate for lower yields, consequently resulting in higher incomes for organic farms (Pacini *et al.*, 2003); (Acs *et al.*, 2007); (European Commission, 2013b). The prices for organic products include the cost of production as well as a premium that captures factors like environmental protection, animal welfare, farmer health, and rural development. Nevertheless, higher labour requirements in organic agriculture may increase variable costs, offsetting expected cost reductions.

Multifunctional farms link farming, the rural area, and visitors through recreational activities such as: agricultural and nature conservation activities, landscape management, local product commercialization, and leisure (Meerburg *et al.*, 2009). Farms can serve a number of functions to link farming and society. This may also result as a diversification strategy to cope with income risk. As one of the characteristics highlighted of organic farming is the higher labor requirement (Acs *et al.*, 2007), this represents an opportunity for community building and the addition of labor force through an open door policy. Farmers may have social and economic motives for these activities but Meerburg *et al.* (2009) highlighted the fact that it helps with integrating urban and rural areas. Multifunctional land management can be an option for increasing social, environmental, and economic sustainability.

This analysis was conducted considering bread making as the preferred product. If the wheat was meant for feed, different factors about the calculation and analysis would change. In the social dimension, for example, the quality requirements would not be as strict, and the indicator values for protein content would probably reach the desirable sustainability level easier. The non-compensability feature of food safety would remain the same because the indicator should comply with legal standards. The environmental dimension would remain almost unchanged because the production activities are the same; surplus wheat or wheat that doesn’t meet bread-making quality requirements is sold as feed (G. Van der Burgt & Timmermans, 2009). In the economic dimension, the main impact could be registered in farm income because the price of wheat for feed is lower than the price of high quality bread-making wheat, yet currently most of the wheat is already sold for feed.

6 Conclusions and recommendations

This study followed the protocol developed by van Asselt *et al.,* (2014) and it aimed to compare and analyze the sustainability of organic and conventional wheat production in the Netherlands. Using the BOA software it was concluded that organic wheat production is more sustainable when compared to a conventional scenario. The BOA tool enables the decision maker to make a more in-depth analysis of the performance of each production system; taking into consideration the three dimensions of sustainability (people, planet, and profit). It is an accessible and user friendly tool for holistic sustainability assessments. Moreover, this tool enables researchers and decision makers to build upon previous research. Input from additional stakeholders can be included in different aspects of the study; for example direct input from farmers and policy makers can be included in the selection of indicators, limits, and in the weighting process.

The results of the study are dependent on the assumptions made throughout the course of the research. Making different assumptions and using different limits and indicator values will change the final results. This study gives a holistic review of the current sustainability of wheat production in the Netherlands from social, environmental, and economic perspectives. Previous studies focused on only one dimension of sustainability or just one product, and from the found literature none focused on the sustainability of wheat production. Even though organic agriculture scored better than conventional in most of the themes, these results cannot be generalized for all situations.

The three dimensions of sustainability (people, planet, and profit) presented an inclination towards being “Pareto optimal”; in this situation it means that one dimension cannot improve without having an effect on the result of the other dimensions. It is important to analyze sustainability from a point of view which considers the three dimensions; the importance given to each dimension depends on the situation, but they must be present. In general terms in cannot be said that one production system is globally better than the other. Both organic and conventional agriculture perform different when factors are individually analyzed.

Sustainability in the social dimension, as considered in this study, is highly dependent on the wheat varieties used by farmers in both organic and conventional agriculture. Moreover, Dutch weather conditions have an effect on the quality and productivity of wheat. Given that Dutch wheat meets quality requirements to a limited extent, the Netherlands is a big importer of wheat. The performance of the social indicators can be improved through practices such as: nitrogen management and the implementation of breeding programs. Accordingly, public investments are increasing in research and market development.

Organic agriculture is characterized by higher labor requirement. This can imply higher costs for the farm, but at the same time it can create an opportunity for bridging the gap between urban and rural areas. Consumers are increasingly becoming interested in how the food they are eating is produced; by volunteering in farms they can experience agriculture and the farm can acquire more labor.

The intensive use of resources, mainly land and fertilizers, in both organic and conventional agriculture, are the factors that have the most effect on environmental sustainability. Agriculture in the Netherlands is tending towards a conventionalization of organic agriculture and “greening” of conventional agriculture. Pesticide use is strictly controlled in both production systems; this is a positive action towards more sustainable agricultural policies.

Organic farms on average require more land than conventional farms; this is attributed to low yields and the need for more space to cultivate nutrient building crops for soil fertility. Furthermore, the main challenges manifested for organic and conventional agriculture lie in focusing efforts of organic farming on improving nutrient availability and increasing yields, while conventional farming should improve soil quality, nutrient recycling and enhancement, and protecting biodiversity.

Regardless of lower yields and higher labor requirements, organic farms may still have an equal or higher income than conventional farms; this is mainly attributed to higher prices paid for organic produce. Nevertheless, depending too much on higher prices is risky because wheat prices are determined by the market; in addition the organic market in the Netherlands is still developing and somewhat unstable. Farm income includes the income share of the different crops in rotation. Individually, wheat does not contribute a high margin to farm income; other crops, like potatoes, contribute a higher margin to farm income.

Further research can be extended to the other steps of the wheat supply chain, for example comparing the sustainability of bread production. Research can also be focused on quantifying the actual impact in emissions caused by practices (like fertilization), from both organic and conventional agriculture, and their impact in the environment; for example, by conducting an LCA study for wheat production in the Netherlands. It is recommended to analyze the impact of reforms made on the Common Agricultural Policy (CAP), especially the subsidies, and their impact on the income and productivity of Dutch farmers. Furthermore, there should be focus in increasing breeding research for Dutch wheat varieties, for both organic and conventional agriculture. This could improve the results in different indicators like: higher protein content, more efficient energy use, plague and fungi resistance, reduced pesticide use, improve plant efficiency, and resistance to weather conditions.

The information resulting from this research leads to conclude that agriculture in the Netherlands is shifting to a more sustainable version of conventional farming. Organic agriculture is a good sustainable alternative to conventional farming. Conventional agriculture did not score as low as expected in the sustainability assessment which is a positive result and it reflects the sustainable agenda in the Dutch agricultural policy, particularly regarding chemical pesticide use. Nevertheless, in light of the intensive resource use, both production systems should reduce intensive resource use and improve nitrogen management, i.e. fertilizer application (organic or synthetic). The land that is currently available for farming will not be increasing in the future, so the most efficient and sustainable use has to be made from this land.

7 References

Acs, S., Berentsen, P., De Wolf, M., & Huirne, R. (2007). Comparison of conventional and organic arable farming systems in the Netherlands by means of bio-economic modelling. *Biological Agriculture & Horticulture, 24*(4), 341-361.

Acs, S., Berentsen, P., Huirne, R., & Van Asseldonk, M. (2009). Effect of yield and price risk on conversion from conventional to organic farming*. *Australian Journal of Agricultural and Resource Economics, 53*(3), 393-411.

Bernhoft, A., Clasen, P.-E., Kristoffersen, A., & Torp, M. (2010). Less Fusarium infestation and mycotoxin contamination in organic than in conventional cereals. *Food Additives and Contaminants, 27*(6), 842-852.

Boogaard, H., Wolf, J., Supit, I., Niemeyer, S., & van Ittersum, M. (2013). A regional implementation of WOFOST for calculating yield gaps of autumn-sown wheat across the European Union. *Field Crops Research, 143*(0), 130-142. doi: http://dx.doi.org/10.1016/j.fcr.2012.11.005

Bos, J. F., de Haan, J., Sukkel, W., & Schils, R. L. (2014). Energy use and greenhouse gas emissions in organic and conventional farming systems in the Netherlands. *NJAS-Wageningen Journal of Life Sciences, 68*, 61-70.

Brentrup, F., Küsters, J., Lammel, J., Barraclough, P., & Kuhlmann, H. (2004). Environmental impact assessment of agricultural production systems using the life cycle assessment (LCA) methodology II. The application to N fertilizer use in winter wheat production systems. *European Journal of Agronomy, 20*(3), 265-279.

Bunte, F., Bolhuis, J., de Bont, C., Jukema, G., & Kuiper, E. (2009). Pricing of food products: Memorandum.

Casagrande, M., David, C., Valantin-Morison, M., Makowski, D., & Jeuffroy, M.-H. (2009). Factors limiting the grain protein content of organic winter wheat in south-eastern France: a mixed-model approach. *Agronomy for Sustainable Development, 29*(4), 565-574.

Cederberg, C., & Mattsson, B. (2000). Life cycle assessment of milk production—a comparison of conventional and organic farming. *Journal of Cleaner production, 8*(1), 49-60.

Council Regulation. (2007). No 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing Regulation (EEC) No 2092/91. *Official Journal of the European Union L, 189*(1), 28.27.

CuiLin, Y., Kaul, H., Kübler, E., Schwadorf, K., & Aufhammer, W. (2001). Head blight (Fusarium graminearum) and deoxynivalenol concentration in winter wheat as affected by pre-crop, soil tillage and nitrogen fertilization. *Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz, 108*(3), 217-230.

Charles, R., Jolliet, O., Gaillard, G., & Pellet, D. (2006). Environmental analysis of intensity level in wheat crop production using life cycle assessment. *Agriculture, Ecosystems & Environment, 113*(1), 216-225.

David, C., Abecassis, J., Carcea, M., Celette, F., Friedel, J., Hellou, G., . . . Peigné, J. (2012). Organic bread wheat production and market in Europe *Sustainable Agriculture Reviews* (pp. 43-62): Springer.

de Ponti, T., Rijk, B., & Van Ittersum, M. K. (2012). The crop yield gap between organic and conventional agriculture. *Agricultural systems, 108*, 1-9.

De Wit, J., & Verhoog, H. (2007). Organic values and the conventionalization of organic agriculture. *NJAS-Wageningen Journal of Life Sciences, 54*(4), 449-462.

Edwards, S. G. (2009). Fusarium mycotoxin content of UK organic and conventional wheat. *Food Additives and Contaminants, 26*(4), 496-506.

Eide, M. H. (2002). Life cycle assessment (LCA) of industrial milk production. *The International Journal of Life Cycle Assessment, 7*(2), 115-126.

European Commission. (2012). The Common Agricultural Policy A partnership between Europe and Farmers.

European Commission. (2013a). Facts and Figures on Organic Agriculture in the European Union.

European Commission. (2013b). Organic versus conventional farming, which performs better financially? (Vol. 4, pp. 10).

Franz, E., Booij, K., & van der Fels-Klerx, I. (2009). Prediction of deoxynivalenol content in Dutch winter wheat. *Journal of Food Protection®, 72*(10), 2170-2177.

Gafsi, M., & Favreau, J. L. (2010). *Appropriate method to assess the sustainability of organic farming systems.* Paper presented at the 9 th European IFSA symposium.

Gauer, L., Grant, C., Bailey, L., & Gehl, D. (1992). Effects of nitrogen fertilization on grain protein content, nitrogen uptake, and nitrogen use efficiency of six spring wheat (Triticum aestivum L.) cultivars, in relation to estimated moisture supply. *Canadian Journal of Plant Science, 72*(1), 235-241.

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., . . . Toulmin, C. (2010). Food security: the challenge of feeding 9 billion people. *science, 327*(5967), 812-818.

Halberg, N. (2012). Assessment of the environmental sustainability of organic farming: Definitions, indicators and the major challenges. *Canadian Journal of Plant Science, 92*(6), 981-996.

Harcz, P., De Temmerman, L., De Voghel, S., Waegeneers, N., Wilmart, O., Vromman, V., . . . De Saeger, S. (2007). Contaminants in organically and conventionally produced winter wheat (Triticum aestivum) in Belgium. *Food Additives and Contaminants, 24*(7), 713-720.

Hoogenboom, L., Bokhorst, J. G., Northolt, M. D., Van de Vijver, L., Broex, N. J., Mevius, D. J., . . . Van Der Roest, J. (2008). Contaminants and microorganisms in Dutch organic food products: a comparison with conventional products. *Food Additives and Contaminants, 25*(10), 1195-1207.

Jansen, K. (2000). Labour, livelihoods and the quality of life in organic agriculture in Europe. *Biological Agriculture & Horticulture, 17*(3), 247-278.

Köpke, U. (2003). Influence of organic and conventional farming systems on nutritional quality of food. *Impacts of Agriculture on Human Health and Nutrition. In: Encyclopedia of Life Support Systems (EOLSS). Developed under the auspices of the UNESCO. Eolss Publishers. Oxford.[http://www. eolss. net]*.

L-Baeckström, G., Hanell, U., & Svensson, G. (2004). Baking quality of winter wheat grown in different cultivating systems, 1992–2001: a holistic approach. *Journal of sustainable agriculture, 24*(1), 53-79.

LEI Wageningen UR. (2013). Monitor Duurzaam Voedsel 2013 (pp. 56). The Hague, The Netherlands: LEI.

Lemmens, M., Haim, K., Lew, H., & Ruckenbauer, P. (2004). The effect of nitrogen fertilization on Fusarium head blight development and deoxynivalenol contamination in wheat. *Journal of Phytopathology, 152*(1), 1-8.

Luttikholt, L. W. (2007). Principles of organic agriculture as formulated by the International Federation of Organic Agriculture Movements. *NJAS-Wageningen Journal of Life Sciences, 54*(4), 347-360.

Mäder, P., Hahn, D., Dubois, D., Gunst, L., Alföldi, T., Bergmann, H., . . . Graf, U. (2007). Wheat quality in organic and conventional farming: results of a 21 year field experiment. *Journal of the Science of Food and Agriculture, 87*(10), 1826-1835.

Meerburg, B., Korevaar, H., Haubenhofer, D., Blom-Zandstra, M., & Van Keulen, H. (2009). The changing role of agriculture in Dutch society. *The Journal of Agricultural Science, 147*(05), 511-521.

Meier, M. S., Stoessel, F., Jungbluth, N., Juraske, R., Schader, C., & Stolze, M. (2015). Environmental impacts of organic and conventional agricultural products–Are the differences captured by life cycle assessment? *Journal of Environmental Management, 149*, 193-208.

Meul, M., Nevens, F., Reheul, D., & Hofman, G. (2007). Energy use efficiency of specialised dairy, arable and pig farms in Flanders. *Agriculture, Ecosystems & Environment, 119*(1), 135-144.

Nemecek, T., Dubois, D., Huguenin-Elie, O., & Gaillard, G. (2011). Life cycle assessment of Swiss farming systems: I. Integrated and organic farming. *Agricultural systems, 104*(3), 217-232. doi: http://dx.doi.org/10.1016/j.agsy.2010.10.002

Nemes, N. (2009). Comparative analysis of organic and non-organic farming systems: A critical assessment of farm profitability. *Natural Resources Management and Environment Department (Ed.) Department (Ed.), FAO, Rome*.

Nuijten, E., & van Bueren, E. T. L. (2013). *Evolutionary wheat breeding in the Netherlands.* Paper presented at the International Symposium on Evolutionary Breeding in Cereals.

Osman, A., Bonthuis, H., Van den Brink, L., Struik, P., Almekinders, C., & van Bueren, E. L. (2015). Adapting Value for Cultivation and Use testing to stimulate the release of improved varieties for the organic sector. The case of spring wheat in The Netherlands. *Organic Agriculture, 5*(2), 101-111.

Pacini, C., Wossink, A., Giesen, G., Vazzana, C., & Huirne, R. (2003). Evaluation of sustainability of organic, integrated and conventional farming systems: a farm and field-scale analysis. *Agriculture, Ecosystems & Environment, 95*(1), 273-288.

Pol, H. (2007). Innovation in the Dutch wheat supply chain: a study into the ways of increasing the utilization of Dutch wheat in bread production by means of supply chain innovation.

Pol, H., & Visscher, K. (2010). The influence of power in supply chain innovation: a case study of the Dutch wheat chain. *Journal on Chain and Network Science, 10*(1), 77-85.

Pussemier, L., Piérard, J.-Y., Anselme, M., Tangni, E. K., Motte, J.-C., & Larondelle, Y. (2006). Development and application of analytical methods for the determination of mycotoxins in organic and conventional wheat. *Food Additives and Contaminants, 23*(11), 1208-1218.

Rossi, F., Bertuzzi, T., Comizzoli, S., Turconi, G., Roggi, C., Pagani, M., . . . Pietri, A. (2006). Preliminary survey on composition and quality of conventional and organic wheat. *Italian journal of food science, 18*(4), 355-366.

Sukkel, W., & Hommes, M. (2009). Research on organic agriculture in the Netherlands. *Organisation, methodology and*.

Timmermans, B. G., Osman, A. M., & Van der Burgt, G. H. (2009). Differences between spring wheat cultivars in tolerance to Fusarium seedling blight under organic field conditions. *European journal of plant pathology, 125*(3), 377-386.

Tuomisto, H., Hodge, I., Riordan, P., & Macdonald, D. (2012a). Comparing global warming potential, energy use and land use of organic, conventional and integrated winter wheat production. *Annals of Applied Biology, 161*(2), 116-126.

Tuomisto, H., Hodge, I., Riordan, P., & Macdonald, D. (2012b). Does organic farming reduce environmental impacts? *Journal of Environmental Management*.

Tuomisto, H., Hodge, I., Riordan, P., & Macdonald, D. (2012c). Does organic farming reduce environmental impacts? – A meta-analysis of European research. *Journal of Environmental Management, 112*(0), 309-320. doi: http://dx.doi.org/10.1016/j.jenvman.2012.08.018

van Asselt, E., Capuano, E., & van der Fels-Klerx, H. (2015). Sustainability of milk production in the Netherlands - A comparison between raw organic, pasteurised organic and conventional milk. *International Dairy Journal, 47*, 19-26. doi: 10.1016/j.idairyj.2015.02.007

van Asselt, E., van Bussel, L., van der Voet, H., van der Heijden, G., Tromp, S., Rijgersberg, H., . . . van der Fels-Klerx, H. (2014). A protocol for evaluating the sustainability of agri-food production systems—A case study on potato production in peri-urban agriculture in The Netherlands. *Ecological Indicators, 43*, 315-321.

van Bueren, E. L., Jones, S. S., Tamm, L., Murphy, K. M., Myers, J. R., Leifert, C., & Messmer, M. (2011). The need to breed crop varieties suitable for organic farming, using wheat, tomato and broccoli as examples: a review. *NJAS-Wageningen Journal of Life Sciences, 58*(3), 193-205.

Van Calker, K., Berentsen, P., De Boer, I., Giesen, G., & Huirne, R. (2007). Modelling worker physical health and societal sustainability at farm level: an application to conventional and organic dairy farming. *Agricultural systems, 94*(2), 205-219.

Van der Burgt, G., & Timmermans, B. G. (2009). Fusarium in wheat. Effects of soil fertility strategies and nitrogen levels on mycotoxins and seedling blight.

van der Burgt, G. J. H. M., Timmermans, B. G. H., Scholberg, J. M. S., & Osman, A. M. (2011). Fusarium head blight and deoxynivalenol contamination in wheat as affected by nitrogen fertilization. *NJAS - Wageningen Journal of Life Sciences, 58*(3–4), 123-129. doi: http://dx.doi.org/10.1016/j.njas.2011.09.005

Van der Ploeg, J. D., & van Dijk, G. (1995). *Beyond modernization: the impact of endogenous rural development* (Vol. 3): Uitgeverij Van Gorcum.

van der Voet, H., van der Heijden, G. W., Kruisselbrink, J. W., Tromp, S.-O., Rijgersberg, H., van Bussel, L. G., & van Asselt, E. D. (2014). A decision support tool for assessing scenario acceptability using a hierarchy of indicators with compensabilities and importance weights. *Ecological Indicators, 43*, 306-314.

van Leeuwen, E., & Dekkers, J. (2013). Determinants of off-farm income and its local patterns: a spatial microsimulation of Dutch farmers. *Journal of Rural Studies, 31*, 55-66.

Vanova, M., Klem, K., Misa, P., Matusinsky, P., Hajslova, J., & Lancová, K. (2008). The content of Fusarium mycotoxins, grain yield and quality of winter wheat cultivars under organic and conventional cropping systems. *Plant Soil Environ, 54*(9), 395-402.

Williams, A. G., Audsley, E., & Sandars, D. L. (2010). Environmental burdens of producing bread wheat, oilseed rape and potatoes in England and Wales using simulation and system modelling. *The International Journal of Life Cycle Assessment, 15*(8), 855-868.