PHD DISSERTATION

Assessing Sustainability of Agricultural Systems: Balancing Context Specificity and Generality

by Vicent Gasso-Tortajada

AARHUS UNIVERSITY

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PREFACE

This PhD thesis is the outcome of three intensive but stimulating years of research. These pages will present the “end product”, but will fall short in describing the personal and professional development triggered by this remarkable journey. These pages hide a myriad of experiences, lessons and wisdom from colleagues, interviewees and friends, which make me still wonder why I am the only author on the front page.

I would like to wholeheartedly thank my supervisors Claus Aage Grøn Sørensen and Frank Willem Oudshoorn for their valuable guidance, mentorship, and encouragement, which have been the essential ingredients allowing the completion of this remarkable journey. You have greatly steered my progress and have always provided me with the space required for expanding my scientific curiosity.

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Vicent Gasso-Tortajada
Viborg, July 2014

CONTENTS

SUMMARY

Sustainability assessment frameworks can range from context-generic to -specific in terms of geographic and sector applicability. Setting the context-specificity level of an assessment framework often implies a number of tradeoffs that affect the practicality and the usefulness of the assessment. For example, context-generic frameworks may be unable to incorporate context-specific features, limiting locally-tuned sustainability improvements, and may constrain the assessment results integrity and local stakeholders' engagement. On the other hand, context-specific frameworks may limit the possibilities for standardisation and results benchmarking (comparison with alternative systems) and tend to be more resource intensive.

The general aim of this thesis was to develop a rationale for balancing the level of context-specificity and -generality of sustainability assessment frameworks in order to optimise these tradeoffs and hence effectively and efficiently assess and incentivise the sustainability of agricultural systems. Three case studies from different assessment perspectives and contexts were analysed in order to develop a rationale sensitive to a relatively wide range of sustainability challenges present in the global agricultural sector. This research focused on three key sustainability assessment components: *themes* (targeted sustainability objectives), *data*, and *benchmarks* (relative reference values of sustainability performance).

The *themes* study analysed the effectiveness of generic themes and sub-themes of existing assessment frameworks for covering the key sustainability issues of a specific case study, i.e. the value chains of maize energy-crop production in southern Denmark. Subsequently, a rationale for setting an optimised context-specificity level for assessment themes and sub-themes was developed. This study demonstrates that context-generic themes may be used in sustainability assessments without impairing the effectiveness in covering context-specific characteristics. Context-generic sub-themes may also be used in the environmental dimension without impairing the coverage effectiveness. However, context-specific sub-themes should be used in the social and economical dimensions when the assessment purpose demands covering context-specific characteristics and benchmarking is not required.

The *data* study analysed the data inventory of a specific sustainability assessment, i.e. a Life Cycle Assessment of the technology of Controlled Traffic Farming for producing wheat in Denmark. Subsequently, a rationale for setting an optimised context-specificity level for assessment data was developed. This study proposes considering site-generic data when local components do not affect the assessment results or when there are no concerns about significant impacts at a local scale. Moreover, technology-generic data may be considered when the assessment aims to represent a variety of systems within more global contexts, and time-generic data when variability over time is not expected. The use of tools such as sensitivity analysis and uncertainty analysis can help to minimise the impact of data inventory limitations in an efficient manner.

The *benchmarks* study first analysed the mechanisms explaining spatial and temporal variations of sustainability indicators, i.e. energy and water use efficiency in the New Zealand viticulture sector. Subsequently, a rationale for designing benchmarks that accommodate context-specific opportunities and constraints for sustainability improvement was developed. The benchmarked-performance (rank) of the analysed vineyards differed widely when benchmarking within the entire sector or within vineyards of equivalent characteristics, specifically agroecological and production related characteristics influencing performance (context-specific benchmarking). Context-generic benchmarks (universal benchmarks comparing farms or products) are likely to best suit consumers and national-level policy makers. However, context-specific benchmarks can better identify local improvement opportunities and constraints, and hence better incentivise change towards sustainability at the farm level.

The findings of these case studies also recommend some degree of stakeholder participation. This approach may help to minimise biases in setting the assessment specificity-level, help with the interpretation of the assessment results, improve stakeholder's sustainability learning, and enhance assessment adoption, trust and ultimately sustainability action.

RESUMEN

Marcos para la evaluación de la sostenibilidad en términos de aplicabilidad geográfica y sectorial pueden ser definidos tanto en un contexto genérico como específico. El establecimiento del nivel de especificidad contextual de un marco de evaluación, a menudo implica una serie de compromisos que afectan a la viabilidad y a la utilidad de la propia evaluación. Por ejemplo, marcos de contexto genérico pueden ser incapaces de incorporar atributos característicos del propio contexto, limitando así las posibilidades de mejora a nivel local, la integridad de los resultados de la evaluación, y la participación y compromiso de las partes interesadas. Por otro lado, marcos de contexto específico pueden limitar las posibilidades de estandarización y de evaluación comparativa con sistemas alternativos (benchmarking) y tienden a ser más intensivos en el uso de recursos para la evaluación.

El objetivo general de esta tesis fue desarrollar directrices para armonizar los niveles de especificidad y generalidad contextual en los marcos para la evaluación de la sostenibilidad de sistemas agrícolas, con el fin de facilitar herramientas que sean capaces de evaluar e incentivar eficaz y eficientemente la sostenibilidad de dichos sistemas. Se analizaron tres diferentes contextos con el fin de desarrollar directrices sensibles a un escenario relativamente amplio de retos de sostenibilidad presentes en el sector agrícola global. Esta investigación se centró en tres componentes clave de los marcos para la evaluación de la sostenibilidad: *temas* (objetivos específicos para la sostenibilidad), *datos*, y *benchmarks* (valores de referencia relativos para los indicadores de sostenibilidad).

El estudio de *temas* analizó la eficacia de temas y subtemas genéricos existentes para cubrir conflictos de sostenibilidad en un estudio de un caso específico: las cadenas de suministro de la producción de maíz en Dinamarca para la producción de biocombustible. Posteriormente, se desarrollaron directrices para el establecimiento de un nivel de especificidad contextual óptimo para temas y subtemas en la evaluación de la sostenibilidad. Este estudio demuestra que temas de contexto genérico se podrían utilizar en la evaluación de la sostenibilidad sin perjudicar la eficacia del marco para cubrir atributos característicos del contexto en particular. Así mismo, subtemas de contexto genérico se podrían utilizar en la dimensión medioambiental sin perjudicar la eficacia de la cobertura. Sin embargo, subtemas de contexto específico deben ser utilizados en las dimensiones sociales y económicas siempre y cuando el propósito de la evaluación requiera la cobertura de atributos característicos del contexto y no requiera evaluación comparativa.

El estudio de *datos* analizó el inventario de datos de evaluación de la sostenibilidad de un caso específico: el análisis del ciclo de vida del sistema de "tráfico controlado" para la producción de trigo en Dinamarca. Posteriormente, se desarrollaron directrices para el establecimiento de un nivel de especificidad contextual óptimo para los datos en la evaluación de la sostenibilidad. Este estudio propone considerar datos de localidad genérica cuando los componentes locales no afecten a los resultados de la evaluación, o cuando no haya previsiones de impactos significativos a nivel local. Por otra parte, datos de tecnología genérica pueden ser considerados cuando se pretenda representar la variedad de sistemas dentro de contextos más globales. En este contexto, el uso de herramientas como el análisis de sensibilidad y el análisis de incertidumbre puede ayudar a minimizar las limitaciones del inventario de datos de una manera eficiente.

El estudio de *benchmarks* en primer lugar analizó los mecanismos que originan las variaciones espaciales y temporales de indicadores de sostenibilidad, en particular: la eficiencia en el consumo energético y de agua en el sector viticultor de Nueva Zelanda. Posteriormente, en este estudio se desarrollaron directrices para el diseño de benchmarks sensibles a las oportunidades y limitaciones locales para la mejora de la sostenibilidad. El ranking relativo de sostenibilidad de los viñedos analizados en la evaluación comparativa difiere ampliamente si la comparación incluye todo el sector (benchmarks de contexto genérico) o solo viñedos de características equivalentes, específicamente características agroecológicas y de producción que influyen en el rendimiento de la sostenibilidad (benchmarks de contexto específico). Benchmarks de contexto genérico son más convenientes para consumidores y legisladores a nivel nacional o internacional. Sin embargo, benchmarks de contexto específico son más sensibles para identificar oportunidades y limitaciones para la mejora de la sostenibilidad a nivel local.

Los hallazgos de estos estudios también recomiendan un cierto grado de participación de las partes interesadas. Este enfoque puede ayudar a minimizar prejuicios en la determinación del nivel de especificidad contextual, facilitar la interpretación de los resultados de la evaluación, mejorar el aprendizaje sobre sostenibilidad en las partes interesadas, y en última instancia, incentivar la acción para el desarrollo sostenible.

RESUMÉ

Vurderinger af bæredygtighed kan strække sig fra kontekst-generisk til kontekst-specifik, både med hensyn til geografi og sektor. Bestemmelsen af niveauet for kontekst-specificitet i forbindelse med en bæredygtighedsvurdering indebærer ofte en afbalancering, som påvirker den praktiske anvendelighed af den konkrete vurdering. Kontekst-generiske vurderinger kan have svært ved at inkludere kontekst-specifikke karakteristika, hvilket begrænser lokalt rettede forbedringer af bæredygtigheden, ligesom det begrænser resultaternes gyldighed og involveringen af lokale interessenter. På den anden side vil kontekst-specifikke vurderinger måske begrænse mulighederne for standardisering og sammenligning af resultater (sammenligning med alternative systemer), og vurderingerne har også en tendens til at være mere ressourcekrævende.

Det overordnede formål med denne afhandling var at udvikle et rationale for afvejning af niveauet for det kontekst-specifikke og det kontekst–generiske i forbindelse med bæredygtighedsvurderinger, således at disse afvejninger kan optimeres for effektivt at kunne fremme bæredygtigheden i landbrugssystemer. Dette studie fokuserer på tre nøglekomponenter i forbindelse med bæredygtighedsvurderinger: temaer (målrettede bæredygtighedsformål), data og benchmarks (relative referenceværdier for bæredygtighed). Tre eksempler (casestudies) blev analyseret ud fra forskellige bæredygtighedsperspektiver, og kontekster blev analyseret for at kunne udvikle et beslutningsgrundlag, der kan dække bredt i forhold til udfordringer til bæredygtigheden i den globale landbrugssektor.

Første eksempel er værdikæder af majs til energiproduktion i Syddanmark. Effektiviteten af de generiske temaer i forbindelse med eksisterende typer af bæredygtighedsvurderinger for tilknyttede nøgleparametre er som et første skridt blevet analyseret. Dernæst er opstillet et beslutningsgrundlag for optimalt valg af kontekst-specificitet for overordnede og underliggende temaer. Resultatet viser, at kontekst-generiske temaer kan bruges i forbindelse med bæredygtighedsvurdering uden at kompromittere effektiviteten af også at dække de kontekst-specifikke karakteristika. Kontekst-generiske underliggende temaer kan også bruges til at vurdere den miljømæssige dimension, ligeledes uden at kompromittere effektiviteten af også at dække de kontekst-specifikke karakteristika. Dog skal kontekst-specifikke underliggende temaer anvendes for at vurdere den sociale og økonomiske dimension, når formålet med vurderingen ikke er at dække kontekst-specifikke karakteristika og benchmarking.

Andet eksempel er livscyklusvurdering af den benyttede teknologi for kontrolleret trafik og hvedeproduktion i Danmark. Data i forbindelse med en bæredygtighedsvurdering er analyseret som grundlag for at bestemme et optimalt kontekst-specifikt niveau for disse data. Resultaterne viser, at der bør anvendes generiske lokaldata, når lokale komponenter ikke påvirker resultatet af vurderingen, eller når der ikke er påviselige, signifikante påvirkninger på lokalt niveau. Yderligere kan generiske data for teknologien anvendes, når formålet med bæredygtighedsvurderingen er at repræsentere varierende systemer inden for en mere global kontekst, og modsat tidsgeneriske når variation over tid ikke forventes. Brugen af værktøjer som følsomhedsanalyser og usikkerhedsanalyser kan afhjælpe usikkerheden i tilfælde af mangelfulde data.

Tredje eksempel er effektiviteten af energi- og vandforbrug i New Zealands vinproduktion. Den spatiale og temporale variation af bæredygtighedsindikatorer er analyseret med hensyn til forklarende mekanismer for sådanne variationer. Analysen er dernæst grundlag for opstilling af et beslutningsgrundlag for design af benchmarks, som belyser kontekst-specifikke muligheder og begrænsninger for forbedringer af bæredygtigheden. Graden af bæredygtighed af de analyserede vinproduktioner er meget forskellig, når der sammenlignes inden for hele sektoren eller inden for vinproduktioner med sammenlignelige karakteristika, specielt i relation til agro-økologisk produktion og produktionsrelaterede parametre. Kontekst-generiske benchmarks (universelle benchmarks, som sammenligner bedrifter og produkter) passer bedst til forbrugere og nationale beslutningstagere. Imidlertid kan kontekst-specifikke benchmarks bedre identificere lokale muligheder for forbedringer og begrænsninger, og derved bedre fremme bæredygtigheden på bedriftsniveau.

Resultaterne fra alle eksemplerne viser, at der også anbefales en vis grad af involvering af interessenter. Derved bidrages til at minimere skævheder, når vurderingens specificitet-niveau bestemmes, ligesom der bidrages til at fortolke vurderingens resultater, ændre interessentens adfærd vedr. bæredygtighed, forbedre tilpasningen af og tilliden til vurderingens resultater, og dermed i sidste øge mulighederne for handling.

Chapter 1

INTRODUCTION

1.1 The paradigm of sustainable development

As we embark on the third millennium, we find ourselves at a crossroads in which, according to Rees (2004), one path leads to global progress and the other to systemic collapse. Today, mankind has developed capabilities unprecedented in human history, such as the capacity to access and share enormous amounts of information, connect individuals worldwide, and foster social mobilisation, with just few "taps" on a computer (Danju, 2013; Micó and Casero-Ripolles, 2014). Simultaneously, mankind is facing critical structural dysfunctions with ecological, social, and financial implications (Mebratu, 1998). For instance, the Stockholm Resilience Centre estimates that mankind has transgressed three environmental "planetary boundaries" within which we can operate safely, specifically climate change, biodiversity loss and nitrogen cycle changes (Rockström et al., 2009). Moreover, the United Nations estimates that globally two in five people in the working-age remain without job, one in eleven children in the primary-education age are not enrolled in a school, one in six people live in extreme poverty, and one in eight people remain chronically undernourished (UN, 2013). This myriad of issues has created the need for developing paradigms such as "sustainable development" in order to overcome the challenges of the present era.

The concept of sustainable development received higher international prominence after the publication of the *World Conservation Strategy* (IUCN, 1980) and *Our Common Future* (also known as the Brundtland report) (WCED, 1987). Nevertheless, the earlier attempt of developing the "theory of environmental limits" by Thomas Malthus (1766–1834) and the different theories on the "scale of organisation", such as in the seminal book *Small Is Beautiful* (Schumacher, 1979), may be considered as the major academic precursors for the concept of sustainable development (Mebratu, 1998). However, the notion of sustainable development is considerably older. Its origins appear to be in ancient indigenous traditions and beliefs, in which the core element was the importance of living in harmony with nature, society, and future generations (Mebratu, 1998; Miller et al., 2005).

One of the most used definitions of sustainable development is taken from the Brundtland report (WCED, 1987), which defines it as: the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". This definition has been highly influential in developing a more holistic view with respect to our planet's future (Daly, 1990). However, its ambiguity results in diverse and controversial interpretations, which depend on individual world-views and values (Hugé et al., 2013; Imran et al., 2014).

One of the few areas of widespread consensus concerning the meaning of sustainable development is that it encompasses environmental, social and economic interdependent dimensions, which are sometimes referred to as the 'three pillars' or the 'triple bottom-lines' (Hacking and Guthrie, 2008). Nevertheless, there are many framework proposals that highlight the importance of considering governance as the fourth dimension (Figure 1), which represents the process of making and implementing decisions (MMSD, 2002; FAO, 2013a; Mutisya and Yarime, 2014).

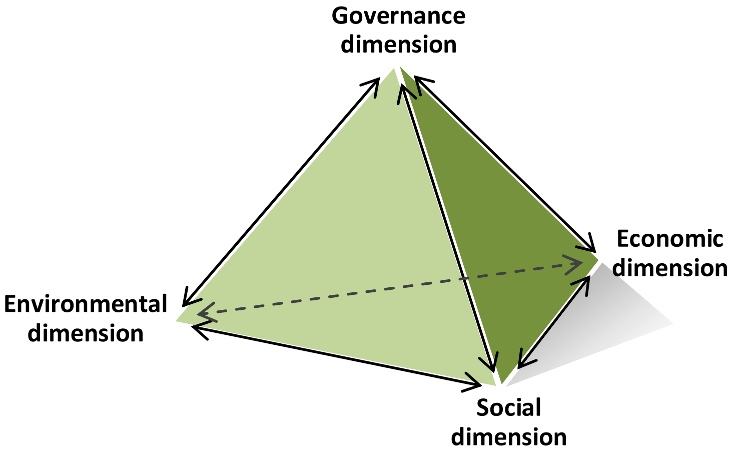

Figure 1. The sustainability dimensions "tetrahedron"

1.2 Sustainability in a "cultivated" planet

Agriculture is mankind's largest managed ecosystem, which covers nearly 40 percent of the planet's land area (FAOSTAT, 2011). Agriculture is responsible for producing most of world's food and part of its fibre, energy and medicine demands. Moreover, it provides livelihoods for 40 percent of the global population (FAO, 2012a). Agriculture can provide additional ecosystem services including regulation of water and carbon cycles, and population dynamics of pollinators and pests. Moreover, it can provide cultural services such as rural lifestyles and spiritual well-being (Swintona et al., 2007; Power, 2010; Stallman, 2011).

However, today's agriculture is one of the major contributors driving environmental impacts beyond the "planetary boundaries" (Rockström et al., 2009). For instance, agriculture is responsible for one third of global greenhouse gas emissions, largely from deforestation, methane emissions from livestock and rice cultivation, and nitrous oxide emissions from fertilised soils (FAO. 2006; Canadell et al., 2007; Vergé et al., 2007; van der Werf et al., 2009). Moreover, agriculture is responsible for 70 percent of global freshwater withdrawals (FAO, 2011).

The environmental impacts of agriculture include those caused by expansion and those cause by intensification (Foley et al., 2011). Agricultural expansion, takes place when agricultural land is extended by replacing natural ecosystems. This expansion has already covered half of the world's temperate deciduous forest and one third of the world's tropical forest (Ramankutty and Foley, 1999; Ramankuttyet al., 2008). This expansion has severely affected global biodiversity and climate change (Tilman et al., 2002; Foley et al., 2005; MA, 2005). Agricultural intensification, takes place when existing agricultural land is managed to be more productive, for instance, by an increased use of fertilisers, pesticides, irrigation and mechanisation (Foley et al., 2011). For example, in the past 50 years, fertiliser use increased by 500%, while the irrigated agricultural area nearly doubled (FAOSTAT, 2011). Agricultural intensification has increased crop yields about 75%, but also caused water degradation, disrupted global nutrient cycles, impaired soil conditions, increased energy use, and contributed to climate change (Matson et al., 1997; Vorosmarty et al., 2000; Foley et al., 2011; Gasso et al., 2013).

Even with current productivity gains, millions of people lack access to food, arising from persistent poverty, and food prices shocks caused by market speculation, bioenergy-crops expansion and climatic disturbances (FAO, 2009; Thurow and Kilman, 2009; Godfray et al., 2010; Naylor, 2011). Moreover, projected population growth, dietary changes (especially meat consumption), and increasing bioenergy use, would require doubling current agricultural production by 2050; unless dramatic changes, such as shifting consumption patterns and reducing waste, take place (FAO, 2009; IAASTD, 2009; TRS. 2009; Cirera and Masset, 2010; Kearney, 2010; Pelletier and Tyedmers, 2010).

The humanity of the twenty-first century faces an enormous challenge: meeting society's agricultural needs while simultaneously minimising (or ideally, eliminating) agriculture's environmental harms. Therefore, agriculture stands as a critical element for the world's sustainable development.

1.3 "Measuring" sustainability

There is an old saying in academic circles that states that "what gets measured, gets managed" (Parris and Kates, 2003). Opportunities for sustainable development can emerge from measuring where we are now and how far we need to go (Wackernagel et al., 1999). In line with this, sustainability assessment has become a rapidly developing area and numerous assessment methods (many for agricultural systems) have been launched in the last decades (von Wirén-Lehr, 2001; van der Werf and Petit, 2002; Rosnoblet et al., 2006; Ness et al., 2007; Bockstaller et al., 2009; Binder et al., 2010).

Sustainability assessment has been defined as ''a tool that can help decision-makers decide what actions they should take and should not take in an attempt to make society more sustainable'' (Devuyst, 2001); or a tool to ensure that ''plans and activities make an optimal contribution to sustainable development'' (Verheem, 2002).

1.3.1 A diversity of assessment approaches

In the last decades, more than 100 countries have established national sustainability strategies (FAO, 2013a) and over 130 voluntary sustainability standards have been documented in the Standards Map of the International Trade Centre (ITC, 2014). Existing sustainability frameworks have been developed by a diversity of institutions, such as universities, corporations, civil society, and national and international organisations; and range from environmental and social standards to corporate codes of good practices and social responsibility, involving different goals and scopes. Moreover, a diversity of technical views and political beliefs and values results in different interpretations of the concept and the implementation of sustainability (Lélé and Norgaard, 1996).

Despite intensive research efforts, there is still a lack of agreement on how to best assess progress towards sustainability (Gasparatos and Scolobig, 2012). Existing sustainability assessment approaches range from monetary- or biophysical-based indexes, to tools based on a set of indicators (Gasparatos and Scolobig, 2012). However, some researchers have called for non-reductionist approaches, specifically moving away from single metrics (e.g. monetary- or biophysical-based indexes) towards more integrated perspectives, such as indicator-based tools, which can allow understanding the multiplicity of sustainability aspects as well as interactions and tradeoffs between them (Kaufmann and Cleveland,1995; Gasparatos et al., 2008; Binder et al., 2010).

1.3.2 A terminology for sustainability assessment

Different practitioners use different terminologies to characterise indicator-based sustainability assessment components and processes. The Food and Agriculture Organisation of the United Nations (FAO) is currently trying to homogenise the sustainability assessment terminology in the global agricultural context, with its Sustainability Assessment of Food and Agriculture systems (SAFA) guidelines (FAO, 2013a). These guidelines provide the basis for defining the terminology used in the present study.

Indicator-based sustainability assessment methods are generally structured according to several hierarchical or aggregation levels. The most general level comprises sustainability *dimensions.* These are general discipline-independent fields, which are normally differentiated into environmental, social, economic, and governance (Section 1.1).

At the intermediate level, each dimension comprises a number of *themes* and *sub-themes*. These are defined as the relatively independent elements associated implicitly or explicitly with specific sustainability goals and objectives (FAO, 2013a). When themes are divided into sub-themes, higher order sustainability goals are connected to the themes, and specific objectives to the sub-themes. Themes and sub-themes are also referred to as principles and criteria (van Cauwenbergh et al, 2007; RSB, 2011), impact categories and subcategories (UNEP/SETAC, 2010), or components (Bélanger et al., 2012). Each theme or sub-theme is linked to one or a number of indicators.

Indicators are the most specific level. These are measureable and verifiable variables or factors that are independent of the aggregation method and allow performance communication (Lenz et al., 2000; FAO, 2013a).

As an example of the different aggregation levels, the "Environmental" dimension may have an "Atmosphere" theme (and associated goal), which includes a "Greenhouse Gases" sub-theme (and associated objective), which in turn uses the "organisation's annual net CO_2-equivalent emissions per tonne of produce" as an indicator.

An indicator value alone does not allow for standardisation and performance improvement unless it is linked to a *reference value* (Acosta-Alba and van der Werf, 2011b). Reference values can be categorised into absolute and relative. Absolute reference values are predefined indicator values that form targets, thresholds or ranges of acceptable risk (Syers et al., 1995; Acosta-Alba and van der Werf, 2011b). Relative reference values are proxy measures of actual performance, i.e. indirect indicators of the target outcomes. They can be used for trend detection and *benchmarking* processes through performance comparisons with other organisations or systems (Andersen, 1999; Acosta-Alba and van der Werf, 2011b; Lebacq et al., 2013).

1.4 Classifying indicator-based sustainability assessments

Extensive reviews have been performed comparing different sustainability assessment approaches (Ness et al., 2007; Binder et al., 2010; Gasparatos and Scolobig, 2012; Schader et al., 2012; Singh et al., 2012). These reviews classify existing indicator-based methods mainly in terms of:

- *framework-design approach*, which can be based on (i) top-down approaches, when experts and researchers design the assessment framework, or (ii) bottom-up approaches, when different stakeholders design the assessment framework;
- *assessment level*, which can include assessment at the farm, supply chain, product life-cycle, sector, regional, national or international level;

- *assessment-implementation participants* and *assessment-results audience for decision-making*, which can include farmers, business partners, researchers, policy-makers, governmental and non-governmental organisations, consumers, or multiple stakeholders;
- *sustainability dimensions coverage*, which refers to the extent in which the assessment includes the different dimension of sustainability; and
- *sustainability perspective*, which can include a societal or an organisational perspective, depending on whether the focus is on sustaining the global society or the targeted organisation.

The *assessment context-specificity level* is a classification category that has not been discussed by the existing reviews (except to some extent in Schader et al. (2012)). This category deserves more attention because it may significantly affect the assessment outcomes (Pastille Consortium, 2002; Fleischer et al., 2003; Mascarenhas et al., 2010). The assessment context-specificity level can range from generic to specific, particularly in terms of geographic and sector applicability and data usage. For instance, an assessment framework can be designed to be applicable within a specific region or within the global arena, as well as within a specific industry or a range of them. Moreover, an assessment framework can use specific data from the analysed case study or sector's average data.

1.4.1 Context-specific assessments

Many research and development projects use context-specific sustainability assessments (e.g. van Calker et al., 2005; van Zeijl-Rozema and Martens, 2010; Bélanger et al., 2012; Oudshoorn et al., 2012; Roy et al., 2013). Context-specific assessments generally involve the design of a framework targeted to the research question and based on context-specific themes, indicators, reference values and data.

Important context characteristics in sustainability assessment include: (i) issues and stakeholders affecting or affected by the assessed operation and the assessment process, (ii) capacities, priorities and values of the stakeholders, (iii) rules and procedures that govern the process, (iv) culture and history of the involved organisations and stakeholders, and (v) timing and resources of the assessment process (adapted from Pastille Consortium (2002)).

The development and implementation of a context-specific assessment framework involves a similar commonly accepted procedure. Apart from a few disparities, this process can be summarised by the following steps (van der Zijpp, 2001; van Calker et al. 2005; Lebacq et al. 2012; Bélanger et al. 2012):

1. Definition of the assessment goal, scope and context, which involves defining the assessment objective, the object or entity to be assessed, the sustainability perspective and principles, the assessment level and boundaries, the stakeholders designing and implementing the assessment and posterior decision making, and other assessment requirements.
2. Identification and definition of sustainability themes/sub-themes, indicators, reference values, and aggregation method.
3. Test the framework to check for usability.
4. Data collection.
5. Analysis.
6. Evaluation and communication of the results to the respective stakeholders and subsequent decision making.
7. Follow up the decision making outcomes.

1.4.2 Context-generic assessments

Globalisation and the need to govern international externalities and global public goods (e.g. climate, biodiversity, financial stability, food safety) can be seen as major drivers in the development of more context-generic assessment frameworks. These frameworks seek standardisation, accreditation, performance benchmarking (comparison) among enterprises, regions or nations, and applicability to a diversity of user groups and contexts (Mineur, 2007; Ness et al., 2007; van Zeijl-Rozema et al., 2011). The development and implementation of a context-generic assessment framework involve a procedure similar to the context-specific one (Section 1.4.1), although the assessment framework design (steps 1-3) is based on more generic conditions. This type of frameworks generally involves context-generic themes, indicators and reference values. Sustainability assessments can also include the use of more context-generic data, such as sector's average data (Fleischer et al., 2003).

A number of context-generic frameworks have been developed for assessing sustainability of agricultural systems (e.g. van der Werf and Petit, 2002; Bockstaller et al., 2009; Binder et al., 2010; Schader et al., 2012; FAO, 2013a). Examples of these frameworks include the Sustainability Assessment of Food and Agriculture Systems (SAFA) (FAO, 2013a), the Response-Inducing Sustainability Evaluation (RISE) (BFH, 2012), and the Committee on Sustainability Assessment tool (COSA) (IISD, 2008). Recently developed and already tested in a diversity of contexts, these frameworks can be considered the state of the art in terms of context-generic indicator-based methods for assessing sustainability of agricultural systems (Coutey, 2013). The main characteristics of these frameworks are summarised in Table 1. The three frameworks have a global geographic applicability, but differ in terms of sector applicability. Specifically, SAFA covers a wider range of industries (cropping, livestock husbandry, forestry, fisheries and aquaculture), while RISE mainly focuses on cropping and livestock husbandry and COSA on cropping industries. SAFA is performed at the supply chain or a single supply chain component (e.g. farm) level, while RISE and COSA are performed only at the farm level. SAFA covers a wider range of sustainability dimensions and aspects, especially in relation to the governance dimension. SAFA and COSA have both societal and organisational sustainability perspectives and target a diversity of stakeholders (e.g. supply chain stakeholders, policy makers and non-governmental organisations), while RISE have mainly an organisational perspective and mostly targets agricultural producers.

The following section presents a more detailed analysis of the context-specificity level limitations and opportunities of the SAFA framework, based on some lessons from the SAFA pilot-studies (Manhire et al., 2013).

1.5 The SAFA pilot studies

1.5.1 The SAFA development

The underlying drivers behind the development of SAFA were the need for more holistic and globally applicable sustainability assessment approaches that consider the complexity and relationships within the components of sustainable development (including the governance dimension) as well as the need for a common understanding and language for sustainability assessment (FAO, 2013a).

The SAFA guidelines version 3.0 (final version) (FAO, 2013a) is the result of five years of participatory development. Since its early phases, these guidelines have been

Table 1. Examples of context-generic indicator-based frameworks for assessing sustainability of agricultural systems.

	SAFA	RISE	COSA
Name and reference	Sustainability Assessment of Food and Agriculture Systems (FAO, 2013a)	Response-Inducing Sustainability Evaluation (BFH, 2012)	Committee on Sustainability Assessment tool (IISD, 2008)
Developer	United Nations' Food and Agriculture Organisation (FAO)	Bern University of Applied Sciences (BFH)	Committee on Sustainability Assessment (COSA)
Geographic applicability	Global	Global	Global
Sector applicability	Agricultural, forestry and fisheries industries (cropping, livestock husbandry, forestry, fisheries and aquaculture)	Agricultural industry (mainly cropping and livestock husbandry)	Agricultural industry (mainly crop production)
Assessment object	Organisation (not product)	Organisation (not product)	Organisation (not product)
Assessment level	Entire supply chain or single supply chain component (e.g. farm)	Farm	Farm
Dimensions covered	Environmental, social, economic and governance	Environmental, social, and economic	Environmental, social, and economic (and, to some extent, governance)
Sustainability perspective	Societal and organisational	Mainly organisational	Societal and organisational
Results audience	Supply chain stakeholders; policy makers; non-governmental organisations; and sustainability standards and tools community	Mainly producers	Supply chain stakeholders; policy makers; non-governmental organisations; and sustainability standards community
Purpose	Self-assessment, learning and management; managing or benchmarking suppliers; planning and legislation development; monitoring projects outcomes; and gap analysis with existing sustainability schemes	Mainly self-assessment, learning and management	Self-assessment, learning and management; managing or benchmarking suppliers; planning and legislation development

designed based on the experience of existing methods and analysing the conceptual framework and indicators sets with different stakeholders. In one of its latest phases, FAO called for voluntary pilot tests of the SAFA guidelines version 1.1 (test version) (FAO, 2012b). Pilot testing was undertaken from September 2012 to March 2013 through spontaneous contributions and comprised 30 different settings. These included cropping, livestock, fishery, aquaculture and forestry small-, medium- and large-scale systems in 19 developed and developing countries within the five continents. The objective during the pilot phase was to ensure the smooth applicability, usefulness, acceptance and scientific soundness of the guidelines version 1.1. Outcomes from the pilot studies were reported and discussed in the SAFA Practitioners and Partners Workshop (FAO, Rome, March 2013) which guided the development of the SAFA guidelines version 2.0 released in

July 2013. Afterwards, a further peer-revision process led to the finalised SAFA guidelines version 3.0 (FAO, 2013a) and the SAFA IT tool (FAO, 2013b) released in December 2013.

Among the 19 participating countries, New Zealand contributed to analyses in four different settings. The New Zealand pilot-studies, which were a component of this PhD research (Manhire et al., 2013), consisted of: (i) a vineyard and (ii) a winery, both with a sustainability standard certification, (iii) 12 dairy farms with organic certification, and (iv) two Māori local foods value chains.

The following section summarises the pilot-studies lessons related with the SAFA context-specificity level and associated limitations and opportunities for properly assessing and incentivising sustainable development in the analysed New Zealand contexts.

1.5.2 Lessons on the SAFA context-specificity level

The general findings of the New Zealand pilot-studies highlighted that the SAFA test-version scope was considerably broad to capture and assist such a wide range of countries, sectors and settings. Consequently, individual indicators and the reference-values scale (best, good, moderate, and insufficient) were necessarily general. However, optimal metrics to stimulate improvements may vary between different contexts (e.g. Mineur, 2007; Efroymson et al., 2013).

According to these pilot-studies, the SAFA test-version framework generally presented a "low bar" (in terms of reference-values) for incentivising performance improvements from a New Zealand perspective. For instance, many of the "best practice" reference scale criteria were mandatory at the national level – a condition that can vary in different countries. This is not to say that agricultural practice is more sustainable in the New Zealand context. Moller et al. (2008) stated that the industrialised and intensive agricultural models of the developed nations, like New Zealand, present high risks (and opportunities for sustainability improvements) in many specific issues (e.g. pollution from nutrients and endemic biota extinction-risk caused by disturbances associated with agriculture).

The SAFA test-version proposed generic boundary criteria for the reference-values scale. However, from basic ecological principles, one might expect critical thresholds to vary depending on the context (Hauschild and Potting, 2005). Moreover, according to these pilot-studies, individual organisations may present differences in opportunities and constraints for sustainability improvement, related to individual agroecological and production characteristics (e.g. climatic conditions, crop varieties or livestock breeds, soil characteristics and production size).

The New Zealand pilot-studies emphasised that the necessarily generic nature of the SAFA test-version reference values and default indicators (including a high proportion of binary "yes/no" or other categorical indicators) may limit the usefulness and the sensitivity of the framework to drive a more nuanced set of changes in farming practice in the New Zealand context.

The possibility of using customised indicators was integrated in the SAFA test-version framework. However, according to these pilot-studies, this customisation can create divergence in the way that different stakeholders assess their performance. Therefore, the standardisation and benchmarking possibilities of SAFA may be eroded by participants claiming that they follow the SAFA framework, yet they are using non-standard (even undeclared) modifications.

Overall, the New Zealand pilot-studies underlined that the SAFA test-version framework has a comprehensive scope which strength comes from its generality. However, customisation and adaptation of local metrics is needed to drive improved sustainability performance in the New Zealand context. Moreover, specific guidelines for customisation are needed to minimise the impairment of the benchmarking and standardisation potentials of the framework.

1.6 A need for balancing specificity and generality

Context-generic assessment approaches have been criticised for not allowing the inclusion of specific characteristics or discourses that are inherent to local contexts (Morse and Fraser, 2005; Lee, 2006). Context-generic approaches have also been criticised for relying on value judgments of external-experts in defining the concept of sustainability, and selecting an arbitrary array of objectives and a method of aggregating them (Lélé et al., 1996). Moreover, the use of context-generic data tends to reduce the accuracy of the assessment results (Fleischer et al., 2003) and the use of context-generic reference values tends to disregard local opportunities and constraints for sustainability improvement (Manhire et al., 2013 and Section 1.5.2). For these reasons, the use of context-generic approaches has been associated with gaps and insufficiency in monitoring critical sustainability issues and the impairment of trust and adoption of improvement measures by the stakeholders (Parkins et al., 2001; van Zeijl-Rozema et al., 2011).

Context-specific assessment approaches have been criticised for reducing the possibilities of standardisation and benchmarking of sustainability performances among different systems (Binder et al., 2010; Mascarenhas et al., 2010). Consequently, the use of context-specific approaches can limit the identification of relative strengths and weaknesses, and the gathering of ideas and coordination of efforts among different systems or places (Pastille Consortium, 2002; Mascarenhas et al., 2010). Context-specific frameworks have also been criticised for isolating the monitoring results from more global sustainability issues and higher level sustainability processes (e.g. governmental regulations) (Mascarenhas et al., 2010). Context-specific assessments can be more time- and resource-demanding due to the need for context analysis, the design of specific sustainability goals and framework components, and perhaps the collection of context-specific data (Binder et al., 2010).

Accordingly, setting the context-specificity level of sustainability themes, indicators, reference values and data implies a number of tradeoffs that can affect the practicality and the usefulness of the assessment. Therefore, there is a need for balancing the level of context-specificity and -generality of the assessment frameworks in order to optimise these tradeoffs and hence effectively and efficiently assess and incentivise sustainable development.

However, balancing the level of context-specificity and -generality of sustainability assessment frameworks requires filling some research gaps. First, although some studies have explored, in terms of practicality and usefulness, the implications of the indicators context-specificity level (Mineur, 2007; Efroymson et al., 2013; Guerci et al., 2013), there is a research gap regarding the implications of the themes context-specificity level. Second, although some studies have discussed to some extent the potentials and limitations of using generic data for assessing sustainability (Fleischer et al., 2003; Zygomalas et al., 2010), there is a lack of specific guidelines for setting an optimal context-specificity level for assessment data. Third, although several studies have developed absolute reference values that are context-specific (e.g. Ekins and Simon, 2001; López-Ridaura et al., 2002; Bastian et al., 2007; van Cauwenbergh et al., 2007), there is a research gap regarding benchmarks (relative reference values) tuned to context-specific opportunities and constraints for improving sustainability performance.

Chapter 2

STUDY AIM AND OUTLINE

The general aim of this study was to develop a rationale for balancing the level of context-specificity and -generality of sustainability assessment frameworks in order to effectively and efficiently assess and incentivise sustainability of agricultural systems.

Specific objectives and the research framework used to fulfil the study aim are outlined in Figure 2. The first objective was to identify potentials and limitations of context-specific and -generic sustainability assessment frameworks. The second objective was to evaluate potentials and limitations associated with the level of context-specificity of key assessment framework elements. These included: (i) assessment themes (targeted sustainability objectives), (ii) assessment data, and (iii) assessment benchmarks (relative reference values). The third composite objective was to develop a rationale for effectively and efficiently assessing and incentivising sustainability of agricultural systems by (i) setting an optimised level of specificity for assessment themes and assessment data and (ii) developing benchmarks accommodating context-specific opportunities and constraints.

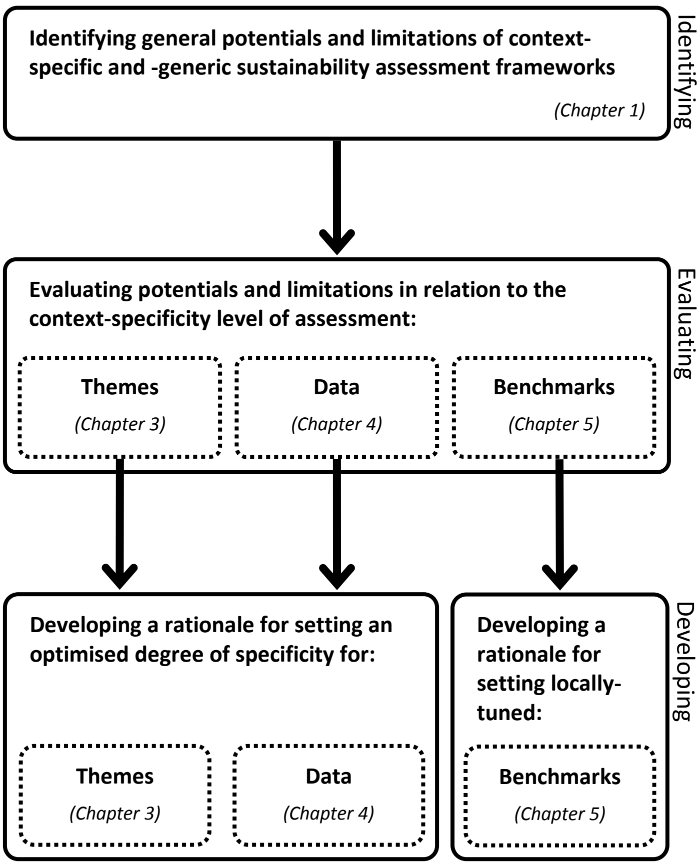

Figure 2. Research framework and thesis outline

The following research questions were derived from the main study objectives:

1. How can an optimised level of specificity, in terms of practicality and usefulness, be set for (i) assessment themes and (ii) assessment data? (Chapters 3 and 4)
2. How can sustainability benchmarks be designed to accommodate context-specific opportunities and constraints for incentivising locally-tuned sustainability improvements? (Chapter 5)

Three case studies from different assessment perspectives and contexts were analysed in order to develop a rationale sensitive to a relatively wide range of sustainability challenges present in the global agricultural sector. The case studies focused on (i) the value chains of maize energy-crop production in southern Denmark, (ii) the technology of Controlled Traffic Farming for producing wheat in Denmark, and (iii) the viticulture sector of the Sustainable Winegrowing scheme in New Zealand.

This thesis has been structured based on a number of scientific publications composing the main PhD research (Chapters 3, 4 and 5). For other publications carried out during the PhD research period, see Appendix B. The introduction chapter was based on a literature review and lessons gained from the New Zealand SAFA pilot-studies, which were a component of this PhD research (Manhire et al., 2013).

Chapter 3 (*Generic sustainability assessment themes and the role of context: the case of Danish maize for German biogas*) presents a scientific article (Gasso et al., 2014a) that analyses the effectiveness of generic themes for covering the key sustainability issues associated with a specific case study – the value chains of Danish maize for German biogas. Subsequently, this article presents a rationale for setting an optimised level of specificity for assessment themes.

Chapter 4 (*Data specificity in sustainability assessment: the case of Controlled Traffic Farming Life Cycle Assessment*) presents a scientific article (Gasso et al., 2014b) involving a Life Cycle Assessment of the use of Controlled Traffic Farming technologies for arable farming, focusing on wheat production in Denmark. Subsequently, this chapter analyses data inventory characteristics and limitations and presents a rationale for setting an optimised level of specificity for assessment data.

Chapter 5 (*Benchmarking for locally-tuned sustainability: the case of energy and water use in New Zealand vineyards*) introduces a benchmarking rationale for accommodating context-specific opportunities and constraints for incentivising locally-tuned sustainability improvements, with focus on energy and water use in New Zealand vineyards.

Chapter 3

GENERIC SUSTAINABILITY ASSESSMENT THEMES AND THE ROLE OF CONTEXT: *The case of Danish maize for German biogas*

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Abstract

The choice of context-generic or -specific themes and subthemes (goals and objectives) for sustainability assessment implies a number of tradeoffs; for instance, benchmarking and resource efficiency vs. coverage and engagement. Analyses of the potentials and limitations of generic assessment themes and sub-themes within specific contexts may help to develop frameworks that minimise the tradeoffs between generic and specific assessment approaches. The aim of this study was to analyse the effectiveness of generic themes and sub-themes of existing frameworks for covering the key sustainability issues of a specific case study – the case of Danish maize for German biogas. The results indicate that generic frameworks can effectively cover context-specific issues related to the environmental dimension of sustainability. Conversely, generic frameworks can be unable to identify context-specific issues related to the social and economic dimensions. This study suggests that the coverage gap of generic themes is mainly an issue of framework incompleteness that can be advanced with additional research. A one-size-fits-all specificity-level for sustainability assessment is not applicable, and the specificity-level should be tailored to the assessment purpose. A certain degree of stakeholder participation is recommended not only in the assessment process, but also during the framework design to support stakeholders' sustainability education and action.

3.1 Introduction

3.1.1 Globalisation and pluralism in sustainability assessment

Following the Brundtland Report (WCED, 1987), a diverse range of methods and tools have been developed for assessing and promoting sustainability (Pope et al., 2004; Pintér et al., 2012). Globalisation and the need to govern international externalities and global public goods (e.g. climate, biodiversity, financial stability, food safety) can be seen as a key driver in the development of various generic assessment frameworks. These frameworks seek standardisation, accreditation, performance benchmarking among enterprises, regions or nations, and applicability to a diversity of user groups and contexts (Mineur, 2007; Ness et al., 2007; van Zeijl-Rozema et al., 2011). For example, the CSD Indicators from the United Nations' Commission on Sustainable Development aim to monitor and benchmark sustainable development at the national level for different countries (UN, 2007).

Despite the need for global and generic assessment frameworks, the sustainability discourse implies a plurality of world views, knowledge and values across individuals and institutions, which depend on the context in which the process is embedded (Lélé et al., 1996). Sustainability assessments raise questions (either explicitly or implicitly) such as: What is to be sustained, in what form, at what scale and within which system boundaries? Over which period of time, and with what certainty level? Through which social process(es), involving whom, and with which tradeoffs against other objectives? (Lélé et al., 1996; Briassoulis, 1999). Some of these questions do not have a single answer. Therefore, sustainability assessment practice involves not only an empirical but also a normative perspective for defining processes and goals for sustainable development (Alrøe and Kristensen, 2002).

In contrast to generalising trends, this pluralism in conditions and world views has contributed to the development of a number of context-specific assessment frameworks (e.g. Reed et al., 2006; Binder et al., 2010; van Zeijl-Rozema and Martens, 2010). The design of these frameworks and their components (e.g. themes, indicators, and reference values) focuses on the specific context in which the sustainability assessment is embedded. Important context characteristics in sustainability assessment include: (i) issues and stakeholders affecting or affected by the assessed operation and the assessment process, (ii) capacities, priorities and values of the stakeholders, (iii) rules and procedures that govern the process, (iv) culture and history of the involved organisations and stakeholders, and (v) timing and resources of the assessment process (adapted from Pastille Consortium (2002)).

3.1.2 The dilemma between generic and specific approaches

Context-generic assessment approaches have been criticised for not allowing the inclusion of specific characteristics or discourses that are inherent to local contexts (Morse and Fraser, 2005; Lee, 2006). Context-generic approaches have also been criticised for relying on value judgments of external-experts in defining the concept of sustainability, and selecting an arbitrary array of objectives and a method of aggregating them (Lélé et al., 1996). Consequently, the use of these approaches has been associated with gaps in monitoring critical sustainability issues and the impairment of trust and adoption of improvement measures by the stakeholders (Parkins et al., 2001; van Zeijl-Rozema et al., 2011).

Context-specific assessment approaches have been criticised for reducing the possibilities of standardisation and benchmarking of sustainability performances among different systems (Binder et al., 2010; Mascarenhas et al., 2010). Context-specific frameworks have also been criticised for isolating the monitoring results from more global sustainability issues and higher level sustainability processes (e.g. governmental regulations) (Mascarenhas et al., 2010). Moreover, context-specific frameworks can be more time- and resource-demanding due to the need for context analysis, and the design of specific sustainability goals and assessment framework components (Binder et al., 2010).

3.1.3 Themes in sustainability assessment

Indicator-based sustainability assessments are generally structured according to several hierarchical or aggregation levels. In the present study, the most general level comprises sustainability *dimension.* These are general discipline-independent fields, which can be differentiated into environmental, social, economic, and governance. At the intermediate level, each dimension comprises a number of *themes* and *sub-theme*s. These are defined as the relatively independent elements associated implicitly or explicitly with specific sustainability goals and objectives (FAO, 2013a). When themes are divided into sub-themes, general goals are connected to the themes and specific objectives to the sub-themes. Each theme or sub-theme is linked to one or a number of indicators. *Indicators* are the most specific level. These are measureable and verifiable variables or factors that are independent of the aggregation method and allow performance communication (Lenz et al., 2000; FAO, 2013a).

Generic assessment approaches make use of generic themes and sub-themes, which require a universal definition of sustainability goals and objectives. Context-relevant sustainability issues may not be captured if themes and sub-themes are very context-sensitive. Although some studies have to some extent explored the context-sensitivity of sustainability indicators (Mineur, 2007; Efroymson et al., 2013; Guerci et al., 2013), there is a research gap on the context-sensitivity of themes and sub-themes. The context-sensitivity of themes and sub-themes is relatively independent to the indicators one, because indicators selection may involve additional context-dependent factors such as assessment resources, data accessibility and availability, and expertise of the users of the indicators (Reed et al., 2006; Binder et al., 2010).

Analyses of the potentials and limitations, in terms of practicality and usefulness, of generic assessment themes and sub-themes within specific contexts may help to develop frameworks that minimise the tradeoffs between generic and specific assessment approaches. The aim of this study was to analyse the effectiveness of generic themes and sub-themes for covering the key sustainability issues of a specific case study. The selected case study consists of the value chains of Danish maize for German biogas.

3.2 Methods

3.2.1 Case study background

In 2000, the German Renewable Energy Act (Erneuerbare-Energien-Gesetz) came into practice to promote the production of renewable energy. This policy has driven Germany to become one of the largest biogas producers in the world (Gömann et al., 2009). Biogas, compared to other bioenergy technologies, has the advantage of having a relatively high energy and resource-use efficiency. The process can convert a wide range of biomass sources, including organic wastes, into fuel (Börjesson and Mattiasson, 2008; Samson et al., 2008; Herrmann, 2013). The main feedstock of the German biogas industry is based on the co-digestion of animal manure and energy-crops (Herrmann, 2013). Whole-crop maize silage has become the dominant German biogas crop (Gömann et al., 2009) due to its high biomass yield, relatively undemanding agronomical conditions, easiness of storage, and high methane production rate (Thyø et al., 2007; Heydemann, 2011).

The German region of Schleswig-Holstein shares a border with Denmark, and has some of the densest distribution of biogas plants in Germany (Heydemann, 2011). The region’s dramatic increase in energy-crops demand and importing opportunities have created a new transnational agricultural market. The Danish region sharing border with Germany (Southern Jutland or Sydjylland), has become an intensive maize supplier for the German biogas industry (Landbrugsavisen, 2011). The Danish area cultivated with maize for German biogas has expanded significantly since 2007 and it is now estimated to be 18.000 ha, distributed up to 100 km north of the German border (Dagbladet Information, 2012).

It is assumed that the expansion of biogas production has a number of environmental, social and economic benefits, such as reducing use of fossil fuels, securing energy supply, and enhancing rural development (FAO, 2007; Heydemann, 2011). However, the cultivation of maize for the German biogas industry is also a source of increasing concern about potential negative impacts to society and the environment (Heydemann, 2011; Dagbladet Information, 2012; Landbrugsavisen, 2012).

This case study was selected due to its distinctive context characteristics: (i) transnational value chain boundaries; (ii) diverse cultural and expertise backgrounds of the involved stakeholders; and (iii) multi-scale and multi-dimensional sustainability tradeoffs (Heydemann, 2011; Dagbladet Information, 2012; Landbrugsavisen, 2012).

3.2.2 Case study analysis

To identify the key sustainability issues from the selected case study, a qualitative in-depth analysis was used based on individual semi-structured interviews with stakeholders.

Purposive sampling was used. In this approach participants are selected because they are likely to possess relevant knowledge for the study. The first stakeholders interviewed were agricultural consultants working within the biogas-maize production region of Sydjylland district, Denmark. The consultants' expertise and network covered a range of agricultural areas. The remaining stakeholders were selected using the snow-ball sampling method in which initial participants identify other potential participants who have direct knowledge relevant to the case study (Bryman, 2001). Ten stakeholders were interviewed, including agricultural consultants, crop farmers, livestock farmers, a biogas producer, researchers, and a non-governmental organisation representative (Table 2). The number of interviews was not extended beyond ten because new sustainability issues and new relevant stakeholder-types (relevant in terms of involvement level and informative capacity) did not appear during the last two interviews.

The individual semi-structured interviews were conducted during summer 2012 in Denmark and Germany at a time and venue chosen by the participants. The individual interviews had a duration ranging from 50 to 90 minutes and were audio-recorded. The interviews were generally structured from more general to more specific questions, to allow the emergence of less biased new issues. First, participants were asked to describe their occupation and their personal and their community relationships and experiences with the Danish maize for German biogas industry. Subsequently, they were asked about their perceptions of environmental, social, and economic sustainability issues (one dimension at a time). These dimensions are generally recognised as the major dimensions of sustainability and are concepts generally understood by the public. Finally, the stakeholders were asked non-structured and more specific questions in relation to particular issues either mentioned by them, previous participants, or the media.

The interviews were transcribed verbatim and were coded by the use of Nvivo9 qualitative data analysis software (Nvivo9, QSR International). The coding enabled the data to be organised into common categories associated with sustainability issues.

The emerging issues and participants' perceptions were systematically organised and reported according to sustainability issues and dimensions. The emerging issues had a significant normative component. For example, there were a variety of responses amongst participants in valuing the importance of different case study issues. Therefore, some issues were reported using quotations to retain their qualitative character.

Table 2. Details of interviewed stakeholders

Main occupation	Responsibilities	Working region
Crop consultant	Advise crop producers, landowners, and public bodies	Sydjylland district, Denmark
Livestock consultant	Advise livestock farmers.	Sydjylland district, Denmark
Environmental consultant	Perform environmental assessments and advise farmers regarding environmental regulations.	Sydjylland district, Denmark
Biogas consultant/ researcher	Advise biogas producers in terms of investment and management, and part time academic research on biogas technologies.	Jutland region, Denmark
Energy-crop producer[a]	Manage energy-crop farms for German biogas.	Sydjylland district, Denmark
Environmental researcher	Research on agro-ecology and energy-crop production (academic and extension), and support to policy-makers.	Denmark
Biogas producer[bc]	Manage a biogas production plant in Germany	Schleswig-Flensburg district, Germany
Self-sufficient livestock farmer[de]	Manage a conventional livestock farm (dairy and pigs)	Sydjylland district, Denmark
Non self-sufficient livestock farmer[fg]	Manage a conventional livestock farm (dairy)	Sydjylland district, Denmark
Wildlife conservation member	Direct scientifically-based projects involving the interaction between agriculture and bird life in a wildlife conservation non-governmental organization	Denmark

[a] *Production size: 1300 ha (owned and rented) and 700 ha (buying and harvesting the crop) with whole-crop maize (80%), grass, and sugar-beet for the German biogas industry.*
[b] *Production size: 2 million m3, 700 kW el.*
[c] *Biogas feedstock supply: 160 ha in Germany and about 100 ha in Denmark cultivated with whole-crop maize and grass (owned), and manure from 800 pigs (up to 200 kg) and 2500 pigs (up to 20 kg) (owned).*
[d] *Production size: 400 conventional dairy cows, and 9 thousand conventional pigs.*
[e] *Livestock feed supply: 750 ha (owned); grain-feed self-sufficient. Additional activities: surplus land normally used to produce whole-crop maize for the German biogas industry.*
[f] *Production size: 350 organic dairy cows and 220 organic calves.*
[g] *Livestock feed supply: 150 ha (owned) and 120 ha (Rented) cultivated with whole-crop maize and grass, and 70 ha (owned) of permanent grass; non grain-feed self-sufficient.*

3.2.3 Coverage analysis of assessment frameworks

Existing generic sustainability assessment frameworks were selected to analyse the effectiveness of their themes and sub-themes in terms of covering the case study sustainability issues.

From an extensive (but not exhaustive) review of scientific and grey literature and expert consultation, 27 generic assessment frameworks were identified (OECD, 2003; methods reviewed in Althaus et al., 2007; UN, 2007; GSCP, 2010; UNEP/SETAC, 2010; GRI, 2011; RSB, 2011; BFH, 2012; CFI, 2012; Elferink et al., 2012; Sedex/Verité, 2012; COSA, 2013; FAO, 2013a).

From these frameworks, only the ones having explicitly reported goals or objectives (instead of only key-words) for each theme or sub-theme were selected to facilitate a more practical and objective analysis of the coverage of themes and sub-themes. From the frameworks that were initially identified, three met the selection criterion (Table 3): (i) Roundtable on Sustainable Biofuels Impact Assessment (RSB, 2011), (ii) Sustainability Assessment of Food and Agriculture Systems (SAFA) (FAO, 2013a), and (iii) Social Life Cycle Assessment (SLCA) (UNEP/SETAC, 2010) (SLCA only at the sub-themes level).

The framework analysis was performed by assessing the extent (complete, partial, or nil) in which each sustainability issue associated with the case study was covered by the goals and objectives of the respective themes and sub-themes.

Table 3. Selected assessment frameworks description

	RSB	SAFA	SLCA
Name and reference	Roundtable on Sustainable Biofuels Impact Assessment (RSB, 2011)	Sustainability Assessment of Food and Agriculture Systems (FAO, 2013a)	Social Life Cycle Assessment (UNEP/SETAC, 2010)
Developer	Roundtable on Sustainable Biomaterials	United Nations' Food and Agriculture Organisation (FAO)	United Nations Environmental Program agency (UNEP) and Society of Environmental Toxicology and Chemistry (SETAC)
Sector scope	Bioenergy and bio-based products industry (biomass and biogas for heat and electricity generation and liquid biofuels)	Food and Agriculture industry (cropping, livestock husbandry, forestry, fisheries and aquaculture)	Generic
Geographical scope	Generic	Generic	Generic
Object of assessment	Organisation	Organisation or site	Product or service
Level of assessment	Production and processing of biofuel feedstock and raw material, and production, transport and use of liquid biofuels	Entire supply chain or single supply chain component	Entire life cycle (from raw materials extraction to disposal)
Dimensions covered	Environmental, social, economic and governance	Environmental, social, economic and governance	Social, economic and governance[a]
Sustainability perspective[b]	Societal	Societal and organisational	Societal
Results audience	Market regulatory bodies, and supply chain stakeholders	Supply chain stakeholders; policy makers; non-governmental organisations; and sustainability standards and tools community	Supply chain stakeholders; product designers; consumers; policy makers; non-governmental organisations; and trade unions and workers representatives
Purpose	Certification and management	Self-assessment and management; managing or benchmarking suppliers; planning and legislation development; monitoring projects outcomes; and gap analysis with existing sustainability schemes	Self-assessment and management; product development; managing or benchmarking suppliers; reporting and labelling; planning and legislation development; and monitoring projects outcomes

[a] *SLCA is complemented by the Environmental Life Cycle Assessment, which addresses the respective environmental dimension (Kloepffer, 2008).*

[b] *organisational or societal, depending on whether the subject to be sustained is the organisation or the society, respectively.*

3.3 Results

3.3.1 Case study sustainability issues

Twenty-two sustainability issues classified according to the environmental, social, economic and governance dimensions were identified by the participants in the case study of Danish maize for German biogas (Table 4). The governance dimension of sustainability was not part of the interview structure; however, it was extensively discussed by one of the

Table 4. Sustainability issues of the case of Danish maize for German biogas

Environmental	Social	Economic	Governance
Greenhouse gas emissions Soil carbon balance Nitrate leaching Pesticide use Native wildlife diversity	Landscape aesthetics Food security Fairness in trading Rural traffic intensity Rural odour Nature cultural and metaphysical services	Marketing resilience Supply resilience Investment capacity Indirect stakeholders economic vulnerability Production process resilience Regional employment opportunities Inter-regional materials procurement Inter-regional costs shifts	Pre-decision making assessment quality Public communication Public participation

participants. Indirect stakeholders refer to those outside the organisations involved in the biogas-maize supply chain. In the following sections, identified issues are presented within the specific case study context and described in terms of trend, tradeoffs, extent and importance according to the different stakeholders.

Greenhouse gas balance

It is widely accepted that the production of renewable energies such as biogas presents an opportunity for reducing atmospheric greenhouse gas (GHG) emissions. Nevertheless, the environmental researcher described the production of maize-based biogas as “absurdly stupid”, because the reduction of GHGs can be non-significant when taking into account the entire life cycle. This fact was also acknowledged by the biogas consultant/researcher. The environmental researcher further explained this issue:

> If you use manure, you will have very large reductions of GHGs because you reduce the methane emissions coming from the manure storage. However, when you use maize or grass, you will have no base emissions reduced. In addition, you have losses of methane. Some is lost through the combustion engine, some from the degassed slurry, and maybe some during the distribution and use if it is feed into the gas grid. So, you may end up having no reduction of GHG gases.

One factor that may also have contributed to an increase in GHG emissions was the increase in transport distances compared to previous practices (self-sufficient livestock farmer; energy-crop producer).

The environmental researcher stated that when taking into account the additional carbon emissions from indirect land-use-changes in other parts of the world, maize-based biogas may lead to an overall increase in the GHG gases. The production of energy crops induce indirect-land use changes including increased deforestation to meet the global food demand. Nevertheless, the biogas producer emphasised that the use of energy crops is necessary because the use of manure alone does not produce a sufficient amount of biogas.

Soil carbon balance, nitrate leaching and pesticide use

It was mentioned that the production of maize tends to deplete soil carbon (environmental consultant; environmental researcher), and can be an important vector of nitrate leaching to ground waters (environmental and crop consultants). Nevertheless, the environmental researcher insisted that these soil carbon and nitrate leaching effects are not important in relation to the impacts of previous land uses involving other annual crops such as barley or wheat in the Danish conditions. This highlighted that "the issue is not that it is getting worse, the issue is that we are not improving" and there is a need to fulfil environmental regulations and targets, such as the EU water framework directive. According to the environmental researcher, the production of maize tends to decrease the amount of pesticide use compared to the average level of the Danish agriculture. In contrast, the environmental consultant warned that the common approach of non-rotation in maize production – "maize after maize" – can induce higher pesticide use than would otherwise occur.

Native wildlife diversity

The wildlife conservation member explained that the cultivation of maize is an important threat to local biodiversity, specifically to farmland birds:

> When farmland birds like the lapwing, the skylark, the corn bunting, or the partridge are coming for breeding in March/April and they look around, they see a lot of fields with grown-up vegetation, because now we have mainly winter crops and no so much spring crops left. So they think: "we should not use those fields because we cannot see predators approaching; but we could use those other fields with bare soil or very small plants [the maize fields]". So they go to the maize fields and start breeding, and suddenly, within few weeks, very tall plants have grown due to the C4-photosynthesis type of maize. So they leave their nests and that generation is lost because it became too late within the season for getting another clutch anywhere else.

The wildlife conservation member stated that typical farmland bird populations are dramatically declining in recent years, both in southern Denmark and especially in Germany, partly due to the increased production of maize.

Some participants mentioned that maize fields can be a good shelter for deer (self-sufficient livestock farmer), as well as providing feeding opportunities for bird species such as geese, crane and pheasant (wildlife conservation member). The wildlife conservation member emphasised that it was important to differentiate between the impacts on native and non-native birds. For instance, the introduced pheasant was seen as a competitor placing pressure on the native partridge (wildlife conservation member).

Given the potential effects of maize production on native farmland birds, the wildlife conservation member commented on the importance of native bird populations for ecosystem resilience, noting that "all types of activities which threaten these birds are not acceptable".

Landscape aesthetics

The effects of maize crop production on landscape aesthetics was a common issue that was raised spontaneously during interviews (crop and environmental consultants; environmental researcher; non self-sufficient livestock farmer). The crop consultant explained that visibility in the countryside is reduced between August and September due to the considerably tall maize plants and the relatively flat landscape-profile of the region. Some participants used the expression "maize deserts", which has become a cliché in the public opinion and the media, referring to the large extent and lack of diversity associated with the production of maize (crop consultant; environmental researcher). The environmental consultant was more explicit about her negative opinion and mentioned that these types of landscape can "change one's mood".

The energy-crop producer – a large scale maize producer – was taking measures to avoid public complaints on landscape aesthetics:

> I have not received any complaints, but I try to prevent them. We are sowing sunflowers at the edges of the maize fields because I want people, when for example have a bicycle trip, to enjoy them, maybe collect them, and go back home happy.

Other participants expressed a neutral opinion on the issue of landscape aesthetics change (energy-crop producer; self-sufficient livestock farmer; environmental researcher). The environmental researcher observed the need to make some tradeoffs between issues. He considered landscape aesthetics as a "kind of luxurious issue", and added that "If we want to save the world, it will have some costs". All the participants producing maize for biogas held neutral opinions on landscape consequences. The crop consultant observed that it was especially people who are not farmers who do not like large extensions of maize. The distinction between farmers and non-farmers may be a reflection of different interests in terms of the services provided by the agricultural landscape, for instance aesthetics or production services.

Food security

Food security was another issue spontaneously arising during a number of interviews (environmental consultant; non self-sufficient livestock farmer; wildlife conservation member). The environmental consultant highlighted issues of global food limitations and the need to find non food-competing alternatives for producing energy. The non self-sufficient livestock farmer mentioned that "it would be better to use wastes; we don't need to make bioenergy from things that cows or people can eat; nobody eats shit!" The environmental consultant explained that some communities within the region, especially in urban areas, do not support the use of land for bioenergy. However, the participants producing energy-crops did not mention the issue of food security. The exception was the biogas producer who expressed a neutral opinion on the use of food for bioenergy, explaining that globally "there is land enough, more than enough" for producing both food and energy-crops.

Fairness in trading

According to the self-sufficient livestock farmer, trust and fairness in trading practices can be impaired due to the non-local business relationships that this trade implies. Furthermore, the biogas producer disclosed that frauds have taken place on both the supply and the demand side (committed by both Danish and German producers).

Rural traffic intensity and rural odour

An increase in the traffic intensity of heavy machinery in the countryside due to the biogas-maize trade has raised some complaints in the respective local communities (self-sufficient livestock farmer; biogas producer). The self-sufficient livestock farmer mentioned that some local communities "are sick and tired" of the tractors transporting maize.

According to the biogas consultant/researcher, the issue of odour improves with the production of biogas, because the biogas digestate (digested manure and energy-crops) is less odorous than the non-digested manure, and farms neighbours "do not complain that much".

Nature cultural and metaphysical services

Seeing the potential effects of the production of maize on native farmland birds, the wildlife conservation member stressed the importance of protecting bird populations, in terms of cultural and metaphysical services:

> Many times we have discussed the value of the song of the skylark. To Danes, at least to Danes of my age [about 50 years], the song of the skylark and the cry of the lapwing belong to the farmland. These are still in our heart, so it means a lot to have those birds. This is a gift which we are rather proud of and very interested in keeping.

Marketing resilience

The marketing resilience of the crop producers is strengthened by the trade of maize for biogas, because it increases demand and marketing possibilities (crop consultant; self-sufficient livestock farmer). The marketing preferences of the crop producers depend on the competition between global agricultural commodities prices and German bioenergy subsidies (crop and livestock consultants; energy-crop producer; self-sufficient livestock farmer; biogas producer). On the other hand, the marketing resilience of crop producers could be negatively affected by lower trust and the potential for fraud associated with non-local business relationships (self-sufficient livestock farmer; biogas producer).

The marketing resilience of biogas producers is relatively strong, due to the existence of long term contracts with the German government. The biogas producer explained that half of the price is set 20 years ahead, and the rest is set every 5 years taking into account current agricultural commodity prices.

Supply resilience

According to the biogas producer, the supply resilience of the biogas producers is relatively weak because they are vulnerable to the biomass availability and biomass price fluctuations. The biogas producer explained that “it is very hard to find whole-crop maize because there are too many biogas plants and the price of maize-grain for livestock is going up so farmers want to grow maize-grain instead”. Some biogas producers have become bankrupt due to the biomass supply difficulties (energy-crop producer, biogas producer; livestock consultant), while others with more biomass self-sufficiency have “a great business”, declared the energy-crop producer.

Investment capacity

Land prices in Denmark have decreased since around 2008-2009 (self-sufficient livestock farmer). However, most stakeholders mentioned that the trade of maize for German biogas has buffered the land price decline and increased the rent price in the southern regions of Denmark (crop and livestock consultants; self-sufficient and non self-sufficient livestock farmers; biogas producer). In Germany, the land price has been significantly rising partly due to the energy-crop demand (biogas producer). The land price in Germany has overtaken the land price in Denmark, leading to the purchase of Danish land by the German biogas industry, as in the case of the interviewed biogas producer.

Higher land prices can strengthen the economic resilience and increase access to bank loans for farmers and producers who own land, which in turn enhances their investment capacity (self-sufficient livestock farmer; crop and livestock consultants; energy-crop producer). The self-sufficient livestock farmer explained that bank loans are more accessibility in the southern regions of Denmark, compared to the rest of the country, due to buffered land-prices.

Conversely, the effects of the maize trade on land and rent prices can impair the economic resilience of biomass farmers who own less land and biogas producers with feedstock deficit, by limiting their land purchasing and renting capacity as well as their access to bank loans (biogas producer; self-sufficient livestock farmer; non self-sufficient livestock farmer). The non self-sufficient livestock farmer reflectively asked "why should always those who have land make the best business?".

Indirect stakeholders economic vulnerability

The feed supply possibilities of cattle farmers with non grain-feed ("roughage") self-sufficiency can be reduced in part due to an intensification of competition for renting land (non self-sufficient livestock farmer; energy-crop producer). The non self-sufficient livestock farmer described the intensity of this competition: "We were five persons participating in an auction for renting some land, including one German biogas guy; and at the end, the land end up being rented by almost double of the price that I wanted to offer".

Pig farmers are less vulnerable than cattle farmers to the feed and land competition, as they have more feed supply possibilities. For example, they can buy the feed from other regions or countries (self-sufficient and non self-sufficient livestock farmers). This feed supply flexibility provides an incentive to pig farmers with land to rent it to the biogas industry instead of cultivating it for their own feed supply, hence reducing production risks (non self-sufficient livestock farmer).

Production process resilience

The production process resilience of the whole-crop maize was seen by the crop consultant as relatively strong because it requires little farmer knowledge and expertise. On the other hand, it was seen by the energy-crop producer as relatively weak because the usability of the machinery for harvesting whole-crop maize depends more on soil moisture levels, in comparison with the machinery for harvesting only grain.

The production process resilience of maize-based biogas was seen by the biogas producer and consultant/researcher as relatively strong because it results in less technical problems compared with other biomasses.

Regional employment opportunities

The creation of additional employment opportunities in Denmark related to the production of maize for biogas is not significant, according to several of the interviewed stakeholders (crop and environmental consultants; self-sufficient and non self-sufficient livestock farmers; energy-crop producer). Part of the employment related to the production of maize is managed by German companies (self-sufficient and non self-sufficient livestock farmers), which do not create value through employment within the Danish region economy. Few additional employment opportunities may arise for transporting biomass to Germany (energy-crop producer). In contrast, the German biogas industry was seen by some of the interviewed consultants as a significant opportunity for employment creation and rural development within Germany (environmental and livestock consultants).

According to several participants, the trade of maize for biogas allows cattle farmers that are more vulnerable to commodity price fluctuations to shift to only biomass production (livestock consultant; biogas producer; energy-crop producer; self-sufficient and non self-sufficient livestock farmers). This in turn helps to keep part of the human capital in the rural and agricultural areas.

Inter-regional materials procurement and costs shifts

The Danish maize for German biogas supply chain involves international imports and exports of raw materials (e.g. exported maize and imported livestock feed), which could otherwise be traded within the region, enhancing regional value creation through tax payment, employment and investment (crop consultant; energy-crop producer; biogas producer). The energy-crop producer observed that "it is a little bit stupid that we make so much maize for Germany, instead of using it for cows or biogas in Denmark". Moreover, international supply chains cause shifts of environmental and other economic costs within countries. For instance, the environmental costs of cultivating maize and the environmental benefits of having biogas, or the economic costs of providing biogas subsidies which will be partially invested in other countries (environmental consultant).

Pre-decision making assessment and public communication and participation

The main governance issue that arose was the potential lack of more holistic analyses before deciding on respective policies (environmental researcher). Specifically, analysis of the societal costs of abating carbon emissions with maize-based biogas, rather than analysis of only farmers- and industry-related costs (environmental researcher).

The environmental researcher highlighted the importance of having public opinion favour biogas development and hence the need for better communication of the reasons and arguments behind the use of maize until alternatives are developed. He also highlights the importance of involving the general public in the decision process:

> If we can involve more the public in the decision, they will feel that it is also their project, a common project to save the globe, and not only for farmers looking for money. Then, I think, people can be more acceptant about, for instance, that you cannot see a pretty landscape in August.

3.3.2 Coverage analysis of assessment frameworks

The effectiveness of themes and sub-themes of sustainability assessment frameworks in covering the sustainability issues of the case study differed depending on the sustainability dimension and the respective frameworks (Tables 5 and 6).

The key environmental issues of the case study (i.e. GHG emissions, soil carbon balance, nitrate leaching, pesticide use, and native wildlife diversity) were completely covered by the themes and sub-themes of the analysed frameworks (Table 5). RSB themes and sub-themes emphasised more explicitly the assessment of GHG emissions within the entire life cycle and with the inclusion of land-use-change effects.

In contrast, the social issues of the case study were less effectively covered by the themes and sub-themes of the analysed frameworks (Table 5). Food security was explicitly covered only using the RSB themes and sub-themes, while SAFA and SLCA only covered it indirectly through broader themes and sub-themes, such as decent livelihood and public health. Fairness in trading was covered by a broad SLCA sub-theme, while the other frameworks' sub-themes only partially covered this by addressing human and labour rights aspects, or responsible demand aspects ignoring the supply side. Rural odour coverage effectiveness was high for the air pollution related RSB and SAFA themes and sub-themes. However, the odour-related SAFA theme goal was more focused on human health rather than a more cognitive wellbeing. The rest of the social issues (i.e. landscape aesthetics, rural traffic intensity and nature cultural and metaphysical services) were not covered by any of the frameworks themes and sub-themes, with the exception of nature cultural and

Table 5. Analysis of the case study issues coverage by the frameworks themes and sub-themes (environmental and social dimensions).

Dimen-sion	Case Study Issue	***RSB*** Theme	Sub-theme[a]	***SAFA*** Theme	Sub-theme	***SLCA*** Sub-theme
Environ-mental	*GHG emissions*	Greenhouse gas emissions (P3)	Lifecycle GHG emissions (C3.b) & Emissions reduction significance (C3.c)	Atmosphere (E1)	Greenhouse gases (E1.1)	n.a.
	Soil carbon balance	Soil (P8) & Greenhouse gas emissions (P3)	Soil quality (C8.a) & Lifecycle GHG emissions (C3.b)	Land (E3) & Atmosphere (E1)	Soil quality (E3.1) & Greenhouse gases (E1.1)	n.a.
	Nitrate leaching	Water (P9)	Water quality (C9.d)	Water (E2)	Water quality (E2.2)	n.a.
	Pesticide use	Soil (P8), Water (P9) & Conservation (P7)	Soil quality (C8.a), Water quality (C9.d) & Ecosystem maintenance (C7.b)	Land (E3), Water (E2) & Biodiversity (E4)	Soil quality (E3.1), Water quality (E2.2) & Ecosystem diversity (E4.1)	n.a.
	Native wildlife diversity	Conservation (P7)	Ecosystem maintenance (C7.b)	Biodiversity (E4)	Ecosystem diversity (E4.1) & Species diversity (E4.2)	n.a.
Social	*Landscape aesthetics*	**	**	**	**	**
	Food security	Food security (P6)	Food security management (C6.a)	Decent livelihood (S1)	*Public health (S5.2)	*Safe and healthy living conditions
	Fairness in trading	*Human and labour rights (P4)	*Law and agreement compliance (C4.e)	Fair trading practices (S2)	*Responsible buyers (S2.1)	Corruption
	Rural traffic intensity	**	**	**	**	**
	Rural odour	Air (P10)	Air pollution management (C10.a)	*Atmosphere (E1)	Air quality (E1.2)	**
	Nature cultural and metaphysical services	**	**	**	**	*Cultural heritage

Frameworks references: SAFA (FAO, 2013a), RSB (2011) and SLCA (UNEP/SETAC, 2010). See the respective reference documents (open access) for a complete description of the goal/objective associated to each theme/sub-theme (not included due to spatial constrains).
Codes between brackets: reference to each theme/sub-theme within the respective literature.
[a] *The respective sub-theme names are not explicitly reported in the reference document, but are implicit within the sub-theme objective.*
n.a.: Not applicable sub-theme because the respective dimension is not targeted by the framework.
***: No coverage by any theme/sub-theme of the framework.*
**: Partial coverage*

Table 6. Analysis of the case study issues coverage by the frameworks themes and sub-themes (economic and governance dimensions).

		RSB		*SAFA*		*SLCA*
Dimen-sion	**Case Study Issue**	**Theme**	**Sub-theme**[a]	**Theme**	**Sub-theme**	**Sub-theme**
Econo-mic	*Marketing resilience*	**	**	Vulnerability (C2)	Stability of market (C2.3)	**
	Supply resilience	**	**	Vulnerability (C2)	Stability of supply (C2.2)	**
	Investment capacity	**	**	Vulnerability (C2)	Liquidity (C2.4)	**
	Indirect stakeholders economic vulnerability	*Rural and social development (P5)	**	Local economy (C4)	**	**
	Production process resilience	**	**	Vulnerability (C2)	Stability of production (C2.1)	**
	Regional employment opportunities	*Rural and social development (P5)	*Local socio-economy (C5.a)	Local economy (C4)	Value creation (C4.1)	Local employment
	Inter-regional materials procurement	*Rural and social development (P5)	*Local socio- economy (C5.a)	Local economy (C4)	Local procurement (C4.2)	Local employment
	Inter-regional costs shifts	*Rural and social development (P5)	**	Local economy (C4)	**	**
Gover-nance	*Pre-decision making assessment quality*	*Planning, monitoring and continuous improvement (P2)	*Impact assessment (C2.a)	*Corporate ethics (G1) & Holistic management (G5)	*Due diligence (G1.2)	**
	Public communication	*Planning, monitoring and continuous improvement (P2)	*Consent (C2.b)	*Accountability (G2)	*Transparency (G2.3) & *Stakeholder dialog (G3.1)	*Access to immaterial resources
	Public participation	*Planning, monitoring and continuous improvement (P2)	*Consent (C2.b)	*Participation (G3)	*Stakeholder dialog (G3.1)	*Community engagement

Frameworks references: SAFA (FAO, 2013a), RSB (2011) and SLCA (UNEP/SETAC, 2010). See the respective reference documents (open access) for a complete description of the goal/objective associated to each theme/sub-theme (not included due to spatial constrains).
Codes between brackets: reference to each theme/sub-theme within the respective literature.
[a] *The respective sub-theme names are not explicitly reported in the reference document, but are implicit within the sub-theme objective.*
***: No coverage by any theme/sub-theme of the framework.*
**: Partial coverage*

metaphysical services that were partially covered by the SLCA cultural heritage sub-theme.

The economic issues were covered differently depending on the framework (Table 6). The SAFA themes covered all economic issues. Issues such as marketing, supply and production process resilience, as well as investment capacity issues were only covered by the SAFA themes and subthemes. The regional economic issues directly associated with the supply chain stakeholders, such as employees and suppliers (i.e. regional employment *opportunities* and *inter-regional materials procurement*), were completely covered by all analysed frameworks' themes and sub-themes, except for RSB, which only provided partial coverage due to its focus on regions of poverty. The regional economic issues indirectly associated with the supply chain (i.e. *indirect stakeholders economic vulnerability* and *inter-regional costs shifts*) were less effectively covered. These issues were covered by broad themes referring to the socioeconomic development and value creation for local communities. These issues were less effectively covered by the frameworks sub-themes.

Governance issues (i.e. *pre-decision making assessment quality*, *public communication* and *public participation*) were partially covered by the themes and sub-themes of the analysed frameworks (Table 6). However, an assessment level mismatch occurred because the governance themes and sub-themes of all analysed frameworks focus on the internal supply chain or life cycle level governance, while the selected case study governance issues focused on a more general sector and national policy-making level of governance. The SLCA sub-themes did not explicitly cover the *pre-decision making assessment quality* issue.

3.4 Discussion

3.4.1 Coverage effectiveness

The results of this study show that environmental context-specific issues may be effectively covered by generic themes and sub-themes and the economic context-specific issues by generic themes, as is the case with SAFA. This distinction is supported by the findings of other studies that have found environmental and economic issues are the dominant ones in the perception of sustainability and in the practice of sustainability assessment in fields such as agriculture (von Wirén-Lehr, 2001; Carof et al., 2013).

Wider coverage of the economic dimension in the SAFA framework probably occurs due to the different interpretation of the concept of sustainability (e.g. organisational or societal). While RSB and the SLCA have a more societal perspective, SAFA has both organisational and societal perspectives (Table 3). From an organisational perspective, the subject to be sustained is the organisation and the focus is, for example, the organisation resilience for using its natural, social and economic resources without depletion while coping with potential shocks. From a societal perspective the subject to be sustained is the society (Schader et al., 2012). These different perspectives could be a reflection of the different frameworks' purposes. For example, SAFA has a strong focus on self- and suppliers' management and planning, whereas RSB mainly aims to provide certification for regulations compliance (Table 3). Organisational perspective themes may better resonate with the investment decisions and management actions that are more commonly exercised by producers, and hence, help to enhance producers' assessment uptake and sustainability action. Therefore, the use of generic frameworks combining both societal and organisational perspectives may help to cover a wider range of stakeholders' needs and concerns. However, caution should be taken in the decision making process to avoid obscuring the societal perspective component and misinterpreting the assessment results. Accordingly, the sustainability-perspective definition should consider the assessment purpose and be clearly reported to the system decision-makers in order to contextualise the decision process.

A mismatch between the level of the assessment (e.g. enterprise, supply chain, region, nation) and the level of the sustainability-affecting processes (e.g. national policy-making) can also affect the coverage of relevant sustainability issues, as shown in the study's governance dimension (Section 3.3.2) and as discussed by van Passel and Meul (2012).

None of the analysed generic frameworks covered social issues such as *landscape aesthetics* and *nature cultural and metaphysical services.* However, other studies designing context-specific bottom-up frameworks based on participatory approaches have included issues associated with landscape aesthetics and nature cultural aspects (e.g. King et al., 2000; Louwagie et al., 2012). In this study, participants held differing views in relation to *landscape aesthetics,* probably due to differences in the frame of reference (values, norms, convictions, interests, and knowledge) as suggested by te Velde et al. (2002). A challenge arises in deciding which themes and sub-themes to include in the framework and establishing who gets to decide. Top-down decisions (Fraser et al., 2006) may help to regulate, for instance, the influence of stakeholders' business-as-usual aspirations. However, this approach places the decision power into a discourse of biased legitimacy. On the other hand, involving stakeholders with different aspirations and values in a dialogue requires more resources (Burgess and Chilvers, 2006), but may help to find common sustainability objectives as well as enhance stakeholders' education, assessment adoption and outcomes acceptance (Reed et al., 2006).

3.4.2 Advancing generic frameworks

The findings of this study suggest that the coverage gap of generic themes is potentially more of an issue of framework incompleteness that can be advanced through an iterative process of validation and reformulation, such as in the framework described by Reed et al., 2006. Therefore, generic themes have the potential for effectively covering context-specific issues in all analysed dimensions if the themes set is enhanced through expanding its coverage. On the other hand, sub-themes and the associated sustainability objectives are more dependent on the pluralistic needs and aspirations of the involved stakeholders. Therefore, the coverage gap of generic sub-themes may be an issue mainly caused by their less context-specific nature and may not be manageable only by expanding the generic sub-themes set. Cross-validation through analysing different contexts and frameworks is required to validate these results.

The expansion of generic framework themes and sub-themes could take place in terms of increasing the number of themes and sub-themes or in terms of increasing their individual scope. In terms of increasing the number of themes and sub-themes, the inclusion of additional social and economic themes and sub-themes for issues involving stakeholders more indirectly related to the respective value chain may significantly enhance the frameworks coverage. For example, the frameworks could also include themes related to protection of cultural heritage and human psychological and cognitive well-being, so case study issues such as *landscape aesthetics, nature cultural and metaphysical services* and *rural traffic intensity* would be better covered. However, the use of a large number of themes and sub-themes and the associated indicators can be a barrier to the framework applicability and adoption by the stakeholders and could complicate the interpretation of aggregated results. Increasing the scope of themes or sub-themes is another possibility for increasing coverage of sustainability issues. For example, RSB's local socio-economy sub-theme could better cover the identified regional economic issues directly associated with the supply chain (*regional employment opportunities* and *inter-regional materials* *procurement*) if the sub-theme objective is expanded beyond the regions of poverty scope. SAFA's atmosphere theme could increase the coverage of rural odour issues if the theme goal is expanded beyond the human health scope.

3.4.3 Balancing generality and specificity

Based on the previous results, this section proposes a rationale to set the specificity-level of sustainability assessment themes and subthemes (Figure 3) for minimising the tradeoffs between generality and specificity (e.g. benchmarking and resource efficiency vs. coverage and engagement).

When the assessment requires results benchmarking against different systems, places or generic standards, the use of generic themes, sub-themes and indicators (generic framework type (Figure 3)) should be considered, otherwise the benchmarking processes can be biased by the use of different goals, objectives or metrics. When results benchmarking is not a requirement, more specific frameworks can be used.

When results benchmarking is not required and a high coverage precision is not a possibility or a requirement due to resource limitations or a low assessment potential impact, the use of generic themes and sub-themes and specific indicators (mixed framework type (Figure 3)) should be considered. In this case, the use of specific indicators is recommended due to their significant context dependency in terms of assessment resources availability, data accessibility and availability, and knowledge and capacities of the indicators users (Reed et al., 2006; Binder et al., 2010). SAFA is partly based on this framework approach because it allows some level of indicators customisation.

When results benchmarking is not required and a high coverage precision is a possibility or a requirement, a specific framework type is recommended (Figure 3). In this case, generic themes (enhanced through expanding its coverage) can still be considered in all dimensions, as well as generic sub-themes in the environmental dimension. For example, this framework type would be appropriate in the case of designing governmental policies to improve the sustainability performance of biogas subsidies.

To involve stakeholders in the assessment specificity-level selection can help to minimise biases in the selection process. For example, affected stakeholders should be informed and consulted about the principal benefits and drawbacks of each option. These procedures may also help to enhance the stakeholders' assessment adoption and outcomes acceptance.

3.5 Conclusions

The study results indicate that generic sustainability assessment frameworks can effectively cover context-specific issues related with the environmental sustainability dimension. On the other hand, generic frameworks can be unable to identify context-specific issues related with the social and economic dimensions, especially at the sub-themes level and for issues involving stakeholders more indirectly related to the respective value chain. This study suggests that at the themes level, the coverage gap of generic frameworks is mainly an issue of framework incompleteness that can be advanced with additional research. At the sub-themes level, the coverage gap of generic frameworks is probably more an issue caused by their less context-specific nature. The design or selection of a sustainability assessment framework should consider characteristics such as the sustainability perspective and the level of assessment, as these can influence the framework

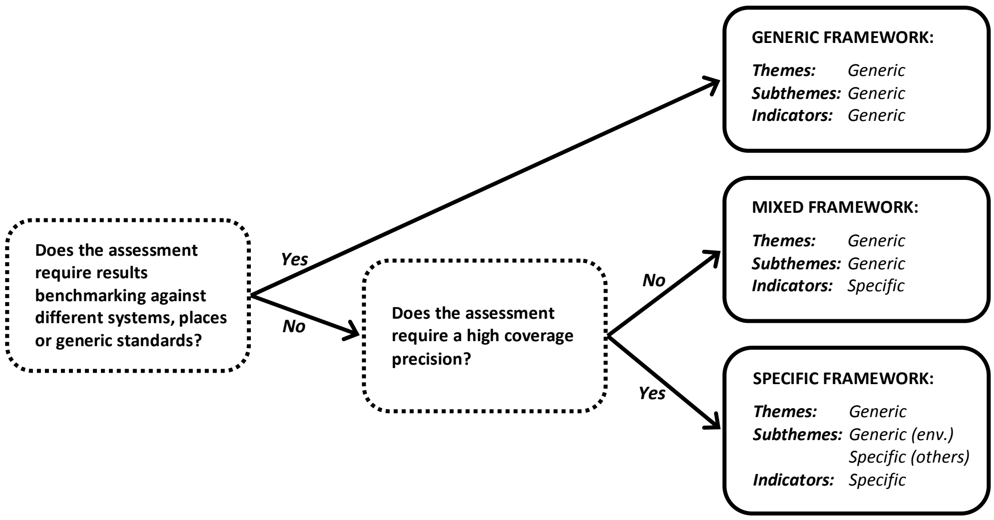

Figure 3. Frame for setting the specificity-level of sustainability assessment themes and sub-themes.

coverage effectiveness. Further research is needed to validate the findings of the study. For example, generic themes and sub-themes coverage should be analysed in different contexts and frameworks.

The choice of a specificity-level implies a number of tradeoffs that should be taken into account; for instance, benchmarking and resource efficiency vs. coverage and engagement. A one-size-fits-all specificity-level is not applicable, and this level should be tailored to the assessment purpose, specifically to the results benchmarking requirements and the coverage precision requirements or possibilities.

A certain degree of stakeholder participation, independent of the chosen specificity-level and despite the additional resource requirements, is recommended not only in the assessment process, but also during the framework design or selection process. Stakeholder dialog should target issues such as reflection on benefits and drawbacks of each available framework design or selection process option, and reconciling common sustainability objectives. This may help to minimise biases in selecting the assessment characteristics, help stakeholders' sustainability education, and enhance assessment adoption, trust and sustainability action.

Chapter 4

DATA SPECIFICITY IN SUSTAINABILITY ASSESSMENT: *The case of Controlled Traffic Farming Life Cycle Assessment*

Abstract

The choice of specific or generic data in sustainability assessment involves a tradeoff between accuracy and practicality. The aim of this study was to develop a rationale for setting an optimised level of specificity of the assessment data in terms of scientific soundness and practicality. This study was carried out by analysing the scope and data inventory of an environmental assessment case study (a Life Cycle Assessment of Controlled Traffic Farming), selected due to its intensive data requirements and lack of specific data availability. The case study illustrates that the level of data specificity can be optimised when aligned with (i) the overall assessment aim, (ii) the process type and sensitivity of individual data-inputs, and (iii) the available assessment resources. Site-generic data may be considered when local components do not affect assessment results or when there are no concerns about significant impacts at a local scale. Moreover, technology-generic data may be considered when the assessment aims to represent a variety of systems within more global contexts (e.g. industry, nation, market) and time-generic data when variability over time is not expected. The use of data sensitivity and uncertainty analyses and proper reporting of the data inventory process may help to minimise the drawbacks of the data inventory limitations in an efficient way.

4.1 Introduction

Data collection is usually the most time- and resource-consuming process in sustainability assessment (Rebitzer et al., 2004). Sustainability assessments often demand a significant amount of data for a wide range of issues and processes from a variety of disciplines and data sources. Data needs can go far beyond the physical boundaries of the analysed organisation, such as in the case of international materials supply. Approaches such as Life Cycle Assessment (LCA) have intensive data requirements associated with broad system boundaries and the possibility of a broad scope of impact categories. Resource limitations do not always allow the collection of factual data. Consequently, a number of assumptions are often required (EPA, 2006). A common approach to bridge data gaps is to use data with a lower level of specificity.

The level of specificity depends on (i) the age of data (temporal dimension), (ii) site and geography characteristics (spatial dimension), and (iii) the technologies or practices involved (technological dimension) (Fleischer et al., 2003). Specific data can be collected from equipment readings, company reports, equipment specifications, stakeholder surveys, and modelling approaches based on case-specific characteristics. On the other hand, generic data is less time, site or technology explicit or consistent. Often it is based on either an average scenario or an alternative-case scenario. Generic data can be collected from databases, industry and governmental reports, consultants and expert panels, laboratory test results, technical articles and books, and modelling approaches based on generic characteristics.

The use of specific data tends to generate more accurate assessment results, compared to the use of generic data (Fleischer et al., 2003). However, time, cost and technical restrictions of specific-data collection can limit the practicality of the assessment (Ross and Evans, 2002). Moreover, intensive resource demands may be a barrier to the uptake and use of the sustainability assessments amongst stakeholders, especially in the case of voluntary self-monitoring. The use of generic data can help reduce assessment costs and bridge data gaps. However, the use of generic data tends to reduce data accuracy (Fleischer et al., 2003). A number of studies have shown that the quality and integrity of assessment data can influence the reliability of sustainability assessment results and the stakeholders' reliance and trust on them (e.g. van den Berg et al., 1999, Ansems and Ligthart, 2002; Björklund, 2002; van Bar and Steen, 2004; Zygomalas et al., 2010). Accordingly, the selection of the data-specificity level implies a number of tradeoffs (e.g. practicality and accuracy).

Some studies have discussed to some extent the potentials and limitations of using generic data for assessing sustainability (Fleischer et al., 2003; Zygomalas et al., 2010). However, there is a lack of specific guidelines for setting an optimal context-specificity level of assessment data for efficiently assessing and enhancing sustainability performance.

The aim of this study was to develop a rationale for setting an optimised level of specificity of assessment data in terms of practicality and usefulness. This study was carried out by analysing the scope and the data inventory of an environmental sustainability assessment case study, selected due to its intensive data demands and significant lack of data availability. The case study consisted of a Life Cycle Assessment of the use of Controlled Traffic Farming technologies for arable farming, specifically wheat production in Denmark. Section 4.2 presents the article of the case study environmental assessment (Gasso et al., 2014b) and section 4.3 analyses and discusses the case study in relation to the data-specificity level.

4.2 Case study sustainability assessment

An environmental Life Cycle Assessment of Controlled Traffic Farming

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4.2.1 Introduction

The size and weight of in-field agricultural machinery have increased as a result of agricultural specialisation (Arvidsson, 2001) and the search for higher efficiency (Sørensen and Bochtis, 2010). The risk of traffic-induced top- and sub-soil compaction, consequently, has also increased (Raper, 2005).

Compaction restricts crop-root functions and growth, reducing crop yields (Hakansson and Reeder, 1994; Chan et al., 2006). Compaction, in addition, increases in-field soil-N_2O (Ball et al., 2008) and NH_3 emissions (Hansen, 1993), losses of nutrients and agrochemicals through runoff (Tullberg et al., 2001; Silgram et al., 2010), and the energy required for primary tillage (Chamen et al., 1994; Tullberg, 2000). Worldwide, the agricultural area affected by detrimental soil compaction in 1991 was estimated as 68 million ha, of which nearly 50% (i.e. 33 million ha) was located in Europe (Oldeman et al., 1991).

Controlled Traffic Farming (CTF) is an in-field traffic management strategy in which the crop zone and traffic-lanes remain permanently separated (Taylor, 1983) by the use of technologies such as satellite navigation and auto-guidance systems (Raper, 2005; Bochtis and Vougioukas, 2008). CTF, consequently, keeps the crop zone unaffected by soil compaction, significantly increasing crop yields (Chamen et al.,1992a,1992b; Li et al., 2007), while the traffic-lanes become compacted, improving vehicle traction efficiency (Taylor, 1992) compared to conventional traffic practices, known as Random Traffic Farming (RTF). CTF, in addition, reduces the need for compaction-removal tillage (McPhee et al., 1995b). The use of auto-guidance, moreover, reduces overlap during application of fertilisers, pesticides and seeds (Nielsen and Sørensen, 1994; Bochtis et al., 2010) compared to conventional RTF systems. CTF, however, can increase the non-productive in-field distance travelled for material handling operations (e.g. harvesting and fertilising) when loading and unloading (Bochtis et al., 2009) and require the use of specially-sized equipment (McPhee et al., 1995a).

Several studies have analysed environmental effects of CTF on specific emissions and stages of the agricultural production system (e.g. Hansen,1993; McPhee et al.,1995b; Hu et al., 2009; Vermeulen and Mosquera, 2009). There is a need, however, to assess environmental impacts of CTF following a systems approach to quantify the environmental relevance of implementing CTF. The aim of this study was to perform a Life Cycle Assessment (LCA) based on a modelling approach to estimate environmental impacts of producing wheat in Denmark using CTF compared to the conventional practice of Random Traffic Farming (RTF).

4.2.2 Methods

Farm scenario

The farm scenario (Table 7) was defined according to a preliminary study based on agricultural reports and interviews with wheat producers and CTF users. A scenario analysis, moreover, was performed with alternative fertilisers (synthetic only vs. manure and synthetic).

Scope

The functional unit (FU), to which the system inputs and outputs were related, was one tonne of winter wheat grain with 84% of dry matter (DM) content after harvest.

System boundaries (Figure 4) were based on the “cradle-to-farm-gate” approach, in which post-farm operations are excluded. The system boundaries included (direct) in-field emissions and indirect emissions associated with the farm inputs (i.e. fertilisers, pesticides, seeds, machinery, fuels and infrastructure), which comprised material extraction, manufacture, infrastructure, transport and disposal. Manure fertiliser emissions allocated to the FU included transport and in-field emissions (i.e. application and emissions from the soil). Manure fertiliser, in addition, displaces the need for synthetic fertiliser; therefore, the avoided synthetic-fertiliser impacts were subtracted from the FU. Grain drying operations were not included, because the grain DM content after harvest was considered the same for the analysed systems.

Table 7. Farm scenario characteristics

Issues	Description
Crop type	Winter wheat
Country	Denmark
Field size	20 ha
Soil texture	Loam
Field slope	5%
Average annual precipitation	712 mm
In-field operations[a]	Seedbed preparation, seeding, trail hose[b] and disc-spreader[c] fertiliser application, pesticide spraying, combine harvesting, mulch tillage
Fertiliser type[d]	Liquid cattle manure and calcium ammonium nitrate
Fertiliser requirements	161 kg N ha^{-1}, 22 kg P ha^{-1}, and 66 kg K ha^{-1}
Irrigation type	Non-irrigated
Crop rotation	Spring barley, winter oilseed rape, winter barley, winter wheat
Crop residue management	Retained in the field
CTF track-width (wheel centre to wheel centre)	2.8 m
Vehicle guidance	Auto-guidance based on satellite navigation systems in CTF; manual in RTF
Period practicing CTF	5 years
Regional storehouse distance	15 km (mineral fertilisers, pesticides, seeds and fuels)
Cattle farm distance	4 km (manure)

[a] *Working widths (RTF and CTF respectively): seeding (6 and 9 m), tillage (5 and 9 m), fertiliser application (24 and 27 m), pesticide application (24 and 27 m), and harvesting (9 and 9 m).*
[b] *For cattle manure.*
[c] *For calcium ammonium nitrate.*
[d] *Use of manure limited by P application threshold; synthetic N fertiliser supplements complete the N application rate.*

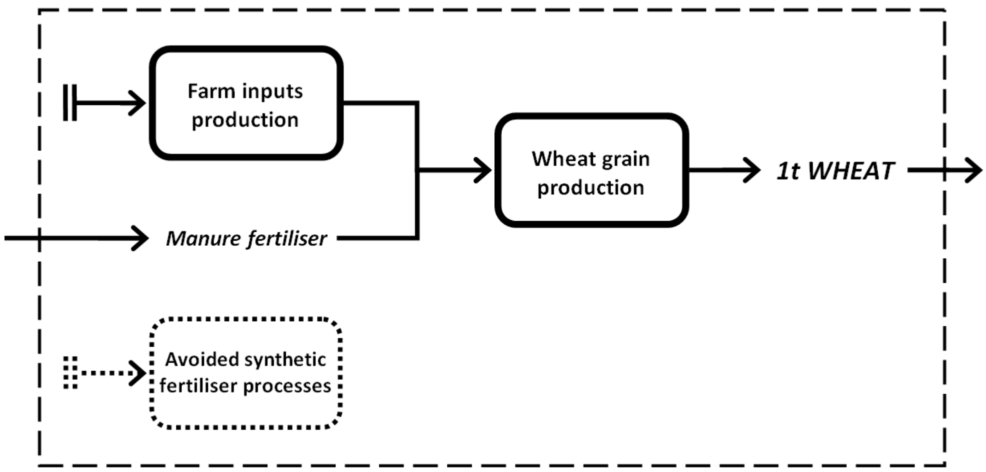

Figure 4. System processes and boundaries.

Data inventory

The data inventory (Tables 8 and 9) was based on the ecoinvent 2.0 database (Nemecek and Kagi, 2007), the C-TOOL model (Petersen, 2010), institutional reports, and a

Table 8. Farm input and output data.

Input and output	Units	Traffic system	Value	Source
Fertilisers (dairy cattle manure)[a]	t ha^{-1}	RTF	32.00	MFLF (2009)
		CTF	(-5%)[b]	Nielsen and Sørensen (1994)
(calcium ammonium nitrate)	kg ha^{-1}	RTF	90.30	MFLF (2009)
		CTF	(-5%)[b]	Nielsen and Sørensen (1994)
Seeds	kg ha^{-1}	RTF	170.0	VLF (2011)
		CTF	(-5%)[b]	Nielsen and Sørensen (1994)
Pesticides	kg ha^{-1}	RTF	[c]	Ecoinvent[d] (Nemecek and Kagi, 2007)
		CTF	(-5%)[b]	Nielsen and Sørensen (1994)
In-field operation fuel (diesel)	l ha^{-1}	RTF	78.83	Ecoinvent (Nemecek and Kagi, 2007)
		CTF	(-23%)	Chen (2008) (cited in Hu et al., 2009)
In-field machinery	---	both	[c]	Ecoinvent (Nemecek and Kagi, 2007)
Grain yield	kg ha^{-1}	RTF	7000	Lamers et al. (1986)
		CTF	7500	Lamers et al. (1986)

[a] *Manure nutrient composition data based on Lithourgidis et al. (2007).*
[b] *Data based on reduction in application overlaps in CTF (% on a per-weight basis).*
[c] *See reference.*
[d] *Wheat grain (integrated production) inventory.*

broad literature review on the environmental impacts of CTF (Gasso et al., 2013). The data selection criterion was the data's representativeness of the scenario characteristics of this study (Table 7). When available CTF-RTF studies were less representative, inventory data were defined by interpolating data from relatively more representative studies of only RTF with relative differences between RTF and CTF values (Tables 8 and 9).

In-field emission types (Table 8 and 9) used were based on the integrated production system of wheat grain inventory found in ecoinvent (Nemecek and Kagi, 2007). Soil-C emissions were estimated by the C-TOOL model (Petersen et al., 2002; Petersen, 2010). Annual soil-C emissions were simulated based on C pools of freshly added matter and soil biota, native soil organic matter (humus), and very slowly decaying matter. Each pool has a first-order decay rate modified by climate. The model considers a soil profile of 100 cm in depth, including carbon transport from topsoil to subsoil and a time horizon of 20 years. Phosphate leaching and nitrogen oxide soil emissions (except nitrous oxide) and heavy-metal runoff, leaching and emissions to soil were considered equivalent in both traffic systems, because CTF data were not available.

Indirect emissions associated with farm inputs were based on ecoinvent (Nemecek and Kagi, 2007). Indirect in-field machinery emissions data were not available, but were considered equivalent in both traffic systems by assuming that their equipment did not have significantly different production inputs or working time. Avoided synthetic-fertiliser indirect emissions were based on those of calcium ammonium nitrate, triple superphosphate, and potassium chloride. Avoided synthetic-fertiliser indirect emissions were considered equivalent in both traffic systems, because the CTF system has lower fertiliser application rates due to less overlap in applications, and the implementation of CTF implies that it replaces RTF.

Impact assessment

Impact assessment was based on EDIP2003 (Hauschild and Potting, 2005) updated with IPCC (2007) greenhouse gas factors, and SimaPro 7 software was used to perform calculations (PRé Consultants, 2008).

Table 9. In-field emissions data.

Emissions	Unit	Traffic system	Value	Source
Soil carbon (C) emissions	kg CO_2 ha^{-1}	RTF	-408.8	C-TOOL model (Petersen, 2010)
		CTF	-438.0	C-TOOL model (Petersen, 2010)
Soil nitrous oxide (N_2O) emissions	kg N_2O ha^{-1}	RTF	5.616	Ecoinvent[c] (Nemecek and Kagi, 2007)
		CTF[a]	(-32%)[b]	Vermeulen and Mosquera (2009)
Soil ammonia (NH_3) emissions	kg NH_3 ha^{-1}	RTF	13.91	Sommer and Ersboll (1994)[d] and Sommer and Jensen (1994)[e]
		CTF	(-24%)	Hansen (1993)[f] and Nielsen and Sørensen (1994)[g]
Soil nitrogen oxides (NO_X) emissions	kg NO_X ha^{-1}	both	1.179	Ecoinvent[c] (Nemecek and Kagi, 2007)
Phosphorous (P) runoff	kg P ha^{-1}	RTF	0.1127	Ecoinvent[c] (Nemecek and Kagi, 2007)
		CTF	(-32%)[bh]	Wang et al. (2008)
Phosphate (PO_4^{3-}) runoff	kg PO_4 ha^{-1}	RTF	0.7520	Ecoinvent[c] (Nemecek and Kagi, 2007)
		CTF	(-32%)[bh]	Wang et al. (2008)
Heavy metals (HM) runoff	---	both	[i]	Ecoinvent[c] (Nemecek and Kagi, 2007)
Nitrate (NO_3) leaching	kg NO_3 ha^{-1}	RTF	306.7	Ecoinvent[c] (Nemecek and Kagi, 2007)
		CTF[a]	(=)[j]	Vermeulen and Mosquera (2009)
Phosphate (PO_4^{3-}) leaching	kg PO_4 ha^{-1}	both	0.2041	Ecoinvent[c] (Nemecek and Kagi, 2007)
Heavy metal (HM) leaching	---	both	[i]	Ecoinvent[c] (Nemecek and Kagi, 2007)
Pesticide compounds to soil	kg ha^{-1}	RTF	[i]	Ecoinvent[c] (Nemecek and Kagi, 2007)
		CTF	(-5%)[k]	Nielsen and Sørensen (1994)
Heavy metals (HM) to soil	---	both	[i]	Ecoinvent[c] (Nemecek and Kagi, 2007)
In-field operations emissions	(l diesel ha^{-1})	RTF	78.83	Ecoinvent (Nemecek and Kagi, 2007)
		CTF	(-23%)	Chen (2008) (cited in Hu et al., 2009)

=: equivalent.
[a] *Seasonal CTF system; harvesting and primary tillage using RTF.*
[b] *Data based on the average of the reported values.*
[c] *Wheat grain (integrated production) inventory.*
[d] *For NH_3 emissions data from cattle manure fertiliser.*
[e] *For the relative variation between manure and synthetic fertiliser NH_4 emissions data.*
[f] *For NH_3 emissions data in compacted/uncompacted soils.*
[g] *For fertiliser application overlap data.*
[h] *Data based on water runoff measurements.*
[i] *See reference.*
[j] *Data based on measurements of soil mineral N.*
[k] *Data based on reductions in application overlaps in CTF (% in weight basis).*

The environmental categories analysed included: aquatic and terrestrial eutrophication, climate change, acidification, human-toxicity, ecotoxicity, and land use. In this method, aquatic eutrophication is divided into that increased by N compounds and that increased by P compounds. Human toxicity is divided into soil, water and air, and ecotoxicity into water acute, and water and soil chronic. Stratospheric ozone depletion and tropospheric ozone formation are also included in EDIP2003; however, they were omitted because they are irrelevant in crop production systems (e.g. Brentrup et al. (2004)).

Normalisation factors were based on EDIP2003 using annual European impact as a reference (Hauschild and Potting, 2005). The normalised impacts were calculated for 139.1 Mt of wheat, the amount of wheat produced per year in the European Union (FAOSTAT, 2011). The normalised impacts, therefore, represented the impacts, in relation to the total European impact, of producing all European wheat with the traffic systems analysed. Normalised ecotoxicity and land-use impacts were not assessed due to lack of reliable normalisation references (Hauschild and Potting, 2005).

Uncertainty and scenario analyses

An uncertainty analysis was performed to determine the effects of a parameter change on the relative differences between the environmental impacts of CTF and RTF. The parameters selected for uncertainty analysis were mainly those with relatively large variability among data sources (i.e. yield, application overlap, in-field NO_3 leaching, P-compound runoff, NH_3 emissions and N_2O emissions). The uncertainty analysis was performed by changing one parameter at a time and defining ranges based on the variability found in the literature or, failing that, expert knowledge (i.e. grain yield, ±5%; application overlap in CTF, ±5%; in-field NO_3 leaching in CTF, ±5%; in-field P-compounds runoff in CTF, ±15%; in-field NH_3 emissions in CTF, ±5%; and in-field soil-N_2O emissions in CTF, ±10%). A scenario analysis was also performed to assess the influence of different fertiliser types (i.e. manure and synthetic fertiliser vs. synthetic fertiliser only).

4.2.3 Results and discussion

General results

CTF had lower environmental impacts than RTF in all impact categories analysed (Table 10). Negative values were estimated for aquatic P-eutrophication, human-toxicity water, and ecotoxicity water due to large avoided synthetic-fertiliser impacts (Figure 5).

Table 10. Environmental impacts of 1 t of wheat in RTF and CTF

Impact category	Unit	Traffic system	Impact
Aquatic N-eutrophication	kg N	RTF	6.552
		CTF	6.006
Aquatic P-eutrophication	kg P	RTF	-0.1187
		CTF	-0.1382
Human-toxicity soil	m^3	RTF	64.00
		CTF	54.47
Human-toxicity air	million m^3	RTF	3416
		CTF	3000
Human-toxicity water	thousand m^3	RTF	-6.536
		CTF	-6.727
Terrestrial eutrophication	m^2	RTF	221.9
		CTF	157.7
Climate change	kg CO_2-eq.	RTF	230.9
		CTF	114.3
Acidification	m^2	RTF	46.98
		CTF	31.36
Ecotoxicity water-acute	m^3	RTF	-365.6
		CTF	-870.4
Ecotoxicity water-chronic	thousand m^3	RTF	-2.376
		CTF	-5.015
Ecotoxicity soil-chronic	thousand m^3	RTF	5.650
		CTF	5.004
Land use	ha	RTF	0.1428
		CTF	0.1333

Process contribution analysis

One main environmental hotspot in the production of wheat in both traffic systems (Figure 5) was indirect fertiliser emissions, which contributed to ecotoxicity water (45–48%), human toxicity water (45%), climate change (27%), and aquatic P-eutrophication (11%) gross impacts (i.e. excluding avoided impacts). Another hotspot was indirect pesticide emissions, which contributed to human toxicity air (90%), human toxicity soil (71%), and ecotoxicity water (10–16 %) gross impacts. Indirect machinery emissions contributed to ecotoxicity water (27–28%) gross impacts. In-field pesticide emissions to soil contributed to ecotoxicity soil (96%) gross impacts. In-field nutrient-related emissions also had large contributions: NO_3 leaching to aquatic N-eutrophication (90%), NH_3 emissions to terrestrial eutrophication (84%) and acidification (76%), soil-N_2O emissions to climate change (57%), and P-compounds runoff to aquatic P-eutrophication (60%) gross impacts.

The CTF system had lower environmental impacts than RTF due to lower in-field and indirect emissions of fertilisers and pesticides resulting from less application overlap, lower soil N_2O emissions resulting from soil conditions decreasing denitrification and increasing root access to nutrients, lower in-field P-compound runoff and NH_3 emissions resulting from higher water infiltration rates, and higher grain yields resulting from soil conditions increasing root growth and decreasing nutrient losses. Higher grain yields in CTF were responsible for decreasing impacts by 6.7% on a grain-weight basis in all impact categories analysed.

Improvement measures

Measures reducing fertiliser and pesticide use can decrease environmental impacts in all impact categories analysed (except land use), because the major hotspots were associated with nutrient and pesticide life cycles (i.e. production and use stages). Reducing in-field nutrient-losses, moreover, can further decrease aquatic and terrestrial eutrophication, climate change, and acidification. Increasing grain yield without extra inputs, moreover, can reduce environmental impacts on a grain-weight basis in all impact categories analysed. The advancement and implementation of measures complying with these goals, therefore, have the potential to reduce environmental impacts of crop production systems.

Uncertainty and scenario analyses

Grain yield changes (±5%) caused large changes in the relative impacts of CTF and RTF in aquatic N-eutrophication, human-toxicity, ecotoxicity soil and land use (Figure 6), because decreasing grain yield by 5% in CTF resulted in relatively low impact differences (1.6–8.9%) between CTF and RTF. CTF impacts, however, were still lower than those of RTF.

Application overlap (of fertilisers, pesticides and seeds) in RTF is highly dependent on driver skills, and in some cases RTF systems can include an element of auto-guidance, which may reduce overlap. Changes in relative application overlap (±5%) caused large changes in human-toxicity and ecotoxicity soil (Figure 6); because an increase in relative application overlap by 5% in CTF resulted in relatively low impact differences (7.0–10.1%) between CTF and RTF. CTF impacts, however, were still lower than those of RTF.

In-field NO_3 leaching changes (±5%) caused large changes in aquatic N-eutrophication (Figure 6), because increasing leaching by 5% in CTF resulted in a relatively low impact difference (4.1%) between CTF and RTF. CTF impacts, however, were still lower than those of RTF.

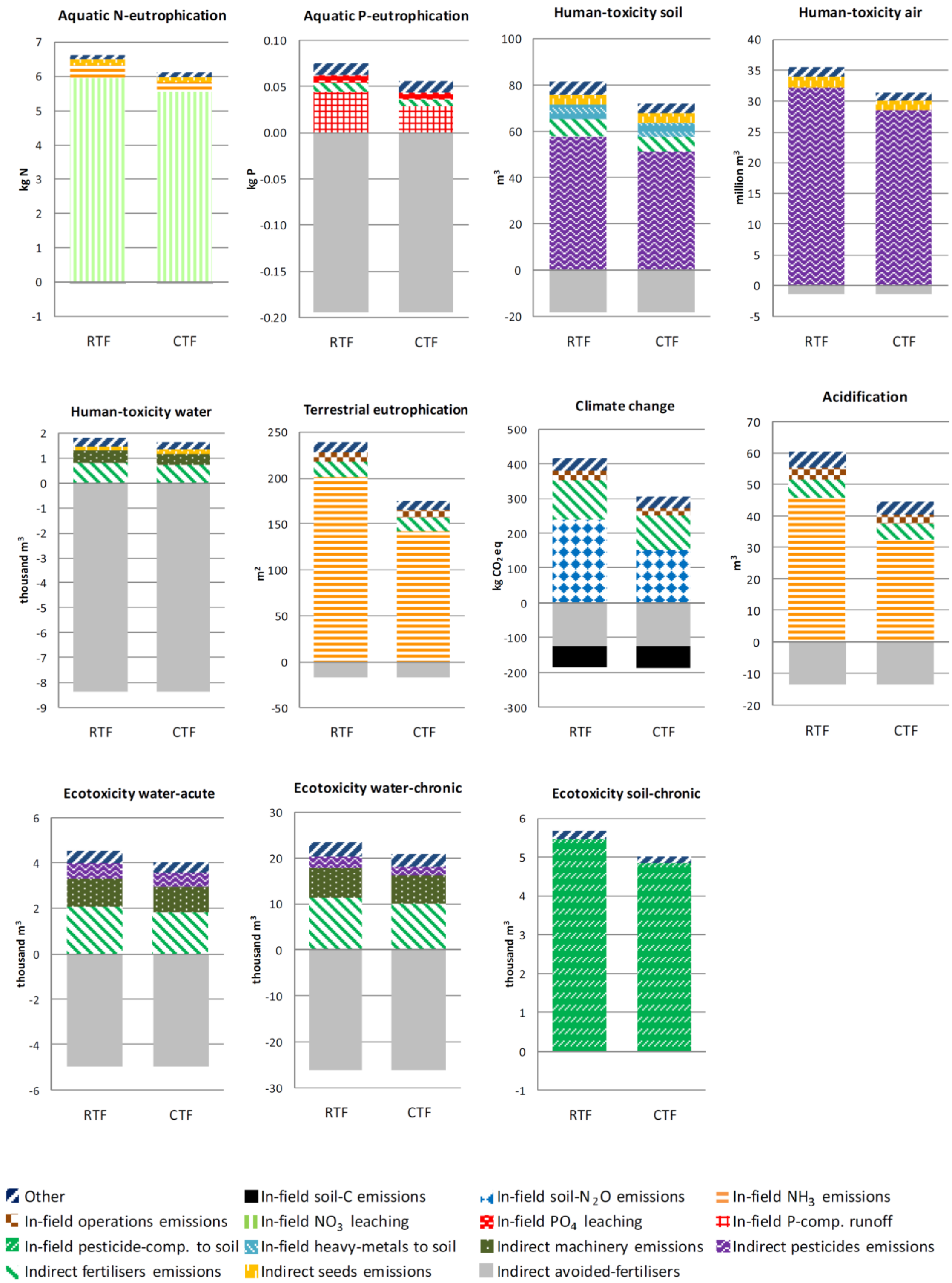

Figure 5. Contribution of production processes to potential impacts of 1 t of wheat grown under RTF and CTF.

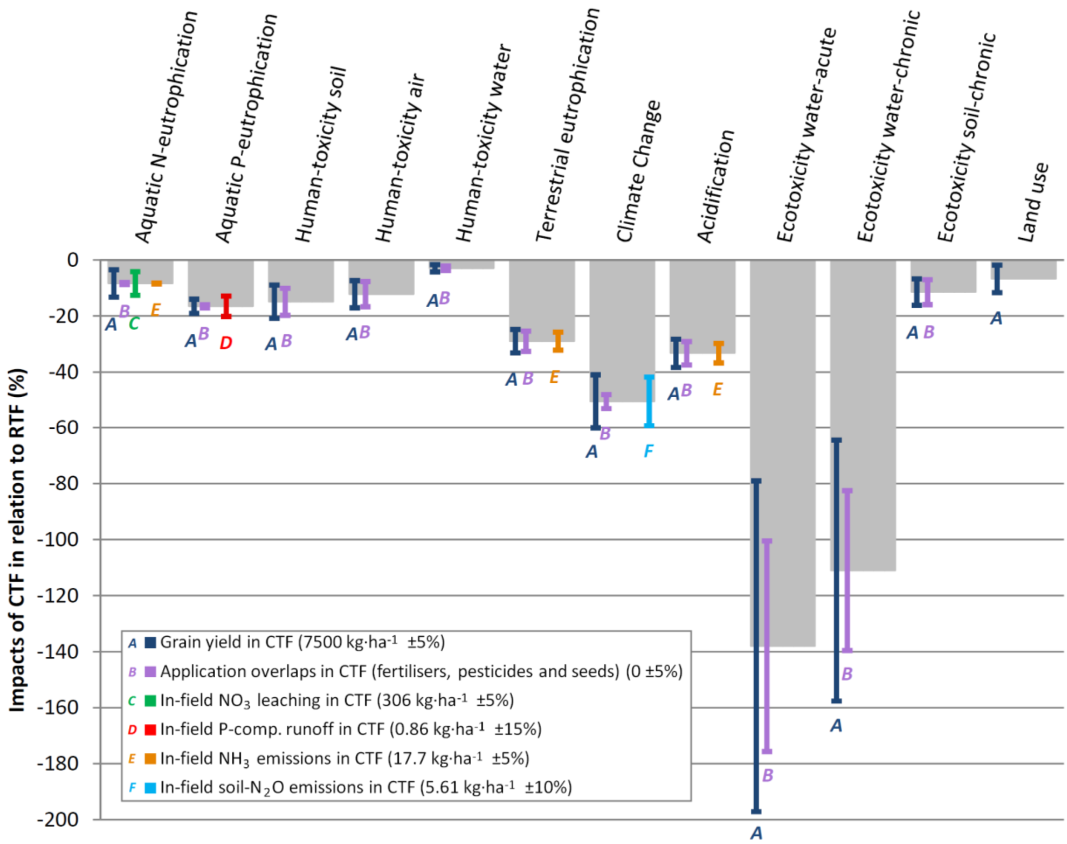

Figure 6. Uncertainty analysis of the CTF impacts in relation to RTF, on a grain-weight basis. Error bars represent the relative impact change caused by a given input data change.

Changes in in-field P-compound runoff (±15%), NH_3 emissions (±5%) and soil-N_2O emissions (±10%) did not notably affect the large impact differences between CTF and RTF (Figure 6).

Fertiliser type changes, i.e. when comparing manure- and synthetic-fertiliser vs. synthetic-fertiliser-only scenarios (Figure 7), showed that CTF was more efficient in reducing aquatic N-eutrophication and terrestrial eutrophication in a manure-fertilised scenario than in a synthetic-fertilised one, due to the higher in-field NH_3 emissions that are significantly reduced in CTF. CTF, in contrast, was more efficient at reducing aquatic P-eutrophication and human-toxicity in a synthetic-fertilised scenario than in a manure-fertilised one, due to the higher use of synthetic fertiliser that is reduced in the CTF system by less application overlap. In both scenarios, CTF impacts were still lower than those of RTF.

Assessment limitations

The data inventory presented some limitations caused by a lack of data availability. Grain yield data (Lamers et al., 1986) were based on a relatively old study. More recent studies were not used, because those available were relatively less representative of the scenario characteristics of this study. Verification during interviews with CTF farmers, however, showed that these data are reliable for current conditions. In-field NO_3 leaching

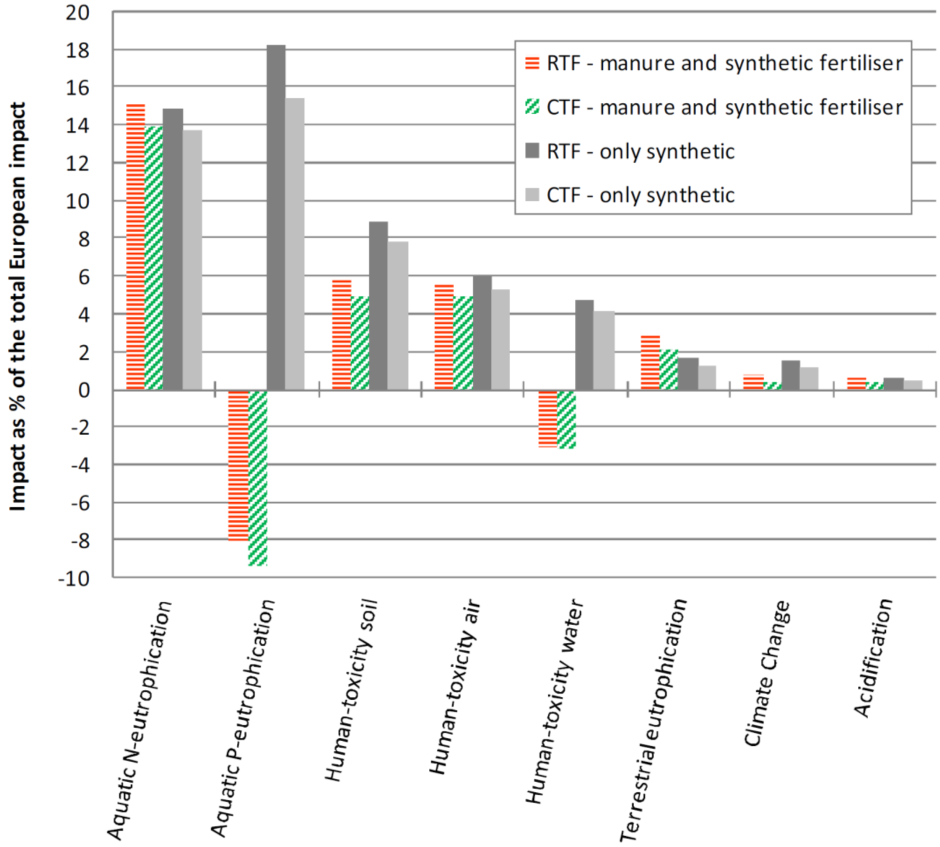

Figure 7. Normalised impacts in RTF and CTF, on a grain-weight basis (i.e. impacts, in relation to the total European impact, of producing all European wheat with the systems analysed) and scenario analysis.

and N_2O emissions CTF data (Vermeulen and Mosquera, 2009) were measurements from a vegetable production system and intensive tillage practices, and infield NH_3 emissions data came from compacted/uncompacted soils in a CTF system rather than from RTF/CTF systems. The use of more accurate data, however, was not possible due to lack of alternate data sources. In-field P-compound runoff CTF data (Wang et al., 2008) were based on a study with climatic conditions drier than those analysed in the farm scenario. Alternate studies were not used, because their climates, slopes and soil types were relatively less representative. Heavy-metal runoff data were considered equivalent in both traffic systems due to lack of data availability. CTF, however, reduces chemical and soil runoff; therefore, a decrease in heavy-metal runoff is expected.

Uncertainty and scenario analyses results indicate that the inventory limitations and the farm scenarios modelled do not affect the validity of the assessment results (i.e. the overall environmental performance of CTF compared to RTF and the respective hotspots), because these analyses were based on data variability from alternate data sources and farm scenarios.

Other impact categories, such as soil quality (i.e. soil properties, functions or processes such as compaction or erosion (Garrigues et al., 2012)), were not analysed due to current methodological limitations in LCA. CTF, however, can improve soil quality compared to RTF (e.g. McHugh et al., 2009).

Potential global implications

The normalised impact results (Figure 7) indicate that implementing CTF in all European wheat production systems has the potential to reduce total European impacts of aquatic N-eutrophication and P-eutrophication by 1.3%, terrestrial eutrophication and human-toxicity soil and air by 0.7–0.9%, and climate change by 0.4%. These results are based on the assumption that CTF has similar effects in all European contexts. CTF has been implemented in many European countries (Chamen et al., 1992a; Vermeulen et al., 2010; Holpp et al., 2012) and has shown reductions in environmental impacts in a diversity of growing conditions (Gasso et al., 2013). Wheat production practices in the rest of Europe, compared to Denmark, are mainly and on average characterised by less use of manure fertiliser and higher rates of synthetic fertiliser (FAOSTAT, 2011). According to the scenario analysis (Figure 7), impacts were lower in CTF than in RTF in all fertilisation scenarios. In the synthetic-fertilised scenario, however, CTF was slightly less efficient at reducing aquatic N-eutrophication and terrestrial eutrophication but more efficient at reducing aquatic P-eutrophication and human-toxicity than in the manure-fertilised one. Agricultural soils in the rest of Europe, compared to Denmark, are on average characterised by finer textures (Eusoils, 2012), which are more susceptible to compaction (Horn et al., 1995) and can therefore enhance the impact reduction potential of CTF in all impact categories on a grain-weight basis due to higher yields and less nutrients loss. The climatic conditions in Europe, which are diverse, influence soil moisture content, which in turn increases the susceptibility of soil to compaction (Raper, 2005) and therefore can enhance the impact reduction potential of CTF.

The reduction potentials represented by normalised impact results (Figure 7) may be considerably higher at the European scale if CTF is also implemented in other crop production systems. CTF has been implemented in the production of crops such as wheat, barley, oats, rapeseed, linseed, grass, maize, sugar beet, potatoes and onions (Tim Chamen, CTF Europe Ltd., Bedfordshire UK). CTF, in addition, has shown reductions in environmental impacts and yield increases for a diversity of crops (Chamen et al., 1992a; Gasso et al., 2013).

Further research is needed for more detailed estimates of the environmental, social and economic implications of the European crop production based largely on CTF.

4.2.4 Conclusions

The comparative LCA of CTF and the conventional RTF in a Danish wheat production system shows that implementation of CTF decreases environmental impacts on a grain-weight basis in all impact categories analysed: aquatic and terrestrial eutrophication, climate change, acidification, human- and eco-toxicity and land use. The normalised results, moreover, show that these environmental improvements are potentially relevant at a global scale. Reductions in environmental impacts in the CTF system analysed are caused mainly by higher grain yields and less soil compaction, which decreases P-compound runoff and in-field soil N_2O and NH_3 emissions, and the use of auto-guidance, which induces less overlap during application of fertilisers and pesticides.

Major environmental hotspot processes are associated with nutrient and pesticide life cycles. Effective measures to decrease environmental impacts on a grain-weight basis of the systems analysed include reducing fertiliser and pesticide use, reducing infield nutrient losses, and increasing grain yields.

The data inventory has some limitations caused by a lack of data availability. Uncertainty analysis results, however, indicate that inventory limitations do not affect the validity of the general findings. An assessment integrating not only environmental but also social and economic issues is needed to determine the overall sustainability of CTF.[1]

4.3 Data specificity analysis and discussion

4.3.1 Specificity level analysis

Section 4.2 presented an environmental assessment case study with intensive data demands, due to the extensive system boundaries (cradle to farm-gate) and a relatively large number of impact categories analysed. Specific agronomical and in-field emissions data were not available for Danish CTF farms and the resources available for the assessment were considerably limited. Therefore, data with a low level of specificity was used in order to bridge data gaps.

Part of the data inventory (Tables 8 and 9) was based on a generic database (Nemecek et al., 2007). The selected in-field emissions from the database presented scenarios with a similar technological dimension to the analysed scenario, but a different spatial dimension (e.g. N_2O emissions and NO_3 leaching data for RTF were based on average Swiss wheat production conditions). Some of the indirect emissions from farm inputs of the database were based on a technological dimension representing the European average (e.g. fertilisers and machinery indirect emissions data). Another part of the data inventory was based on technical articles (Tables 8 and 9). Some of these articles represented different spatial dimensions (e.g. P-compound runoff data were based on Chinese conditions), technological dimensions (e.g. NO_3 and N_2O emissions data for CTF were based on vegetable production systems and intensive tillage practices), and temporal dimensions (e.g. production yield data were based on relatively old trials).

Data with a low level of specificity are generally less representative and less accurate. But how much accuracy is actually required? In-field emissions and production yield inaccuracies were evaluated by an uncertainty analysis based on the variation found in the literature or otherwise based on expert knowledge (Section 4.2.3). The results of this analysis suggest that these inaccuracies do not affect the validity of the findings related to the study aim, which was to compare the overall environmental performance of CTF and RTF. Moreover, indirect emissions from farm inputs using European average data can be considered representative because these processes normally involve external suppliers, which vary in time according to market conditions (e.g. availability and prices).

4.3.2 Recommendations

In order to establish an appropriate level of data specificity and accuracy, it is essential to consider the assessment aim, scope and available resources. For example, site-generic data can be sufficient when the assessment purpose is to compare the overall performance of technologies, practices or policies that are relatively independent of local conditions, as in the case of the CTF study. On the other hand, site-specific data should be considered when local components can significantly affect assessment results or when there is a concern about local impacts. Examples include decisions about the location of facilities or the assessment of projects at sites that have a high sensitivity to sustainability impacts, as suggested by Moberg (2006). Technology-generic data, such as nation- or market-average values, should be considered when an assessment aims to represent the country or the

[1] *end of article*

market as a whole. Conversely, technology- and practice-specific data should be considered when the assessment purpose is to optimise products or operations. Time-generic data should be considered when variability over time is not expected.

To differentiate the system's processes and sustainability impacts, and subsequently define individual levels of data specificity, can also be a useful approach to delimit the use of specific data. For example, site- and technology-generic averaged data can be suitable for processes that imply external suppliers and vary according to market conditions such as availability and prices (e.g. input materials extraction and production), as proposed by Fleischer et al. (2003). Generic average data may also be representative for processes that tend to be less variable and common within alternate systems (e.g. transport and perhaps energy supply). A further approach consist of performing a preliminary screening with non-resource intensive sources and conducting a sensitivity analysis. A sensitivity analysis modifies the input data according to a predefined range and recalculates the model's output to test the respective effects (May and Brennan, 2003). This analysis can help to identify the sensitivity and relative importance of each data input, helping to delimit the use of more specific data for certain production stages or impacts.

The use of uncertainty analyses, especially when using generic and less representative data, can be a valuable and relatively resource efficient approach to determine how data inaccuracies affect the validity of the assessment results. An uncertainty analysis consists of evaluating the effects of a data uncertainty range on the model's output (May and Brennan, 2003). When an estimate of the actual uncertainty range is not known, the uncertainty analysis can be based on an arbitrary range. This may be based on expert knowledge or variability within or between alternate data sources, as was the case in the CTF study.

The data inventory process should be documented in a transparent manner and should consider consulting key stakeholders (e.g. affected parties) about critical assumptions. The documentation process should describe the level of specificity and representativeness, and discuss the inventory limitations, variability, and likely impacts on study results. This approach may enhance acceptance and facilitate proper interpretation of the assessment results by the system decision-makers.

4.4 Conclusions

Setting the level of data specificity in sustainability assessment can involve trading off accuracy against practicality. This can influence the assessment results reliability and utility and may influence uptake of voluntary assessments amongst stakeholders and trust in the assessment outcomes. High levels of accuracy are not always required for the effective and efficient assessment of sustainability performance.

The level of data specificity can be optimised in terms of practicality and usefulness, when aligned with (i) the available assessment resources, (ii) the overall assessment aim (e.g. compare, optimise, geographically locate), and (iii) the individual data-inputs sensitivity and process-type (e.g. market supplies, common processes). In general, site-generic data may be considered when local components do not affect assessment results or when there are no concerns about significant impacts at a local scale. Moreover, technology-generic data may be considered when the assessment aims to represent a variety of systems within more global contexts (e.g. industry, nation, market) and time-generic data when variability over time is not expected.

The use of tools such as sensitivity analysis (for delimiting the use of more specific data) and uncertainty analysis (for determining the importance of data inaccuracies) can help to minimise the impact of data inventory limitations in an efficient manner.

Communicating the data inventory process and quality to the key stakeholders (e.g. system decision-makers), in a transparent and effective manner, may facilitate stakeholders' acceptance and proper interpretation of the assessment results. This has the potential to improve learning and enhance sustainability performance.

Chapter 5

BENCHMARKING FOR LOCALLY TUNED SUSTAINABILITY: *The case of energy and water use in New Zealand vineyards*

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Abstract

Sustainability benchmarking is the process of comparing indicators of performance with other organisations to identify, adapt and implement best practice approaches for sustainability improvement. The benchmarking process is more likely to incentivise and guide sustainable practice if it is based on fair and sensible comparisons, accommodating features such as local biophysical and economic constraints, in order to place all farmers on a "level playing field". This study developed a benchmarking rationale accommodating local opportunities and constraints for effectively incentivising locally-tuned sustainability improvements. This was carried out by analysing energy and water use on the 1,103 vineyards enrolled in the Sustainable Wine-growing New Zealand scheme. Regression models to predict spatial and temporal variations of energy and water use explained relatively large proportions of the resource use variance. Production area and region were common and significant predictors of resource efficiency. A 59% increase over time in fuel efficiency took place in vineyards instigating energy reduction plans and actions. The vineyards' rank performance differed widely when benchmarked within the entire sector or within other vineyards of equivalent characteristics, specifically for agroecological and production related characteristics influencing performance. For example, one vineyard ranked at the 20 percentile in fuel efficiency within the sector, yet at the 75 percentile when compared against vineyards in its own region and with a similar production area. Aggregated and non-locally tuned benchmarking might best suit consumers and national-level policy makers, but they do not capture the local and diverse challenges faced by the individual farmers. Use of locally-tuned benchmarking approaches can better identify actual sustainability improvement opportunities and may enhance farmers' trust in the sustainability exercise, improve participation and better incentivise change towards sustainability.

5.1 Introduction

5.1.1 Benchmarking in sustainability assessment

Many indicator-based frameworks have been developed since the Brundtland Report (1987) called for global assessment of the sustainability of food and fibre production (Pope et al., 2004; Pintér et al., 2012; McLeod and Moller, 2013). Sustainability indicators allow the measurement and communication of sustainability performance (Lenz et al., 2000; Veleva and Ellenbecker, 2001). This enables farmers and policy makers, for instance, to determine whether changes in farming practice are needed and whether innovations for sustainability, such as the use of monitoring technologies and sustainability investment and planning, are succeeding. However, an indicator value alone does not allow for performance improvement and standardisation unless it is linked to a "reference value" (Acosta-Alba and van der Werf, 2011b).

Reference values can be categorised into absolute and relative. Absolute reference values are predefined indicator values that form targets, thresholds or ranges of acceptable risk (Syers et al., 1995; Acosta-Alba and van der Werf, 2011b). Absolute reference values are normally based on scientific knowledge, government policies, or stakeholders' participatory sources (van Cauwenbergh et al. 2007; Bockstaller et al. 2008; Acosta-Alba and van der Werf, 2011b). Relative reference values are proxy measures of actual performance, i.e. indirect indicators of the target outcomes. They can be used for trend detection and "benchmarking" processes through performance comparisons within alternatives systems (Andersen, 1999; Acosta-Alba and van der Werf, 2011b; Lebacq et al., 2013).

Benchmarking has been defined as the "process of comparing products, services, processes and outcomes with other organisations or exemplars, for the purpose of improving outcomes by identifying, adapting and implementing best practice approaches" (ECU, 2011). Benchmarks can be based on groups or individual partners. They may be the median of the group, the organisation's ranking within the group, a top-performers range of the group, or the potential best-practice partner (Acosta-Alba et al., 2011a; EC, 2011; Lebacq et al., 2013).

Several studies have reported that benchmarking often leads to significant improvements in organisational performance (McNair et al., 1995; Andersen, 1999; Simatupang et al., 2004; Wainwright et al. 2005; Pérez-Lombard et al., 2009). Benchmarking within a peer-group can challenge the organisation's current management, assist in defining more practical targets, help to silence mangers' doubts over potential for improvement, highlight problem areas and assist in formulating successful improvement plans and strategies (Meade, 1998; Camp, 2004; de Snoo, 2006; Henning et al., 2011). Benchmarking within a peer-group does not normally require the definition of absolute reference values, such as thresholds, which are not always available (Syers et al., 1995; Christensen and Krogman, 2012).

Benchmarking is more likely to incentivise and guide sustainable practice if it is based on fair and sensible comparisons. All organisations need to be placed on a "level playing field" for their benchmarking to be a reliable indicator of relative performance amongst equivalent peers.

5.1.2 The need for "local tuning"

Agricultural production is highly dependent on local agroecology and the specific socioeconomic setting (Cowell et al., 1996; von Wirén-Lehr, 2001). Important opportunities for agricultural sustainability can arise from tuning farming practice to local conditions (Hansen et al., 1996; van Calker et al., 2005; Mascarenhas et al., 2010). The ARGOS study (www.argos.org.nz) has demonstrated that sustainability performance of New Zealand organic, Integrated Management and conventional farming systems have relatively small average differences in outcomes, yet the performance of individual farms and orchards within each system is enormous (Campbell et al. 2011; Manhire et al. unpubl.). The ARGOS study has suggested that important sustainability gains can be achieved by understanding and lifting the performance of individual farming practices within each system rather than only promoting one general production system (e.g. certified organic or Integrated Management) over another.

Analysing the drivers that determine individual sustainability performance may guide farmers and policy makers to understand how the system works, and hence to identify management opportunities to promote improved sustainability. Improvement opportunities may rest on adjusting individual farming practice to spatially-dependent characteristics (e.g. soil type, climate) as well as temporally-dependent ones (e.g. weather, farm inputs prices). Measurement of temporal fluctuations of performance is also an important requirement to reliably detect trends, estimate the power of sustainability monitoring tools to signal unacceptable or improving trends (Manhire et al., 2012; Monks and MacLeod, 2013), and determine the effects of new strategies or interventions trialled in an "adaptive management" approach (Walters and Holling 1990).

"Once-size-fits-all" benchmarking approaches tend to disregard the local conditions and diversity of environmental, economic and cultural drivers that affect individual production performance (von Wirén-Lehr, 2001; Nader et al., 2008; Huggins, 2008 [cited in van Zeijl-Rozema et al., 2011]; Kato et al., 2011). Decoupling the benchmarking process from these drivers presents the risk of setting non-practicable targets, discouraging farmers' adoption of the information for learning, and undermining trust in the whole sustainability exercise. Improved performance of individual farming practices may be best incentivized by using a benchmarking process that is relevant to the actual opportunities and constraints of individual farms.

Several studies have developed assessment approaches using absolute reference values tuned to local conditions (e.g. Smyth et al., 1993; Nijkamp and Vreeker, 2000; Ekins and Simon, 2001; López-Ridaura et al., 2002; Bastian et al., 2007; van Cauwenbergh et al., 2007). Current sustainability benchmarking approaches also tend to intuitively consider some local aspects (e.g. region) that may influence performance differences among entities (Huggins, 2008). However, further research is required, detailing a systematic rationale for benchmarking approaches that are sensitive to a wide range of local determinants of sustainability performance.

The general aim of this study was to develop a benchmarking rationale sensitive to local opportunities and constraints for effectively incentivising locally tuned sustainability improvements. The benchmarking rationale concerned energy and water use in New Zealand vineyards, specifically those farmers participating in the Sustainable Wine-growing New Zealand (SWNZ) scheme. This rationale was carried out through the development of regression models explaining the drivers behind spatial and temporal variations of energy and water use in the SWNZ viticulture sector.

5.2 Methods

5.2.1 Data collection and treatment

This study analysed data provided by the vineyards that have voluntarily become part of the SWNZ scheme. SWNZ is a certification scheme for New Zealand vineyards and wineries, which aims to provide continued improvement toward sustainability as well as market recognition of compliance to sustainable practices (http://www.nzwine.com /sustainability/sustainable-wine-growing-new-zealand). It is based on seven key areas of focus: energy; water, air and soil; biodiversity; chemicals; by-products; people; and business practices. The SWNZ program was introduced in 1995. Ninety-one percent of the total New Zealand producing vineyard area were enrolled in the scheme by 2012, covering all of the country's grape growing regions (NZWINE, 2014a).

Farmers' data was collected through the SWNZ "scorecards". Completion of self-assessed scorecards is mandatory if the vineyard is to be accredited membership of the SWNZ scheme. They are completed annually, usually by the vineyard managers. The scorecards report performance and practice information related to the seven SWNZ key focus areas, as well as vineyard production and context data, such as location (NZWINE 2014b). The assessment applies to the whole "enterprise" as a single unit, irrespective of the number of separate "vineyards" within it, because some of these did not keep individual vineyard records (about 20% of the enterprises comprising 40% of the total SWNZ area presented multiple vineyards). The scorecards are completed online with the aid of guidance notes and manuals. An external audit is performed on a three-year basis to ensure the accuracy of the information provided in the scorecards. Rainfall and temperature data were collected from the national climate database (NIWA, 2013). Each enterprise was matched to data from the nearest of two weather stations within the region. Key irrigation periods were identified for each region based on irrigation scheduling software data (CropIRlog, 2011).

The data used for this study consisted of the scorecards of SWNZ accredited vineyards for the seasons of 2010/2011 (in this study referred as the 2011 season) and 2011/2012 (referred as the 2012 season), accessed from the SWNZ database as of 14th January of 2013 (Figure 8 and Table 11). The analysed variables included the enterprise's production system characteristics and management issues (Table 12). The dataset was divided into three sub-sets (fuel, electricity and soil-irrigation user datasets); not all vineyards used electricity and irrigation (Table 11). For practical reasons only soil-irrigation was modelled in this study and frost-control irrigation (11% of the sector's water use) was excluded (see Snyder and Melo-Abreu (2005) for a description of frost-control principles and methods).

The respective datasets were analysed in two ways: (i) comparison between all enterprises providing the 2012 season's data (more advanced and complete scorecards were returned in that season); and (ii) comparison between the 2011 and 2012 seasons' data for the subset of vineyards that provided scorecards in both seasons. For the latter analysis, the 2012 scores were subtracted from the 2011 ones for each enterprise. When a binary score was being compared, "Yes" and "No" were assigned 1 and 0, so that any change between years could result in a -1, 0 or +1 change. Production (weight of grapes measured in tonnes, t) and production-based variables (e.g. water use measured in m^3 of water per tonne of grapes) were not available for 2011. Fuel use was reported in litres and the type of fuel used was not recorded in 2011. Therefore, total fuel use could only be expressed in litres instead of mega-joules in the comparison between years.

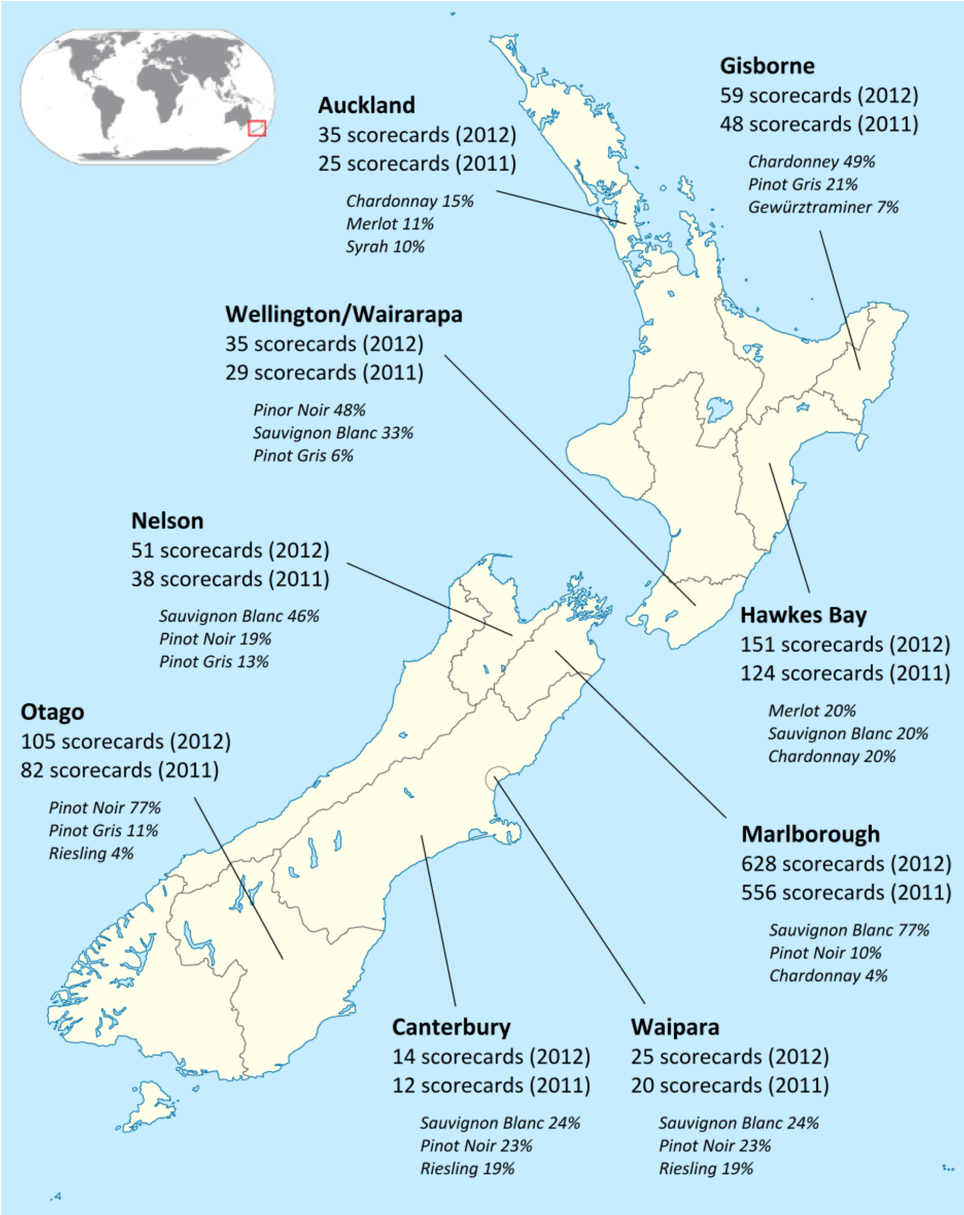

Figure 8. Regional distribution of the analysed vineyards/scorecards and major grape varieties produced.

Plausibility checks were conducted to remove any apparent data entry errors. The criteria for determining apparent data entry errors were established by an expert with practical and technical knowledge about the SWNZ sector. The exclusion criteria consisted of fuel use outside the 40 to 2,000 L/ha range, electricity use above 3,000 kWh/ha, and soil-irrigation water use above 7,000 m3/ha. As a result, up to 14 data entries were removed from each dataset. Crosschecks with parallel scorecard entries were performed to differentiate between genuine zeros and genuine missing values, and apparent errors corrected.

Table 11. Analysed dataset of vineyard scorecards recording fuel, electricity and water use in 2011 and 2012 seasons.

	2011 season	2012 season
Total scorecards/enterprises (number)	934	1,103
Total production area (ha)	24,000	32,000
Number of fuel-user scorecards	934	1,103
Percent of the fuel-user scorecards with missing values[a]	59%	44%
Number of electricity-user scorecards	246	369
Percent of the electricity-users scorecards with missing values[a]	11%	11%
Number of soil-irrigation users scorecards	675	773
Percent of the soil-irrigation users scorecards with missing values[a]	25%	21%

[a] *at least one missing value within the data entries used as potential variables for the respective models.*

5.2.2 Statistical analysis

Multiple linear regressions were used to find the models that best explained the variation in SWNZ farmers' fuel, electricity and soil-irrigation water use and change in use. Statistical inference was necessary because of missing data, which may have been distributed unevenly for different seasons, regions, or production size etc. Statistical models were accepted when an explanatory variable was associated with a response variable at the $p<0.05$ level. The statistical modelling was conducted using Genstat (Genstat 15th ed., VSN International Ltd., Oxford, UK).

Fifteen models were defined, in which the respective response variables were (a) fuel use, (b) electricity use, (c) soil-irrigation water use, and (d-f) the way each of these changed between 2011 and 2012 seasons. Within each of these comparisons, the response variable was expressed (i) per enterprise, (ii) per hectare under production, and (iii) per tonne of grapes produced (except that (iii) was not possible for the seasonal comparison models).

Potential explanatory variables (Table 12) were mainly selected for expected relevance, to avoid co-linearity, and to include key interactions that were expected to influence benchmarking. Co-linearity between potential explanatory variables was tested using correlation analysis and variance inflation factor (VIF) values. When variables presented a high co-linearity (VIF>10), the more redundant variables were dropped from the set of potential explanatory variables.

A stepwise procedure was used for selecting relevant model explanatory variables from the set of potential explanatory variables. This selection procedure sequentially adds new potential explanatory variables if a statistically better model is produced or removes existing ones if a statistically worse model is not produced. The stepwise test criterion of 1 (Genstat default) was used.

Transformations (none, quadratic, square root or log10) were applied to both response and explanatory variables until a best fit to model assumptions and maximum explained variance was achieved. Non-normality and heteroscedasticity were tested by inspecting the residual plots for uneven distribution of residuals. To meet the modelling assumptions, up to 13 outliers flagged by Genstat were removed per model.

The detail of the model selection and their final parameters are included in the Appendix A tables A1 to A6, and their general structure is summarised in Tables 13 and 14 of the main text.

Table 12. List and definition of vineyard variables analysed for building regression models explaining fuel, electricity and water use.

Variables
Region *(Auckland, Canterbury, Gisborne, Hawkes Bay, Marlborough, Nelson, Otago, Waipara, Wellington/Wairarapa)*
Accreditation status in the previous season *(Accredited, Suspended, Tentative, New member, Other)*
Production-weight (t) (tonnes of grape produced)
Production-area (ha) (area under production)
Production yield (t/ha)
Number of vineyards per enterprise
Fuel use is recorded *(Yes, No)*
Electricity use is recorded *(Yes, No)*
Fuel use, total (MJ/enterprise, MJ/ha[a], MJ/t[b])
Electricity use (kWh/enterprise, kWh/ha[a], kWh/t[b])
Diesel use; Petrol use; LPG use; and Biofuel use (L/enterprise, L/ha[a], L/t[b])
Diesel/total fuel ratio; Petrol/total fuel ratio; LPG/total fuel ratio; and Biofuel/total fuel ratio
Plans/actions are in place to reduce energy use *(Yes, No)*
Preference to select energy suppliers on the basis of sustainability standards *(Yes, No)*
Soil-irrigation is used *(Yes, No)*
Soil-irrigation water use is recorded *(Yes, No)*
Soil-irrigation water use (m^3/enterprise, m^3/irrigated ha, m^3/t[b])
Soil-irrigated area (ha)
Water application is optimised to plant requirements *(Yes, No)*
Water application optimisation by: using computer irrigation-modelling; by measuring evapotranspiration and crop requirements; by measuring soil moisture; by measuring rainfall; by visually assessing soil moisture; by visually assessing vines water requirements; by assessing weather predictions data; by other methods *(Yes, No (each))*
Additional plans/actions are in place to reduce water use *(Yes, No)*
Irrigation design records are filed *(Yes, No)*
Irrigation system performance is monitored *(Yes, No)*
Irrigation system performance monitoring by external audit within last 2 years; by external audit within last 5 years; by internal audit annually; by internal audit within last 2 years; by preseason internal audit; by scheduled monitoring and maintenance; by water quality monitoring; by other approaches *(Yes, No (for each))*
Rainfall, growing season average (mm)
Rainfall in the key soil-irrigation periods average (mm)
Temperature, growing season average (°C)
Temperature in the key soil-irrigation periods average (°C)
Frost control water is used *(Yes, No)* (water flipper/overhead sprinkler irrigation to provide frost protection (e.g. Snyder and Melo-Abreu, 2005)
Frost control water use is recorded *(Yes, No)*
Frost control water use (m^3/enterprise, m^3/frost-controlled ha, m^3/t[b])
Frost controlled area (ha)

[a] *enterprise hectares under production*
[b] *enterprise tonnes of grape produced*

5.2.3 Benchmarking process

A subset of four focal vineyards was selected to illustrate the effect of different bases for benchmark comparisons on relative performance ranking for fuel, electricity and water use efficiency. This subset consisted of the vineyards that were nearest to the 20th, 40th, 60th and 80th percentiles in each cumulative distribution of fuel, electricity and soil-irrigation water use efficiency for the entire SWNZ panel. Their relative ranking was calculated by (i) comparing amongst all SWNZ (national) panel; by (ii) comparing amongst vineyards matching for relevant single parameters (e.g. matching for region); and (iii) by comparing amongst vineyards matching for all relevant parameters (e.g. matching for both region and production area). Relevant parameters consisted of those agroecological and production related characteristics that explained significant ($p<0.05$) proportions of the fuel, electricity or water use variance. Only Marlborough vineyards were used for this comparison because this region had most data entries. Continuous variables, such as production area, were used divided into quartiles of the frequency distribution.

5.3 Results

5.3.1 Modelling resource use variation between enterprises

Best models explained 82% and 78% of the variation in fuel use per enterprise and per tonne of grapes produced, but only 11% of the variation per hectare under production (Table 13). Production area and region were significant ($p<0.05$) and consistent predictors of fuel efficiency. A significant interaction between area and region appeared only once for Canterbury and once for Marlborough.

Fuel use per tonne decreased as production area increased (Figure 9). There is relatively little gain in fuel efficiency once more than five hectares of vineyard are being managed. About 22% of the enterprises were within the 0 to 5 ha range that exhibited rapid changes in efficiency, while 26% were between 5 and 10 ha where production area had relatively little influence on efficiency.

Regional effects on fuel use per enterprise (Figure 10) showed Canterbury and Auckland as the least fuel efficient production regions on average. The difference is considerable – Marlborough (the most fuel efficient wine producing region) uses just half as much fuel per tonne of grapes produced as Auckland winegrowers, and a third as much as their Canterbury neighbours.

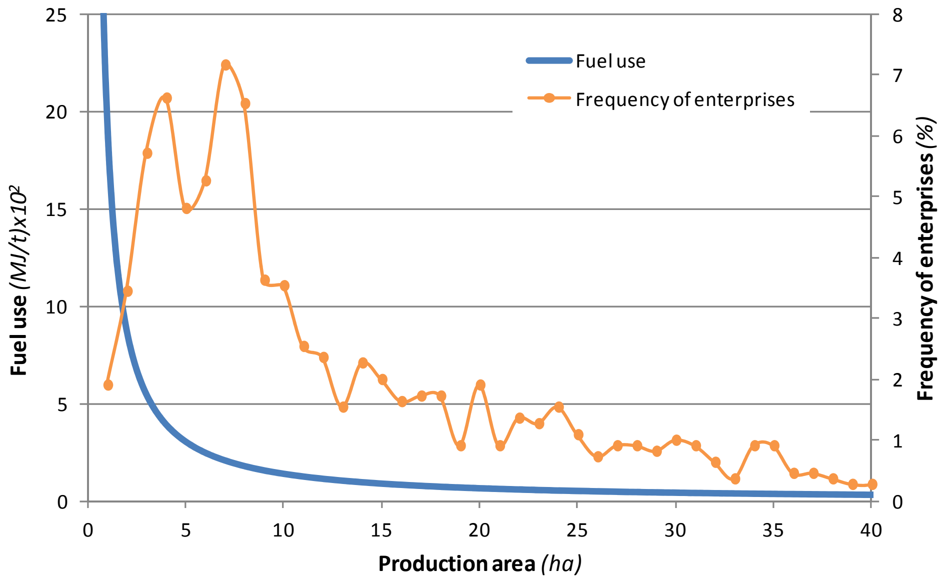

Figure 9. Production area associations with fuel use per tonne of grapes produced after effects of region have been taken into account. The frequency distribution of production area of enterprises is presented in the right axis.

Table 13. Summary of the regression models for resource use in the 2011 season. This presents the models explained variance, the significant explanatory variables and their direction (for full descriptions see Appendix A tables A1 to A3).

Response variable	**Fuel use (log)** (MJ/en-terprise)	**Fuel use (log)** (MJ/t)	**Fuel use (log)** (MJ/ha)	**Electricity use (square root)** (kWh/en-terprise)	**Electricity use (square root)** (kWh/t)	**Electricity use (square root)** (kWh/ha)	**Soil-irrigation water use (square root)** (m^3/en-terprise)	**Soil-irrigation water use (square root)** (m^3/t)	**Soil-irrigation water use (square root)** (m^3/irrigated ha)
Explained variance (%)	82.4	78.0	11.3	69.8	36.2	24.3	65.2	26.9	13.4
Significant explanatory variables ($p<0.05$)	**Direction**								
area under production (log) (ha)	+	–							
area under production (ha)				+					
area under soil-irrigation (log) (ha)							+	+	
region	*	*	*		*				
area under production (ha)·region	*	*							
soil-irrigation water use (m3/irrigated ha)				+	+	+			
frost-control water use (m3/controlled ha)					+	+			
soil-irrigation water use (m3/irrigated ha)·area under production (ha)				+					
rainfall (square root) (mm)									–
yield (t/ha)							–	–	–
measurement of evapotranspiration								–	–
measurement of soil moisture								+	+
use of computer irrigation-modelling							+		
yield (t/ha)·rainfall (mm)·region							*	*	*

Log follows the equation: $Log_{10}(X+1)$.
Square root follows the equation: $(X+1)^{1/2}$.
** Direction depends on the specific factor*
Blank spaces indicate non-significant variables or variables not included in the models.

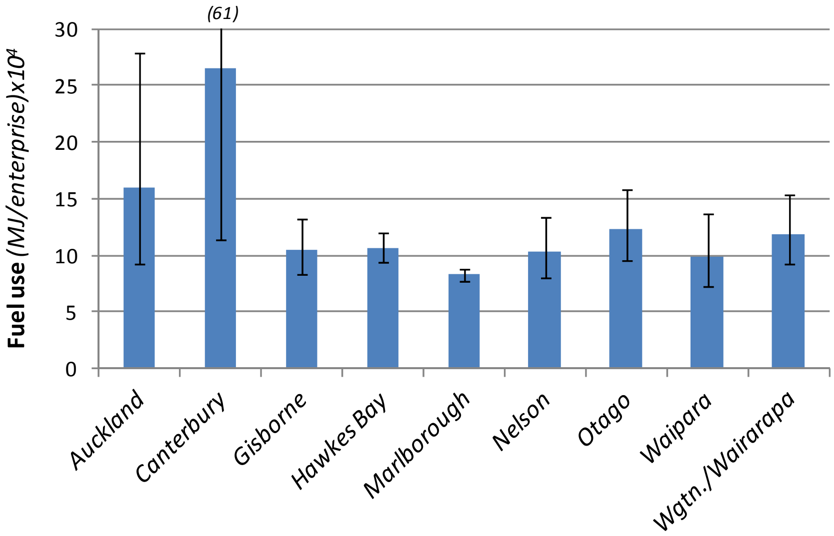

Figure 10. Region associations with fuel use per enterprise after effects of production area have been taken into account. The error bars here and in subsequent figures show 95% confidence intervals.

Best models explained 70, 36 and 24% of the variation in electricity use per enterprise, per tonne of grapes produced and per hectare under production (Table 13). Soil-irrigation water use and frost-control water use were significant predictors ($p<0.05$). Region was a significant predictor only sporadically (once for Otago in relation to Auckland in the electricity use per tonne of grapes produced model).

Electricity use increased with increasing soil-irrigation water use and frost-control water use (Table 13 and Figure 11), because irrigation pumps are mostly driven by electric engines. Frost-control water use (water sprinkled) was only taking place in 12% of electricity users. Otago appeared to be the least electricity efficient region (Figure 11).

Best models explained 65% and 27% of the variation in soil-irrigation water use per enterprise and per tonne of grapes produced, but only 13% of the variation per hectare under irrigation (Table 13). Soil-irrigated area, yield of grapes produced, rainfall, measurement of evapotranspiration and soil moisture, computer irrigation-modelling, and interaction between production yield, rainfall and region were significant predictors ($p<0.05$).

Soil-irrigation water use per tonne of grapes produced increased logarithmically as the soil-irrigated area increased (Figure 12). There was a relatively small decrease in water use efficiency once more than 12 hectares of vineyard is being managed. About 50% of the enterprises were within this range of 0-12 ha, experiencing a rapid change in efficiency.

Soil-irrigation water use decreased with increasing production yield (Table 13).

Measurement of evapotranspiration reduced mean water use per tonne by 18% (Figure 13a). Evapotranspiration measurements aimed to assess the amount of water lost from soil evaporation and vines' transpiration to estimate crop water requirements. This measurement was performed by 27% of the analysed soil-irrigated enterprises.

Measurement of soil moisture was associated with an 18% increase in mean water use per tonne of grapes produced (Figure 13b). This measurement was performed by 55% of the analysed soil-irrigated enterprises.

The use of computer irrigation-modelling was associated with a 26% increase in mean water use per enterprise (Figure 14). This modelling was used by 15% of the analysed soil-irrigated enterprises.

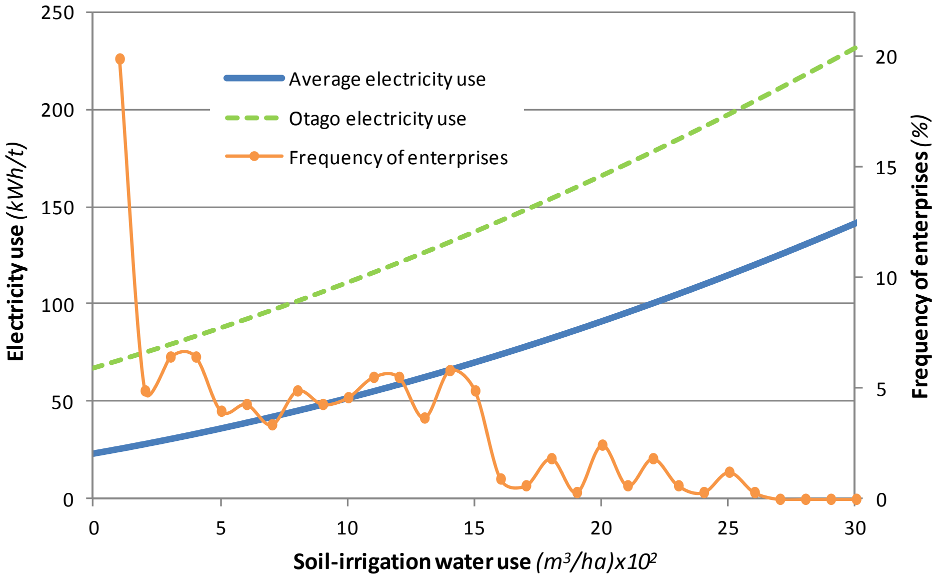

Figure 11. Soil-irrigation water use associations with electricity use per tonne of grape produced (average and Otago) after effects of production area and frost-control water use have been taken into account. The frequency distribution of soil-irrigation water use of enterprises for all dataset is presented in the right axis.

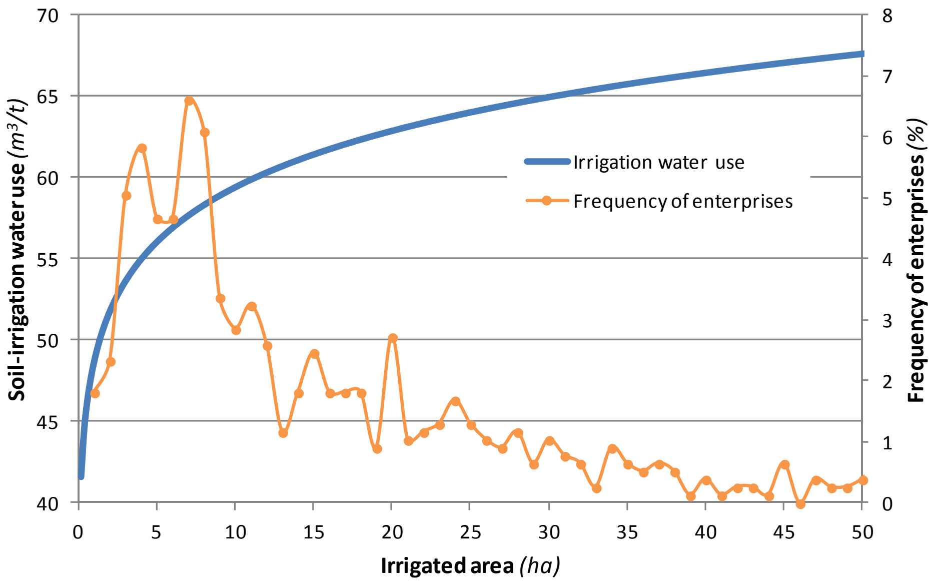

Figure 12. Soil-irrigated area associations with soil-irrigation water use per tonne of grapes produced, after effects of the other model parameters have been taken into account. The frequency distribution of soil-irrigated area of enterprises is presented in the right axis.

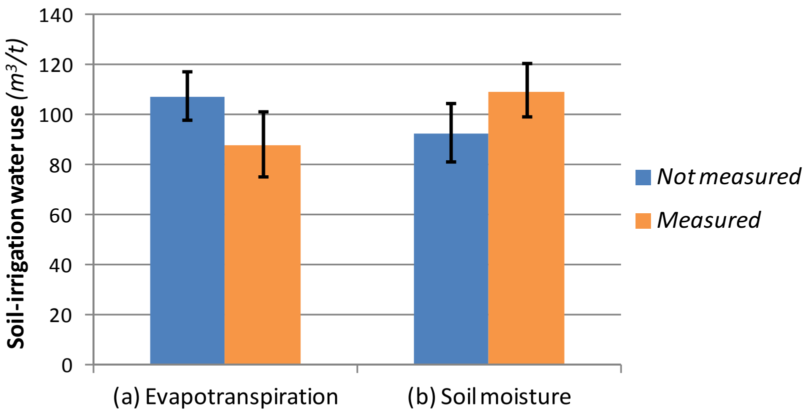

Figure 13. Measurement of (a) evapotranspiration and (b) soil moisture for estimating irrigation requirements associations with soil-irrigation water use per tonne of grapes produced, after effects of the other model parameters have been taken into account.

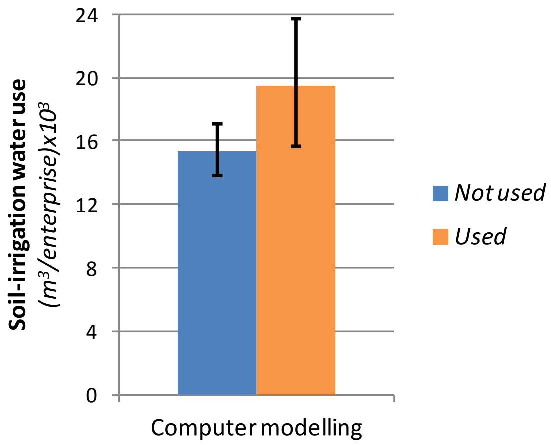

Figure 14. Use of computer modelling for estimating irrigation requirements associations with soil-irrigation water use per enterprise, after effects of the other model parameters have been taken into account.

5.3.1 Modelling resource use variation between seasons

The best models explained 75% and 18% of the variance in fuel use change between seasons per enterprise and per hectare (Table 14). Region, instigation of energy reduction plans in the 2011 season, number of vineyards per enterprise and change in number of vineyards were significant predictors ($p<0.05$).

Auckland showed large increases in fuel use in the 2012 season compared to the 2011 one, whereas average fuel use decreased at Waipara and Nelson over the same period (Figure 15).

Table 14. Summary of the regression models for resource use change between 2012 and 2011 seasons. This presents the models explained variance, the significant explanatory variables and their direction (for full descriptions see Appendix A tables A4 to A6).

Response variable	**Fuel use change** (L/enterprise)	**Fuel use change** (L/ha)	**Electricity use change** (kWh/enterprise)	**Electricity use change** (kWh/ha)	**Soil-irrigation water use change** (m^3/enterprise)	**Soil-irrigation water use change** (m^3/irrigated ha)
Explained variance (%)	75.4	17.8	29.6	19.6	16.1	5.8
Significant explanatory variables (p<0.05)	**Direction**					
area under production change (ha)	+					
area under production (ha)			–			
area under soil-irrigation change (ha)					+	
area under soil-irrigation (ha)					–	
region	*	*	*	*		
number of vineyards per enterprise	–					
number of vineyards per enterprise change	+					
number of vineyards·area (ha)	+					
number of vineyards change·area change (ha)	+					
energy reduction plans in the 2011 season		–				
soil-irrigation water use change (m^3/irrigated ha)·energy reduction plans change			–			
soil-irrigation water use change (m3/irrigated ha)			*	*		
measurement of evapotranspiration in the 2011 season					–	–
measurement of soil moisture change						–
yield in the 2012 season (t/ha)· rainfall (mm)·region					*	*

** Direction depends on the specific factor*
Blank spaces indicate non-significant variables or variables not included in the models.

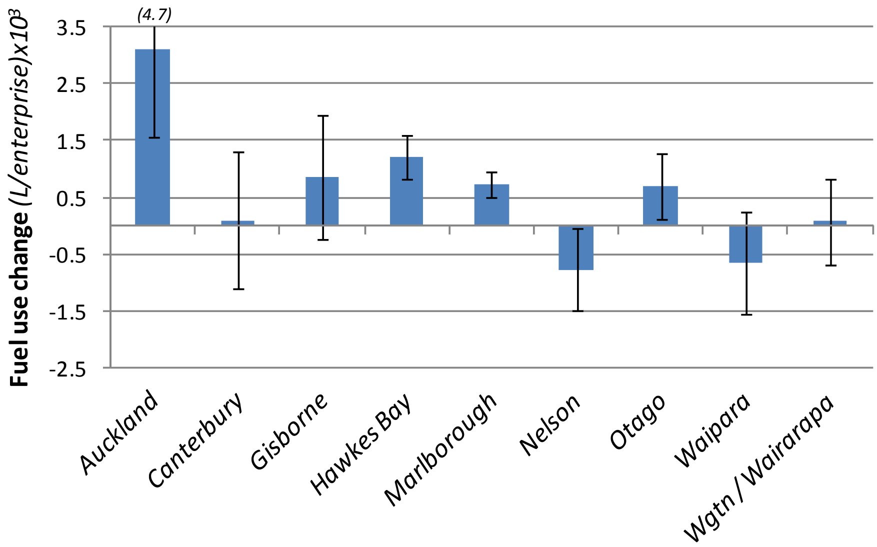

Figure 15. Regional differences in fuel use change per enterprise between 2011 and 2012 seasons after effects of the other model parameters have been accounted.

Enterprises instigating energy reduction plans or actions in the 2011 season still increased their fuel use in the following season, but not by as much as enterprises with no energy conservation plans or actions (Figure 16). This equated to a 59% decrease in fuel use per hectare for enterprises with a fuel reduction plan, a considerable improvement in efficiency. Eighty-four percent of the enterprises mentioned that they had instigated energy reduction plans or actions in the 2011 season. There is no evidence ($p>0.05$) that enterprises with higher fuel use per enterprise or lower use efficiency are more likely to have instigated such plans/actions.

Enterprises which added more vineyards to their enterprise between years accordingly increased fuel use, whereas enterprises with larger number of vineyards were associated with a lower fuel use increase between 2011 and 2012 seasons (Table 14).

Best models explained 30 and 20% of the variance of the electricity use change between seasons per enterprise and per hectare (Table 14). Production area, change in soil-irrigation water use and the interaction between change in energy reduction plans and change in soil-irrigation water use were significant predictors ($p<0.05$). Region was a significant predictor only sporadically (once for Nelson).

Electricity use change between seasons per enterprise decreased linearly with production area; accordingly, larger production areas were associated with smaller electricity use increases over time (Figure 17).

Those vineyards instigating energy reductions plans in 2011, but not in 2012, used 27% more electricity in the second year than vineyards instigating them in 2012 (Figure 17). There is no evidence ($p>0.05$) that enterprises with higher electricity use per enterprise or lower electricity use efficiency are more likely to have instigated such plans/actions.

Best models explained 16% of the variance of the soil-irrigation water use change between seasons per enterprise, but only 6% of the variation per hectare under irrigation

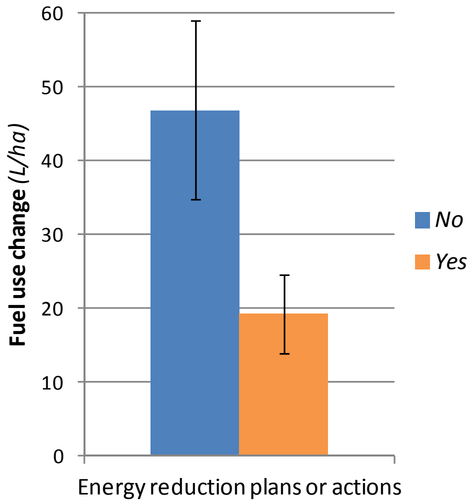

Figure 16. Fuel use change per hectare under production between 2011 and 2012 seasons for vineyards that instigated structured plans and actions for fuel conservation, after effects of the other model parameter have been accounted.

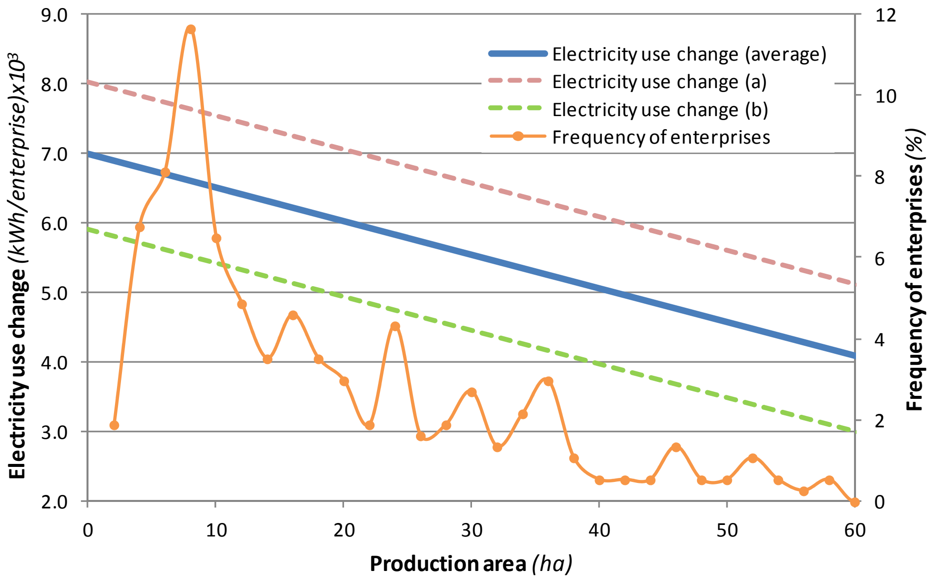

Figure 17. Electricity use change per enterprise between 2011 and 2012 seasons for vineyards with and without energy reduction plans, after effects of the other model parameters have been taken into account. (a) refers to those enterprises instigating energy reduction plans/actions in 2011, but not in 2012; (b) refers to those enterprises not instigating them in 2011, but instigating them in 2012.

(Table 14). Soil-irrigated area, measurement of evapotranspiration in the 2011 season, change in measurements of soil moisture and interaction between production yield, rainfall and region were significant predictors ($p<0.05$).

Soil-irrigation water use change between seasons per enterprise decreased linearly with increasing irrigated area (Table 14), i.e. there was greater reduction in water use between the two years on vineyards with a larger irrigation area (Figure 18).

Measurement of evapotranspiration in 2012 was associated with about 25% improvement in water use efficiency per enterprise in successive seasons compared to those enterprises that did not measure evapotranspiration (Figure 18). Enterprises with higher water use are more likely to perform such measurements (significant difference between soil-irrigation water use means ($p<0.05$)).

Measuring soil moisture in 2011, but not in 2012, was associated with about 50% increases in water use per hectare in the second season compared to those enterprises measuring soil moisture in 2012 (Figure 19). Enterprises with higher water use are also more likely ($p<0.05$) to perform such measurements.

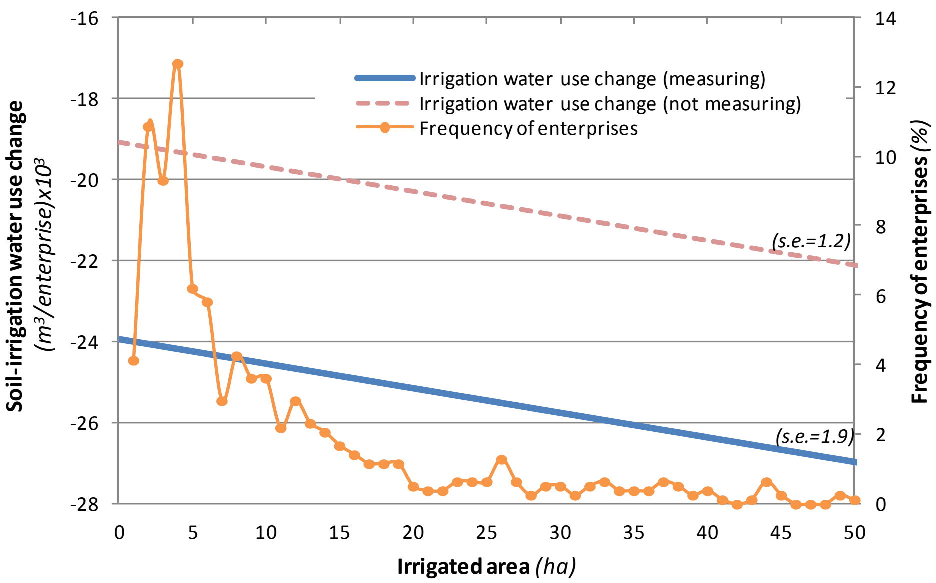

Figure 18. Soil-irrigation use change per enterprise between 2011 and 2012 seasons in relation to irrigated area and whether or not the vineyard measured evapotranspiration in 2012, after effects of the other model parameters have been taken into account.

5.3.2 Locally tuned benchmarking

Different benchmarking approaches affected the rank scores of individual vineyards to a great degree (Figures 20 to 22). For example, the enterprise "A" ranked near the 20% of the vineyards with lower fuel use benchmark from the entire (national) SWNZ sector (Figure 20); but it was near the top (75%) when compared only with enterprises of the same region and similar production area. In other cases the opposite effect occurred. For

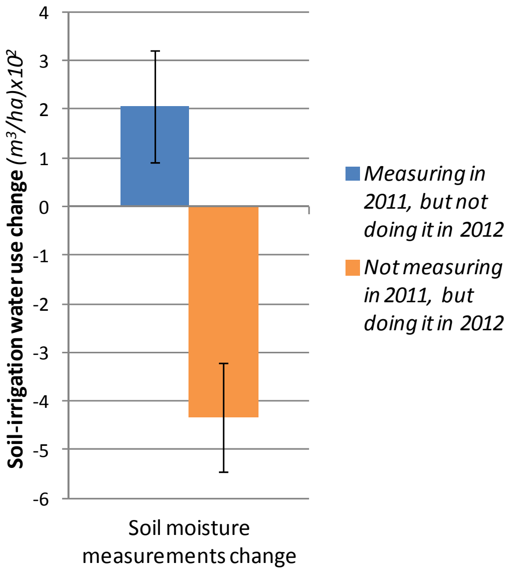

Figure 19. Soil-irrigation water use change per hectare under production between 2011 and 2012 seasons for (a) enterprises performing soil water measurements in 2011, but not in 2012, and (b) enterprises not performing soil water measurements in 2011, but performing them in 2012.

instance, the enterprise "G" ranked near the 60% of the vineyards with lower electricity use within the entire sector, but only 30% when compared only with enterprises of the same region and similar water use (Figure 21). Water use efficiency benchmarks also showed discrepancies between locally and non-locally tuned benchmarks (Figure 22).

Performance ranks based on several relevant explanatory parameters were also different from approaches using a single parameter for benchmarking. For example, soil irrigation water use of Vineyard "K" leapt from about 62% to 82% when all four predictors of irrigation water use efficiency (region, area, yield and rainfall) were combined rather than considered separately (Figure 22).

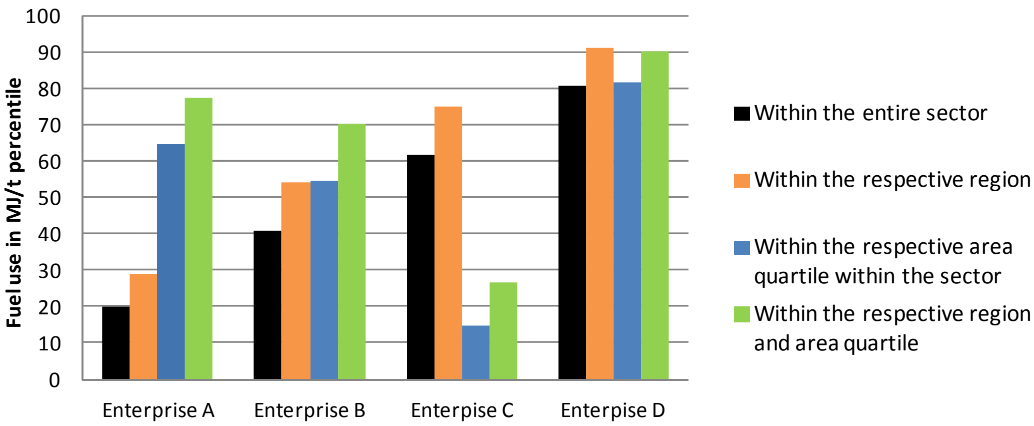

Figure 20. Effects of different benchmarking approaches on the fuel use percentile rank of the sampled vineyards.

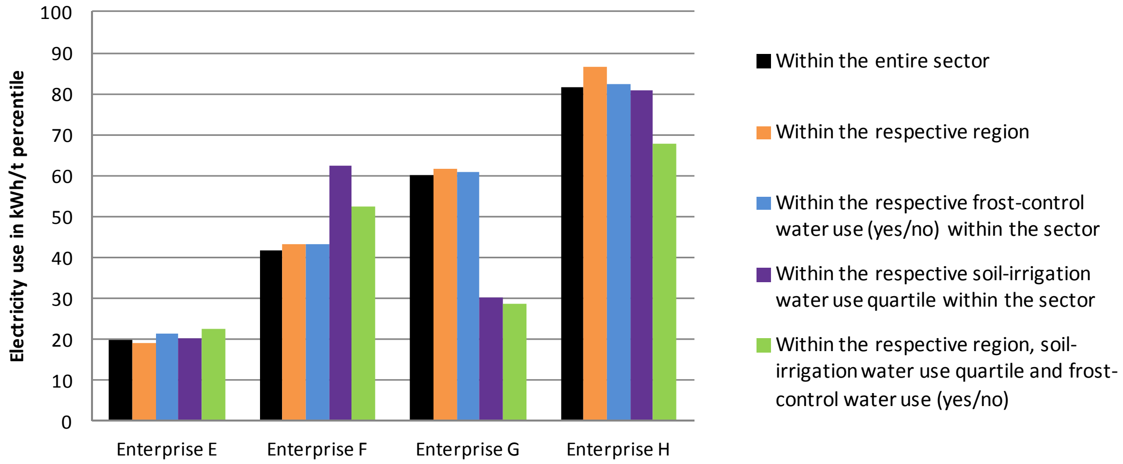

Figure 21. Effects of different benchmarking approaches on the electricity use percentile rank of the sampled vineyards.

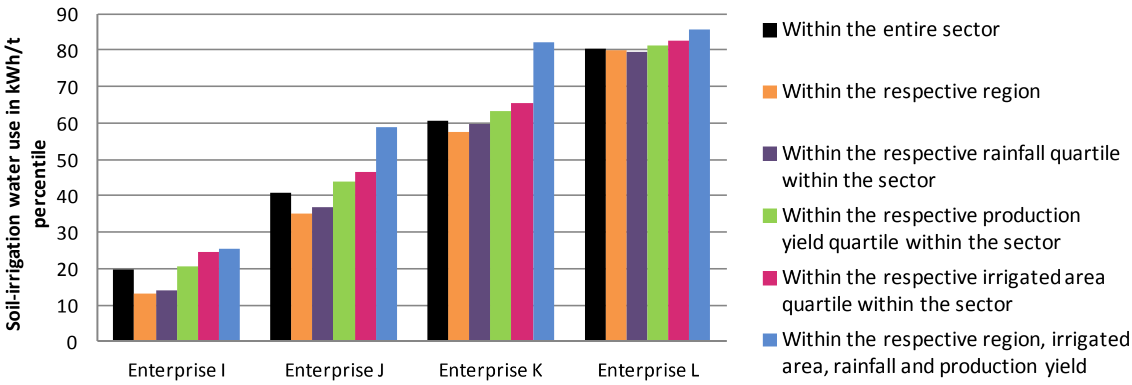

Figure 22. Effects of different benchmarking approaches on the soil-irrigation water use percentile rank of the sampled vineyards.

Within this sample of vineyards, discrepancies between locally and non-locally tuned benchmarking were generally larger for fuel than for electricity and water use efficiency (Figures 20 to 22). The effects of considering region or area were larger for fuel use efficiency. Fuel use efficiency was also the model with stronger regional and area associations in comparison with the electricity and the water use efficiency ones.

5.4 Discussion

5.4.1 Modelling resource use variation between enterprises

The results of this study have uncovered important variation in resource use efficiency within the SWNZ viticulture sector. Many of the statistical models explained relatively large proportions of the resource use variance and some strong local predictors emerged in logical directions.

Effects of agroecological and production characteristics

Fuel use efficiency was directly related to production area (Figure 9). Other studies have also found higher fuel use efficiency with increasing crop production area (Shahin et al., 2008; Pishgar-Komleh et al., 2012; Sefeedpari et al., 2013). In one of these studies, this relationship was explained by larger farms using more fuel efficient machinery (Pishgar-Komleh et al., 2012). Larger production systems can potentially invest in machinery with higher fuel efficiency and possibly higher materials handling capacity (for fertilisers, pesticides, and crop), allowing a reduction in the number of trips associated with materials charge/discharge (Hunt, 2001a).

Some enterprises using contractors potentially have more difficulties in reporting complete fuel use data. The use of contractors is likely to have been higher for larger vineyards. Some enterprises are likely to include off-vineyard fuel use for provisioning the operations (delivery of grapes to wineries, gathering supplies, transport of labourers and managers) and private purposes. Inclusion of fuel use for off-vineyard activities (or even private vehicle use if fringe benefit tax is paid) is a legitimate part of the taxation relief offered to New Zealand wine-growing enterprises. An off-vineyard fuel use add-on would represent a smaller share of the large enterprises fuel use than of the small enterprises one. Therefore, contractors unreported fuel use and off-vineyard fuel use could have contributed to the logarithmic decrease in apparent fuel use per tonne of grapes with production area depicted in Figure 9. It was conspicuous that fuel use models showed much stronger evidence of curvilinear relationships between efficiency and production area than did the models for electricity or water use, both of which involve less possibilities for off-vineyard activities.

Electricity use was associated with soil-irrigation and frost-control water use (Table 13). This is a logical result as water pumps are mostly driven by electric engines. In contrast with the fuel use models, there was no evidence that production area was a significant predictor of electricity use efficiency (Table 13).

Fuel use and electricity use associations with region (Figures 10 and 11) may be related to regional variations in grape varieties (Figure 8) and climate, and therefore subsequent differences in pesticide application needs, for example. Fuel and electricity associations with region may also be related to inter-regional differences in farming practices rather than just biophysical challenges of efficient production in an area. Some differences in practices could take place due to inter-regional differences in grape-growing traditions, farmer's networking level, infrastructure and investment capacity. A number of studies have stated that farms with higher human, social, physical and financial capital are more likely to adopt more sustainable practices and technologies (e.g. PFI, 1995; Kuyvenhoven et al., 2002; Pretty, 2002; Alston, 2012). Understanding the factors driving this variation may present opportunities to improve the overall energy use efficiency of New Zealand vineyards by locally-tuning management practices.

Enterprises with smaller irrigated areas had higher water use efficiency than those with larger irrigated areas (Figure 12). Another study analysing scale effects on water use also found higher water use efficiencies in medium scale orchards compared to larger ones (Dhehibi et al., 2012). Smaller production systems might have more precision and control over the irrigation process due to the agroecosystem complexity reduction. This theory is supported by a study finding that resource allocation and management in smaller farms are less complex and require less advanced knowledge (Edeh et al., 2009).

Lower water use for higher production yields (Table 13) may occur because yield and water use are associated via soil characteristics. Soil characteristics may be functioning as a common cause variable as they relate to soil water holding capacity, which in turn influences grape yield and water input requirements (Williams et al., 1990; Rees et al., 2010). Enhanced soil quality causing higher yields and less irrigation water use could explain the interaction we observed between production yield, region and rainfall (Table 13), because region and effective rainfall are also closely related with soil characteristics. Grape variety may also have functioned as a common cause variable between production yield and water requirements, as grape variety can affect these parameters (Babeş et al., 2010; Joshi et al., 2012).

It is important not to interpret lower water use efficiency simply as an indicator of better vineyard management, because parameters such as grape production yield and composition (and hence wine quality) define the optimal effective water needs (Babeş et al., 2010). Grape quality is a premier target of viticulture and in some situations may be inversely related with production yield (van Leeuwen et al., 2009; Babeş et al., 2010). Therefore, indicators that express resource use per tonne of grapes produced must be interpreted with caution. Driving management to maximise just resource use efficiency may undermine the sustainability performance of the enterprise in some situations.

Effects of monitoring and decision support

This study provides strong evidence that the measurement of evapotranspiration and soil moisture and the use of computer modelling tools to aid irrigation scheduling affects water use efficiency (Figures 13 and 14). Caution should be exercised before interpreting this as proof that water use has been optimised. Measurement of evapotranspiration appeared to induce less water use (Figure 13), which suggests that (a) vineyards not using evapotranspiration measurements tend to over-irrigate, or (b) the vineyards using them tend to under-irrigate. In contrast, measurements of soil moisture and use of computer irrigation-modelling appeared to induce more water use (Figure 13 and 14), which suggests that (i) vineyards not using soil moisture measurements or computer modelling tend to under-irrigate, or (j) soil moisture measurement and computer modelling leads to over-irrigation. Moreover, (k) parameters not used in the model can act as common-cause variables. For example, vineyards with higher water-holding capacity soils – which require less water consumption (Williams et al., 1990; Rees et al., 2010) – may be less likely to use soil moisture measurements and computer irrigation-modelling. Water deficits and perhaps soils with less water-holding capacity typically involve reductions in grape production yields (Reynolds et al., 1994; Rees et al., 2010; Basile et al., 2012; Junquera et al., 2012). However, we found no evidence of significant interactions between use of such decision support tools and grape production yield, which does not support the under-irrigation (b and i) and the soil quality common-cause variable hypotheses.

5.4.2 Modelling resource use variation between seasons

Effects of agroecological and production characteristics

Fuel use change between the analysed seasons showed different associations in different regions (Figure 15), which could be associated with different regional weather variations affecting management responses, such as pesticide application. The association between reductions in fuel use between the analysed seasons and reductions in the number of vineyards between the analysed seasons (Table 14) probably takes place due to the respective reductions in off-vineyard distance travelled, such as vineyard-to-vineyard vehicle use.

Reductions in electricity use between the analysed seasons for enterprises with larger production areas (Figure 17) may occur because larger production systems are more likely than smaller ones to invest in higher-capacity water pumps, which are generally more energy efficient (Mora et al., 2013). This theory is supported by the tendency that when enterprises instigate energy reduction plans, the effective electricity reductions potential is likely to be higher for enterprises with higher water use (Table 14) and potentially installing higher-capacity water pumps.

Reductions in soil-irrigation water use between the analysed seasons for larger production areas (Figure 18) suggests that system scales that are less water use efficient (the larger ones (Figure 12)) may have higher water use reduction potentials. Caution should be exercised before interpreting water use reduction as water use optimisation.

The large shifts in resource use metrics registered between the two analysed seasons emphasise the temporal dependence of grape growing. An important part of the sustainability performance of grape growing depends on optimising management and interventions to fine-tune production in the different seasons. This underlines the need for formal power analyses to estimate trends in resource efficiency and the need for gathering a long-term database before reliable trends and their drivers can be identified (Moller and MacLeod, 2013; Monks and MacLeod, 2013).

Effects of monitoring and planning for improved performance

Reductions in water use between the analysed seasons were associated with measuring evapotranspiration and measuring soil moisture in the second season (Figures 18 and 19). There is evidence that enterprises using more water are more likely to perform such measurements. Therefore, water use could have interacted as a common-cause or confounding variable.

The scorecard data have demonstrated a remarkably strong association between improved energy use efficiency and energy reduction plans/actions (Figures 16 and 17). There is no evidence ($p>0.05$) that enterprises with higher fuel use per enterprise or lower fuel use efficiency are more likely to have instigated such plans/actions, so efficiency gains from active planning were apparently effective across the board. These plans potentially included, for instance, the establishment of energy reduction targets and the investment in more energy efficient techniques and practices. However, a *post hoc* analysis of the exact wording of the respective scorecard question[2] suggests a need for caution when interpreting this result. Many farmers would believe that their actions conserve or reduce energy use. None will have intentionally wasted energy, so they are unlikely to have ticked the "No" option in the responses. This may explain the high percent (84%) of enterprises reporting that "plans/actions are in place to conserve (reduce) energy use". Nevertheless, there seems no reason why poor standardisation of the question should be aligned with a remarkable

[2] *"Plans/actions are in place to conserve (reduce) energy use".*

59% reduction in fuel use. Any fuzziness in farmers' interpretation of the question would more simply add unexplained variance. That might help explain the lack of significant associations with energy reduction plans in the spatial models (Table 13 and Appendix A tables A1 to A3). Follow-up research is needed to understand which type of plans or actions were undertaken by farmers, in order to learn what works best to reduce energy use.

5.4.3 Opportunities for improved monitoring, modelling and benchmarking

The resource use metrics being gathered by the SWNZ scorecards already offer a useful first step in defining industry goals and pointing to some potential measures for reducing resource use. However, the actual agronomic and ecological causes of the associations are still poorly understood and deserve further research.

Improving understanding of resource use efficiency may be achieved by increasing the models' explained variance. Increasing the explanatory power of the fuel use models could be achieved by, for instance, including data on soil characteristics, performed operations, and tractor's engine power, which are also associated with fuel use (Hunt, 2001b; Handler et al., 2009). The incorporation of energy use boundaries (e.g. contractors' energy use, and domestic energy use) may considerably improve the models' explained variance. Additional valuable information may include the type and characteristics of energy reductions plans/actions. There is a need for more variables to make better sense of the regional variation, such as grape varieties, and variables relating to financial, human, and social capital. In the electricity use models, additional information on the energy efficiency of water pumps may help to improve the models' explained variance. In the water use models, the incorporation of soil characteristics and grape varieties could considerably increase the explained variance. Constructing a longer-term database may help to reliably identify trends and develop models explaining larger proportions of resource use change over time.

There is some evidence of reporting mistakes potentially associated with measurement-units mistakes. Measures for minimising sampling and reporting mistakes and errors, such as better guidance and audits, are likely to increase the model's explanatory power. From 2014, a new data collection and reporting system called WiSE (Wine Industry Sustainability Engine) will be introduced. This system has the ability to set limits, either based on an expected range or as a percentage of a members' previous response.

Reliable monitoring and modelling of farmers' collective data can lead to the identification of the local mechanisms driving performance and effective optimisation measures (as seen in the case of instigating energy reduction plans). Then, closing the loop and communicating back to individual farmers the collective lessons, in conjunction with locally-tuned benchmarking, may allow the identification of the "room for improvement" of the individual farmer.

5.4.4 Locally tuned benchmarking

The models' results have shown that farm sustainability indicators, such as energy and water use efficiency in New Zealand vineyards, can be significantly associated with local agroecological and production related features. The benchmarking results (Figures 20 to 22) have shown that benchmarks considering these features can create very different sets of "sustainable" and "unsustainable" vineyards. A vineyard can score a low rank when compared with the entire sector, while a high rank when using individually-tuned comparisons (e.g. Figure 20G). In this case, non-locally tuned benchmarks do not capture the local and diverse challenges faced by the individual farmer and will not allow for locally tuned sustainability improvements. A vineyard can also score a high rank when compared with the entire sector, while a low rank when using individually tuned comparisons (e.g. Figure 21A). In this case, the non-locally tuned high scores will not provide incentives to improve sustainability, even though significant opportunities still exist. In both cases, farmers will be permanently consigned to either the bottom or top ends of the ranking, which will not allow trend analysis and the consequent learning.

Nevertheless, the use of non-locally tuned benchmarks may be more appropriate for stakeholders at wider-levels of action (e.g. policy makers and regulators, consumers) in order to steer, for instance, land use changes (e.g. by only incentivising the most resource efficient regions) or market shifts (e.g. by only buying and hence incentivising the most resource efficient products). Moreover, benchmarks accounting for a diversity of local features might confuse stakeholders operating at wider-levels. Sustainability benchmarking becomes a complex exercise, which may have political and socioeconomic implications, as well as effects on the sustainability-learning exercise. This demonstrates a need to clearly define the goals of the monitoring exercise at the outset, so the benchmarking level can be matched to the primary agendas of the decision-makers.

Understanding the drivers behind sustainability indicators is essential for designing effective benchmarks to incentivise improvements at the individual enterprise level. For this purpose, it is necessary to monitor a representative sample (or entire population) of enterprises within the analysed sector (e.g. SWNZ vineyards) and to build models with a sufficiently high power to explain the respective sustainability indicators variance. Subsequently, it is important to distinguish between features that are manageable and non-manageable by the enterprise decision maker, to enable the design of benchmarks tuned to the scope of action of the decision maker. In the example of water use, individual farm improvements can be best incentivised by using benchmarks comparing water use efficiency metrics between enterprises that are matched for soil type, irrigated area, region and rainfall, which are water use explanatory features that are outside the scope of action of the farmer. In contrast, the use of evapotranspiration and soil moisture measurements and computer irrigation-modelling, which are optional features of a farmer's management, should be left out of the water use efficiency comparison process. The proposed approach requires datasets with a very high sample size or complete coverage because locally tuned ranks involve ranking within data subsets. The SWNZ scorecards provide a remarkable opportunity for reliable inference and locally-tuned benchmarking precisely because a very high proportion of the New Zealand vineyards are participating.

The use of benchmarks accounting for local farming challenges and potentials may enhance farmers' identification and trust to the sustainability exercise, increasing participation and encouraging the adoption of new practices. Farmers' identification and trust can also be enhanced in such benchmarks because the performance target is not imposed by external decision makers (e.g. governmental agencies or scientists); as stated by Reed et al. (2006) for the case of designing indicators.

Benchmarking approaches only incentivise improvements within the limits of the existing performance of the analysed sector, but not within its actual potential based on the current state of knowledge and technology. As a consequence, incentivising improvements is less likely when analysing sectors with a relatively poor sustainability performance. However, a progressive improvement of the sector performance may be reached by a continuous loop of benchmarked performance reporting from the sustainability tool to the individual farmer (Figure 23 (1)) and performance change reporting from the individual farmer to the sustainability tool (Figure 23 (3)) for all sector farms. This can lead to the delivery of benchmarks approaching more and more the actual farms potential, assuming that reporting benchmarked performance with the aid of decision support contributes to farmers learning and practice change (Figure 23 (2)).

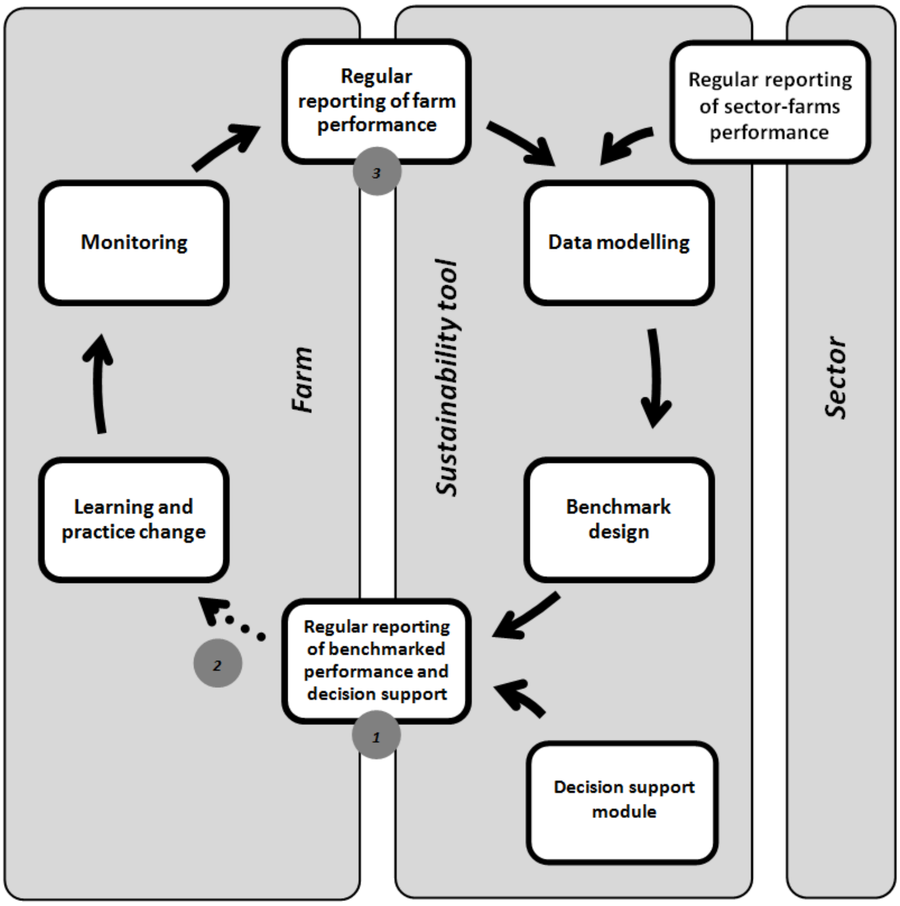

Figure 23. Benchmarking framework for incentivising individual farm performance improvements

5.5 Conclusions

The results of this study demonstrate that analysing the factors driving spatial and temporal variation in resource use can provide important opportunities for improving the performance of New Zealand wine-growing enterprises. Sustainability indicators, such as energy and water use efficiency in New Zealand vineyards are significantly associated with local agroecological and production related features, many of which cannot be managed by the farmer. Region and production scale are frequent drivers of resource use efficiency.

Even the first prototypes of wine-growing scorecards demonstrate significant improvements in energy use efficiency when energy conservation plans are instigated. Longer term monitoring, together with enhanced collection of context indicators that predict local constraints and enablers of efficient agriculture, will be extremely valuable for a proper accountability and verification of sustainability credentials and, most of all, learning for sustainability in the New Zealand wine industry.

Different benchmarking approaches considerably affect the rank scored by a specific enterprise and potentially have different political and socioeconomic implications. Non-locally tuned benchmarks do not capture the local and diverse challenges faced by the individual farmer and may impair incentivisation for improvement. On the other hand, locally-tuned benchmarks can better inform about actual sustainability improvement opportunities and may enhance farmers' trust in the sustainability exercise, improve participation and better incentivise change towards sustainability.

Chapter 6

GENERAL REFLECTIONS AND CONCLUSIONS

6.1 Introduction

Setting the context-specificity level of a sustainability assessment framework often implies a number of tradeoffs that affect the practicality and the usefulness of the assessment. For example, context-generic frameworks may be unable to incorporate context-specific features, limiting locally-tuned sustainability improvements, and may constrain the assessment results integrity and local stakeholders' engagement. On the other hand, context-specific frameworks may limit the possibilities for standardisation and results benchmarking and tend to be more resource intensive (Chapters 3, 4 and 5).

The general aim of this thesis was to develop a rationale for balancing the level of context-specificity and -generality of sustainability assessment frameworks in order to optimise these tradeoffs and hence effectively and efficiently assess and incentivise the sustainability of agricultural systems. This study has focused on three key sustainability assessment components: themes (targeted sustainability objectives), data, and benchmarks (relative reference values of sustainability performance). These components were chosen due to their relevance for assessment practicality and usefulness, and because there is currently a research gap in these areas. The specific research questions were:

1. How can an optimised level of specificity, in terms of practicality and usefulness, be set for (i) assessment themes and (ii) assessment data?
2. How can sustainability benchmarks be designed to accommodate context-specific opportunities and constraints for incentivising locally-tuned sustainability improvements?

To address these questions, a number of case studies have been analysed, from a variety of settings, i.e. different geographies (Denmark and New Zealand), politico-economic arenas (regulated and neoliberal), production systems (bioenergy and food production from arable farming to horticulture), and levels of assessment (value chain, product/technology and sector). Different settings were selected in order to develop an approach that is sensitive to a relatively wide range of sustainability challenges present in the global agricultural sector. For instance, different geographies and productions systems can experience diverse sustainability issues (e.g. food security issues caused by the production of energy-crops, or irrigation water use in drier climate zones). Different politico-economic arenas require different mechanism to incentivise sustainability (e.g. governmental regulatory/subsidy driven, or voluntary and market driven). Different levels of assessment are associated with a range of assessment framework types (e.g. targeted at the farm or national level).

This chapter combines the findings of the different case studies and discusses synergies between them, in order to establish the general reflections and conclusions of the thesis. Section 6.2 provides a summary of the main findings of the previous chapters and presents an overall rationale for balancing the level of specificity and generality of sustainability assessment frameworks. Section 6.3 describes the implications of the thesis findings and further research opportunities. Section 6.4 presents a new assessment framework paradigm to boost sustainability action by reconciling specificity and generality.

6.2 A rationale for balancing specificity and generality

This research shows that a sustainability assessment framework with a one-size-fits-all specificity level is not applicable. Rather, the specificity level should be tailored to the respective assessment setting (Chapters 3, 4 and 5). The specificity level should be established independently for the different framework components (themes, sub-themes, indicators, data and benchmarks) because these can differ in terms of context-sensitivity and function.

Chapter 3 presents a rationale for setting an optimised specificity level for assessment themes (research question 1(i)). This rationale recommends tailoring the specificity-level of the themes and sub-themes (and indicators) to (i) benchmarking requirements (e.g. market comparisons, regional comparisons, none) and (ii) context-characteristics coverage precision requirements. This rationale proposes three assessment frameworks types (i.e. generic, mixed and specific) depending on the assessment setting. Generic themes may be used in any framework type without impairing effectiveness in covering context characteristics if the current themes-sets are sufficiently enhanced. Generic sub-themes may also be used in the environmental dimension of any framework type without impairing the coverage effectiveness. However, specific sub-themes should be used in the other sustainability dimensions when it is necessary to cover context-characteristics and benchmarking is not required. When designing sub-themes special attention should be given to issues involving stakeholders that are more indirectly related to the main organisation or product under analysis, as these issues comprise some of the major coverage gaps found in this study.

Chapter 4 presents a rationale for setting an optimised specificity level for assessment data (research question 1(ii)). This rationale recommends tailoring the data specificity-level to (i) the available assessment resources, (ii) the overall assessment purpose (e.g. compare, optimise), and (iii) the individual data-inputs sensitivity and process-type (e.g. market supplies, common processes). This rationale differentiates between three data-specificity components (i.e. site, technology, and time). Site-generic data may be considered when local components do not affect assessment results or when there are no concerns about significant impacts at a local scale. Moreover, technology-generic data may be considered when the assessment aims to represent a variety of systems within more global contexts (e.g. industry, nation, market) and time-generic data when variability over time is not expected. The use of tools such as sensitivity analysis (for delimiting the use of more specific data) and uncertainty analysis (for determining the importance of data inaccuracies) can help to minimise the impact of data inventory limitations in an efficient manner.

Chapter 5 suggests tailoring the benchmarks specificity-level to (i) the targeted sustainability-action level (e.g. individual farm, industry, or global market) and (ii) individual indicators context-sensitivity. Context-specific benchmarks (benchmarks accounting for the performance potentials of the individual organisation) should be considered for incentivising improved performance at the organisation level, and especially for highly context-sensitive indicators (e.g. irrigation water use efficiency in New Zealand vineyards). On the other hand, context-generic benchmarks (universal benchmarks comparing organisations or products) are likely to be more practical when a wider-level of action is involved. Chapter 5 presents a rationale for designing benchmarks that accommodate context-specific opportunities and constraints for sustainability improvement (research question 2). This benchmarking approach consists of comparing organisations matched for parameters that (i) explain the sustainability performance variation within the sector and (ii) are outside the decision-maker targeted scope of action.

Figure 24 links the themes, data and benchmarks findings and presents a concept map of the factors to consider for setting an optimal context-specificity level of sustainability assessment frameworks in terms of practicality and usefulness. The overall factors that have the greatest influence on the specificity-level choice are the assessment purpose and the available resources. These two factors define the context-specific characteristics coverage requirements, which in turn contribute to set the specificity-level of all analysed framework components (themes, sub-themes, indicators, benchmarks and data) (Figure 24). Moreover, the context-sensitivity of the framework components (e.g. environmental sub-themes, or common process data-inputs) defines the context-specific characteristics coverage requirements. The assessment purpose defines the benchmarking requirements, which in turn contribute to setting the specificity-level of themes, sub-themes, and indicators. The assessment purpose also defines the targeted sustainability-action level (e.g. individual farm, industry, or global market), which in turn sets the benchmarks specificity-level. Therefore, (i) the setting of a sound assessment purpose, (ii) a proper analysis of the available resources, and (iii) a transparent reporting of both (i and ii), may facilitate the design of more optimal sustainability assessment frameworks.

The proposed rationale for setting the assessment specificity-level recommends some degree of stakeholder participation (Figure 24) (Chapters 3 and 4). Stakeholder dialog should target issues such as reflection on benefits and drawbacks of each framework design options and prospective assumptions. This approach may help to minimise biases in setting the assessment specificity-level, improve stakeholder's sustainability education, help with the interpretation of assessment results, and enhance assessment adoption, trust and ultimately sustainability action.

6.3 Looking ahead with specificity and generality

This research contributes to advances in the development of more practical and useful sustainability assessment frameworks. Specifically, this research establishes (i) guiding principles for sustainability assessment practitioners in order to set more appropriate context-specificity levels and (ii) a basis for sustainability assessment researchers to further advance the state-of-the-art of sustainability assessment.

Further research opportunities include the validation of the proposed rationales in different contexts. For example, generic themes coverage could be analysed in different geographical and production system settings, such as in developing countries, where sustainability issues may differ. Data requirements could be analysed in assessment exercises that are more dependent on local conditions, such as in the development of regional agricultural policies. Locally tuned benchmarking could be analysed in more global and product-diversified accreditation and regulatory schemes at the global market level, where the practicality of the current approach may differ in terms of communication capacity and data compilation and model building possibilities. Further research could also extend the proposed rationales into different sustainability indicators and dimensions, specifically the economic and social dimensions in the data and benchmarking rationales. An important research priority is to include testing the power of the proposed frameworks to incentivise stakeholders' learning and sustainability actions. Moreover, further research could extrapolate the proposed rational and guiding principles into a framework to practically set the level of specificity during the design process of sustainbility assessment frameworks.

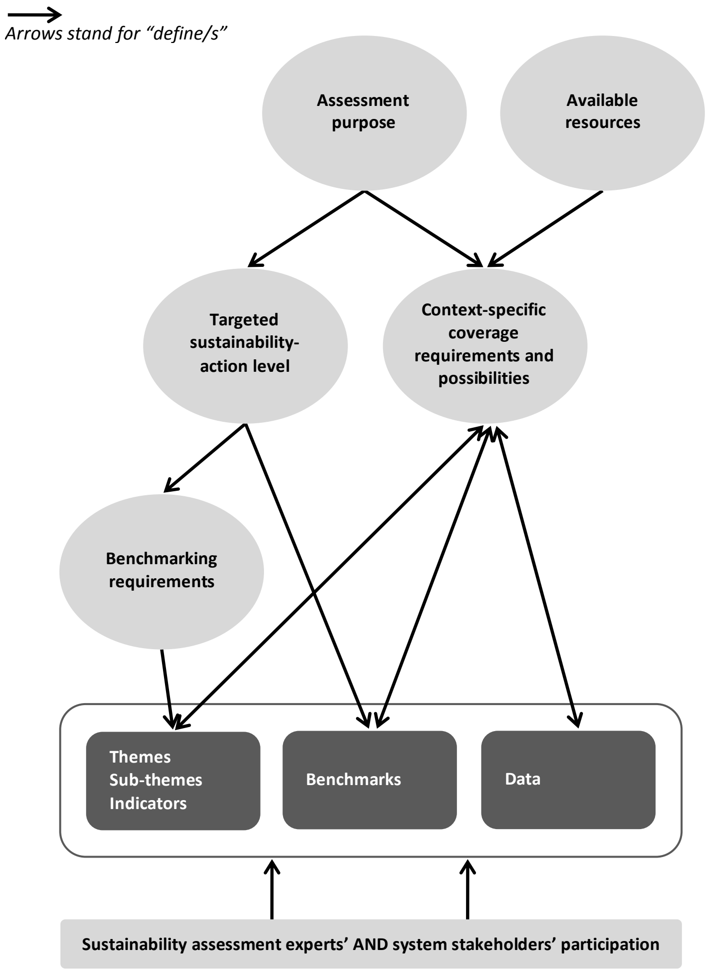

Figure 24. Concept map of factors to consider when setting an optimal context-specificity level of sustainability assessment components (themes, sub-themes, indicators, benchmarks, and data) in terms of practicality and usefulness (arrows stand for "define/s")

6.4 Reconciling specificity and generality for sustainability action

Opportunities for agricultural sustainability improvements are available at both global and local levels (e.g. global market, nation, or individual farms). At a more global level, improvements can be achieved by global shifts in general aspects of farming approaches (e.g. organic, extensive, and biodynamic) through regulations and accreditation schemes and changes in consumer behaviour. On the other hand, at a local level, improvements can be achieved by addressing specific potentials and constraints within the individual production sites (Chapter 5).

Local stakeholders, such as farmers, call for case-specific and stakeholder-designed (bottom-up) frameworks (Fraser et al., 2006). However, these types of frameworks may not fulfil global standardisation and benchmarking demands for guiding sustainability at wider-levels of action and covering global sustainability issues (Chapter 3). For example, farmers may be more concerned about production efficiency and management issues within the farm, than their individual contribution to climate change or global food security. On the other hand, the concerns of stakeholders at wider-levels of action, such as consumers, governments and industries, impose universal and more externally-designed (top-down) frameworks (Fraser et al., 2006). However, these types of frameworks may eclipse the local and diverse issues and challenges faced by individual stakeholders (Chapters 3 and 5) and hence impair their potential for locally-tuned sustainability improvements as well as their production and marketing possibilities. Moreover, these frameworks present a risk of having little acceptance and weak influence on key local decision-makers (e.g. farm managers) because they tend to resonate less with the local stakeholders' concerns. They may even be seen as more of a threat (benchmarking and compliance) than a learning and improvement opportunity. The framework acceptance of stakeholders may be especially important in less regulated politico-economic contexts, such as New Zealand, in which sustainability improvements rely more on voluntary actions. Considering these challenges, an important question arises: How can we satisfy local and global demands at the same time?

Conventional sustainability assessment practices tend to view the concepts of specificity and generality as incompatible (e.g. Binder et al., 2010). This study challenges the validity of this premise and proposes a paradigm shift from the "Vs" to the "And". Exploring the potential for compatibility between specificity and generality may help to better fulfil both local and the global demands within a single assessment framework.

An example of an approach that applies the *And* paradigm arose from the pilot-studies lessons of the Sustainability Assessment of Food and Agriculture (SAFA) test-version (Manhire et al., 2013). These pilot-studies propose the combination of (i) default indicator sets for granting some level of global standardisation, and (ii) context-customised indicators for granting a more nuanced display of locally-tuned potentials and progress. In the finalised SAFA framework (FAO, 2013a), from a five scale performance rating (best, good, moderate, limited and unacceptable), default indicators/criteria are used to provide the ratings for best and unacceptable performances, and open context-customised indicators for intermediate performance levels.

Chapter 3 also applies the *And* paradigm by proposing frameworks combining both context-specific and -generic themes and sub-themes. This approach will help to enhance standardisation possibilities and the inclusion of more global sustainability issues for fulfilling global demands, while better covering context-specific issues and potentially enhancing local stakeholders' acceptance and engagement.

Chapter 5 applies the *And* paradigm by proposing a locally-tuned benchmarking rationale. This rationale could be the basis for a more profound reconciliation between specificity and generality: to better inform global stakeholders for making decisions with more ethical and constructive implications at the local level.

Chapters 3, 4 and 5 also follow the *And* paradigm by proposing a sensibly balanced participation of both local stakeholders (bottom-up) and external/global experts (top-down) during the framework design or selection process, the assessment process, and the post-assessment evaluation process. Some degree of top-down decision-making may help to guide sustainability on a sufficiently large scale, while bringing consciousness to local stakeholders about their global implications. In addition, some degree of bottom-up decisions may help to include the local and diverse issues faced by individual stakeholders as well as to develop local stakeholders' sense of ownership, which may enhance trust, education, and ultimately sustainability action of key local decision-makers (e.g. farm managers (Chapter 5)).

Figure 25 presents a summary of findings for improved fulfilment of both local and global demands within a single assessment framework.

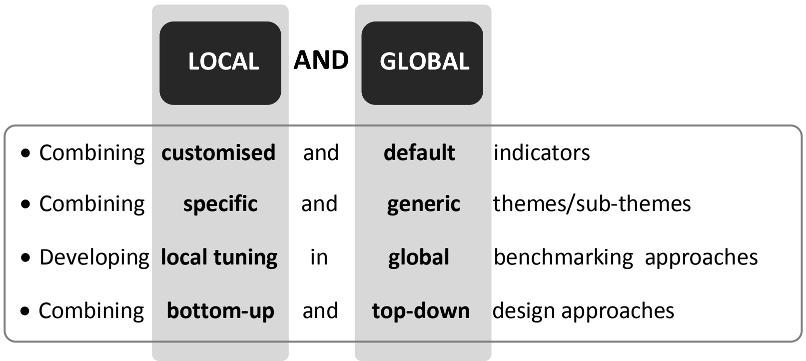

Figure 25. Summary of findings for improved fulfilment of both local and global demands within a single assessment framework.

If sustainability assessment tools are not designed for the purpose of putting sustainable development into practice, they will lose their utility and will remain an academic paradigm. Therefore, sustainability assessment should go far beyond a mere measuring exercise. It should be a tool used to better connect stakeholders (e.g. consumers and producers; scholars and farmers) and to enhance learning, consciousness change, and sustainability action.

AFTERWORD

Some time before this project was born, a myriad of doubts and questions arose in my mind after meeting for first time the concept of "sustainability assessment": Can we really grasp the essence of something as vast and uncertain as sustainability? Can we really measure it? Is sustainability assessment not just a "utopia"?

Curiously, a few weeks before this research started, all these doubts transformed into clarity and motivation for deepening in this area. It all happened while a beautiful quote from the Argentinian filmmaker Fernando Birri appeared in front of me:

Utopia is like the horizon.
If we walk one step ahead,
it will move one step ahead.
No matter how far we walk,
we will never reach it.
What, then, is the purpose of it?
The purpose of utopia is that
– to keep us walking.

I hope this long and winding road may have some part to play, however minor, in helping to rethink sustainability assessment practice and, most of all, keep us walking towards a better world.

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APPENDIX A:
Resource use regression models from New Zealand vineyards

Table A1. Regression models for fuel use in the 2011/2011 season

Response variable, Y	Fuel use (log) *MJ/enterprise*			*MJ/t*			*MJ/ha*		
Explained variance (%)	82.4			78.0			11.3		
Explanatory model, X_i	b_i	*se*	*p*	b_i	*se*	*p*	b_i	*se*	*p*
constant	**3.965**	**0.083**	**<.001**	**3.844**	**0.103**	**<.001**	**128.8**	**6.170**	**<.001**
area under production (log) (ha)	**1.172**	**0.041**	**<.001**	**-1.151**	**0.049**	**<.001**			
region-Auckland	ref			ref			ref		
region-Canterbury	**-0.606**	**0.132**	**<.001**	**-0.472**	**0.158**	**0.003**	**-41.15**	**9.940**	**<.001**
region-Gisborne	**-0.374**	**0.099**	**<.001**	**-0.784**	**0.121**	**<.001**	**-42.91**	**7.680**	**<.001**
region-Hawkes Bay	**-0.346**	**0.088**	**<.001**	**-0.551**	**0.106**	**<.001**	**-42.14**	**6.630**	**<.001**
region-Marlborough	**-0.483**	**0.083**	**<.001**	**-0.869**	**0.101**	**<.001**	**-52.43**	**6.320**	**<.001**
region-Nelson	**-0.391**	**0.101**	**<.001**	**-0.567**	**0.121**	**<.001**	**-46.25**	**7.840**	**<.001**
region-Otago	**-0.381**	**0.090**	**<.001**	**-0.446**	**0.109**	**<.001**	**-43.85**	**7.050**	**<.001**
region-Waipara	**-0.385**	**0.117**	**0.001**	**-0.370**	**0.141**	**0.009**	**-41.96**	**8.720**	**<.001**
region-Wgtn./Wairarapa	**-0.321**	**0.105**	**0.002**	**-0.387**	**0.127**	**0.002**	**-38.64**	**7.730**	**<.001**
area (ha)·region-Auckland	-0.005	0.004	0.196	-0.007	0.005	0.163			
area (ha)·region-Canterbury	**0.018**	**0.007**	**0.006**	0.008	0.008	0.274			
area (ha)·region-Gisborne	0.000	0.001	0.970	0.001	0.001	0.137			
area (ha)·region-Hawkes Bay	-0.001	0.001	0.366	0.000	0.001	0.521			
area (ha)·region-Marlborough	0.000	0.001	0.776	**0.002**	**0.000**	**<.001**			
area (ha)·region-Nelson	0.000	0.001	0.825	0.001	0.002	0.690			
area (ha)·region-Otago	0.002	0.002	0.280	0.002	0.002	0.322			
area (ha)·region-Waipara	0.000	0.001	0.682	0.000	0.001	0.990			
area (ha)·region-Wgtn./Wairarapa	0.000	0.002	0.981	0.000	0.002	0.855			
number of vineyards·area (ha)	0.000	0.000	0.369						
energy reduction plans·area (ha)	-0.001	0.001	0.261						
energy reduction plans				-0.010	0.035	0.787			
Outliers removed	2			4			10		
Dropped potential variables	number of vineyards, energy reduction plans, sustainable suppliers preference, diesel/total fuel ratio, diesel/total fuel ratio·area, diesel/total fuel ratio· number of vineyards			number of vineyards, sustainable suppliers preference, diesel/total fuel ratio, number of vineyards·area, energy reduction plans·area, diesel/total fuel ratio·area, diesel/total fuel ratio· number of vineyards			number of vineyards, energy reduction plans, sustainable suppliers preference, diesel/total fuel ratio, area·region, number of vineyards·area, energy reduction plans·area, diesel/total fuel ratio·area, diesel/total fuel ratio· number of vineyards		

The model follows the formula: $Y=\Sigma(b_i \cdot X_i)$
Log: follows the equation: $Log_{10}(X+1)$.
bi: slope of the model parameter i; se: standard error; p: probability value; ref.: reference factor.
Energy reduction plans: refers to the existence of available or instigated plans to reduce energy use. The reference factor of this parameter is No plans. Sustainable suppliers preference: refers to the existence of preference to select fuel suppliers on the basis of sustainability standards. The reference factor of this parameter is No preference.
Blank spaces indicate parameters not included in the models.

Table A2. Regression models for electricity use in the 2011/2011 season

Response variable, Y	**Electricity use (square root)**								
	kWh /enterprise			***kWh /t***			***kWh /ha***		
Explained variance (%)	69.8			36.2			24.3		
Explanatory model, X_i	b_i	*se*	*p*	b_i	*se*	*p*	b_i	*se*	*p*
constant	**31.05**	**4.790**	**<.001**	**3.520**	**1.220**	**0.004**	**11.30**	**2.980**	**<.001**
area under production (ha)	**0.826**	**0.087**	**<.001**	0.010	0.006	0.062			
soil-irrigation water use (m^3/irrigated ha)	**0.016**	**0.005**	**0.001**	**0.003**	**0.000**	**<.001**	**0.006**	**0.001**	**<.001**
frost-control water use (m^3/controlled ha)	0.008	0.004	0.063	**0.001**	**0.000**	**0.005**	**0.002**	**0.001**	**0.020**
soil-irrigation water use (m^3/irrigated ha)·area (ha)	**0.000**	**0.000**	**<.001**	0.000	0.000	0.258			
region-Auckland				ref			ref		
region-Canterbury				3.210	2.460	0.193	4.540	6.690	0.498
region-Gisborne				-0.430	1.540	0.781	-2.960	3.920	0.451
region-Hawkes Bay				0.690	1.330	0.607	-1.470	3.280	0.654
region-Marlborough				-0.540	1.280	0.676	-1.540	3.120	0.622
region-Nelson				-1.720	1.740	0.325	-3.710	4.370	0.397
region-Otago				**4.210**	**1.430**	**0.004**	4.370	3.580	0.223
region-Waipara				0.940	1.760	0.592	1.000	4.140	0.809
region-Wgtn./Wairarapa				0.600	1.550	0.698	-0.880	4.010	0.827
Outliers removed	9			10			7		
Dropped potential variables	energy reduction plans, region, soil- irrigation water use·energy reduction plans, frost-control water use·area			energy reduction plans, soil-irrigation water use·energy reduction plans, frost-control water use·area			energy reduction plans, soil-irrigation water use·energy reduction plans		

The model follows the equation: $Y=\Sigma(b_i \cdot X_i)$
Square root: follows the equation: $(X+1)^{1/2}$.
bi: slope of the model parameter i; se: standard error; p: probability value; ref.: reference factor
Energy reduction plans: refers to the existence of available or instigated plans to reduce energy use. The reference factor of this parameter is No plans.
Blank spaces indicate parameters not included in the models.

Table A3. Regression models for soil-irrigation water use in the 2011/2011 season

Response variable, Y	Soil-irrigation water use (square root)								
	m^3/enterprise			*m^3/t*			*m^3/irrigated ha*		
Explained variance (%)	65.2			26.9			13.4		
Explanatory parameters, X_i	***b_i***	***se***	***p***	***b_i***	***se***	***p***	***b_i***	***se***	***p***
constant	26.60	57.00	0.640	**20.41**	**3.780**	**<.001**	**48.99**	**9.870**	**<.001**
area under soil-irrigation (log) (ha)	**169.8**	**5.950**	**<.001**	**0.735**	**0.374**	**0.050**			
yield (t/ha)	**-11.90**	**5.300**	**0.025**	**-1.248**	**0.347**	**<.001**	**-2.729**	**0.916**	**0.003**
rainfall (square root) (mm)	-11.47	6.890	0.096	-0.765	0.456	0.094	**-2.750**	**1.210**	**0.024**
Measurement of evapotranspiration	-9.420	5.920	0.112	**-0.986**	**0.384**	**0.010**	**-2.240**	**1.020**	**0.028**
Measurement of soil moisture	9.590	5.720	0.094	**0.851**	**0.373**	**0.023**	**3.693**	**0.946**	**<.001**
Use of computer irrigation-modelling	**15.59**	**7.450**	**0.037**						
yield (t/ha)·rainfall (mm)·region-Canterbury	0.028	0.150	0.849	-0.004	0.010	0.680	0.006	0.026	0.816
yield (t/ha)·rainfall (mm)·region-Gisborne	0.177	0.112	0.116	0.012	0.007	0.103	**0.048**	**0.020**	**0.015**
yield (t/ha)·rainfall (mm)·region-Hawkes Bay	0.042	0.083	0.615	0.002	0.005	0.677	0.019	0.014	0.180
yield (t/ha)·rainfall (mm)·region-Marlborough	**0.176**	**0.089**	**0.049**	0.011	0.006	0.060	**0.046**	**0.015**	**0.003**
yield (t/ha)·rainfall (mm)·region-Nelson	0.099	0.053	0.061	0.005	0.003	0.189	**0.021**	**0.009**	**0.021**
yield (t/ha)·rainfall (mm)·region-Otago	0.158	0.993	0.113	**0.013**	**0.007**	**0.043**	**0.047**	**0.017**	**0.007**
yield (t/ha)·rainfall (mm)·region-Waipara	**0.233**	**0.109**	**0.033**	0.011	0.007	0.141	**0.047**	**0.019**	**0.013**
yield (t/ha)·rainfall (mm)·region-Wgtn./Wairarapa	0.015	0.082	0.850	0.001	0.005	0.882	0.015	0.014	0.285
Outliers removed	11			10			5		
Dropped potential variables	Measurement of rainfall, visual assessment of soil moisture, visual assessment of vines water requirements, assessment of weather predictions data, additional water-reduction plans			Use of computer irrigation-modelling, measurement of rainfall, visual assessment of soil moisture, visual assessment of vines water requirements, assessment of weather predictions data, additional water-reduction plans			Use of computer irrigation-modelling, measurement of rainfall, visual assessment of soil moisture, visual assessment of vines water requirements, assessment of weather predictions data, additional water-reduction plans		

The model follows the equation: $Y=\Sigma(b_i \cdot X_i)$
bi: slope of the model parameter i. se: standard error. p: probability value.
Square root follows the equation: $(X+1)^{1/2}$; and Log the equation: $Log_{10}(X+1)$.
The reference factor of the assessment- and planning-related parameters is No assessment/planning.
Rainfall: average rainfall of the key soil-irrigation months for each region.
Blank spaces indicate parameters not included in the models.

Table A4. Regression models for fuel use change between 2011/2012 and 2010/2011 seasons

Response variable, Y	**Fuel use change**					
	L/enterprise			***L/ha***		
Explained variance (%)	75.4			17.8		
Explanatory model, X_i	b_i	*se*	*p*	b_i	*se*	*p*
constant	**4537**	**1537**	**0.003**	**645.1**	**80.20**	**<.001**
area under production change (ha)	**73.10**	**20.50**	**<.001**			
region-Auckland	ref			ref		
region-Canterbury	**-3626**	**1840**	**0.050**	**-578.4**	**87.00**	**<.001**
region-Gisborne	-2858	1774	0.108	**-567.1**	**84.70**	**<.001**
region-Hawkes Bay	-2772	1494	0.065	**-591.3**	**80.00**	**<.001**
region-Marlborough	**-3158**	**1465**	**0.032**	**-604.7**	**79.40**	**<.001**
region-Nelson	**-3810**	**1604**	**0.018**	**-592.9**	**82.00**	**<.001**
region-Otago	**-3096**	**1543**	**0.046**	**-594.1**	**80.80**	**<.001**
region-Waipara	**-4203**	**1677**	**0.013**	**-617.0**	**83.40**	**<.001**
region-Wgtn./Wairarapa	-2845	1608	0.078	**-619.3**	**82.10**	**<.001**
number of vineyards change·area change (ha)	**39.43**	**5.650**	**<.001**			
number of vineyards·area (ha)	**10.59**	**1.530**	**<.001**			
number of vineyards	**-547.0**	**183.0**	**0.003**			
number of vineyards change	**746.0**	**357.0**	**0.038**			
energy reduction plans in 2012	-722.0	424.0	0.090			
energy reduction plans in 2011				**-27.70**	**13.40**	**0.040**
Outliers removed	10			13		
Dropped potential variables	area, energy reduction plans change, energy reduction plans in 2011, sustainable suppliers preference, diesel/ total fuel ratio			number of vineyards, number of vineyards change, energy reduction plans change, energy reduction plans in 2012, sustainable suppliers preference, diesel/total fuel ratio		

The model follows the formula: $Y=\Sigma(b_i \cdot X_i)$

bi: slope of the model parameter i; se: standard error; p: probability value; ref.: reference factor.

Energy reduction plans: refers to the existence of available or instigated plans to reduce energy use. The reference factor of this parameter is No plans. Sustainable suppliers preference: refers to the existence of preference to select fuel suppliers on the basis of sustainability standards. The reference factor of this parameter is No preference.

Area and Number of vineyards is the average of both seasons. Suppliers preference refers to 2010/2011 season data. Diesel/total fuel ratio refers to 2010/2011 season data.

Models per tonne of grapes produced were not compiled due to lack of data in the 2010/2011 season.

Blank spaces indicate parameters not included in the models.

Table A5. Regression models for electricity use change between 2011/2012 and 2010/2011 seasons

Response variable, Y	**Electricity use change**					
	kWh/enterprise			***kWh/ha***		
Explained variance (%)	29.6			19.6		
Explanatory model, X_i	b_i	*se*	*p*	b_i	*se*	*p*
constant	-1153	8301	0.890	-28.00	188.0	0.881
area under production (ha)	**-48.30**	**19.80**	**0.016**			
soil-irrigation water use change (m^3/ irrigated ha)·energy reduction plans change	**-12.80**	**3.560**	**<.001**			
soil-irrigation water use change (m^3/ irrigated ha)	**2.590**	**1.250**	**0.041**	**0.133**	**0.034**	**<.001**
region-Auckland	0.000	*	*	0.000	*	*
region-Canterbury	ref			ref		
region-Gisborne	664.0	14242	0.963	285.0	326.0	0.385
region-Hawkes Bay	-1750	8638	0.840	-80.00	197.0	0.686
region-Marlborough	-1211	8349	0.885	-80.00	190.0	0.675
region-Nelson	**72587**	**12943**	**<.001**	**559.0**	**260.0**	**0.034**
region-Otago	6237	9065	0.493	151.0	218.0	0.489
region-Waipara	-6930	9972	0.489	-304.0	220.0	0.170
region-Wgtn./Wairarapa	-61.00	9292	0.995	-163.0	210.0	0.439
energy reduction plans change	-4337	2758	0.119			
area under production change (ha)	147.7	99.50	0.141			
Outliers removed	8			11		
Dropped potential variables	soil-irrigation water use, energy reduction plans in 2011, energy reduction plans in 2012			soil-irrigation water use, soil-irrigation water use change, energy reduction plans change, energy reduction plans in 2011, energy reduction plans in 2012, soil-irrigation water use change·energy reduction plans change		

The model follows the equation: $Y=\Sigma(b_i \cdot X_i)$

*bi: slope of the model parameter i; se: standard error; p: probability value; ref.: reference factor; *: not computed because the parameter is aliased with terms already in the model.*

Energy reduction plans: refers to the existence of available or instigated plans to reduce energy use. The reference factor of this parameter is No plans.

Area and Irrigation water use is the average of both seasons.

Models per tonne of grapes produced were not compiled due to lack of data in the 2010/2011 season.

Blank spaces indicate parameters not included in the models.

Table A6. Regression models for soil-irrigation water use change between 2011/2012 and 2010/2011 seasons

Response variable, Y	**Soil-irrigation water use change**					
	m^3/enterprise			***m^3/irrigated ha***		
Explained variance (%)	16.1			5.8		
Explanatory parameters, X_i	***b_i***	***se***	***p***	***b_i***	***se***	***p***
constant	**7927**	**3482**	**0.023**	198.0	117.0	0.090
area under soil-irrigation change (ha)	**368.9**	**70.10**	**<.001**			
area under soil-irrigation (ha)	**-60.70**	**22.40**	**0.007**			
measurement of evapotranspiration in 2011	**-4859**	**2297**	**0.035**	**-134.2**	**67.50**	**0.048**
measurement of soil moisture change				**-319.0**	**108.0**	**0.003**
yield in 2012 (t/ha)·rainfall (mm)·region-Canterbury	**-301.4**	**55.70**	**<.001**	**-6.050**	**1.710**	**<.001**
yield in 2012 (t/ha)·rainfall (mm)·region-Gisborne	1.600	26.10	0.950	1.104	0.801	0.169
yield in 2012 (t/ha)·rainfall (mm)·region-Hawkes Bay	**-22.47**	**9.210**	**0.015**	**-0.738**	**0.371**	**0.047**
yield in 2012 (t/ha)·rainfall (mm)·region-Marlborough	**-12.40**	**6.290**	**0.049**	-0.322	0.195	0.100
yield in 2012 (t/ha)·rainfall (mm)·region-Nelson	**-31.81**	**8.550**	**<.001**	0.025	0.507	0.961
yield in 2012 (t/ha)·rainfall (mm)·region-Otago	-21.90	16.10	0.173	-0.704	0.540	0.193
yield in 2012 (t/ha)·rainfall (mm)·region-Waipara	-19.70	24.70	0.427	-0.848	0.771	0.272
yield in 2012 (t/ha)·rainfall (mm)·region-Wgtn./Wairarapa	-29.10	16.70	0.081	-0.264	0.621	0.670
rainfall change(mm)				-9.580	5.820	0.100
Outliers removed	10			12		
Dropped potential variables	yield in 2012, rainfall change, rainfall (square root), measurement of evapotranspiration change, measurement of soil moisture change, measurement of soil moisture in 2011, measurement of soil moisture in 2012, measurement of evapotranspiration in 2012, additional water-reduction plans			yield in 2012, rainfall (square root), measurement of evapotranspiration change, measurement of soil moisture in 2011,measurement of soil moisture in 2012, measurement of evapotranspiration in 2012, additional water-reduction plans		

The model follows the equation: $Y=\Sigma(b_i \cdot X_i)$
bi: slope of the model parameter i; se: standard error; p: probability value.
The reference factor of the assessment- and planning-related parameters is No assessment/planning.
Rainfall: average rainfall of the key soil-irrigation months for each region.
Area and Rainfall data is the average of both seasons.
Models per tonne of grapes produced were not compiled due to lack of data in the 2010/2011 season.
Blank spaces indicate parameters not included in the models.

APPENDIX B:
List of publications carried out during the PhD research period

Publications and reports included in the main part of the thesis

Gasso, V.; Oudshoorn, F.W.; de Olde, E.; Sørensen, C.G. Generic sustainability assessment themes and the role of context: the case of Danish maize for German biogas. Ecological Indicators 2014, 49, pp 143-153.

Gasso, V.; Oudshoorn, F.W.; Sørensen, C.G.; Pedersen, H.H. An Environmental Life Cycle Assessment of Controlled Traffic Farming. Journal of Cleaner Production 2014, 73, pp 175-182.

Gasso, V.; Barber, A.; Moller, H., Oudshoorn, F.W.; Sørensen, C.G. Benchmarking for locally tuned sustainability: the case of energy and water use in New Zealand vineyards. Aarhus University, Agribusiness Group and University of Otago. June 2014.

Other publications carried out during the PhD research period

Barber, A; Gasso, V.; Moller, H.; Manhire, J.; Oudshoorn, F.W.; Sørensen, C.G. Eco-verification and incentivising improvement using the New Zealand Sustainability Dashboard: benchmarking energy and water efficiency in New Zealand wine production. In proceedings of The 29th International Horticultural Congress, August 2014, Brisbane, Australia.

Cannon, C.; Gasso, V.; Rosin, C.; Skeaff, S. Greenhouse gas emissions of the meat and meat alternatives food group consumed in New Zealand: Dietary changes to reduce individual carbon footprint. Manuscript submitted for publication, July 2014.

Gasso, V.; Barber, A.; Moller, H.; Manhire, J.; Oudshoorn, F.W. Measuring energy sustainability in global and local agricultural systems: Sustainable Winegrowing New Zealand assessed by the SAFA framework. In proceedings of The Energy Conference, Energy at the Crossroads. February 2013, Wellington, New Zealand.

Manhire, J.; Barber, A.; Gasso, V.; Moller, H.; Reid, J. Four SAFA trials from New Zealand (memo to SAFA development team of the Food and Agriculture Organisation of the United Nations). Research report: IN 13/20. Agriculture Research Group on Sustainability, February 2013, Christchurch, New Zealand.

Gasso, V.; Sørensen, C.G.; Oudshoorn, F.W.; Green, O.; Controlled Traffic Farming: A review of the environmental impacts. European Journal of Agronomy 2013, 48, pp 66-73.

Gasso, V.; Jakobsen, C.; Oudshoorn, F.W. Role-plays for learning sustainability - paths towards ethical, critical, systemic and transdisciplinary thinking. In proceedings of SETAC 18th, Sustainability Assessment in the 21st century, Tools, Trends & Applications. November 2012, Copenhagen, Denmark.

Green, O.; Bartzanas, T.; Løkke, M.M.; Bochtis, D.D.; Sørensen, C.G.; Jørgensen, O.J.; Gasso, V. Spatial and temporal variation of temperature and oxygen concentration inside silage stacks. Biosystems Engineering 2012, 111 (2), pp 155-165.

Gasso, V.; Sørensen, C.G.; Oudshoorn, F.W.; Bochtis, D.D.; An environmental evaluation of agricultural in-field traffic and tillage practices. In proceedings of CIOASTA Conference, Efficient and safe production processes in sustainable agriculture and forestry. July 2011, Vienna, Austria. pp 79-81.

Wiebensohn, J.; Sambra, A.; Gasso, V.; Information flow in organic and conventional agriculture. In proceedings of the NJF Seminar 441, Automation and System Technology in Plant Production. July 2011, Herning, Denmark. pp 40-41.