Sustainability assessment of agro-ecological innovations at territorial and value chain scale

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Abstract: With growing awareness of global environmental problems caused by agricultural production, producers and retailers increasingly strive to introduce sustainability led changes at farm level. A propagation of cooperative approaches has led to a diversity of niche developments worldwide with multiple but small-scale effects on sustainable land use. The potential for a broader impact is often inhibited by the failure to appropriate the value creation necessary for a long term establishment in the market. The study reported here was conducted as an intermediate step in developing assessment and management tools for innovations in a smallholder farm environment. Semi-structured interviews were analysed based on network analysis, content analysis and case comparison in order to answer the following questions: (i) what environmental, economic or social values are expected from the innovation as a contribution to sustainable land use?; and (ii) what is the potential and what are the limits of integrating sustainability assessment into innovation management processes in regard to value chain and territorial approaches? Ethical issues and diversification in farm structure were found more relevant to the sector oriented approach of poultry production. The regional case differed in highlighting consensual strategies, a strong recognition of future generations, property rights and provision making. Issues of local added value, closed circular systems and capacities for development were found to link both territorial and value chain approaches. The approach is discussed for its potential in making explicit the societal and environmental value creation and for fulfilling aspects of plausibility and applicability by the practitioners involved in the project.

Keywords: Sustainability, innovation management, content analysis, transdisciplinary research, agricultural innovation, value chain

Introduction

With growing awareness of global environmental problems caused by agricultural production, producers and retailers increasingly strive to introduce sustainability led changes at farm level. From a consumer-oriented perspective the willingness to pay for sustainable production of food has increased in Europe over the recent years (de-Magistris & Gracia, 2016; Vecchio & Annunziata, 2015). This development fuels the legitimate expectation that sustainability led changes in agricultural production can contribute to the development of new opportunity recognitions and entrepreneurship by finding new ways of production and creatively developing alternative markets.

Previous studies in ecological economics suggest that competitive advantage in changing environments is determined by employing dynamic and entrepreneurial capabilities rather than by valuable, rare or inimitable resources (Newbert, 2007, Alvarez & Busenitz, 2001, Porter, 1985). An assessment of resource combinations for responsible innovations in small and medium enterprises calls for new business models that source from collaboration in multi-actor networks (Halme & Korpela, 2013). A propagation of cooperative approaches in recent years has led to a diversity of agriculture-based niche developments worldwide with multiple but small-scale effects on sustainable land management (e.g. Little et al., 2010). The potential for a broader impact is often inhibited by the failure to appropriate the value creation necessary for a long term establishment in the market. The development of new products is challenged by not reaching a competitive advantage over conventional management practices.

The overall objective of the study reported here was to assess the potentials and limitations of integrating sustainability assessment into innovation management processes. The question is addressed in the frame of a transdisciplinary project accompanying an ongoing innovation process for two case studies in north-eastern Germany. The first case aims at using surplus biomass for small-scale thermal production in wet grasslands. This will be enabled by a cooperative production strategy by pooling wet grassland farm area in the Biosphere Reserve Spree Woods/Błota in the federal state of Brandenburg. In the second case, smallholder farmers aim to realise the value of traditional quality breeds produced in a mixed poultry production system. This is explored through joint marketing of eggs and meat in Brandenburg and Berlin via Naturland Marketing, a trading farmer association for organic farmers. Semi-structured interviews were analysed based on network analysis, content analysis and case comparison in order to answer the following questions:

What environmental, economic or social values are expected from the innovation as a contribution to sustainable land use?

What is the potential and what are the limits of integrating sustainability assessment into innovation management processes in regard to value chain and territorial approaches?

Agro-ecological innovation

Agro-ecological initiatives born in the organic movement aim to extend the use of local resources as an alternative to the mainstream regime of industrialised agriculture (Barbier & Elzen, 2012; Wezel et al., 2009). Activities often involve practices that call for low factor inputs per land unit, thereby favouring farm systems in regions with low yield potential or traditional cultivation practices.

The creation of alternative production practices as a new form of agriculture requires a comprehensive approach that differs for example from approaches of transforming conventional to organic farming by depending on multi-level and multi-actor cooperation to a larger extent, e.g. due to missing linkages with supply chains. Similar to processes of radical innovations, value realisation of innovative sustainable land management practices is challenged by quantity effects in implementation (economies of scale) as well as efficiency constraints in production and marketing. In regions, where value chains have adapted more or less completely to agricultural systems that follow the rules of economies of scale, alternative production systems find themselves in a situation where they are “too big to ignore, but too small to survive” (personal communication - smallholder farmer). Positive impacts at a landscape level (spatial effects) then depend on coordinated and overlapping strategies between actors, e.g. in distribution and marketing. An improved linkage to supply chains (sector effects) depends e.g. on interaction of actors between sectors based on spatial proximity. Furthermore, an achievement of synergies as well as access rights to resources requires interaction between stakeholder groups previously unrelated in production practice. Termed system innovation (Elzen et al., 2004; Geels, 2005), these type of innovations were found to encompass technological change by requiring a broad change process including adaptations in farm management, the production system or the business model as well as new combinations of resources allocations. Figure 1 illustrates the analytical framework for the assessment of farms that in order to develop new production processes are faced with constraints that can be partly explained by theories from small enterprise development (Glover et al., 2016, Porter, 1985), and partly with theories from adoption of sustainable management practices (Schot & Geels, 2008).

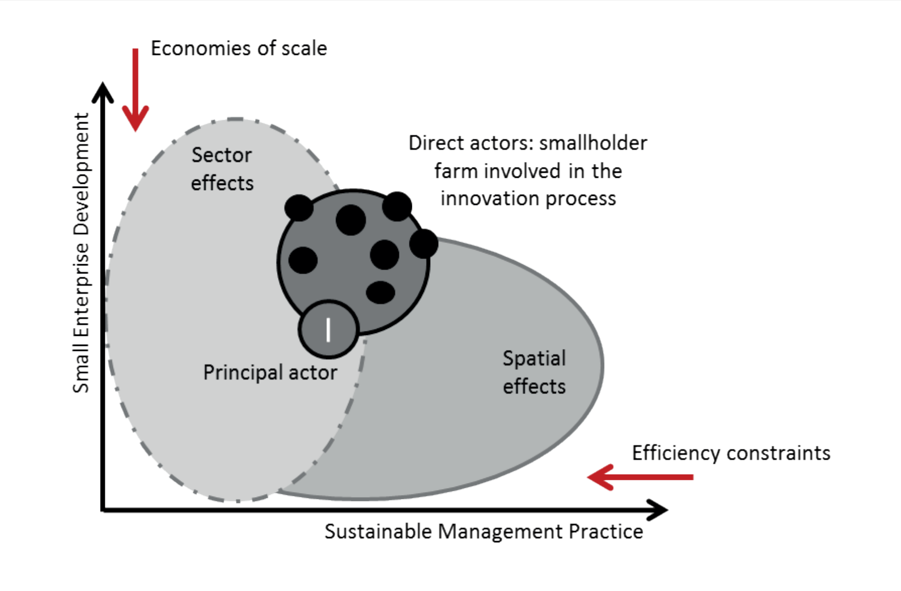

Figure 1. Agro-ecological innovation systems influenced by economies of scale and efficiency constraints *(Author's illustration)*

Linking impacts at territorial and value chain scale

Traditional environmental impact assessment of production processes on farms generally targets spatial criteria. Units are based on ha of land, and impacts are often measured in emissions or effluents. Agro-ecological indicators for an optimisation of integrated farming systems have been developed for example by Bockstaller et al. (1997). These indicators estimate the impact of cultivation practices on the environment, and enable farmers to adapt their cultivation practices to the requirements of an integrated farming system, from one cropping year to the next. Successive tools for assessing environmental, economic and social aspects of sustainable management practices in farming systems have differentiated between sustainability at farm-level and contributions to sustainable development at a regional scale (Ghadban et al., 2013).

Assessments in innovation processes on the other hand are often related to the value chain. Units are generally described per kg of product, such as in life cycle assessments (Lindner et al., 2010), while evaluations additionally put a strong focus on the stakeholders linked to the product (Sieber et al., 2015). An integration of the supply chain perspective and the production site with its natural environment remains a challenge due to trade-offs between the different characteristics of scope (Schader et al., 2014).

Method

The study of agriculture based innovations for sustainable land use was conducted in north-eastern Germany in a range of up to 300 km from Berlin. Economic activity declines with distance from Berlin, and the main area is characterised by agriculture, coal mining, renewable energies, and increasingly tourism. Agricultural practice is dominated by large farm enterprises with an average size of 238 ha, which is four times the German average. Grain, field forage and oil seed make up relevant crops in terms of land use. In light of current price developments, farms on marginal areas face increasing challenges to operate profitably in the long term. The overall development calls for economically viable alternatives based on innovative approaches. Often these are developed in a niche market environment, for example by making use of a demand for local, organic or high-quality products in the urban environment of Berlin.

The integration of two ongoing innovation management processes into a transdisciplinary research project on sustainable land use was the starting point of the analysis. The innovation in both cases was a combination of a product based on a new type of production process that is perceived as sustainable, and an organisational innovation based on a new form of cooperation between actors. In the first case, local farmers aim to explore the use of surplus biomass for small-scale thermal production in wet grasslands by implementing a joint strategy enabled by pooling smallholder farm land. In the second case, smallholder farmers in the poultry sector cooperate with Naturland Marketing, a marketing platform for organic farmers, in order to realise the value of traditional quality breeds based on mixed poultry production systems.

The overall approach is defined by participatory action research, characterised by the joint solution-oriented collaboration between practitioners and researchers (Pelenc et al., 2015; Padilla & Filho, 2012; McIntyre, 2008). The aim was to facilitate the development of the innovation towards higher market relevance and to achieve long term establishment of the innovation outside its initial niche. The process was being driven by practitioners while the role of the researchers was to reflect, assess and consult during the process of development and adaptation. The study reported here was conducted as an intermediate step in developing tools for an assessment of innovations for sustainable land use.

Case comparison and data collection

In both case studies, sustainable management practices were introduced that can be described in terms of innovative change. Both case studies stand out due to their setting and situation:

- the innovation process is based in the agricultural sector and is in a phase of a conceptual or actual proof-of-concept;
- the sustainable management practice implicates additional costs that require compensation. The break-even threshold was not reached at individual farm level, mainly because additional benefits were not acknowledged by consumers. This component, however, was not clearly defined by the stakeholders at the outset of this study;
- the stakeholders were not aware of benchmark figures, instruments for resources planning or tools for integrated assessments such as RISE (Grenz, 2013) or SMART (Schader et al., 2016). A production process “as is” has either phased out or did not exist from the start. In consequence, we found that the actors themselves employed

no heuristic instruments for a quantified assessment of resources, outcomes or impacts e.g. based on book-keeping data.

Two main data collection methods were applied in the study, namely key informant interviews and focus group discussions. For each case study we conducted an on-site inspection together with actors involved in the innovation process followed by a transdisciplinary focus group workshop with experts from practice, and a workshop for reflection with researchers from different fields of sustainability science. Open-ended interviews were conducted with people linked to the innovation as well as additional stakeholders from each sectoral and regional surrounding areas. The interviews were taped and transcribed. Focus group discussions and excursions were documented by protocols and used additionally to understand interactions and relationships between actors. Data was analysed by content analysis and case comparison to identify the value perceptions of actors linked to the innovation.

Key informant interviews

Semi-structured interviews with open questions were conducted for both case studies. In regard to sustainability value perceptions, a response to questions can differ between open and closed questions. The question: “What do you associate with sustainability?” posed as an open question will often be responded to by an individual interpretation of the concept of sustainability, while a closed question may lead to socially expected responses.

Actors for the interviews were identified by their proximity to the innovation process via network analysis. Actors were categorised at three different levels of cooperation (Table 1).

A **principal actor** was identified who is closely linked to the idea or invention. The principal actor was characterised by the ability to recognise an entrepreneurial opportunity and initiate the process of combining and organising resources. In both case studies, this person was not a farmer. The exploitation of the entrepreneurial potential, however, was strongly dependent on the commitment of a collective group of farmers who committed to the idea for implementation.

The group of smallholder farmers committed to the innovation process was identified as the group of **direct actors.** The direct actors brought their own resources into the innovation process. The relationship to the principal actor is one of mutual dependence and joint ownership of the innovation process. The relationship between the principal actor and the group of direct actors is characterised by negotiation processes mainly aimed at improving the product or the production process.

The third group was termed **indirect actors**. This group was linked to the invention by loose ties in the sense that there was no engagement in the innovation process with own capital resources. Interaction with this group of actors, however, was seen as vital for success in the respective sector and region. Moreover, this group can be positively or negatively impacted by implementation, for example as a final beneficiary of improved regional assets for tourism or better quality products. The direct and indirect actors felt committed to the innovation process on the basis of regional proximity in case study 1 and sector proximity in case study 2.

Table 1. Description of actor relationships in the case studies

	Principal actor	Direct actors	Indirect actors
Case study 1: Small scale thermal energy production	UNESCO Biosphere Reserve Spree Woods, State Office for Environment	10 smallholder farmers with joint land ownership of 1000 ha in the Spree Woods/Błota	Tourism Nature conservation Hunters and fishermen
Case study 2: Mixed poultry production	Naturland Marketing GmbH	8 farmers with total poultry production of 3000 hens produced and marketed in cooperation with Naturland	Processors (meat) Extension services Breeders Marketing organisations

Content analysis

Content analysis was applied to all transcribed interviews in order to understand the objectives associated with sustainable development by the actors involved in the innovation process. The concept was based on the understanding that value perceptions have an effect on resource allocations and decision making for example in ecosystem services assessments (MEA, 2005), and thus should be recognised in innovation management, particularly when it comes to economic analysis. It was also used in order to reduce complexity by identifying the relevant objectives that linked the innovation process to concepts of sustainability.

Aligned with the overall participatory approach in the project, the content analysis was applied as an empirical method for qualitative and inductive research (Elo & Kingäs, 2007). Whole sentences were coded based on attributes of value perception and indicated by words such as “relevant”, “important”, “prior”, “it is about”, “essential” and “crucial”. The open codings were grouped under higher order headings according to similarity. 15 interviews were analysed for case study 1 and 13 interviews for case study 2.

In a first step, 46 sub-criteria were identified and classified into 15 generic criteria used to explain the sustainability aspects of the innovation. The criteria were cross-checked against the three pillar approach of social, economic and environmental criteria. In a second step, three main categories were retrieved from further abstraction of sustainability objectives that ran across social, environmental and economic criteria.

Results

The principal, direct and indirect actors involved in the innovation process had a clear idea of the values expected from the innovation in regard to sustainable development. The criteria formulated in each case study differed in minor points at the level of sub-criteria, while at the levels of higher abstraction all criteria were considered relevant by the actors in both case studies. An attribution of criteria to social, economic and environmental aspects showed that the range of criteria equally covered all three dimensions of sustainable development (Table 2). In the following, the main differences between case studies are described, and an example is presented for each of the three main objectives identified, namely local added value, closed circular systems and capacities for development. Details of the content analysis are presented in Table 3.

Expectations of the stakeholders in regard to sustainability

The component of remuneration and compensation in financial terms was termed a natural objective of the innovation process by almost all interviewed actors. One main concern was the difficulty of reaching long-term market establishment in spite of the self-imposed constraint by committing to small-scale production.

The interviewed actors were fully aware of the fact that eggs, meat and biomass held little potential for a unique selling proposition as long as the additional benefit of the production system was not made explicit. The main product asset articulated in case study 1 was to achieve local effects by offering the extra service of “keeping the landscape open” in order to preserve a cultural landscape with a distinct aesthetic value and biodiversity. This was considered relevant for the local communities in the region of the biosphere reserve, and furthermore a requirement for the survival of the region as a tourist destination. In case study 2 the main product asset was seen in: “ethical production” that involved raising equal numbers of male and female chickens in order to avoid premature slaughter; improved animal welfare such as small herds held in free-range husbandry; as well as a general support of smallholder farming systems.

Criteria of diversification in farm structure were considered more relevant by case study 2, next to ethical issues. The actors took pride in achieving non-standardised production processes, in the sense that every farm was encouraged to pan out how the requirements of the production process would fit best to the local circumstances of the farm. Therefore, the notion of developing alternative approaches “other” or “better” than existing organic or conventional farming practices were considered basic criteria of sustainability.

Contrary to this, consensual decision making was articulated only by case study 1, due to a strong sense of accountability for land development. This was underlined by a strong recognition of land ownership in the present generation as well as for future generations in terms of farm succession and community stability. The notion of preservation of farm structures and land as is were considered elementary criteria of sustainability that were not mentioned by case study 2.

Table 2. Social, economic and environmental criteria for sustainable agro-ecological innovation

Criteria	Sub-Criteria	Social	Economic	Environ-mental
Economic efficiency	a) full cost recovery of costs and inputs b) achievement of net profit c) achievement of a competitive market position		x	
Product demand	a) acknowledgement of product criteria b) purchase of the product c) willingness to pay a surcharge		x	

	d) regular purchase			
Integrated production	Best practice in terms of: a) farming practice; b) resources efficiency	x	x	x
Employment	Production and marketing generate: a) new sources of income; b) new options for employment	x		x
Growth	Production and marketing: a) implemented according to expectation; b) improved via horizontal linkages; c) improved via vertical linkages; d) transferred to the next generation (future ability)		x	
Continuity	Quality and quantity of production is: a) stable and permanent; b) assured against risks; c) secured by ownership and property rights; d) contributing to the environment and livelihood of the region	x	x	x
Regionality	Production and marketing rely on: a) integration of local actors; b) integration of local resources; c) generation of local benefits	x	x	x
Cooperation	Production and marketing lead to: a) communication and interaction with actors along the value chain; b) joint activities with other actors for mutual benefit; c) merging of activities between actors along the value chain; d) collaborative decision making	x		
Circular material flow	Production and marketing support: a) recycling of resources and materials; b) closed cycle of goods and products; c) diversification of assets and risks	x	x	x
Quality	Production and marketing meet the requirements of the consumer in regard to:a) taste and aesthetic perception; b) state of condition and shelf life; c) general standards defined by market and trade; d) criteria extra to common standards	x	x	
Diversification	Production and marketing are based on: a) non-standardised farm size and structure; b) non-standardised production processes; c) diverse and	x	x	

	inclusive staff structure; d) alternative approaches in product handling; e) improvement of existing approaches in product handling		
Independence	Production and marketing approaches can be decided and implemented independent of actors along the value chain	x	
Biodiversity	Production and marketing do not negatively impact the conservation of: a) species; b) genetic resources; c) habitats		x
Climate	Production and marketing comply with best practice in climate relevant emissions		x
Ethical aspects	Production and marketing comply with: a) ethical production standards; b) reduction of waste; non-renewable resources and surplus produce; c) reduction of input resources beyond the necessary (e.g. large packaging)		x

Local added value

Local added value was defined as feedback effects expected from the implementation of the innovation in the immediate surroundings, implying financial, social and environmental benefits. “Local” was understood in reference to the unit of observation. The direct actors mainly referred to the farm in a village environment, or the village in the district environment, while indirect actors and principal actors referred to the district, the region or the federal state.

Benefits included financial returns for people working in adjacent sectors considered sensitive or worth protecting in the region, such as tourism in case study 1, and food processing in rural agricultural regions in case study 2. The expectation was that the implementation of the agro-ecological production processes would achieve additional income sources and indirectly contribute to the survival of small scale farmers, but also producers and processors.

Closed circular systems

The notion of closed circular systems was defined in a broader context encompassing a balanced nutrient flow in order to include an efficient use of natural resources with no surplus or unutilised waste production and recycling of materials. Furthermore, closed cycles were also understood in social terms in the sense of well-functioning networks for cooperation within the sector or region.

The aspect of closed cycles was often linked to regional anchorage, but was also extended to the meaning of exploiting the full value chain by coupling elements needed for production and marketing independent of distance. For example, in the case of mixed poultry production the smallholder farmers had calculated that for approximately every 180 eggs produced one stock chicken was raised. The reduction of surplus production in this case included the objective of a balanced supply and demand for example by good customer relations. In case study 1 the exploitation of previously underused biomass was considered the major element for closing perceived gaps in the functioning of local social structures and local monetary flow.

Capacities for development

Although conscious of the constraints of small-scale production, a strong expectation of growth potentials was communicated in the interviews. Capacities for development were defined as a potential to develop the innovation along horizontal lines, such as replicating the production process in other regions by including more smallholder farmers into the programme, but also along vertical linkages, for example by the ability to address marketing structures outside the organic sector. Actors in both case studies referred to capacities based on diversification and de-centralisation, but also communication and knowledge transfer.

Table 3. Main objectives associated with the agro-ecological innovation as perceived by the actors involved in the innovation process. *(Interviews were coded SPx for Spree Woods/Błota, and ECx for Naturland Marketing).*

Main objectives	Small scale thermal production (Case study 1)	Mixed poultry production (Case study 2)	Criteria
Local added value	The key formula was not organic farming, but grown here, produced here, processed here, and exploited by the local people (SP1). In consequence, financial returns will flow back to the producers and into the region via tourism. (SP2). It can contribute to the diversification of income sources. (SP3). It can generate financial returns that should be available for those who work in those farm areas. (SP6). The use of biomass requires technical resources; logistical questions need to be addressed. I need partners with land, entrepreneurs with financial backup who have the capacity to join in. The kind of information we need is: we have sold so much honey, and we have won ten new bee keepers. They will survive because of these activities. (SP17) And then the value chain is set. Not for mass production, but in the sense of an honest regional product. (SP22).	What we see as a basic element is the potential for the region: buying feed in Germany, breeding of animals in the region. That eggs will be marketed in the region. As well as the meat. (EC1). We say, organic farming is sustainable, so what do we do on top? The regional location of slaughter and marketing are on top. (EC3). The principles of Naturland define organic farming as "a contribution to the conservation of the natural resources and livelihood. This includes biodiversity, climate conservation and animal welfare". For smallholder farmers it pays off to set up mixed poultry production as an additional income source. This is relevant in order to convince the farmers that mixed poultry is not only more work, but pays off financially. (EC4). When we start a project like this, it is all about the creation of jobs, continuity and keeping people employed, starting from the work in the stall, the care for the animals down to the packing of eggs. (EC16).	Economic efficiency Employment Regionality Independence Biodiversity Climate
Closed circular systems	Practically joining circular systems. To be able to say: "we have this area with surplus biomass, but we can save costs by exploiting the energy in situ by coupling cycles". The local benefit will increase manifold when we	I would define sustainable land use as linkage with all adjacent elements. Socially, this is the village, the surrounding area, the region. Environmentally, I see the in- and output in agriculture, and in terms of marketing, it is a closed value chain in the near region. (EC1).	Product demand Integrated production

	achieve a coupling of local cycles. It means we can generate value and keep jobs in the region. (SP1) From the narrow perspective of nature conservation only two things are relevant: 1) taking out plant nutrient matter, 2) making sure, the meadows have enough moisture. What happens with the biomass is next to irrelevant. (SP4). And that is it, overall, that we come to the point where we have closed regional cycles that may be able to continue to other levels. Then we will have a true innovation, specific for this location. (SP17).	We need closed cycles in organic farming. If we now had someone innovative in processing, someone who uses surplus meat in food processing, we'd be even better set. (EC2). All chicks are raised. Wonderful. (EC3). For every 180 eggs one chicken must be eaten. The information is that this project will survive only when the meat is eaten. Customers need to have this information. (EC7). I liked the idea. We wanted to keep poultry. And we also needed the manure. The circular system is very important. So we thought, this is a good thing, so we set up this type of poultry production. (EC14).	Circular material flow Ethical aspects
Capacities for development	We could make it bigger and broader. The destination of this innovation is more than just the Spree Woods. The aspect of decentralisation is the actual approach where I see the potential innovation. (SP1). Where we slowly and carefully have to see to the formation of other small networks. The Biosphere Reserve must become one of several performers. (SP2).	It is relevant to look at marketing structures outside of organic trade. We need to get out of the niche. (EC1). In my opinion, this produce will always be a niche for few smallholders. But I imagine that it can be transferred to other regions. (EC3). We implement what we think is the right idea. We get experience and try to grow. We would like to come to the point where we can say we have a project that can be communicated broadly, so that we win more farmers who set up more mixed poultry production sites. (EC14).	Growth Continuity Cooperation Quality Diversification

Discussion

Innovations, according to the actors involved in the innovation process, are considered sustainable when they a) achieve local beneficiary effects for as many people as possible, b) contribute to closed cycles in production and marketing, and c) improve the capacity for horizontal and vertical development. The combined effect is perceived as an additional asset extra to local, organic or conventional smallholder production by the actors.

All three main objectives for an agro-ecological innovation illustrate the relevance of local anchorage. For agrifood systems, localised production systems have been analysed based on the systemic nature of relationships maintained by actors who jointly shape a territory through cooperation and joint products (Torré & Wallet, 2013). Spatial differentiation, cooperation and bottom-up development are linked with this approach. The results from this study add elements of regional autarky. In the case studies this becomes evident by the actors expectation to exceed the regular requirements for common organic agricultural production, e.g. of Naturland Marketing (Naturland, 2015) and to gain independence from mainstream sector relationships.

Making explicit societal and environmental value creation

In both cases, the innovative approach for agro-ecological production exceeds the regular requirements for organic agricultural production. Thus, the production is affected by a self-restriction to produce low quantities and therefore consciously refuse to use economies of scale. Consumers, however, are mainly unaware of these extra efforts for sustainable land use. At the same time, the actors cannot benchmark their activities against common requirements such as a product label or standard based on common farm statistics. An assessment of sustainability objectives during the innovation process can support the actors in articulating the benefits of the agro-ecological innovation, particularly at the level of the principal actor who takes the role of the entrepreneur. An entrepreneur is characterised by typically facing high ambiguity and uncertainty in the pursuit of a new venture. Decision making is largely built on individual heuristics and beliefs, while factual-based logic may be either too overwhelming or not available where an innovation is created (Alvarez & Busenitz, 2001). While the particular benefits of the agro-ecological innovation were not clearly defined at the outset of the study, the actors could harmonise their target and product criteria during the course of the study. The result was perceived as a basis for advancing marketing measures and customer relationships as well as communication between actors.

Plausibility and applicability of the approach

Local added value, closed circular systems and capacities for development are found to link both territorial and value chain approaches. The innovation is considered successful by the actors when the additional product assets are achieved and financed by revenues. One specific of the innovations analysed here is the dependency of success on the willingness of a group of farmers who commits to implementing the innovation in joint cooperation. Case study 1 requires a minimum number of farmers to achieve the aim of open landscape conservation. In case study 2 a critical amount of eggs and meat is indispensable to target the market.

All three main objectives have a clear resonance with value chain assessments for example in supporting linkages with other actors along the value chain, upgrading returns from production and generating financial flows that become an integral part of the region and sector involved (e.g. Graef et al., 2014; Kaplinsky & Morris, 2001). The application of the criteria is strongly actor-oriented. This can be a detriment when it comes to an assessment of site-related environmental impacts. While the criteria showed a comprehensive approach in addressing the sustainable and efficient practices needed for transformation towards sustainable development, environmental criteria were selected to a lesser extent by the actors.

Conclusion

The study was conducted as an intermediate step in developing assessment tools for sustainable agro-ecological innovations in a smallholder farm environment. The integration of sustainability assessment in innovation management was found useful particularly by the principal actors, namely the biosphere reserve management and Naturland Marketing. The benefit is seen in the clarification of objectives in management, and in communication with direct and indirect actors. The criteria were grouped along three main objectives that encompass both value chain and territorial approaches as well as social, economic and environmental values. The results indicate possible development pathways for an assessment tool that supports the actors in innovation management with the aim of improving capabilities for long-term market establishment and sustainable land management, e.g. via life-cycle assessment or balancing methods. The tool, however, must implicitly ensure equal consideration of environmental impacts next to social and economic impacts, as these were considered to a lower extent by the interviewed actors.

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Sustainability assessment in Luxembourgish dairy production by CONVIS: a tool to improve both environmental and economical performance of dairy farms.

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Abstract: The paper describes the sustainability assessment tool developed by CONVIS s.c., a Luxembourgish farm cooperative active in the field of animal husbandry. After giving an overview of the components of the tool, the paper shows how data are collected, processed and reported. A concrete example of results is given for dairy farms, illustrating the relation between GHG-emissions and economic profitability of farm groups. In particular, it was found that the farms with the best environmental performance also tend to have the best economic results. Finally, the paper describes how these results are used to improve sustainability of dairy farms and points out the potential of the tool for supporting long term changes in various environmental fields.

Keywords: Environmental performance, resource efficiency, economical profitableness

Introduction

CONVIS s.c., a Luxembourgish cooperative society for cattle and pig breeders, has been carrying out a sustainability assessment for member farms since 1996. From the start the aim was to improve both the environmental and economic efficiency of these farms, but also to improve the image of the agricultural sector in general and of animal husbandry in particular. The sustainability assessment was originally carried out for a label of beef meat production in Luxembourg and for a special programme co-financed by the Luxembourgish State with the specific aim of improving the environmental performance of agricultural farms. These two main application fields are still running today. In the last 4 years, the sustainability monitoring was also carried out for a dairy producer cooperative which aims to achieve marketing advantages by applying the assessment on farm and by communicating sustainability results to the consumer. For more information on the tool see the short video on YouTube (https://www.youtube.com/watch?v=HcolpJDRlGw).

The sustainability assessment is developed and carried out by the advice department staff of CONVIS. As shown in Figure 1, the self-concept of the advice department is as an institution dedicated to filling the gap between the research and the practice level in agriculture by organising the knowledge transfer between these two levels. The sustainability assessment of CONVIS is an essential tool to implement such knowledge transfer and was consistently developed and improved over the course of time. At present, the assessment includes energy, nutrient and humus balance (arable land) at farm level, as well as calculation of feedstuff self-reliance (autarchy), GHG-emissions and an economic analysis of costs and incomes for the principal farm production branches (milk, beef meat, cereals). In addition, specifically for dairy production, the sustainability assessment also takes into account parameters which illustrate the consumption level of the most important production means (feedstuffs, fertilisers, fuel, electricity, investments), thus showing the resource efficiency of dairy farms. The proposed contribution will give an overview of the sustainability assessment carried out by CONVIS s.c. (data sampling, data processing and data reporting). Furthermore, using the relation observed between environmental (mainly greenhouse gas emissions) and economic results for dairy farms, is an attempt to show how recommendations for improving sustainability of dairy production in Luxembourg could be used to achieve changes in the agricultural practice.

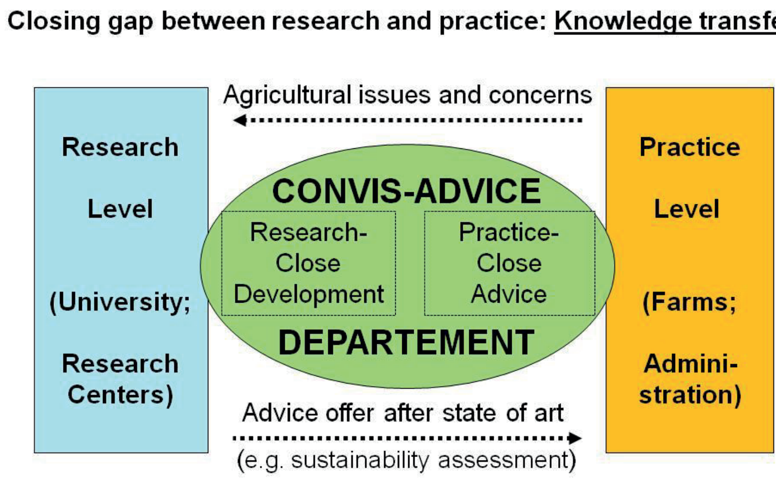


Figure 1. Self-concept of CONVIS-Advice Department

Material and methods

The CONVIS sustainability assessment for agricultural farms

To assess the sustainability of farms (in this specific case: dairy farms) CONVIS developed a tool capable of estimating their efficiency of resource use, environmental impact and economic results. Thanks to software developed for this specific purpose, data are collected from the book keeping as well as from the fertilisation planning of the farm (Figure 2). The software was programmed to take into account the structure of the book keeping. Concerning in particular data about surfaces, livestock, input (production means) and output (products), there is absolute coherence between the way the data are organised in the book keeping and the input mask of the software. Thus, it is possible to reduce the time for collecting data to a minimum.

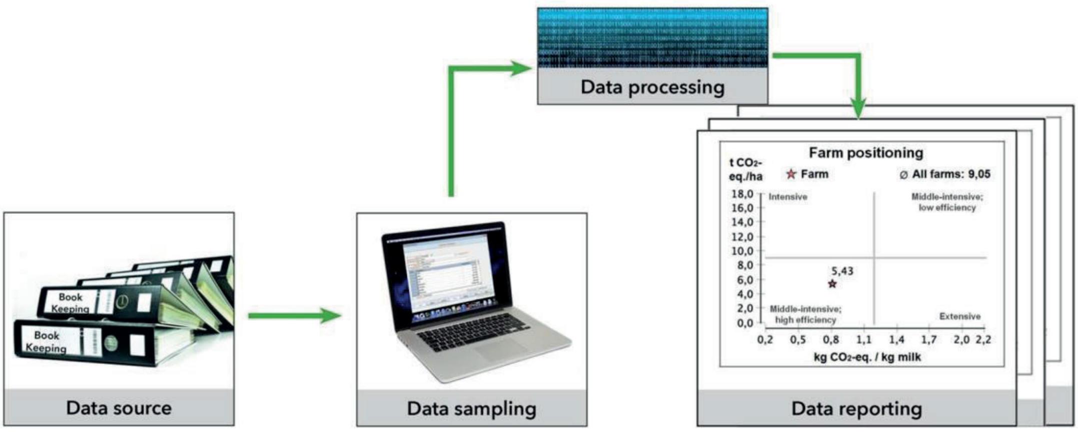
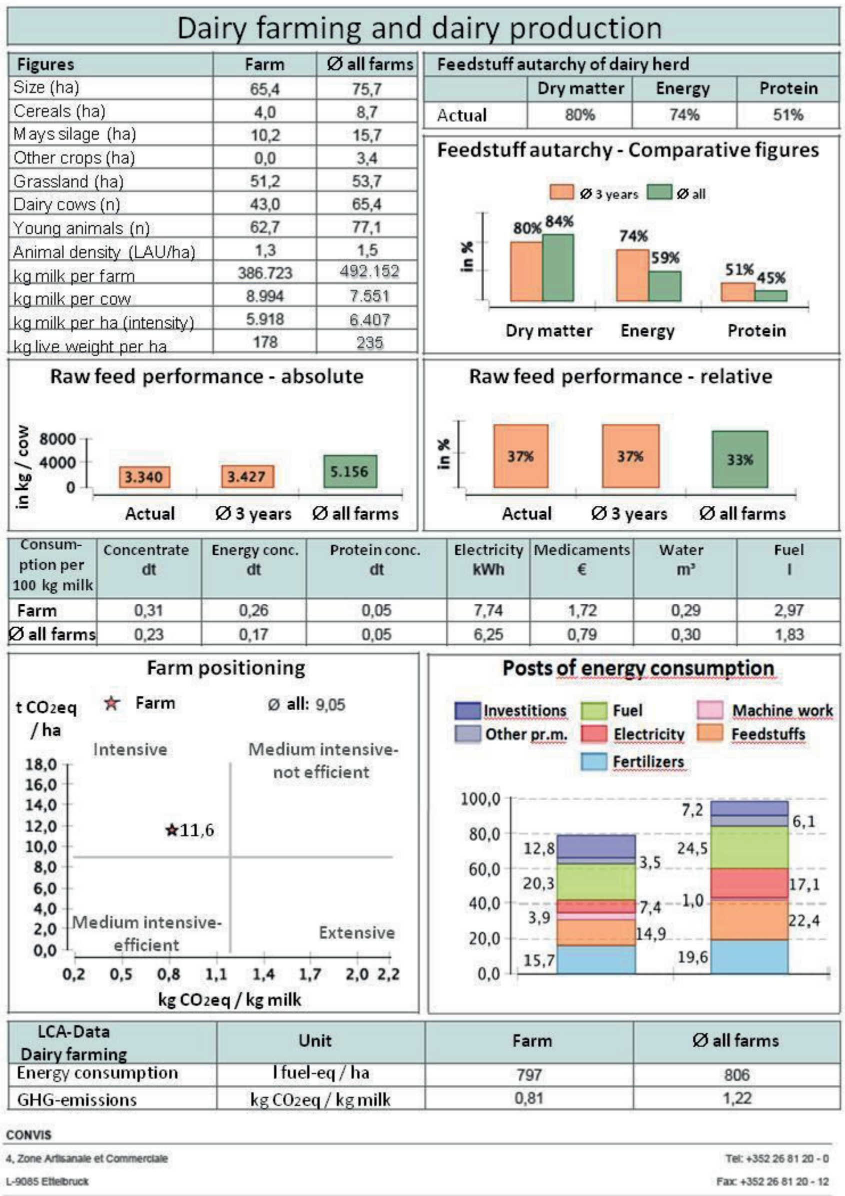


Figure 2. Scheme of dataflow in CONVIS sustainability assessment

Almost all farmers involved in the assessment make use of book keeping carried out by accredited institutions. If this is not the case (rarely), the farmers are requested to fill in a form that has the same input mask as the software. In total, approximately 240 farms are assessed every year. These farms cover a bit less than a quarter of the agricultural area (cropland and grassland) of Luxembourg.

The data are sent via the internet and processed in a few seconds by a provider. Finally, the results are summarised in a report which contains the most important technical, environmental and economic parameters of the farm for a given book keeping year. The duration of the whole process from data collection to printing the report is about 1.5 to 2 hours. Depending on the amount of time at the farmer's disposal, data collection is carried out either in CONVIS offices or directly on the farm. After the collection, data are discussed with the farmer on the basis of the sustainability report (Figure 3 gives an example of the sustainability report part for the dairy farmers).



Dairy farming and dairy production

Figures	Farm	Ø all farms
Size (ha)	65,4	75,7
Cereals (ha)	4,0	8,7
Mays silage (ha)	10,2	15,7
Other crops (ha)	0,0	3,4
Grassland (ha)	51,2	53,7
Dairy cows (n)	43,0	65,4
Young animals (n)	62,7	77,1
Animal density (LAU/ha)	1,3	1,5
kg milk per farm	386.723	492.152
kg milk per cow	8.994	7.551
kg milk per ha (intensity)	5.918	6.407
kg live weight per ha	178	235

Feedstuff autarchy of dairy herd

	Dry matter	Energy	Protein
Actual	80%	74%	51%

Consumption per 100 kg milk	Concentrate dt	Energy conc. dt	Protein conc. dt	Electricity kWh	Medicaments €	Water m³	Fuel l
Farm	0,31	0,26	0,05	7,74	1,72	0,29	2,97
Ø all farms	0,23	0,17	0,05	6,25	0,79	0,30	1,83

LCA-Data Dairy farming	Unit	Farm	Ø all farms
Energy consumption	l fuel-eq / ha	797	806
GHG-emissions	kg CO2eq / kg milk	0,81	1,22

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Figure 3. Example of sustainability assessment report for dairy farms/branches *(translated from the original in German)*

The major part of the graphs and tables of the report are self-explanatory. However, there is an important exception: the graph regarding farm positioning. This part of the report refers to the GHG emissions, one of the main environmental impacts of dairy farms. We will show and discuss here some important results related to the graph mentioned above beginning with the methodology used. Finally, we will illustrate how these results could be used to improve sustainability of dairy farms in Luxembourg.

The method used by CONVIS to estimate GHG-emissions considers the emissions resulting from production means, animal husbandry and plant production on the one hand, and the carbon credits resulting from the storage of carbon in the soil as well as via renewable energy, on the other hand. This means that the GHG-emissions shown are net emissions. An important particularity of the assessment method used by CONVIS is that many of the dairy farms in Luxembourg are mixed farms with more than one production branch. This means that GHG sources concerning dairy production have to be separated from those related to other production branches (e.g. beef meat or cash crop production). In order to do so, several allocation keys are applied to allow an automatic separation of energy and material flows among the branches of a farm. An exhaustive description of the method applied including emission factors and allocation keys can be downloaded as a pdf-file from: www.convis.lu (Manuel méthodologique - Méthode CONVIS, see References section). The only deviation from the method described is that minimum tillage is not considered in the present paper: there is now some evidence that minimum tillage only changes the distribution of carbon stock, but not its total amount in the soil profile (Powlson et al., 2014).

Apart from figures concerning environmental impact and efficiency use of production means, the economic figures of farms are also produced by the data sampling, and allocation keys are used to separate the data of the dairy branch from other branches. The economic analysis is carried out here on the basis of incomes and costs, and the profitability of the farm (dairy branch) is defined only in terms of the difference between these two factors, not taking into account subsidies and calculating costs.

Main figures of the investigated farms

All the results presented here refer to the average of 50 CONVIS member farms which were monitored in the years 2013 and 2014 (the last two years before the withdrawal of the milk quota in the EU). The average size of the farms was 124 ha, of which 75 ha (60%) were used for dairy production, 27% for beef production and 13% for cash crops (Table 1).

Table 1. Whole farm and dairy branch indicators (mean values of the investigated farms)
**LAU: Large animal unit*

Indicators	Unit	Whole Farm	Dairy branch	St. deviation
Size	ha	124	75	49%
Forage surface	%	87%	100%	0%
Cereals	ha	23	6	111%
Silage maize	ha	18	14	56%
Other crops	ha	4	1	388%
Grassland	ha	80	54	48%
Animal density	LAU*/ha	1.47	1.61	19%

Nitrogen excretion	kg N-org/ha	124	147	19%
N-surplus (farm gate balance)	kg N/ha	120	134	31%
Energy consumption	GJ/ha	31	37	31%

The dairy branch showed a higher animal density than the corresponding value for the whole farm. Consequently, the nitrogen surplus of the dairy branch as well as its energy consumption were also higher than the result at farm level.

Table 2. Dairy production indicators (mean values of the investigated farms)

Indicators	Unit	Values	St. deviation(1)
Dairy cows	n	74	55%
Milk produced per farm	kg	549.443	124%
Production intensity	kg milk/ha	7.289	30%
Cow performance	kg milk/year	7.406	15%
Basic ration performance	kg milk/year	2.941	35%
Basic ration performance	%	40%	35%
Protein autarchy	%	52%	27%
Concentrate per cow and day	kg	6.12	30%
Concentrate per kg milk	kg	0.30	23%
Concentrate per dairy farm	t	166	157%

In comparison with the long-term average data of CONVIS farms (Lioy et al., 2014), these farms showed a higher level of animal density and a higher importance of dairy production in comparison with other production branches. The figure of protein autarchy (Table 2) refers to valorization of the farm's own protein sources in feeding the dairy herd. In the case of the investigated farms, only 52% of the protein needed by the cows came from farm sources, with 48% coming from outside (concentrates).

Results and discussion

The GHG-emissions (surface and product related, Table 3) as well as the economic data of the farms investigated (Table 4) showed a wide spread in the results. In the case of economic figures, the spreads of incomes and costs were relatively small, those of the profit were however very large. The main aim of this section is to examine the origin of the variability, and in particular the influence of farm structure and management on the result.

Table 3. Surface and product related GHG-emissions of investigated farms

	t CO2eq / ha	kg CO2eq / kg ECM
Mean value	**10.3**	**1.22**
St. deviation	26%	21%
Max	22.5	1.82
Min	6.6	0.79

Table 4. Economic figures of farms analysed (mean 2013-2014, values in €cent/kg ECM)

	Mean	St dev.%	Max	Min
Milk	40.51	3%	42.61	36.99
Meat	4.63	49%	11.96	1.92
Other incomes	2.45	107%	17.82	-0.01
Sum incomes (1)	**47.58**	**8%**	**65.16**	**42.77**
Farm feed production	16.01	24%	25.71	10.43
Feedstuff purchase	8.98	28%	17.18	5.02
Other costs for animal husbandry	10.40	27%	16.44	4.78
Other general costs	4.99	49%	12.27	1.60
Sum costs (2)	**40.38**	**18%**	**63.61**	**24.48**
Profit (1)-(2)	**7.21**	**92%**	**27.77**	**-3.85**

As in the past (Lioy et al., 2014; Lioy et al., 2012), we observed that the behaviour of surface- and product-related emissions were divergent, if expressed as a function of the production intensity (kg milk/ha, Figure 4).

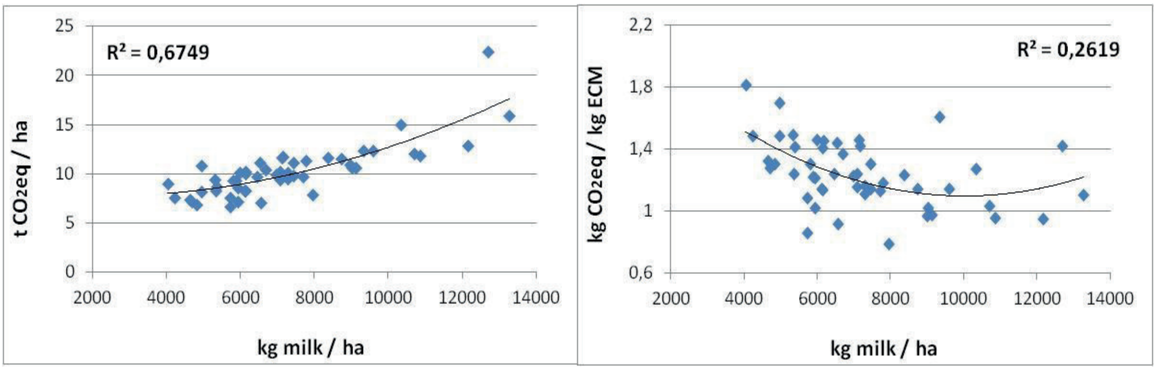

Figure 4. Behaviour of surface and product related GHG-emissions in function of production intensity

This observation led us to divide the farms into 4 groups as a function of their results in surface- and product-related emissions in comparison to the mean value of all farms (Figure 5).

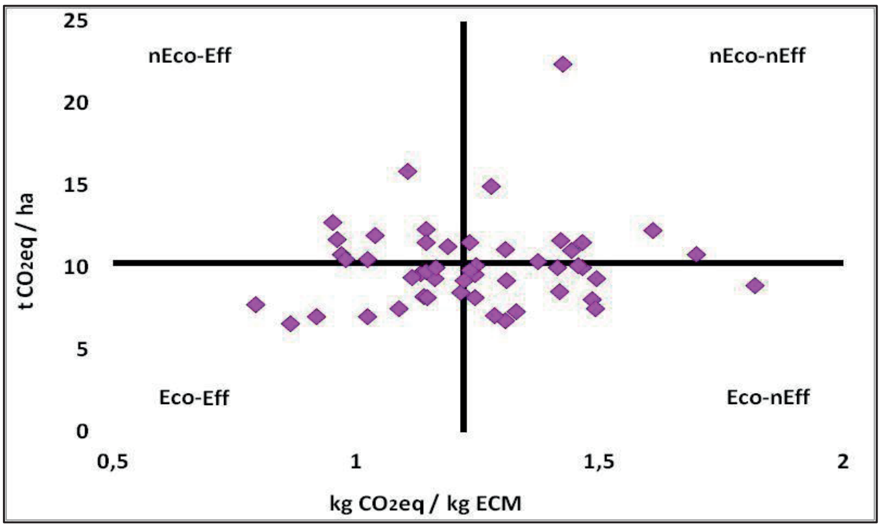

Figure 5. Division of the farms examined in groups as a function of their position in relation to the mean value

The first group (Eco-Eff) and the last group (nEco-nEff) showed results in GHG-emission per ha and per kg ECM respectively lower and higher than the average (Table 5). The second and the third group had an intermediary position: nEco-Eff showed a higher result in surface-related GHG-emissions and a lower result in product-related ones; Eco-nEff behaved antithetically to nEco-Eff.

Table 5. Mean values of GHG-emissions of farm groups in comparison with mean value of all farms

Farm groups	t CO2eq / ha	St.Dev.%	kg CO2eq / kg ECM	St.Dev.%
All farms	**10.3**	**26%**	**1.22**	**21%**
Eco-Eff	8.5	14%	1.06	12%
nEco-Eff	12.0	13%	1.02	9%
Eco-nEff	9.0	13%	1.37	11%
nEco-nEff	12.7	29%	1.39	10%

To characterise the four generated groups more precisely, it is helpful to have a look at the values of their production intensity (Table 6). The groups nEco-Eff and Eco-nEff had an intensity which was farther from the mean value. For simplicity, we will subsequently call these farm groups **intensive** (nEco-Eff) and **extensive** (Eco-nEff). The intensity of the other two groups (Eco-Eff and nEco-nEff) was closer to the main value of all farms. We will from now on call these last two groups **medium intensive-efficient** (Eco-Eff) and **medium intensive-not efficient** (nEco-nEff) farms.

Table 6. Production intensity (kg milk/ha) of different farm groups

Farm groups	kg milk/ha	StDev%
All farms	**7,289**	**30%**
Eco-Eff (*medium intensive-efficient*)	6,721	12%
nEco-Eeff (*intensive*)	10,280	17%
Eco-nEff (*extensive*)	5,546	16%
nEco-nEff (*medium intensive-not efficient*)	8,000	28%

As we can observe in Figure 6 the intensity minimum value of the intensive farms was higher than the maximum value of the extensive farms. This means that these two farm groups were well separated in terms of production intensity and it could be expected that the results of these two farm groups were mainly influenced by the farm structure. The other two groups were positioned in the middle of the intensity (medium intensive farms). Given the lower difference of structure described by the production intensity, the difference in the results of the medium-intensive groups could be influenced mainly by the farm management.

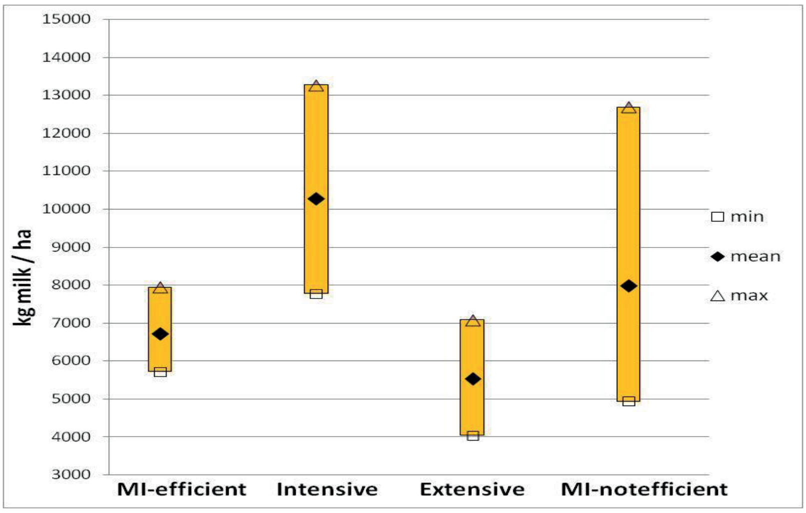

Figure 6. Mean value and spreads of production intensity of farm groups

We now take a look at the economic results of the four farm groups. It can be observed (Table 7) that the mean value of the profit was higher (for medium intensive-efficient) and respectively lower (medium intensive-not efficient) in the farm groups with the medium production intensity. Intensive and extensive farms occupied a middle position, with slightly better scores for the intensive ones. In addition, medium intensive-efficient had the lowest level of costs, but not the higher level of incomes, which was reached by the extensive farm group. The variability of the results was lower in the group medium intensive efficient, although, as shown in Figure 7, the spread between minimum and maximum reached the highest level in this group (medium intensive-efficient).

Table 7. Incomes, costs and profit (all in €cent / kg milk) of farm groups

	All farms	Medium intensive-efficient	Intensive	Extensive	Medium intensive-Not efficient
Sum incomes (1)	**47.6**	47.0	46.9	48.3	48.0
Sum costs (2)	**40.4**	36.8	38.9	41.9	43.2
Profit (1)-(2)	**7.2**	10.2	7.9	6.5	4.9
St. dev.%	**92%**	74%	89%	89%	118%

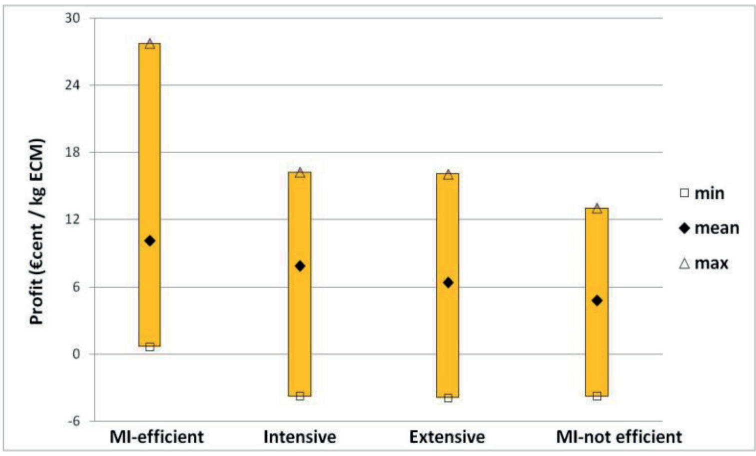

Figure 7. Mean value and spreads of profit for farm groups

How can the observed hierarchy of results be explained? In both GHG-emissions and economic figures, we observe that the farm group with the best results in the mean value was the medium intensive-efficient one, followed by the groups intensive, extensive and medium intensive-not efficient. We can characterise the different farm groups with the help of Table 8 which gives an overview of principal farm indicators. The first observation is that the best group (medium intensive-efficient) had the smallest size of all. In addition, the total amount of kg milk produced per farm as well as the number of dairy cows was the smallest in the group medium intensive-efficient compared to all other groups. In terms of intensity, the animal density confirms that the second group (intensive) contained the most intensive farms. It seems that smaller farms are under stronger pressure to produce efficiently, in particular concerning the use of concentrate and raw feed performance.

The farm group with the best results (medium intensive farms) purchased less concentrate than the other groups, and had as a consequence the best raw feed performance (milk produced from grass and silage maize) as well as the best protein autarchy (valorization of own farm protein sources). In the other groups, the extensive farms had a better raw feed performance than the intensive farm, and the last group (medium intensive-not efficient farms), although less intensive on average than the intensives, had the lowest level of feeding efficiency, revealed by a small value in raw feed performance and protein autarchy.

Table 8. Indicators of different farm groups – *(1) in kg milk/cow/year*

Indicator	All	M. intensive-efficient	Intensive	Extensive	M. intensive-not efficient
Size (ha)	75.4	56.0	79.3	85.3	79.8
Cereals (%)	8%	9%	7%	8%	8%
Maize silage (%)	19%	18%	21%	15%	23%
Grassland (%)	73%	73%	72%	75%	68%
Dairy cows (n)	74	54	93	70	89
Produced milk per farm (kg)	549.443	376.375	815.682	472.838	638.421
Production Intensity (kg milk/ha)	7.289	6.721	10.280	5.546	8.000
kg milk/cow/year	7.406	6.979	8.767	6.750	7.198
Animal density (LAU/ha)	1.61	1.57	1.83	1.41	1.80
Concentrate (kg/cow/day)	6.12	4.57	7.50	5.16	7.16
Concentrate (kg/kg milk)	0.30	0.24	0.31	0.28	0.36
Concentrate per dairy farm (t)	166	90	255	132	232
Raw feed performance *(1)*	2.941	3.641	3.289	2.981	1.971
Raw feed performance (%)	40%	52%	38%	44%	27%
Protein autarchy (%)	52%	66%	45%	59%	39%

When we look at the cost and income structures of the farm groups (Figure 8), we find that the costs for purchasing concentrates were lowest in the medium intensive-efficient group. Although the intensity difference between the better group (medium intensive-efficient) and the group with the worst mean values (medium intensive-not efficient) was the smallest, we observe the highest difference in the total amount of costs between these two groups of farms. Still with regard to the purchase of concentrates, the last group had costs higher by almost 50% than the best group. There was a huge efficiency gap between the best and the worst farm group.

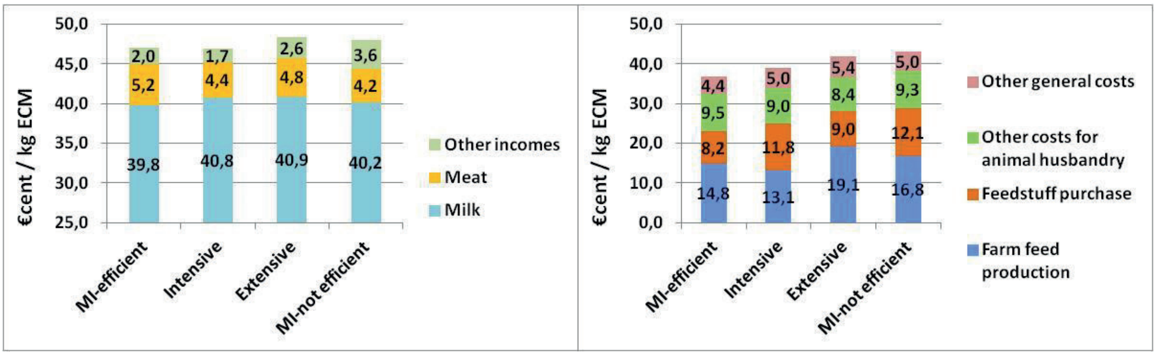

Figure 8. Income and cost structure of farm groups

The results of the intermediate groups (intensive and extensive) are a bit more difficult to explain. The one group (intensive farms) had lower total costs than the other (extensive farms). The greatest difference was related to the costs for the farm feed production, which was considerably higher in the extensive farms. This could be explained by the bigger size of the latter farms and with their higher grassland surface, which caused higher costs than silage maize. The higher costs for the extensive group, in comparison with the intensive group, was not compensated for by a higher income, so that the main value of profit for the extensive farms was lower than the correspondent value for the intensive farms (see also Table 7).

The structure of CO2-balance of the different farm groups (Figure 9) allows us to confirm that there is a gap in the efficiency of the resource use between the medium intensive-efficient and the medium intensive-not efficient groups, given that the intensity of the two groups was relatively close. Nevertheless, in all the figures of the CO_2-balance, the medium intensive-not efficient group had higher amounts of GHG emissions, no matter whether these are expressed per ha or per kg ECM. In the other two cases, the structure of the farm (intensity) played a very important role: in the case of more intensive farms we can expect that the result is better if related to the product; and in the case of extensive farms, the result is better if related to the surface. We would like to stress that for a correct interpretation of the environmental impact specifically for these farms, both functional units are needed.

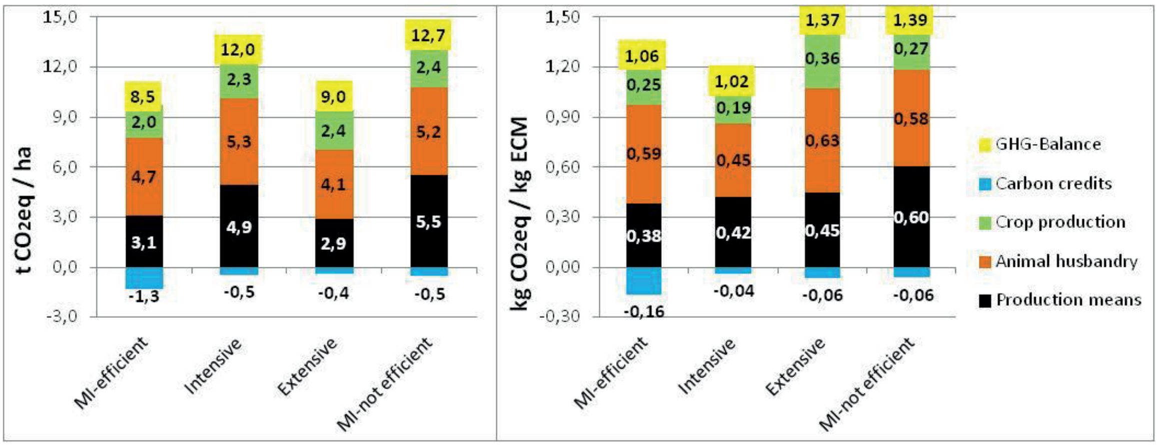

Figure 9. Structure of CO_2-balance of farm groups

Main conclusions

The sustainability assessment of dairy farms carried out with the CONVIS-methodology allows evaluation of the optimisation potential in dairy production. The estimation concerns GHG-emissions as well as economic figures.

To correctly assess the improvement potential of CO_2-balance, a combined analysis of both surface and product-related emissions is necessary. With the method illustrated here, it is possible to divide farms into homogeneous groups depending mainly on the structure (e.g. production intensity) of dairy farms.

The farms with a medium intensity of production differed mainly in the efficiency of production mean use, while the result of the most intensive or most extensive farms was mainly influenced by their structure.

The basic ration performance and the protein autarchy were key management indicators for a good (or bad) CO_2-balance as well as for a good (or bad) economic result. Farms with the best indicators in this field work efficiently both in the environment as well as in economic terms.

The same rank of results was observed in both fields (environment and economics), with better performances for efficient medium-intensive farms followed by intensive, extensive and not efficient medium-intensive farms.

The results which are presented here refer to the last two years before the withdrawal of the milk quota in the EU. It is also necessary to extend the analysis to the years after the withdrawal of the milk quota in order to find out whether intensive farms can exploit their higher cost reducing potential and thus improve their position.

How results will be used to achieve practical changes

The results presented in this paper will be disseminated in several ways, addressing various target groups:

1. Individual on-farm consulting on the basis of sustainability assessment report (240 farms).
2. Publication of results in the CONVIS quarterly magazine “de Lëtzebuerger Ziichter”. This magazine can also be found online on the CONVIS website (www.convis.lu). Addressees of the magazine are not only farmers, but also consultants and other stakeholders in the agriculture sector.
3. CONVIS organises an annual one day info-event where important results are shared and discussed with farmers, consultants and administrators.
4. Specifically for the dairy producer cooperative mentioned earlier in this paper, an info-meeting will be organised in 2016.

Potential for catalysing practical change of the CONVIS sustainability assessment tool

Due to the fact that the evaluation method for GHG emissions of dairy farms presented here has been implemented in the CONVIS sustainability assessment tool for only two years, it is not possible yet to present long term change effects. However, long term tendencies in neighbouring environmental fields analysed by the CONVIS tool are available. Regarding nutrient farm gate balances (for example nitrogen, phosphorus, potassium - Figure 10), the average surpluses of the farms could be significantly reduced from 1996 to 2010 (the increase of the nutrient surpluses since 2011 can be explained by adverse weather conditions and by the fact that farmers purchased more production means in expectation of the withdrawal of the milk quota system).

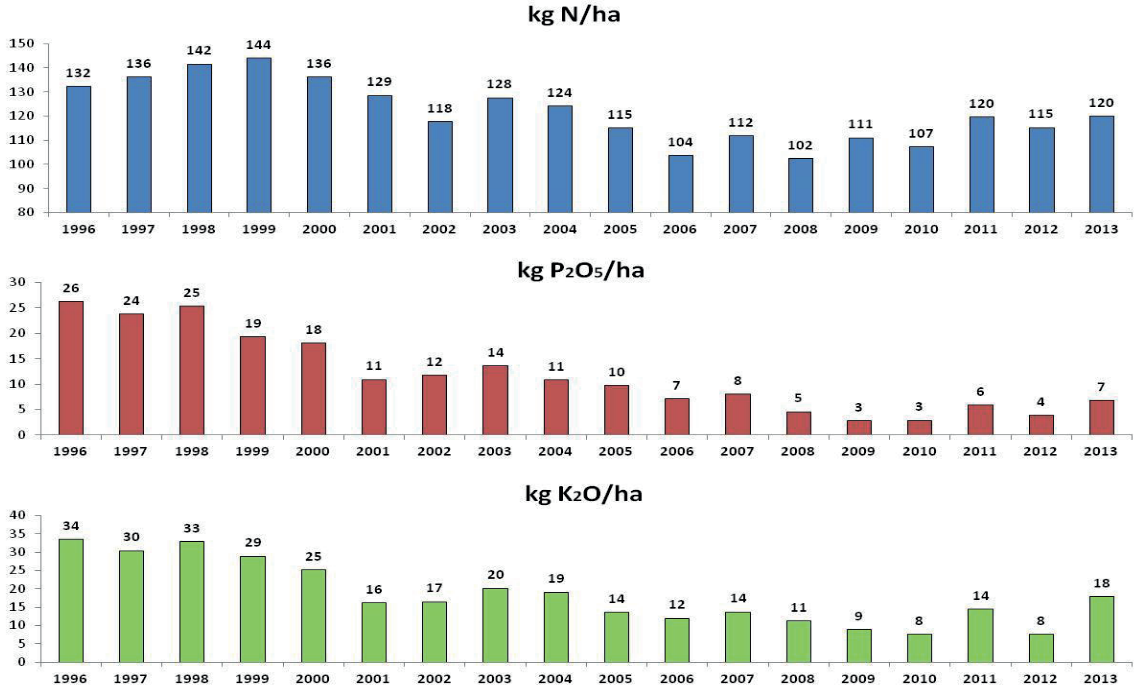

Figure 10. Long term nutrient farm gate balances of CONVIS assessed farms

In addition, the CO_2-balance at farm level could be significantly improved in the last 10 years (Figure 11). This improvement is not the result of reduction of GHG-emissions, but of the increase of carbon credits due to biogas production and more wide-spread use of minimum tillage practices.

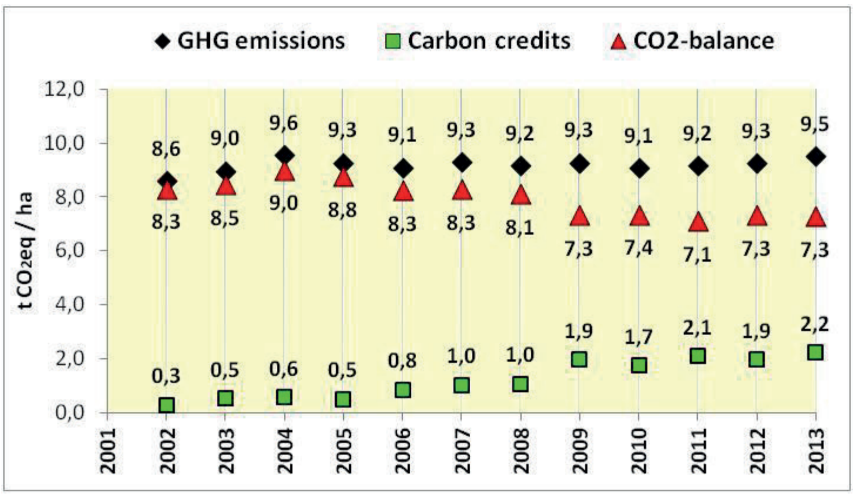

Figure 11. Long term CO_2-balance at farm level of CONVIS assessed farms

The CONVIS sustainability assessment tool allows us to register changes and to address the direction of the advice service in order to improve farm sustainability. We also feel confirmed in our approach because farmers react very positively to a tool where, as in our case, environmental and economic figures of the farm are closely linked. This helps to reduce the gap between research and practice and, as a consequence, to increase the acceptance of advice work.

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Farm transformation process of the Groundnut Basin and perceptions of farmers linked to the climate change issue

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Abstract: Family farms of the groundnut Basin bear the brunt of the effects of climate change and experience severe mutations as well as facing changes to their social, cultural and technical arenas. Agriculture, historically the main activity in the area, has less and less importance due to the deterioration of the means of production. In response, it is imperative to identify the constraints and risks affecting farms. Farmers have focused on structural constraints such as lack of inputs and farm equipment and climatic hazards such as insufficient rainfall. The analysis of the forms of risk shows that there is a large spatial and temporal variability in rainfall with different droughts that have impacted negatively on farming activities. These events have increased the vulnerability of farms in addition to the low level of adoption of technology and the low level of market integration. The indicators related to the means and factors of production are behind the vulnerability of farms.

Keywords: Family farm , constraints, risk, groundnut Basin, climate change

Introduction

Family farming is linked indissociably to national and global food security. In developing countries as in developed countries, it is the main form of agriculture in the food production sector (FAO, 2014). It corresponds to a form of production that is characterised by the particular structural link between economic activities and family structure. It sustains 2.6 billion people and provides work for 40% of the global workforce (Agropolis International, 2014). It ensures at least 56% of agricultural production (FAO, 2014). In sub-Saharan Africa, most of the farms are family (nearly 80%) and the sector employs nearly 75% of the workforce (www.repaoc.org).

Family farms in the groundnut Basin bear the brunt of the effects of climate change and experience severe mutations as well as facing changes in their social, cultural and technical arenas. Agriculture, historically the main activity in the area, has less and less importance due to the deterioration of the means of production. In response, it is imperative to identify the constraints and risks affecting farms. The risks (natural, agricultural, economic) are felt most acutely, accentuating vulnerability. Understanding vulnerability, conceptualised through the exposure, sensitivity and adaptive capacity is therefore essential to study the potential effects of risks

Methodology

The complexity and heterogeneity of the targeted family farms and the extent of the study area has led us to adopt a sampling method known as "multi-stage". The first step is the identification of the study areas using a reasoned choice based on the information acquired via various projects involved in the field. The second step is a reasoned choice of representative villages in these areas. The last stage involves the random selection of family farms in the selected villages. For the Basin area, we selected 200 family farms (100 per zone). Several questionnaires on sociodemographic and structural data of the risks were administered to farms. For the typology, we took only the area surface as a discriminatory criterion. We divided our sample according to the typology proposed by the last global census of population, housing, agriculture and livestock (RGPHAE, 2013).

Quantitative vulnerability assessment is performed by the development of a "vulnerability index" resulting from different types of vulnerability indicators related to farming. These indicators are variables (quantitative or qualitative) that must reflect the exposure, sensitivity and adaptive capacity of the farms facing risks, To standardise these indicators, we used the Human Development Index (HDI) of the UNDP (ICRISAT, 2009) that allows us to get free data units so that all values are between 0 and 1.

Results and Conclusions

The analysis of the forms of risk shows that there is a large spatial and temporal variability of rainfall with different droughts that ended up impacting negatively on farming activities. Farmers have focused on structural constraints such as lack of inputs and farm equipment before putting emphasis on the climatic conditions with insufficient rainfall. These risks have very different implications not only through time and spatially but also on socio-economic factors in the different types of farms. For exposure, the variables taken into account are the rainfall and temperature. The main activities (agriculture and livestock) are not viable without the presence of water and are highly impacted by temperature due to existing production systems in the Basin. For sensitivity, we have focused on the key factors of production: land, labour, inputs and farm equipment, Most of these variables have relatively important clues showing their role in farm vulnerability. For adaptive capacity, variables concerned the provisions of farms in relation to markets, education, income, relationships with organisational and financial institutions. These indicators allow us to appreciate the dynamism among farm members and the sources of income or financing.

The vulnerability index at farm level is relatively high (0.66). The indicators related to adaptive capacity and sensitivity are the most important. These incidences have increased the vulnerability of farms in addition to the low level of adoption of technology, and the low level of market integration. The indicators related to the means and factors of production are behind the vulnerability of farms. Thus, it is in the understanding of these issues that we can find the political options for securing livelihoods in order to establish a sustainable production and living environment.

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Integrated assessment of agro-ecological systems: the case study of the “Alta Murgia” National Park in Italy

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Abstract: Several indicators and methods have been already applied for sustainability assessment in agriculture. The links between sustainability indicators, agricultural management and policies are not well explained (Wei et al., 2009). The aim of this study is to combine biophysical and monetary sustainability assessment tools to support agriculture policy decision-making. Three methodological steps are considered: i) the environmental impacts of farms are assessed using terrestrial acidification, freshwater eutrophication, soil and freshwater ecotoxicity as well as natural land transformation; ii) the most relevant indicators of agricultural damage on ecosystems' quality are aggregated into an index; and iii) the farm index score is combined with farm assets, land and labour, into the Sustainable Value Approach (SVA), as an indicator of natural resources used by farms. The methodology was applied in a case study on arable farms with and without animal husbandry in the "Alta Murgia" National Park. The sampled crop farms have a higher sustainable value using their economic and environmental resources. Mixed farms need to improve their resource use efficiency. Although crop farms have lower land-use efficiency than mixed farms, our results suggest, that specialised crops farms generally perform better in terms of ecosystems' quality preservation. Finally, we find that Life Cycle Assessment (LCA) providing a measure of the environmental impacts of farms clearly enriches the SVA.

Keywords: Farm sustainability, ecosystem quality damage, sustainable value, integrated assessment.

Introduction

Sustainability assessment is considered an important step towards sustainable human activities (Pope et al., 2004). Scientists have developed several different sustainability evaluation tools in the last thirty years such as biophysical, monetary tools and sustainability indicators to deal with the triple bottom dimensions of sustainability (environmental, economic and social) (Gasparatos & Scolobig, 2012; Van Passel & Meul, 2012; Kloepffer et al., 2008). Interesting reviews of different approaches for sustainability assessment can be found in Neumayer (2003), Gasparatos et al. (2008), Jeswani et al. (2010) and Van Passel & Meul (2012). However, the scientific debate between supporters of monetary or biophysical tools remains unsolved (Gasparatos & Scolobig, 2012). Moreover, biophysical and monetary assessment methods differ also in their basic concept of value, relying on cost of production and utility theories of value respectively (Gasparatos et al., 2009). According to Gasparatos et al. (2009), sustainability assessment based on only monetary or biophysical tools ignores the interaction between the two different approaches resulting in a marked deterioration of the decision making process. The combination of biophysical and monetary tools may help to achieve a wider sustainability perspective. These "hybrid approaches" (Gasparatos et al., 2008) were strongly fostered in order to balance the simplicity, the wider acceptance and the easy communication characteristics of monetary tools with the more strict and objective relation with ecosystem functions and flows of the biophysical ones, with a logical effect on the improvement of systems' sustainability. In order to avoid critical issues related to consistency and weighting between environmental, economic and societal priorities (Hoogmartens et al., 2014), monetary and biophysical sustainability assessment approaches could help to provide decision makers with tools for a simplified and standardised sustainability assessment (Jeswani et al., 2010).

Several indicators such as water withdrawal, threatened species, soil organic carbon content, soil nutrient retention capacity, fertilisers and pesticides use, etc. (Reytar, et al., 2014) were developed to understand the complex relationships between agriculture and environment, but links between sustainability indicators and agricultural management are not well explained (Wei et al., 2009).

The aim of this study is to cover this deficiency by exploring options for combining biophysical and monetary sustainability assessment tools to support agriculture policies decision-making at local, regional or national level. To achieve this goal, the Life Cycle Assessment (LCA) methodology (biophysical tool) was integrated into a monetary sustainability assessment tool: the Sustainable Value Approach (SVA). LCA has been used to define the environmental impacts of the agricultural activities at the farm level, while SVA allows local policy makers to compare the sustainability performances of different farm management strategies. The proposed methodology was applied in a case study to the agricultural system of the "Alta Murgia" National Park (hereinafter simply referred to as Park). According to the EC Regulation 1242/2008 - establishing a community typology for agricultural holdings - the typologies of agricultural holdings inside the Park are: mixed crops-livestock; specialist field crops and specialist grazing livestock (Ente Parco Nazionale dell' Alta Murgia, 2010).

This study was a cradle-to-farm gate study, in which all the raw materials and processes are included from raw material extraction or production, to crops or livestock production.

This paper addresses the following research questions: a) is it possible to combine biophysical and monetary sustainability assessment tools in a meaningful and consistent way to agro-ecosystems?; b) is this methodology suitable for investigating structure policy measures to improve the sustainability of agriculture in natural areas?

The paper is structured as follows. The next section focuses on the logical framework and the methodologies used in the assessment of the environmental and socio-economic impacts of the farm activities inside the Park. The main results are then presented and the paper concludes with a discussion and conclusions section.

A pathway to a more integrated sustainability assessment

An integrated sustainability assessment of agro-ecosystems

Agro-ecosystems are arguably the most managed ecosystems in the world (Stoorvogel et al., 2004; Wei et al., 2009). In the past, agro-ecosystems were managed and evaluated overemphasising their social and economic components (Wei et al., 2009). According to different authors, this has caused many changes to ago-ecosystems such as land degradation, loss of biodiversity, groundwater depletion, greenhouse gas emissions and erosion (Conway, 1985; van der Werf & Petit, 2002; Dale & Polansky, 2007). The increasing concern about the negative impacts of agricultural activities on natural resources underlies the development of many methods for their evaluation (for a thorough review see van der Werf & Pertit, 2002; Payraudeau & van der Werf, 2005). In this context, sustainable agriculture can be defined as the management of the agro-ecosystem in such a way that it can maintain its biological diversity, productivity and regeneration capacity today and for the future (Van Cauwenbergh et al., 2007). In more detail, Pretty et al. (2008) defined agriculture sustainability as the capability of agricultural systems to: (i) integrate biological and ecological processes, (ii) minimise the human-made inputs, and (iii) make productive use of farmers' knowledge and their collective capabilities. Several models integrate biophysical and economic assessment of agro-ecosystems sustainability (for a thorough review see Janssen & van Ittersum, 2007). Stoorvoegel et al. (2004) propose the so-called Trade-off Analysis Model, an integrated biophysical and economic approach for assessing sustainability of agro-ecosystems, highlighting the role of temporal and spatial scales to supply policy-makers with useful indicators. Wei et al. (2009) used the force-pressure-state-impact-response approach to identify the interactions between biophysical and economic models in order to provide a comprehensive evaluation of farms' performance. Paracchini et al. (2015) presented another approach to sustainability assessment at different spatial levels (single farm, farming region, etc.) in combination with a wide range of indicators. According to Dantsis et al. (2010), the application of multiple criteria in agricultural system sustainability assessment requires several assumptions and simplifications although it also has several advantages (e.g. representation of the current agricultural management practices, the simplification of the composite concept and its applicability to different spatial scales). An interesting evaluation of the pros and cons of aggregate indicators for agricultural sustainability assessment is given by Gomez-Limon and Sanchez-Fernandez (2010). Usually, these "indicator lists" (Gasparatos et al., 2009) have been developed in order to capture sustainability issues relevant for a specific context. Therefore they are not widely applicable. One example of this approach is the project "Agroecosistemi"[1] supported by the Park. This approach is based on the AESIS (Agro-Environmental Sustainability Information Systems) framework, developed by Pacini et al. (2011). The project aims to identify a list of indicators according to the different sustainability dimensions (environmental, economic and social) for the assessment of farms' sustainability performance and their contribution to the needs of the "Park System". Economic, biological and physical components describing the agro-ecosystem contribute to the overall sustainability (Belcher et al., 2004). Moreover, the complex trade-offs between these components call for a holistic approach to agro-ecosystems sustainability assessment in order to identify sustainable management practices (Pacini et al., 2015). However, the dependency of farms activities on natural resources and human-made resources requires a better understanding of the links between environmental indicators, farm management activities and policies. Integrated sustainability assessment tools may be appropriate to identify policies' priorities for creating more sustainable agro-ecosystems.

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1 http://www.parcoaltamurgia.gov.it/officinadelpiano/index.php?option=com_content&view=article&id=856&catid=41

Methodological framework

To account for the requirements of sustainability assessment of agro-ecosystems described above, we structured our analysis in three steps: (i) the life cycle environmental impacts assessment of the studied farms, (ii) the aggregation of some impacts categories into the ecosystem quality damage index, and (iii) the incorporation of this index into the SVA algorithm. Figure 1 illustrates the approach to assess sustainability of agricultural production systems combining LCA and SVA.

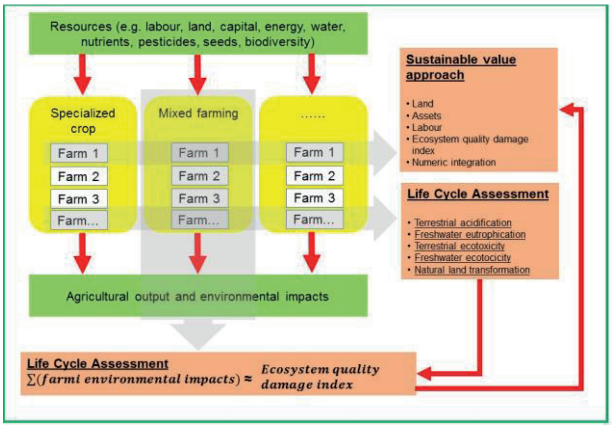

Figure 1. A framework for an integrated sustainability assessment of agro-ecosystems

The sustainable value of different farms and agricultural sectors (specialised crop and mixed farms) is calculated to compare their role in guaranteeing the sustainability of agro-ecosystems. The farms' contribution to environmental sustainability can be monitored using LCA. Within the LCA methodological framework, the ReCiPe endpoint impact assessment method (Goedkoop et al., 2012) was selected in order to combine a problem (CML) and a damage oriented (Eco-indicator 99) approach. Although traditional LCA is a steady-state tool which does not account for the uniqueness of the environmental systems affected and their sensitivities to emissions sources (Reap et al., 2008) this bias has been reduced by means of:

I. Consideration of only the most affected environmental impact categories by this site-specificity bias, such as: terrestrial acidification, freshwater eutrophication, soil and freshwater ecotoxicity (Reap et al., 2008).
II. Further reduction of the impact categories according to the main geo-morphological and ecological characteristics of the studied area.

While the ReCiPe method uses the data on registered species at the European or Global level, in this study the selected impact categories were normalised using data at the Mediterranean spatial level[2]. The ReCiPe methodology assumes that the quality of ecosystems is adequately represented by the diversity of species (Goedkoop et al., 2009). Hence the five impact categories terrestrial acidification, terrestrial ecotoxicity and freshwater ecotoxicity, freshwater eutrophication and natural land transformation (measured in terms of *species lost/year)* have been considered as a good proxy for the damage caused to ecosystems' quality. Assuming a

[2] *Data from 2000 have been used according to Brooks et al. (2002) in order to be consistent with the normalisation procedure used in the ReCiPe impact assessment method.*

linear relationship, an aggregated index has been designed (the ecosystem quality damage index), accounting for the overall effects of the farm's management activities on ecosystems' quality. The ecosystem quality damage index has been incorporated into the SVA algorithm representing the natural resources used by farms to create value added for the society. However, by definition, the outcomes of the SVA compensate for the negative impacts generated by farms with the positive ones. Therefore, the value contribution (the Return to Cost ratio) for each category of capital was calculated in order to identify on which resource category (capital, land, labour, natural) the efforts should be focused in order to achieve a more sustainable agro-ecosystem within the Park.

Materials and methods

To broaden the general insights into the integration and combination of sustainability assessment tools and to answer the call for methodological pluralism in holistic sustainability assessment (Gasparatos et al., 2009), this study performs a sustainability evaluation of farming systems both at the farm level and at the regional level. Therefore, LCA and SVA are integrated. Combining these two methods is feasible because they satisfy the request of complementarity, consistency and ability to address all the perspective of sustainability (Van Passel & Meul, 2012).

Application of this method is illustrated in a case study involving 14 mixed and specialised crops farms located in the Park. All the relevant farm characteristics are summarised in Table 1.

Table 1. Average descriptive statistics of the data sample of crop and mixed farms

	Unit	Crop Farms		Mixed Farms	
Farm size and land use		Mean value	Range	Mean value	Range
Cultivated area (UAA)	ha	178	40 - 410	313	94 - 1040
Crops area	ha	178	40 - 410	60	4 - 121
Grassland area	ha			224	19 - 1000
Forage area	ha			40	9 - 67
Farm Intensity					
Annual crop production	q./ha	20	3 - 37	26	15 - 56
Annual livestock production[a]	q./yr			56	0 - 150
Herd size	Number of heads			293	90 - 520
Financial capital	KEUR	96	22 - 318	173	16 - 307
Subsidies	KEUR	70	14 - 126	30	4 - 44
Labour	Average Work Unit	1	0,1 - 2	2	1 - 2

[a] *The production of one of the mixed farms was excluded in the calculation because it is the only case that produces sheep meat*

The LCA approach

LCA was applied for analysing the interactions between agricultural activities and the environment, allowing the evaluation of the main environmental impacts of farm activities in the Park area. The goal of this LCA study was to assess the relationships between farm activities and ecosystems' quality loss within the Park. Data from the commercial farms that participated in the project "Agroecosistemi" (n=14) were used and refer to the year 2013. Data were collected on farm management strategies, yields, fertiliser and pesticide use and water consumption, as well as the technique of animal husbandry (semi-wild or tethering), types and amount of animal feeding materials, etc. Data acquisition was performed using questionnaires that had been provided to participating farmers. An area based functional unit (FU) was defined for this study, since the sampled farms belong to the same class of "land use intensity". In order to account for land size effect, each farm is considered as a single production unit and it has been employed as a reference point for the estimation of environmental impacts.

The FU used within this study is thus a farm with UAA equal to 40 ha, which corresponds to the surface of the least extensive farm in our sample. For each farm, a detailed cradle-to-farm-gate life cycle assessment, including on and off farm pollution and avoided impacts, was performed (Figure 2).

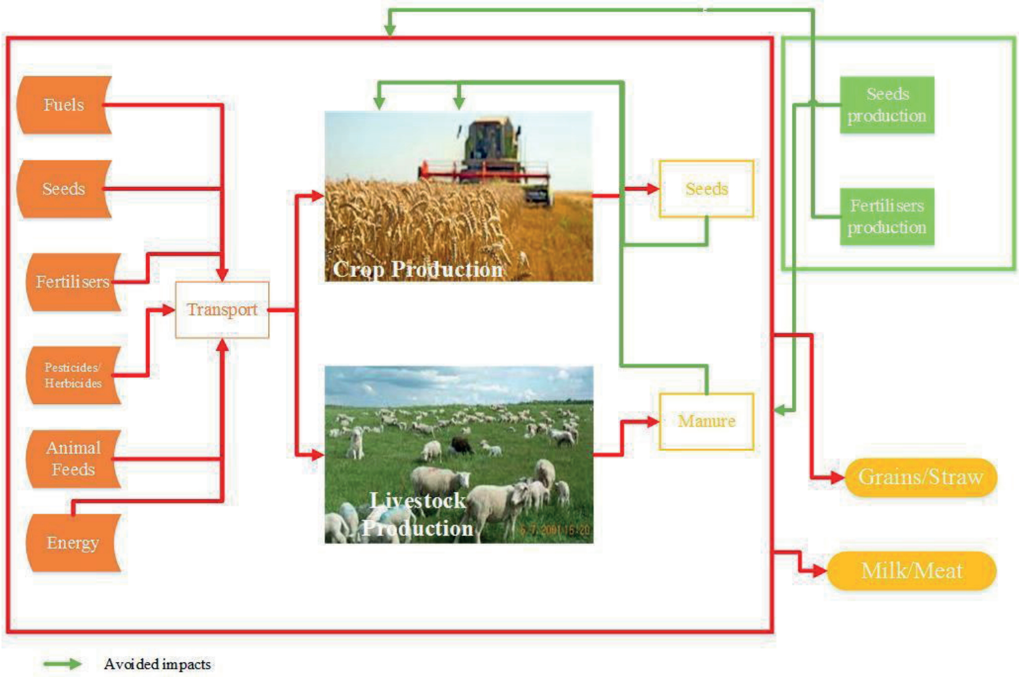

Figure 2. System boundaries used for the environmental impact assessment of the sampled farms.

The Ecoinvent database (version 2.2) was consulted, for collecting the data concerning raw materials' production and transports. Simapro 7.3.3 was used as a calculation platform. Transports inside the farm were excluded from the system boundaries. The use of manure and recycling of seeds were accounted for in the system as prevented impacts due to the avoided production of, respectively, nitrogen and phosphorus fertilisers and commercial seeds. The amount of fertiliser produced was determined based on the mean N and P content of bovine and sheep manure respectively (Brentrup et al., 2000; Azeez et al., 2010). The emissions of N fertiliser and manure were calculated according to Brentrup et al. (2000), using different references to estimate the N-balance for the different crops (Ryden et al., 1984; Köpke & Nemecek, 2010; Garabet et al., 1998). The leaching fraction of applied P fertilisers was estimated according to Nest et al. (2014). Pesticide emissions were assessed using the PestLCI model (Dijkman et al., 2012). Methane emissions to air and N_2O emissions to water and soil from livestock breeding and grazing were assessed using the IPCC tier 2 approach (IPPC, 2006).

Table 2. Life cycle inventory of crop and mixed farms (yearly based)

	Crop farms							Mixed farms						
	1	2	3	4*	5	6*	7*	8	9**	10	11	12	13	14
Land size (ha of UAA)	75	165	250	400	145	40	240	90	121	130	101	155	146	195
Herd size (n° of heads)								520	262	90	160	384	410	
Inputs - agriculture														
Gasoil (l)	7,150	6,750	30,500	51,780	58,000	4,233	11,076	8,906	13,195	4,768	7,715	7,900	7,884	9,805
Lubrificant oil (l)	179	152	763	1,376	1,528	103	277	344	330	112	193	198	325	245
Seeds (q)		169	348	835	1,758	68	298	153	235	385	160	42	117	209
Fertilisers (q)				1,260										
Herbicide (l)				2		60								
Pesticide (l)						120								
Manure (q)					14,820			320		100		1,815	160	4,518
Inputs - livestock														
Animal feed (q.li)									106	20	62		12	806
Electricity (kWh)								3508	2,425	300	1,496	3,508	2,588	4,139
Gasoil (l)									269	31	200	300		1,660
Lubrificant oil (l)									7	1	5	8		42
Emissions - agriculture														
Carbon dioxide (q)	210.92	184.06	324.03	5,933.02	746.28	12,043.53	233.46	102.51	330.58	96.78	239.64	258.29	170.86	119.51
Carbon monoxide (kg)	55.68	33.17	56.83	1,457.08	121.34	3,722.36	48.10	18.35	42.04	12.48	38.66	37.67	30.94	16.11

Methane (kg)	0.88	0.77	4.84	24.66	3.10	50.45	0.97	0.76	1.37	0.42	1.00	1.07	0.71	0.50
Sulphur dioxide (kg)	6.83	5.98	10.57	191.93	24.22	391.48	7.59	3.59	10.71	3.14	7.78	8.37	6.31	3.87
Nitrogen oxides (q)	2.79	2.72	4.80	78.16	10.86	198.72	3.52	1.38	4.67	1.32	3.50	3.67	2.51	1.70
Ammonia (q)	0.001	0.001	1.60	552.90	37.13	5.69	114.88	0.03	0.002	1.03	0.002	0.05	1.65	91.83
Nitrate (q)				534.38	124.48	12.02	111.04	12.16		3.81		0.18	6.64	514.25
Phosphorus (q)					672.43			21.95		6.86		14.28	21.95	222.29
Fenoxaprop-p-ethyl ester (q)				0.03										
Emissions - livestock														
Methane (kg)								24.53	19.66	18.23	19.63	23.44	18.23	27.77
Nitrous oxide (kg)								548.84	5.36	262.04	501.92	1,604.2	2,139.5	3,083.7

* *Are managed using conventional agricultural practices*

** *Livestock using only indoor rearing techniques*

For the life cycle impact assessment (LCIA) the endpoint ReCiPe method (Goedkoop et al., 2012) was used, which integrates the 'problem oriented approach' of CML-IA (Guinée et al., 2002) and the 'damage oriented approach' of Eco-indicator 99 (Goedkoop & Spriensma, 2001). Both these approaches have strengths and weaknesses related to: (i) the level of uncertainty; and (ii) the interpretability of the results. The ReCiPe method implements both strategies and has both midpoint (problem oriented) and endpoint (damage oriented) impact categories. The "Alta Murgia" is the main water resource for the entire Apulia Region (Canora et al., 2008) and it is highly important in terms of vascular plants and animal biodiversity (Perrino et al., 2006; Cotecchia, 2010). To account for these typical traits, the impact categories used for this study were water -use and land-use changes (Chapin III et al., 2000). The ReCiPe normalisation factors are based on data at both the European and global level, whereas policy makers often are interested in using smaller regions as reference systems (Sleeswijk et al., 2008). In this study, the selected impact categories were normalised based on the rate of yearly species lost for the Mediterranean basin in the year 2000 as explained by Brooks et al. (2002).

Taking into account the "*conceptual and data limitations*" existing for the inclusion of biodiversity and ecosystems quality into the LCA framework (Toumisto et al., 2012; Curran et al., 2011; Schmidt, 2008) the selected impact categories were considered as a good proxy for assessing the damage produced by farm activities to the quality of ecosystems, landscapes and wildlife habitats. The other impact categories which associate with the human health and resources areas of protection (see Goedkoop et al., 2012) were excluded from the study. The assumption for this choice was that the Park Authority was more interested in understanding how agriculture activities affected biodiversity and ecosystems' quality at the local level, which can provide a more direct link to political goals (Sleeswijk et al., 2008). Land occupation (agricultural and urban) impact categories are usually estimated based on the species richness ignoring human distortion (de Schryver et al., 2010). Therefore, these impact categories are also excluded from the study to avoid overestimated damages.

The Sustainable Value Approach (SVA).

The SVA methodology assumes that a firm contributes to sustainable development whenever it uses its resources more efficiently than other companies, reducing or unchanging the overall resource used (Van Passel & Meul, 2012). The methodological steps to calculate the sustainable value of a firm are:

(i) Define the aims of the analysis and determine the addressed stakeholders;

(ii) Determination of the relevant resources with regard to sustainability performance of the firms or the economic sector;

(iii) Determine the benchmark values. The benchmark determines the costs of the resource that a firm (or economic sector) must exceed in order to produce sustainable value;

(iv) Comparison of the productivity level of a company resource with the corresponding benchmark while keeping the overall resource use constant. When the productivity of the company exceeds the opportunity cost, the company contributes to a sustainable use of the considered resource.

The opportunity cost of a resource form is the cost of the most valuable alternative and can be calculated as:

$$opportunity\ cost\ = value\ added_{benchmark}/resource\ _{benchmark} \qquad (1)$$

A firm generates sustainable value by using resources more efficiently than the benchmark. Accordingly, the *value spread* by the *company$_i$.* is calculated by subtracting the opportunity cost from the efficiency of resource use for the company (2).

$$value\ spread_i\ = value\ added_i/capital_i\ -\ value\ added_{benchmark}/resource_{benchmark} \qquad (2)$$

Therefore, the sustainable value of the *company$_i$ is* assessed by summing up the value contribution for every category of resource (3) that will be estimated by multiplying the *value spread$_i$* for a certain category of resource by the amount of resource used by the *company$_i$*.

$$sustainable\ value_i\ = \frac{1}{n}\sum_{s=1}(value\ spread_i^s * capital_i^s)\quad \begin{matrix} for\ s\ [1,k] \\ k = n^\circ\ of\ resource \end{matrix} \qquad (3)$$

According to Van Passel et al. (2007), dividing by the number of resources *n* allows us to correct for the overestimation of value created, avoiding double counting (Figge & Hahn, 2005). In order to account for the company size, the Return to Cost Ratio (RTC) for farm *i* was calculated (Van Passel et al., 2009) according to equation 4.

$$Return\ to\ Cost\ ratio_i\ =\ value\ added_i/(value\ added_i - sustainable\ value_i) \qquad (4)$$

A RTC above one means that the company is more efficient in resource allocation than the benchmark. The most criticised aspect of this method is the definition of the benchmark (Mondelaers et al., 2011). This is due to the fact that the method is not able to capture whether the overall resource use ensures a sustainable outcome (Figge & Hahn, 2004a); and so the benchmark may be defined in such a way that it does not describe a sustainable resource use (Ang et al., 2011). Although, the choice of the benchmark strongly affects the explanatory power of the analysis (Figge & Hahn, 2005), Van Passel et al. (2007) showed in an application on Flemish dairy farms that the ranking of the companies does not differ between several types of benchmarks. An interesting alternative approach is the construction of a sustainability benchmark using appropriate agro-environmental farm models (Merante et al., 2015). Unfortunately, these models were not available for the assessment of agricultural systems in the studied area.

For the above mentioned reasons, the average for each resource has been used as a benchmark. To test the robustness of the sustainable value calculations, the rank correlation (Spearman's rho) of RTC using different benchmarks is calculated (Table 3). The correlations are high and significant.

Table 3. Correlation between the return-to-cost ratio using different benchmarks

Return-to-cost	Benchmark 1	Benchmark 2	Benchmark 3
Benchmark 1[a]	1	0.9428***	0.6131**
Benchmark 2		1	0.6440**
Benchmark 3			1

[a] *Benchmark base using the average for each form of resources*
** significant at 10% ** significant at 5% ***significant at 1%*

The different forms of capital considered were: (i) labour, (ii) farm capital, (iii) used land (ha) and (iv) ecosystem quality damage (species lost*yr). For each farm, labour was measured in Annual Working Unit (AWU). Farm capital (assets) was calculated as the total capital minus the value of land to avoid double counting; while the ecosystems quality damage index was calculated by summing the considered environmental impact indicators of the LCA analysis. Therefore, in this study the Sustainable Value was expressed as a function of farm capital, used land, labour and ecosystems' quality damage (Equation 5).

$$sustainable\ value_i = f\ (farm\ capital_i, used\ land_i, labor_i, ecosystem\ quality\ damage_i) \quad (5)$$

This highly relevant selection of several resources categories is ignored by previous studies (Van Passel et al., 2007; Van Passel et al., 2009). This is especially critical for natural resources for which the choice was merely data driven without a sound selection method (see Ang et al., 2011; Van Passel et al., 2009; Van Passel et al., 2007). Only Merante et al. (2015) and Pacini et al. (2015) used agro-environmental models to outline environmental thresholds that can be used as farm sustainability benchmarks.

Results

There is a large within-group variability for the indicators scores between specialized crops farms and mixed farms. The ecosystem quality damage scores for the sampled farms range between 3.60E-05 and 3.89E-02 species lost*yr as shown in Table 4. Specialized crop farms have less impact on the environment in terms of cumulative ecosystems quality damages, accounting for almost the 30% of the total estimated damages to ecosystems (Table 4).

Table 4. Characterisation of the environmental impacts of crop and mixed farms (species lost*yr$^-$)

		Terrestrial acidification	Freshwater eutrophication	Terrestrial ecotoxicity	Freshwater ecotoxicity	Natural land transformation		Ecosystem quality damage index
Farm 1	CF	1.88E-06	2.84E-07	-3.89E-08	4.43E-08	3.38E-05		3.60E-05
Farm 2	CF	1.44E-05	3.47E-07	6.17E-06	1.79E-07	6.43E-05		8.54E-05
Farm 3	CF	-6.73E-06	4.72E-07	-1.48E-05	-1.87E-08	1.75E-04		1.54E-04
Farm 4	CF	4.01E-03	3.99E-05	1.21E-04	5.31E-06	3.42E-03		7.60E-03
Farm 5	CF	1.80E-04	2.14E-03	1.11E-02	1.38E-03	2.00E-04		1.50E-02
Farm 6	CF	9.64E-05	2.27E-05	2.75E-05	2.46E-06	3.53E-04		5.02E-04
Farm 7	CF	1.03E-03	8.34E-06	1.98E-05	1.01E-06	4.82E-04		1.54E-03
Farm 1	MF	-6.94E-05	2.82E-03	1.46E-02	1.82E-03	8.38E-05		1.92E-02
Farm 2	MF	6.62E-06	2.21E-06	1.94E-05	3.76E-07	3.22E-04		3.51E-04
Farm 3	MF	7.54E-05	7.46E-04	3.86E-03	4.80E-04	7.86E-05		5.24E-03
Farm 4	MF	-3.79E-06	1.32E-08	1.36E-07	-4.28E-08	4.97E-05		4.60E-05
Farm 5	MF	2.39E-05	7.92E-04	4.09E-03	5.09E-04	5.38E-04		5.95E-03

Farm 6	MF	-3.93E-05	1.91E-04	9.72E-04	1.23E-04	1.26E-04	1.37E-03
Farm 7	MF	6.25E-04	5.58E-03	2.89E-02	3.59E-03	1.40E-04	3.89E-02
SD		0.001	0.002	0.008	0.001	0.001	0.01

CF = crop farms; MF = mixed farms; SD = standard deviation

Specialised crop farms score better for freshwater use and terrestrial ecotoxicity; while they have higher impacts for terrestrial acidification and transformation of natural land. Farm 5 CF and Farm 1 MF show significant impacts in terms of terrestrial ecotoxicity which consistently affect the overall ecosystem quality damage outcome. These high impacts are due to the consistent amount of manure used (Table 2), which consequently determines a high level of phosphorous leached into water bodies.

These results can be explained by the higher use of human-made resources for crop farms such as gasoil, seeds, fertilisers and pesticides. Usually, mixed farms produce only the forage needed for feeding the livestock and use natural pastures for grazing their animals. Therefore, they have less cultivated land for crop production, leading to a decreasing number of soil tillage operations and a less intensive use of chemicals. Moreover, seed recycling is more widely practised in mixed farms generating lower impacts on soil, natural land transformation and climate changes. The higher impacts of mixed farms on freshwater (ecotoxicity and eutrophication) and terrestrial ecotoxicity are determined by freshwater nitrogen and phosphorus leaching as a result of animals grazing and manure management.

The performance of the crop and mixed farms clearly differs (Figure 3). Overall, most of the specialised crop farms are sustainable showing a RTC above 1, whereas most of the mixed farms are less sustainable showing RTC below 1. However, both farm groups exhibit frontrunners with a RTC above 1.

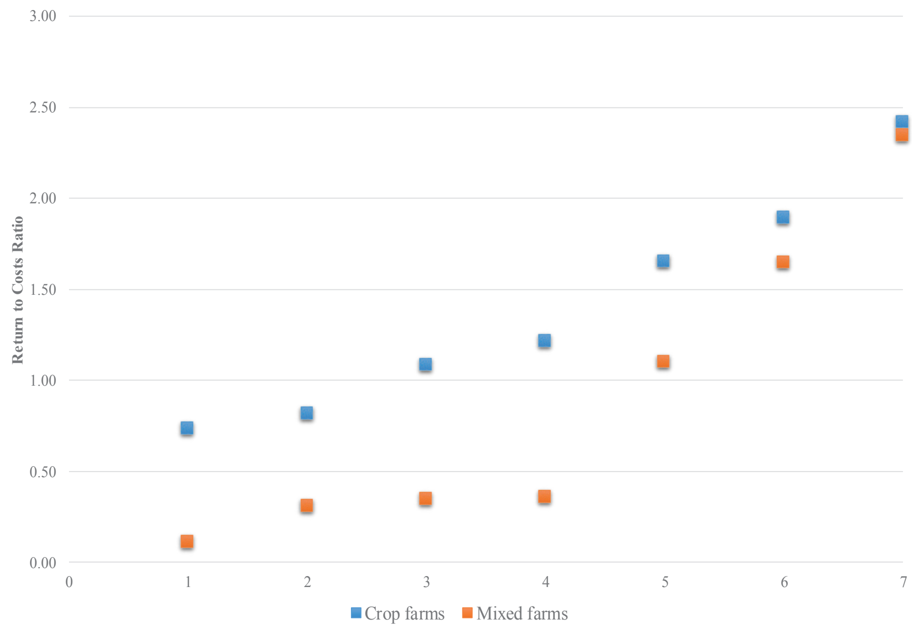

Figure 3. Return to cost ratio using the average benchmarks

The variables in our data set that may explain the difference in farms' performance are the capital productivity and eco-efficiency (Table 5).

Generally, the most sustainable farms maximise the productivity of capital, labour and land while minimising the ecosystem quality damage index. Mixed farms perform well in terms of land productivity, while specialised crop farms achieve better results in terms of labour and capital productivity and have a lower impact on ecosystem quality. From these calculations of the sustainable value, it can be concluded that the focus should be put on the reduction of ecosystem quality damage of mixed farms. Further, the higher land productivity of crop farms is important to strengthen the sustainability performance of agricultural activities within the Park.

Table 5. Average resource productivities and eco-efficiency of crop and mixed farms.

	Capital productivity (€/€)	Labour productivity (M€/AWU)	Land productivity (€/ha)	Eco-efficiency (€/species lost *yr)
Crop farms	1.79	1.40	514.09	2.82E+08
Mixed farms	0.997	0.44	848.90	1.75E+08

Discussions and Conclusions

In this paper, we explored the possibilities of integrating biophysical and monetary sustainability assessment tools through combining the impacts of agriculture activities on ecosystems with the concept of natural capital. To achieve this goal we performed a case study where Life Cycle Assessment and Sustainable Value Approach were simultaneously used to assess the sustainability of agricultural systems within the Park. The methodology presented in this study allowed an integrated assessment of the economic and environmental dimensions of sustainability, providing decision makers with an overview of the effects of agriculture activities on local sustainable development. Moreover, the use of a benchmark to measure the overall performance of farms and their relative efficiency can be useful to highlight opportunities of improvement both at farm and regional level. The main goal was to develop a novel framework for combining biophysical and monetary oriented tools to assess sustainability of agricultural systems. However, considering the large variability in farm accountancy data and agriculture management practices, a higher number of farms needs to be sampled in order to avoid the inference on outcomes of frontrunners and laggards. Further research is needed to improve the benchmarks such as the efficiency frontiers which require more data availability in order to guarantee the robustness. Although further improvement is needed, the new methodology for measuring farm sustainability proved to be promising.

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Evaluating economic implications of agricultural innovations. A theory based impact assessment of biochar as a soil amendment and improved wastewater irrigation in West African cities

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Abstract: This paper proposes a methodology for systematically assessing the economic implications of agricultural innovations on different stakeholder groups, exemplified by biochar as a soil amendment and improved wastewater irrigation in the West African cities of Tamale (Ghana) and Ouagadougou (Burkina Faso). Intensive cultivation of vegetables on small urban open-space plots has resulted in declining soil fertility and yields. Insufficient irrigation and nutrients have promoted the use of wastewater irrigation amongst urban vegetable farmers, exposing urban producers and consumers to health-related risks. Productivity-enhancing innovations may simultaneously improve the livelihoods of urban farm households as well as, through reduced market prices, increasing the food security of consumers. Additionally, improved irrigation technology to reduce pathogen loads on vegetables may enhance food safety but increases farmers' production costs. In order to assess the economic impacts of such technology enhancements ex-ante, a household production function for urban vegetable farmers that integrates soil fertility indicators is developed, alongside an aggregate supply and demand model for urban vegetable markets. This will allow the dynamic estimation of income effects on urban farmers due to production changes with resulting price changes at the market level. To scrutinise further assumptions pertaining to consumers' and producers' perceptions of the costs of illness, studies on the opportunity cost of wastewater-related illness and willingness to pay for safe, certified food are being conducted. The combination and integration of a farm-level assessment of productivity changes, analysis of market-level changes and contingent valuation studies on consumers' preferences allows for a holistic, systematic assessment of the sustainability of agricultural innovations from the perspective of various stakeholder groups.

Keywords: Agricultural innovations, stakeholders, biochar, contingent valuation, cost-benefit analysis, impact assessment, market method, production function, soil fertility, wastewater irrigation.

Introduction

To meet the global challenge of food and nutrition security for a steadily growing and increasingly urban population, sustainable agricultural intensification will be inevitable (Tscharntke et al., 2012; Tilman et al., 2011). This particularly applies to Sub-Saharan Africa and other developing regions with persistent shortfalls in agricultural productivity and resulting poverty (FAO, 2014; Dzanku et al., 2014; The Montpellier Panel, 2013). Agricultural innovations play a key role in intensification but must be rigorously assessed for all relevant dimensions of sustainability in a particular local context. Apart from the technical feasibility, the ecological impacts and the socio-cultural appropriateness, the economic desirability of an innovation must be examined before a widespread roll-out can be recommended.

With growing urban populations and demand for food, a multitude of livelihood opportunities related to agricultural cultivation and trade have emerged. Due to inadequate storage and transportation infrastructures in much of the Sub-Saharan region, perishable crops such as vegetables are produced in close proximity to urban markets (Cofie et al., 2003). Despite its importance for livelihoods and food security, agriculture in West African cities such as Tamale and Ouagadougou increasingly come under pressure from urban sprawl and competing land use options. The intensive cultivation of vegetables on small, urban, open-space plots has resulted in declining soil fertility and yields. This has promoted the use of nutrient-rich but unsafe water sources such as wastewater for irrigation of locally produced vegetables, exposing urban producers and consumers to health-related risks (Drechsel & Keraita, 2014; Wichelns & Drechsel, 2011).

To enhance soil fertility and reduce the health-related risks of wastewater irrigation, "Urban Food Plus" (UFP), an on-going multi-disciplinary African-German research project aimed at increasing resource use efficiency in West African urban agriculture (www.urbanfoodplus.org), has proposed biochar as a soil amendment and improved wastewater filtration technologies. Scientific interest in biochar, i.e. charcoal from various types of biomass such as unused crop residues and stems from research on so-called "*terra pretas*" in the Amazon rainforest (Lehmann, 2007). While not having fertilising properties per se, biochar may possibly improve soil characteristics. In addition, biochar holds the promise of being an effective carbon sink, thus curbing greenhouse gas emissions (Steiner, 2007; Glaser, 2001; Marris, 2006). The project also examines the properties of biochar as a medium for wastewater filtration. Apart from investigating the effects of biochar addition and improved wastewater irrigation on soil fertility and yields, the adoption potential and wider socioeconomic implications of these innovations have to be established. Since mid-2013, UFP has been conducting multifactorial field trials in the cities of Tamale (Ghana) and Ouagadougou (Burkina Faso), along with crop and livestock production surveys, anthropological studies, food flow surveys and on-farm field trials. In the second phase (2016-2018), research activities will be replicated in Bamenda (Cameroon) and Bamako (Mali).

While research activities are still ongoing, this contribution proposes an integrated, theory based methodology developed in the context of the UFP project to comprehensively and systematically evaluate the *economic* impact of agricultural innovations on different stakeholder groups and on urban food security and poverty alleviation through an ex-ante evaluation (i.e. before implementation).

Assessing agricultural innovations from the perspective of local stakeholders

Our research aims at exploring the effects of biochar application and wastewater filtration on the livelihoods of urban farmers, and, via effects on food quality, supply and prices, on urban food security and food safety. The UFP project is proposing a comprehensive, holistic approach towards assessing the sustainability of innovations that integrates the perspectives of urban farmers and consumers. Drawing on a variety of data on farm-level production and cultivation patterns, soil quality, household structure, income sources, farm households' costs of illness and urban consumers' willingness to pay (WTP) for safer, certified produce, the assessment combines insights from the natural sciences (soil science and agronomy), engineering sciences (wastewater engineering) and economics. Other social science disciplines such as geography (GIS-based spatial sampling and analysis) and anthropology (long-term ethnography of urban food markets and technology adoption) make further important contributions to the empirical investigation.

While the integration of various analytical perspectives and multiple data sources is innovative, the theoretical concepts on which our empirical assessment rests are not new, drawing on well known and well-tested approaches developed in welfare economics that are typically applied for environmental valuation. These include revealed preference and stated preference approaches to cost-benefit analysis (King & Mazzotta, 2000; Carson & Bergstrom, 2003; Bockstael & McConnell, 2007; Bergen et al., 2013).

Farm-level assessment

As potential adopters, urban vegetable producers are the primary stakeholder group affected by the agricultural innovations proposed by UFP. Applying a production function for these urban farmers, we estimate the role of various input factors in determining agricultural output in the specific context of Tamale and Ouagadougou. Based on our theoretical assumption that biochar may not just alter the role of traditional production factors (e.g. intermediate inputs and labour) but also the quality of land via changes in soil fertility, the production function also accounts for landholding size moderated by soil quality parameters.

Standardised household data from 168 randomly sampled open-space farmers in Tamale and 237 in Ouagadougou were collected in 2014/2015. Along with the socio-economic data, soil samples were taken from each surveyed farm to determine the influence of various soil parameters on agricultural output. By integrating knowledge from UFP's field experiments and secondary literature on the interactions between biochar, other inputs, soil parameters and yields, (as well as taking into account the costs of technology adoption), the potential net welfare effect of using biochar as a soil amendment on agricultural output can be simulated ex-ante. Focus group discussions with urban farmers complement the quantitative investigation and further explain the empirical observations.

Market-level assessment

For the farm-level analysis, we assume constancy of market prices, as long as only few farmers adopt and food markets remain unchanged. However, with increasing adoption, production quantities of vegetables are expected to increase on the urban market. This will have an effect on market prices and hence an impact on the welfare of urban consumers and producers. The assessment of welfare changes caused by widespread adoption of the proposed innovations focuses on simulating changes in production quantities on urban food markets and resulting price effects. Consequences for the food security of urban consumers (through more affordable vegetables) and corresponding income effects on urban producers (through reduced market prices) are expected. For the empirical analysis, aggregate supply and demand models for urban vegetable markets are developed, using time series data of the past 30 years on a regional and national level.

Assessing costs of illness and consumers' willingness to pay for food safety and food certification

To get an even more comprehensive and realistic picture of the adoption potential of the UFP proposed innovations, further empirical studies explore farmers' costs of illness and urban consumers' willingness to pay for enhanced food safety, as achieved through wastewater filtration and food certification. Both analytical perspectives focus on the adoption potential of improved wastewater irrigation technologies. A prototype for a small-scale, low-cost wastewater filtration and drip irrigation plant has been developed by the UFP engineers and is currently being tested under field conditions in Tamale. The economic viability of such a technology depends not just on the initial investment cost but more importantly on farmers' perceptions of longer-term benefits and disadvantages of adoption, i.e. the net balance between increased returns and increased production costs.

As wastewater-using farmers are exposed to particular health risks such as worm infections and other gastrointestinal disorders (Drechsel & Keraita, 2014), a study among 300 urban farmers in Tamale was conducted to establish illness-related costs and to explore causalities between wastewater use and illness incidence. Apart from potentially reduced illness costs, farmers could also be motivated to adopt improved wastewater irrigation technologies if they can achieve higher prices for their products. We are therefore also establishing urban farmers' willingness to pay (WTP) for safely irrigated and certified vegetables. To establish this WTP, a first contingent valuation study was conducted in Tamale among 300 urban consumers. Corresponding cost of illness and WTP studies are planned for Ouagadougou.

Conclusions

As argued initially, assessing the sustainability of agricultural innovations has to go beyond the technological, social or ecological assessment level, i.e. the question of whether an innovation "works" and is socially and ecologically acceptable or not. Our assessment approach will reveal whether the adoption of the UFP-proposed innovations "makes sense" from the perspective of urban farmers and consumers. Farmers will only have reason to adopt agricultural innovations if such innovations lead to the desired net productivity enhancements and increase their income, be it via a reduction in production costs, reduced opportunity costs (e.g. costs of illness) or better prices for their agricultural commodities.

The results to date clearly confirm the suitability of our theoretical and methodological approach. For instance, first regression results demonstrate a strong link between soil quality parameters and farmers' agricultural income. This confirms that an integration of socioeconomic and biophysical data is not just possible but highly desirable to assess the sustainability of agricultural innovations. However, quite a few analytical steps towards integrating data and research findings are still outstanding, as the research tasks of UFP are not yet completed. This particularly applies to modelling the interactions between urban vegetable production, markets and food security.

The ex-ante, forward-looking perspective of our investigations, i.e. the simulation of impacts of the proposed innovations before widespread adoption, is stressed as particularly useful, as it avoids a waste of scarce resources and experimentation with potentially unsustainable solutions on the back of poor urban farmers in Sub-Saharan Africa.

Acknowledgement

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Understanding the impacts of technology on farming system design using a linear programming approach to resource optimisation – a case study of increasing pasture production in New Zealand hill country environments

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Abstract: New farming technologies may have definite benefits when studied in isolation, but can be disruptive when implemented. This reduces the potential uptake and integration of such technologies. A project was developed to provide a framework for understanding impacts of new science and technologies on farm system dynamics. Elements of the work will help understand the role of risk and variability in decision-making and uptake. A range of land class and variability scenarios were tested to set current potentials and understand the effect of future technologies on-farm. The objective was to investigate the impact of improved ryegrass use to increase pasture productivity on whole farm profitability and inform the design of future farming systems. How does the farm system respond to increasing feed availability on part of the farm? Three real farming properties in three distinct geo-climatic regions (cool temperate (1280 ha), dry temperate (3136 ha) and warm temperate (1159 ha)) were modelled using INFORM, an optimisation model developed in-house, that maximises farm EBITDA (Earnings before interest, tax, depreciation and amortization) using farm resources. Information from current physical and financial data were used to generate input parameters for the models. Three base models that mimicked current farm practices as near as possible were developed for baseline comparisons. Models were then generated to assess the impact of increasing pasture production from the current production of 7t DM/ha, to 15t DM/ha on 100, 200, 300 and 400ha blocks of land within each farm. Increasing pasture production resulted in a linear response of EBITDA with increasing area of improved land. EBITDA increased by $33,000, $10,000, and $32,000 for every 100 hectares of improved land up to 400 hectares for the cool temperate, dry temperate and warm temperate geo-climatic regions respectively. Only small adjustments were made to the farming enterprises with increasing area of improved land. The outcome from investigating this first technology, a linear increase in pasture productivity, through the application of new ryegrass genetics, provided a predictable and non-disruptive change in the farm system. The types of livestock enterprise were mainly unchanged, suggesting that a technology of this type would be relatively simple to implement, provided the appropriate management practices to maximise the pasture production were also simple to implement.

Keywords: Farm system, geo-climatic, profit, animal enterprise, pasture

Introduction

New Zealand is dominated by mountainous and hilly landscapes. Mountain land above 1000 m occupies about 20% of the land surface, while steep, non-arable hill country below 1000 m comprises a further 40% (Blaschke et al., 1992). These lower steeplands are known popularly in New Zealand as "hill country" and comprise two main areas that support livestock grazing enterprises. These are North Island hill country, which covers 3.5 million ha (28% of farmland in New Zealand) (Mackay et al., 1993), and South Island pastoral high country (also known as tussock grasslands, run country, rangelands) which comprises about 3.4 million ha (Anon, 1994).

The development of New Zealand's hill country for pastoral farming has had a long and interesting past (Suckling, 1966; Levy, 1970; White, 1973; Blaschke et al., 1992; White, 1999). Significant events include clearance of large tracts of evergreen conifer/broadleaf forests in the 19th and 20th centuries, destruction of areas of tall tussock grasslands, enhancement of soil fertility through application of lime and fertiliser, particularly superphosphate, subdivision to enable improved stock management and control of grazing pressure, and introduction of new species or improved cultivars and selections of existing species. The aerial application of fertiliser and seed using fixed-wing aircraft, commencing in the 1950s, and later the helicopter revolutionised development and management of hill country pastures.

If subdivision, topdressing and utilisation are advanced to the stage where further gains are sought, introducing new germplasm may have potential. Lambert et al. (1985) described some benefits of introducing improved plants to existing hill pastures as enhanced annual or seasonal production of forage, higher nutritive value of forage, and more tolerance to factors such as drought, grazing, trampling, pests, or low fertility. They also highlighted the potential value of introducing new germplasm to exploit the many different micro-sites present in hill pastures, and to allow for situations where the material was not introduced earlier, or was introduced but did not persist perhaps because of inappropriate management.

Pasture production in New Zealand hill country can range widely (McNamara, 1992) and produces an average of 5-9 t DM/ha depending on the rainfall (Daly, 1990). However, much higher yields of between 15 and 20 t DM/ha can be achieved when intensive grazing management is applied in conjunction with nitrogen fertiliser, regardless of low rainfall (Lambert et al., 2003; Mills et al., 2006).

When farmers aim to increase productivity and profitability, changes are often required to the farming system. In the first instance current data from operating farms can be used to test whether improvements to the feed supply add value to the farm enterprise. Secondly, changes in enterprise must be assessed to determine the suitability of the changes to the achievable practices.

Farm systems analysis was used to investigate the potential impacts of increasing pasture production through the perpetual use of Italian ryegrass on part of hill country farms on whole farm systems configuration, using real farm data from three sheep and beef breeding farms (2 North Island and 1 South Island). The data were supplied by Landcorp Farming Ltd, a state-owned farming company in New Zealand. Whole farm scenarios and variability were investigated using a response surface approach to maximise profit by optimising the chosen system and then providing investment analyses.

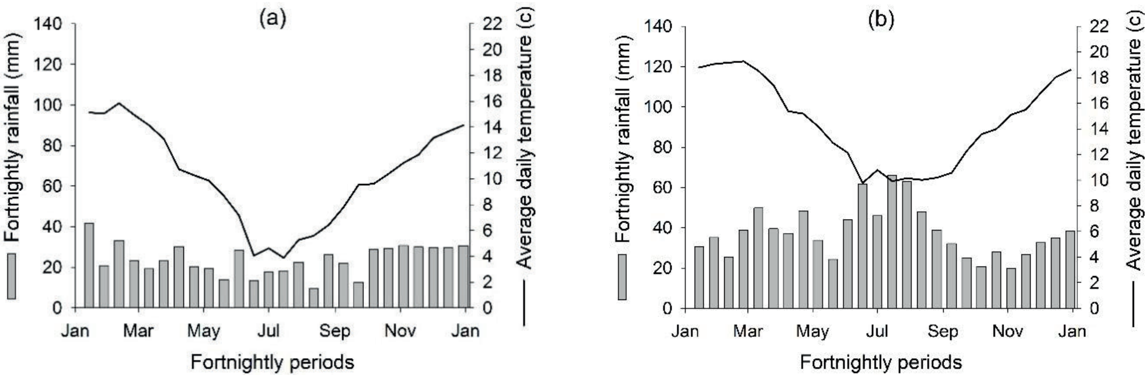
Briefly, the process used existing real farm data to investigate potential maximum profit by optimising the use of current resources to provide a base comparison for potential changes. An increase in resource was investigated by adding a specialist ryegrass area to the farm (producing 15t DM/ha/yr).

Methods

Farm system analyses were performed using INFORM (Integrated Farm Optimisation and Resource allocation Model) (Rendel et al*.,* 2013, 2015), a linear programming model that maximises EBITDA (Earnings before interest, tax, depreciation and amortization), by optimising resources over a one year timeframe. INFORM is a single year steady state model. Initially base scenarios were developed that replicated, as near as possible, the physical properties and the animal performance parameters that were achieved in the previous year on three Landcorp Farming Ltd properties in three distinct New Zealand geo-climatic regions (cool moist temperate (Otago, 1280 ha), warm dry temperate (Gisborne, 3136 ha) and warm wet temperate (Northland, 1159 ha) (Figure 1).

Figure 1. **Approximate position of the farms in three geo-climatic zones in New Zealand.**

The three properties were modelled to assess the impact of increased pasture production from an intensive pasture renewal programme on profitability and farm enterprise choice. The three properties represent a range of climatic conditions (Figure 2) that are experienced around New Zealand.



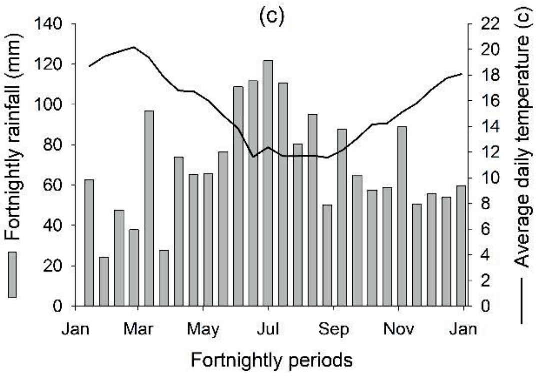


Figure 2. Fortnightly rainfall (mm) and average fortnightly temperature (ºC) for Otago (a), Gisborne (b) and Northland (c) demonstrate the relative differences between these geo-climatic zones.

Baseline farm models

Three baseline farm scenarios were developed from the physical data provided by Landcorp Ltd. Pasture and animal performance input tables were populated using information extracted from these files. Actual expenditure files were used to create animal, per hectare and enterprise costs following Thompson et al (2015) (Table 1). Per animal costs were further partitioned into ewe, lamb, cow and growing cattle costs assuming that labour costs are 30% greater for sheep than cattle and animal health costs are 50% greater for cattle than sheep on a per head basis.

A twelve month fortnightly price schedule was developed for prime beef and lamb based on weekly prices sourced from www.interest.co.nz for the 2014 year. Separate schedules were developed for the North and South Island, with adjustments for carcass grade to reflect published market pricing. Store animal prices were adjusted to reflect the schedule price as per local information. Recorded animal liveweight gain and reproductive performance were used to ensure that INFORM replicated enterprise performance comparable to the current farms.

Otago and Northland properties were of similar size (1280 and 1159 ha respectively) while the Gisborne property was considerably larger (3136 ha). The properties were divided into land management units (LMU) based on the pasture productivity of the land resource. Both Otago and Gisborne properties consisted of two LMU while the Northland property had four LMUs in the base model. Latitude for each property was estimated at 45.9°S, 38.7°S and 35.1°S for Otago, Gisborne and Northland properties respectively (Figure 1). Latitude strongly affects seasonal pasture growth patterns in New Zealand.

Table 1. Per animal *(includes costs associated with animal health, breeding, shearing, salaries, casual wages, ACC levies, electricity and vehicle fuel),* **per hectare** *(includes costs associated with dogs and horses, weed and pest control, amenity planting and shelter belt maintenance, pasture maintenance, urea, lime and fertiliser application, freight, farm stores, repairs and maintenance, rates and other costs)* **and per enterprise** *(includes costs associated with livestock recording, professional services, stationary, office supplies, subscriptions, communications and travel)* **cost for the three farm systems modelled**.

	Otago	Gisborne	Northland
Enterprise ($)	15889.63	22937.67	12104.77
Hectare ($/ha)	164.53	169.00	233.86
Ewe ($/ewe)	26.79	22.50	37.58
Lamb ($/lamb)	11.48	7.05	10.10
Cow ($/cow)	36.34	26.33	32.47
Finishing cattle ($/animal)	26.24	26.33	39.67

Increased pasture production scenarios

Four scenarios for each baseline farm were created to investigate the effect of increased pasture production on a restricted area of the farm, on farm enterprise structure and overall EBITDA. This was achieved by creating a new land management unit (LMU) that consisted of 100, 200, 300, or 400 ha with a pasture production of ~15000kg DM/ha. This LMU was named "Improved ryegrass" to reflect the use of Italian ryegrass as the base forage (Figure 3). It was assumed that Italian ryegrass is a two year crop with an annual cost per hectare of $185.40 (Table 2) above the standard LMU cost. Nitrogen fertiliser (N) was also used to boost pasture production. The first 40kg of N used had a response rate of 30:1 with the remaining 30kg of N having a response of 24:1. It was also assumed that best management practice for ryegrass grazing would be implemented to maximise growth. The LMU in Italian ryegrass would be used on a two year cycle of renewal in perpetuity. Pasture energy content and animal performance traits remained the same as in the baseline models. The Gisborne farm was significantly larger than the Otago or Northland farms and so further scenarios of 250, 500, 750 and 1000 ha were also investigated to test the importance of scale.

Table 2: Assumed Italian ryegrass establishment costs excluding fertiliser for a two year life. This value is then halved to represent an annual cost and assigned directly to the LMU as an operational cost for EBITDA calculations. A further analysis of these costs was done using an investment analysis to compare the two approaches.

	Cost ($/ha)
Grass seed	$170.40
Glyphosate	$16.89
Clopyralid	$43.52
Chemical application	$20.00
Direct drilling	$120.00
Total	**$370.81**

Pasture growth curves were supplied for each LMU (Figure 3) from current information and were converted to a fortnightly profile for each property.

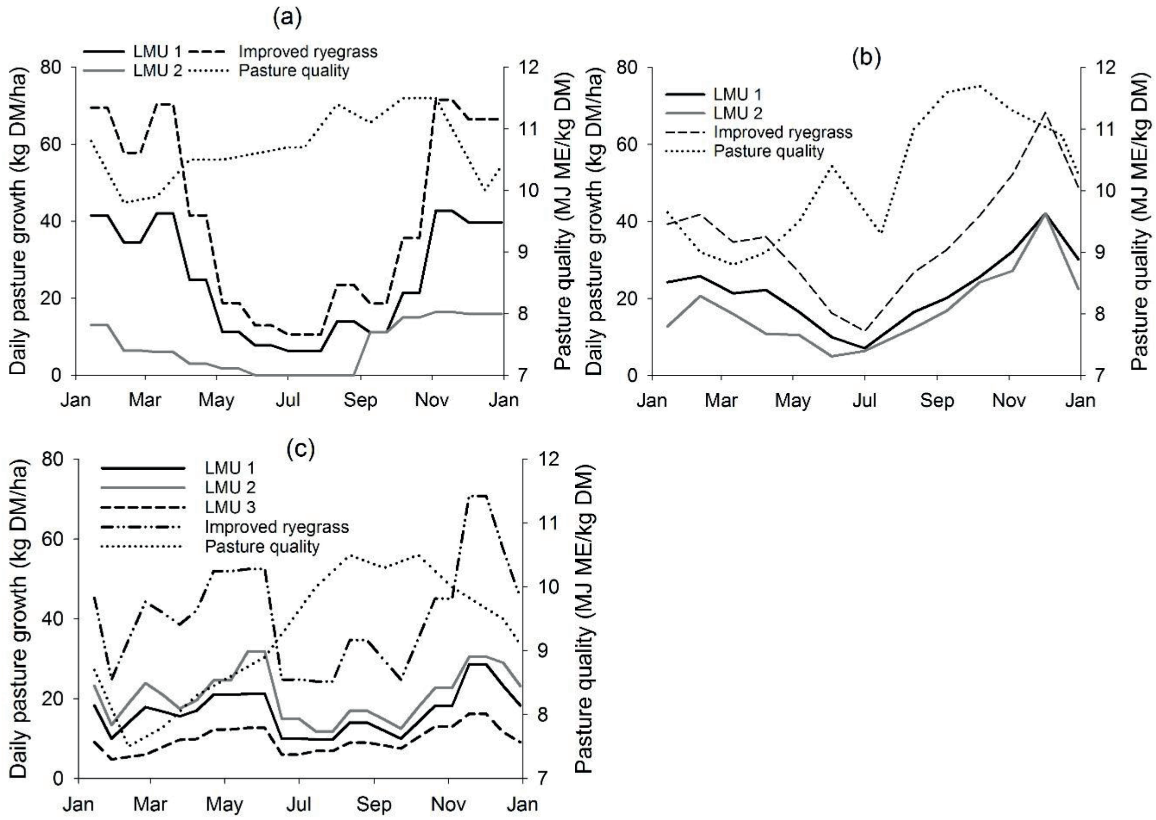


Figure 3. Seasonal pasture growth rates (kg DM/ha/d) for individual land management units (LMU) of the Otago (a), Gisborne (b) and Northland (c) properties, and average pasture quality (MJME/kg DM) for each property *(Litherland et al., 2002).*

Table 3. Beef animal performance data for the baseline model of each property that was used as inputs into the INFORM model.

Variable	Otago	Gisborne	Northland
Pregnancy scan date	5th April	5th April	26th March
Dry at scanning (%)	8	10	7
Scanning %[1]	100	100	93
Start calving date	07th October	16th October	12th September
Heifer birth weight (kg)	36	36	27
Bull birth weight (kg)	40	40	27
Weaning date	25th April	30th March	21st March
Weaning %[2]	84	81	90
Heifer wean weight (kg)	220	215	216
Steer wean weight (kg)	250	230	216
Bull wean weight (kg)	250	230	216
Cow replacement (%)	40	35	22
Cow death rate (%)	2	4	5
Cow cull date	16th May	16th May	31st March
Rising 1 yr old death rate (%)	1	1	3
Rising 2yr old death rate (%)	1	1	2.8
Heifer carcase yield %	47	47	47
Steer carcase yield %	44	44	44
Bull carcase yield %	44	44	44
Cow carcase yield %	50	50	50
Maternal breed	A	A	A
Terminal breed	A	A	A

[1]*Scanning % of animals pregnant at scanning*
[2]*Based on cows pregnant and present at the start of calving*

Table 4. Sheep animal performance data for the baseline model of each property that was used as inputs into the INFORM model.

Variable	Otago	Gisborne	Northland
Ewe carcase yield %	50	50	50
Milk fed lambs carcase yield %	47	47	47
Prime lamb carcase yield %	44	44	44
Ewe cull date	2nd February	22nd February	15th December
Ewe death rate (%)	9	6	9.6
Lamb wean weight	27.3	26	24.6
Prime lamb death rate (%)	2	2	5
Replacement rate (%)	28	28	22
Pregnancy diagnosis date	2nd August	30th June	23rd June
Non-pregnant rate %	2	2	5
Pregnancy status (%[1])	179	177	171
Start lambing date	8th October	12th September	17th August
Weaning date	6th January	11th December	14th November
Lambs weaned (%[2])	142	142	135

[1]*Lambs observed using ultrasound pregnancy diagnosis as a % of pregnant ewes*
[2]*Lambs present at weaning (approximately 100 days of age) as a % of ewes pregnant and present at the start of lambing*

Animal growth rates were taken from data supplied and converted into fortnightly periods post weaning. Lamb growth rates were constrained to zero in winter. Growth rates of replacement females were also taken from the data supplied.

An investment analysis was carried out to investigate the impacts of changing stock numbers on the value of the returns using the approach outlined by Rendel et al. (2015). A 20 year time frame was used. The capital value of livestock was calculated from the stock reconciliation using standard tax values at the time. The net present value of each scenario was calculated. The annual cost of the Italian ryegrass improvements were added to the cost of re-establishing a permanent pasture ($1,000/ha) at the end of the 20 year cycle and this was compared to net increase in present value to calculate the return on investment in the new technology. An annuity value was calculated from the net present value and the net increase in annuity calculated.

Results and Discussion

INFORM is an optimisation model which is important when interpreting the results. As feed resources are an input, the model already knows when and how much feed is available for each period of the year. It therefore can both alter the type of stock class and optimise the number of animals including sale dates (prime and store) that it uses to ensure feed is utilised if it leads to a greater economic surplus.

The model also runs within a defined set of parameters pertaining to pasture cover. The pasture growth was based on perennial grass/white clover and average pasture covers on any LMU were constrained between 1200-2500 kg DM/ha to ensure pasture quality, pasture growth rate and animal intake assumptions were valid (Bircham & Hodgson, 1983; Lambert et al., 2004). As such, the model must keep the pasture cover within this range and thus makes decisions to achieve this outcome while maximising profit within those constraints.

The enterprise chosen in any case was the result of optimising the resource use in the most profitable way. So we see an interaction between inputs and outputs. Generally we see the most profitable outcome was a trade-off between maximising resource use at minimal cost, as the influence of pricing options was usually relatively limited in sheep and beef schedules. Increasing the availability of pasture maintained the current enterprise structure. Variations in pasture quality or seasonal feed supply may alter the enterprise mix.

Profitability analysis

Increasing the overall pasture supply to 15000 kg DM/ha on a portion of the farm using a combination of Italian ryegrass and nitrogen fertiliser resulted in a steady increase in EBITDA (Figure 4) in every geo-climatic zone.

In the Otago region improvement of 100 ha of land increased farm EBITDA by approximately $33,000 (~5% on base). The EBITDA per hectare increased from $484.39 for the base model up to $591.53 when 400 ha was improved. The number of breeding ewes, lambs purchased and sold store increased with increasing area of land improved (Figure 4a). Breeding cows featured in the base model but disappeared with improved production of land and was reflected in a greater increase in sheep numbers in the first increment of 100 ha developed than subsequent sheep number changes.

For the Gisborne region, farm EBITDA was increased by approximately $21,000 (~1.8% of base value) per 100 ha improved (Figure 4b). The small increase in comparison to the Otago property may be due to the comparative size of the properties. A 100 hectare block of land in the Gisborne property represents only 3% of the total land area, whereas for Otago it represents approximately 8% of the land area. Increasing the improved land in Gisborne from 100 ha to 250 ha increments (representing approximately 8%) resulted in EBITDA increases of approximately $56,000 per increment. This increase was 4.9%, and so the Gisborne property exhibited a similar increase in profit to Otago when a similar proportion of the farm was developed. Profit per hectare was $365.38, $394.61, and $437.33 for the base, 400 ha and 1000 ha models respectively. Increasing pasture production resulted in increases in the number of breeding ewes and cows (Figure 4b). This trend continued with the 250 ha incremental changes up to 1000 hectares. No dramatic shift in enterprise selection occurred.

Increasing pasture production on the Northland property increased farm EBITDA (Figure 4c) by approximately $32,640 (representing a 14% increase on base EBITDA) for every 100 ha improved up to 400 hectares. One hundred hectares represented around 8% of the total land area, similar to the Otago property and hence a similar increase per 100 hectares of development. Per hectare EBITDA increased from $198.01 to $306.37 from the base to the 400 ha improved land model. There was a large increase in the number of breeding ewes with the increase in the amount of area improved, which translated into more lambs sold prime and store (Figure 4c). Breeding cow and cattle finishing numbers decreased with increasing area of improved pasture production. Average prime lamb selling date did not shift significantly from the base model of 8 April. Cattle were sold at 30-36 months of age in December in all models.

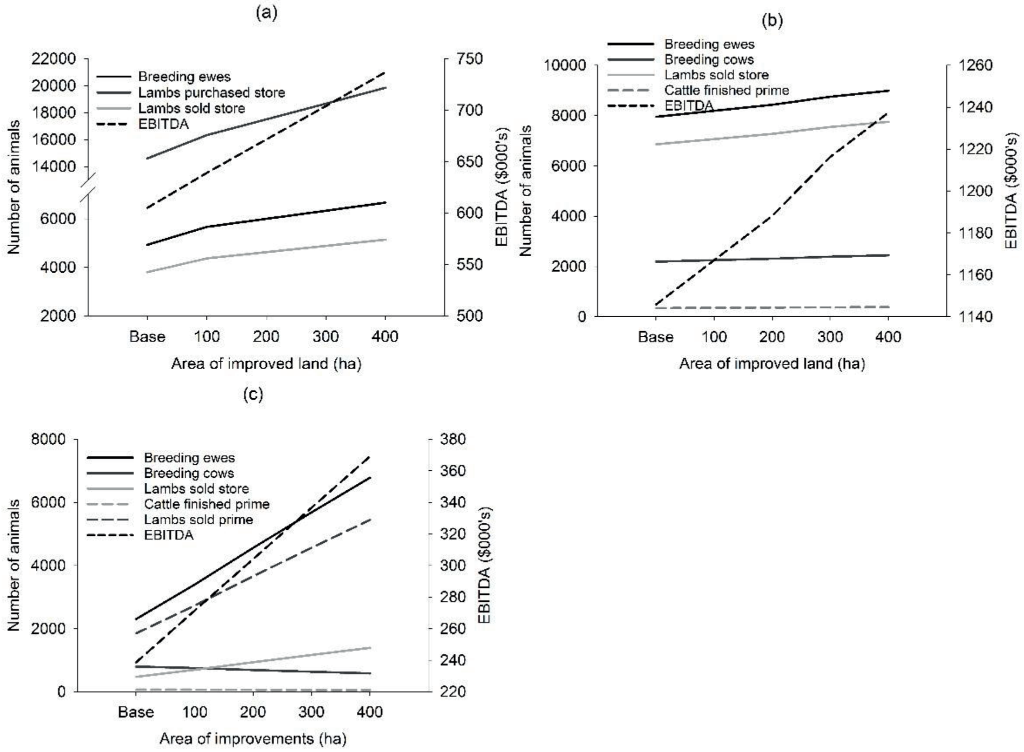


Figure 4. **Profitability (EBITDA) and productivity parameters when improving pasture production on 100, 200, 300 and 400 ha of typical hill country farms in the Otago, Gisborne and Northland regions.**

Investment analysis

An investment analysis was carried out on the development of the extra land area into a high producing Italian ryegrass (Table 5). The greatest return on investment of 75% was in the Otago region, while the Gisborne region showed a negative return. The return in Northland was relatively small.

Table 5. **Investment analysis when improving pasture production on 100, 200, 300 and 400 ha of typical hill country farms in three geo-climatic regions of New Zealand using a 20 year investment time frame.**

	Area of improved pasture				
	Base	100 ha	200 ha	300 ha	400 ha
Otago					
Stock Capital Value ($)	$ 792,946	$ 835,082	$ 884,020	$ 932,958	$ 982,590
NPV ($)	$ 7,045,244	$ 7,869,273	$ 8,668,121	$ 9,466,969	$ 10,270,568
Return on Investment %		75%	72%	71%	71%
Annuity per ha planted ($)		$ 661	$ 651	$ 648	$ 647
Gisborne					
Stock Capital Value ($)	$ 3,258,760	$ 3,350,967	$ 3,441,652	$ 3,562,910	$ 3,655,117
NPV ($)	$12,249,007	$12,649,157	$13,050,256	$13,520,183	$ 3,920,333
Return on Investment %		-15%	-15%	-10%	-11%
Annuity per ha planted ($)		$ 321	$ 321	$ 340	$ 335
Northland					
Stock Capital Value ($)	$ 1,093,052	$ 1,203,409	$ 1,306,854	$ 1,415,138	$ 1,519,853
NPV ($)	$ 2,292,471	$ 2,826,281	$ 3,363,663	$ 3,895,920	$ 4,429,557
Return on Investment %		13%	14%	14%	13%
Annuity per ha planted ($)		$ 428	$ 430	$ 429	$ 429

While the implementation of technologies and strategies to increase pasture production appear to be profitable, an understanding of the environment into which those changes are proposed is required.

The modelling highlights a significant shift towards lamb finishing in the Otago example. While this may be profitable, consideration must be given to the availability of lambs for purchase before this change in system might be undertaken. The variability of pasture growth due to climatic variations in temperature and rainfall must also be accounted for, though a lamb trading and finishing operation may be more flexible in the face of these changes if purchasing and selling decisions are well managed.

The buying and selling of store stock is one area that may create slightly aberrant behaviour. The on-going cost of finishing cattle seems to drive a majority of calves to be sold at weaning. This indicates that there may be significant gains to be made to keep costs of finishing cattle to a minimum to ensure profitability. Buying and selling store lambs at weaning in the model appears to be driven by the price differential in the model, though in some environments the pasture growth profile, associated with a relatively low cost of finishing lambs, drives the model to purchase large numbers of lambs.

The relatively low returns for the investment in increasing pasture production in the Gisborne example is indicative of current farmer practices in this region. Very little pasture renewal is undertaken. One critical influence on this approach is the uncertainty of climatic variations during the establishment of a new pasture during autumn, leading to variable pasture production responses and a propensity for weed ingress as a result.

In the Northland example the enterprises chosen were dominated by sheep. While the base system achieved the performance levels documented, this may not be the case if sheep numbers were increased. Animal health problems of facial eczema (a fungal toxin that causes liver damage) and internal parasites (*Haemonchus contortus*) in a relatively warm humid environment mean that sheep production can be quickly compromised.

Increasing the availability of pasture at a cost of $ 184/ha/annum increased cash flow profit in every environment, and was proportional to the amount of pasture improved. The average cost of this improvement was approximately 3 c/kg DM, while the total return ranged from 5.8 to 7.1 c/kg DM. This suggests that the break-even price to gain these benefits would be between $356 and $435/ha. Often pasture renewal programmes can cost between $800 and $1000/ha, requiring the benefits of pasture renewal to last for 3 or more years. The implementation of a programme as outlined in this research would require an area of land available to meet the requirements of a low cost pasture improvement programme. Investment analysis demonstrated that increasing pasture production provided a positive annuity, though only provided a positive return on investment in 2 of the 3 environments. However, the return on investment per annum varied between environments from -15% to +75% when a 20 year time frame was chosen and the changes in capital stock were accounted for.

The influence of variability in the farming environment leads to farming enterprise configurations that may not be the optimal fit for the average conditions. These case studies provide a useful example of the principles of sub-optimal configuration of complex adaptive systems. While profit may be a major driver of farm systems configuration, the final configuration of the system becomes sub-optimal to allow for resilience in the face of environmental variability.

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