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LCA FOR AGRICULTURE

On the link between economic and environmental performance of Swiss dairy farms of the alpine area

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Abstract
Purpose Promoting the economic and environmental performance of Swiss farms is a major objective of Swiss agricultural policy. In the present paper, we investigate the relationship between the economic and global environmental performance of the Swiss dairy farms in the alpine area.
Methods The analysis relies on a sample of 56 dairy farms from the Farm Accountancy Data Network, for which highly precise and comprehensive Life Cycle Assessments have been carried out. The work income per family work unit is used as indicator of the economic performance of a farm. The so-called global environmental performance of a farm is, for its part, measured by means of an eco-efficiency indicator for each environmental impact considered (demand for non-renewable energy resources, eutrophication potential, aquatic ecotoxicity potential, human toxicity potential and land use) and of an aggregate eco-efficiency indicator assessed using a Data Envelopment Analysis-based approach. The relationship between economic and global environmental performance is assessed by means of non-parametric Spearman's rank correlation analysis.
Results The results of the analysis reveal the existence of a positive relationship between economic and global environmental performance. This positive relationship exists for all environmental issues considered and thus also for the aggregate eco-efficiency indicator. Its strength, however, substantially varies from one issue to another.
Conclusions This study provides the evidence that there is no trade-off between economic and global environmental farm performance. When they improve their economic performance, farms also tend to improve their global environmental performance and vice versa. This finding is of central relevance for policy-makers as it should contribute to improving the acceptance among farmers of the environmental objectives of Swiss agricultural policy in terms of an increase in environmental resource use productivity. In this sense this work provides valuable insights into the sustainable performance of the Swiss dairy sector in the alpine area.

Keywords Agriculture · Dairy farming · Eco-efficiency · Farm economic performance · Farm environmental performance · Life cycle assessment (LCA)

1 Introduction

Promoting sustainable agriculture is a major objective of Swiss agricultural policy, this objective being enshrined in the Swiss Federal Constitution (S.R. 101 article 104). The Swiss legislator does not only stipulate the promotion of sustainable agriculture but has also incorporated in the Swiss legislation the principles of a regular evaluation of the performance of the agricultural sector and of the Swiss

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agricultural policy from a sustainability perspective (S.R. 919.118). As a consequence, the Swiss Federal Office for Agriculture has designated the sustainability principle as the keynote of the Swiss agricultural research (Agroscope and FOAG 2007). Despite the omnipresence of the sustainability issue in the debate on Swiss agriculture and on the future of its agricultural policy, no comprehensive assessment of the sustainable performance of Swiss agriculture has yet been made at micro-level (Jan et al. 2008). One major reason for this lies in the absence of precise and comprehensive environmental and social data for a representative sample of farms.

The LCA–FADN[1] Project, launched by the Agroscope Reckenholz-Tänikon Research Station ART together with the Swiss Federal Office for Agriculture in 2003, aimed at collecting precise environmental data—Life Cycle Assessments (LCA)—for a sample of farms of the Swiss Farm Accountancy Data Network (Swiss FADN) for the years 2006–2008. The combination of Life Cycle Assessments and Farm Accountancy Data offers the unique possibility of analyzing the relationship between economic and environmental farm performance, two important dimensions of sustainable performance.

There are two main reasons why improving our knowledge of the relationship between environmental and economic performance is of central importance (Telle 2006). Firstly, the existence of a positive relationship between environmental and economic performance could be used to increase environmental awareness among company managers or owners (Telle 2006). Secondly, if such a positive relationship can be scientifically attested, then there may be less need for further governmental intervention in relation to environmental regulations, and some existing regulations could probably be relaxed (Telle 2006). Policy-makers should then focus on spreading knowledge about the positive effect of environmental performance on the economic one.

The objective of the present paper is to analyze the relationship between the environmental and the economic performance of Swiss dairy farms located in the hill and mountain region. This investigation should provide insights into the synergies and trade-offs existing between farm environmental and economic performance. It should thus represent a valuable basis for the further enhancement of the sustainable performance of the Swiss dairy sector in the hill and mountain region.

The paper is organized as follows. "Section 2" outlines the material and methods used for the present investigation, with a particular focus on the approach used for the assessment of environmental performance. The empirical results follow in "Section 3". We then discuss these results and their limits in "Section 4" and, finally, draw general conclusions.

2 Material and methods

2.1 Environmental impact assessment using the SALCA approach

The environmental impacts of the farms of the sample investigated are assessed using Life Cycle Assessments. The Life Cycle Assessment (LCA) approach is a methodological framework for estimating and assessing the environmental impacts of a good or service (both called a "product" in the LCA) throughout its entire life cycle from cradle to grave, i.e. considering all relevant stages (phases) of its life cycle, from raw-material extraction to disposal (Rebitzer et al. 2004). The LCA technique has been increasingly used since the late 1990s to assess the environmental impacts of agricultural production systems or, more generally, of agro-food chains. For the dairy sector, many of the LCA investigations performed at farm level have focused either on comparing organic and conventional farming in terms of the environmental impacts generated (e.g. Cederberg and Mattsson 2000; Haas et al. 2001; Grönroos et al. 2006), or on analyzing the effect of farming intensity on farm environmental performance (see, for example, Haas et al. 2001; Basset-Mens et al. 2009). Several other LCA applications for the dairy sector have gone beyond the farm gate, extending the scope of the analysis to the processing phase, and even in some cases to the consumer and waste management phases (see, for example, Eide 2002; Hospido et al. 2003; Sonesson and Berlin 2003).

The present investigation uses the SALCA (Swiss Agricultural Life Cycle Assessment) approach, originally developed with the aim of performing a comprehensive environmental impact assessment for a wide variety of agricultural systems (Gaillard and Nemecek 2009). A summary presentation of this approach follows.[2]

2.1.1 Definition and description of the system investigated

The spatial system boundary is set at the farm gate. The system under consideration is made up of the agricultural production system defined in a narrower sense, i.e., without any forestry and para-agricultural activities such as agritourism or food processing on the farm. It encompasses all agricultural commodities as well as all inputs and processes necessary for the production of these commodities. A schematic description of the agricultural inputs, production processes and agricultural outputs under consideration can be found in Fig. 1.

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[1] Life Cycle Assessment–Farm Accountancy Data Network

[2] A detailed and comprehensive description of this approach can be found in Baumgartner et al. (2011) in German, whilst a more synthetic overview is available in Nemecek et al. (2010) and Gaillard and Nemecek (2009) in English.

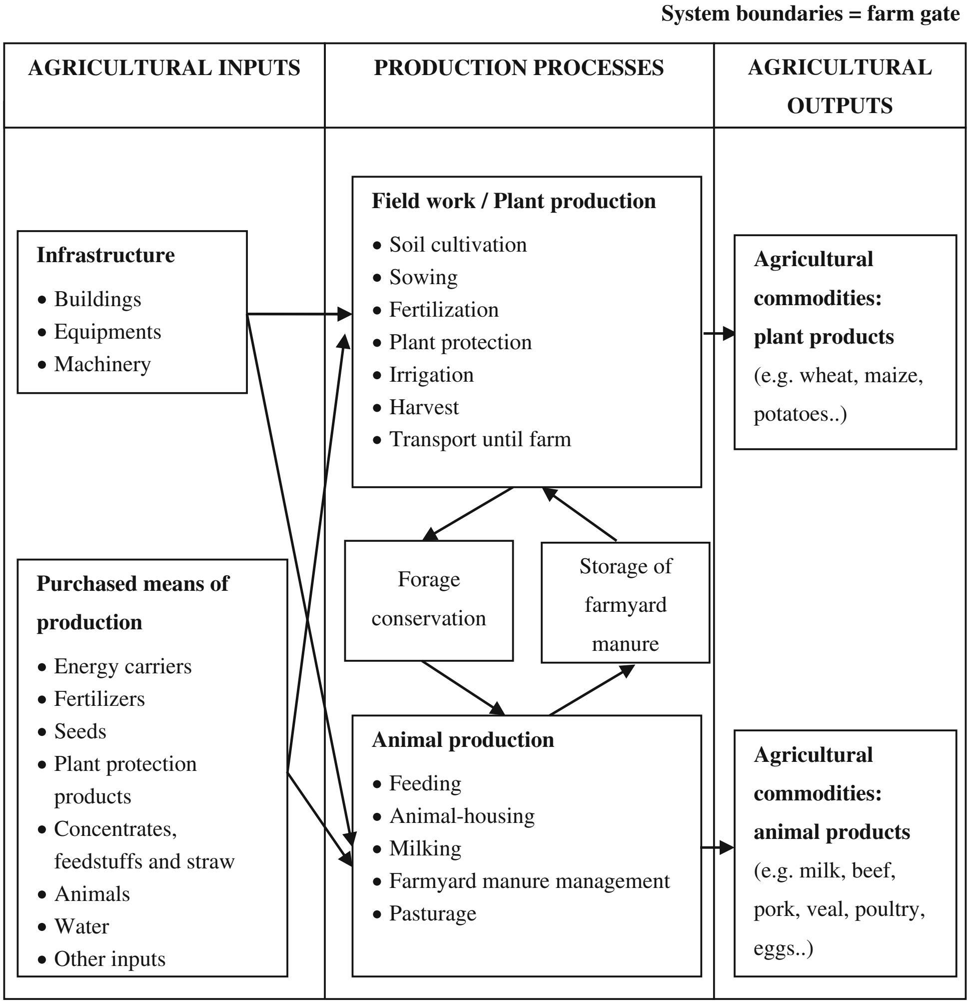

Fig. 1 Schematic representation of the system under consideration (own representation adapted from Baumgartner et al. 2011)

Regarding the temporal system boundaries, with the exception of arable crops, the assessment covers the calendar year from 1st January until 31st December for the year under investigation. For arable crops, the period covered by the LCA is determined at parcel level, the assessment starting the day after harvesting the previous crop and ending with the day when the current crop on the parcel under consideration is harvested.

2.1.2 Life cycle inventory assessment

The production inventories of the farms investigated were collected with the help of the farm management software AGRO-TECH (© Agridea) which is used by farmers among others for keeping the various records stipulated by the Swiss legislation. This software had, however, to be adapted and extended in order to cover all the data requirements of the assessment performed within the scope of the LCA–FADN project. The data collected by the farmers related to the following issues: inputs and infrastructure used, production processes and outputs produced as described in Fig. 1. The data gathered was highly detailed and precise and included both quantitative and qualitative data necessary for the LCA.

The life cycle inventories of the farms are assessed on the basis of their production inventories and a life cycle inventory database, the Ecoinvent database version 2.0 (Frischknecht et al. 2007; Nemecek and Kägi 2007). To assess the direct emissions (NH_3, N_2O, phosphorus, NO_3^-, heavy metals and methane) released at field and farm level, specific models have been implemented in the SALCA approach (Gaillard and Nemecek 2009). A brief overview of the models used is given in Table 1. A detailed description of these models is available in Nemecek et al. (2010).

Based on the life cycle inventories, the environmental inputs and outputs are converted into environmental impacts. Several impact categories and mid-point impact assessment methods relevant to the study of agricultural systems were selected for this purpose within the SALCA framework. The method for assessing a given environmental impact category was selected on the basis of an evaluation of how appropriate each available environmental impact

Table 1 Overview of the models used for the assessment of direct field and farm emissions

Emission	Short description of the model used for quantification of the amount of emissions released	Reference
Ammonia (NH_3)	Takes into account the type of fertilizer and the moment and technique of application. For slurry and liquid manure, the climatic conditions during the spreading of these organic fertilizers are also considered. The emission from animal husbandry and manure management are estimated taking into account animal category, housing system, type of manure (liquid or solid) and pasture.	Menzi et al. (1997)
Nitrous oxide (N_2O)	Considers direct emissions and induced emissions from ammonia and nitrate losses	IPCC (2006)
Phosphorus (P, PO_4^{3-})	Three paths of phosphorous emissions to water are included: (i) run-off as phosphate and (ii) erosion as phosphorous to rivers as well as (iii) leaching to ground water as phosphate. Soil characteristics and topography are taken into account.	Prasuhn (2006)
Nitrate (NO_3^-)	Nitrate leaching is determined specifically for each crop on the basis of a monthly balance.	Richner et al. (2006)
Heavy metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn)	The assessment is carried out using an input–output balance considering inputs and outputs (harvest, erosion and leaching).	Freiermuth (2006)
Methane (CH_4)	Assessment of the methane emissions from enteric fermentation and manure management in consideration of the amount and quality of the feed and the manure management system	IPCC (2006)

Source: own representation based on Nemecek et al. (2010)

assessment method was for agricultural applications (Gaillard and Nemecek 2009; Nemecek et al. 2005). The evaluation was performed using multicriteria analyses (for illustration see Kägi et al. 2008, who compared toxicity methods with a focus on pesticide application strategies). The environmental impact categories listed hereinafter are assessed.

- Demand for non-renewable energy resources (oil, coal and lignite, natural gas and uranium) using the ecoinvent method (Frischknecht et al. 2004). It measures the amount of non-renewable energy resources directly (e.g. diesel, electricity) or indirectly (e.g. for the production of concentrates or fertilizers) consumed.
- Global warming potential over 100 years according to the IPCC method (IPCC 2007). This category measures the radiative forcing caused by greenhouse gases.
- Eutrophication potential using the EDIP97 method (Hauschild and Wenzel 1998). This assesses the impact of the nitrogen and phosphorous losses to aquatic and terrestrial ecosystems.
- Acidification potential using the EDIP97 method (Hauschild and Wenzel 1998). This environmental impact category measures the impact of the release of acidifying substances (such as sulfur and nitrogen oxides) into ecosystems.
- Ecotoxicity (aquatic and terrestrial) in accordance with the CML01 method (Guinée et al. 2001). Aquatic and terrestrial ecotoxicities are mainly due to pesticides and heavy metals originating principally from fertilizers.
- Human toxicity according to the CML01 method (Guinée et al. 2001). This category assesses the impact of toxic pollutants on human health.
- Land use in square meters in accordance with the CML01 method (Guinée et al. 2001). This category assesses the overall land use (all types of land use).

In the same way as Rossier and Gaillard (2004), Nemecek et al. (2005), Mouron et al. (2005) and Nemecek et al. (2008), we also use a grouping procedure based on an analysis of the correlation between the environmental impact categories to reduce the dimensionality of the life cycle impact assessment performed and thus to avoid any redundancy between the environmental impact categories considered. This analysis shows that the eight environmental impact categories can be summarized into five categories representing four major groups of environmental issues:

- Resource management: this group is represented by the environmental impact category “demand for non-renewable energy resources”.
- Nutrients management: this group is represented by the impact category “eutrophication potential”.
- Management of toxic substances: the environmental impact categories “terrestrial ecotoxicity” and “human toxicity” represent this group.
- Land use which is both a group and a single environmental impact category.

2.2 FADN data

In addition to the environmental data assessed within the LCA, very detailed economic data collected within the framework of the Swiss FADN[3] is also available for each farm.

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[3] A very detailed and comprehensive description of the Swiss FADN’s accounting approach is available in Hausheer Schnider (2008a) in German, and in Hausheer Schnider (2008b) in French.

2.3 Sample of farms investigated

The investigation relies on an unbalanced pooled sample[4] of dairy farms in the hill or mountain region observed in either 2006, 2007 or 2008. A total of 56 observations over the 3-year period of 2006–2008 are available. A dairy farm is thereby defined as a farm whose proportion of gross revenue from its dairy activity is higher than 60 % of the total farm output without direct payments. To ensure the comparability of the accountancy data of the farms observed in 2006 with those of the farms of the years 2007 and 2008, i.e. to correct for changes in market prices for both economic inputs and outputs over time, all economic variables of the farms observed in 2008 and 2007 are deflated and expressed in 2006 prices. The direct payments are also deflated on the basis of the relative change of the direct payment rates since 2006. The deflation is performed at each single economic input or output level using price indexes from the official Swiss agricultural statistics (SBV 2009) or official documentation of the Swiss Federal Office for Agriculture on the evolution of the direct payments rates (FOAG 2007, 2008, 2009).

2.4 Defining an indicator to assess farm's environmental performance

2.4.1 Indicators of environmental performance in agriculture: a literature review

In the relevant literature, many indicators have been proposed to measure the environmental performance of a farm. Halberg et al. (2005) have performed an in-depth review, comparison and analysis of the tools and indicators used in agriculture for the purpose of assessing the environmental impacts of various livestock production systems at farm level. Based on this review, they draw conclusions as regards the selection of indicators suitable for environmental performance benchmarking between farms. A major recommendation is that, for environmental issues with a global dimension, the indicator should be product-based. For environmental issues having a local or regional target, an area-based indicator should be used to assess farm environmental performance. Halberg et al. (2005) furthermore emphasize that the definition of an indicator should be consistent with the system boundaries. This implies that area-based indicators should include only the environmental impacts occurring at farm-level, whereas product-based indicators should preferably include not only the environmental impacts that are generated at farm-level but also those generated in the upstream stages of farm inputs production (Halberg et al. 2005). Based on this distinction between local and global environmental issues, we shall in the following paper differentiate between the global and local environmental performance of a farm.

As far as the present analysis is concerned, due to the fact that the outcome of the life cycle impact assessment performed does not enable us to differentiate between the "on-farm" and "off-farm" impacts,[5] the assessment of the environmental performance carried out can only be done from a global perspective, i.e. using one or several product-based indicators of environmental performance.

2.4.2 Defining and specifying eco-efficiency

The so-called "product-based" indicator of global environmental performance to which Halberg et al. (2005) refer is, according to the eco-efficiency typology proposed by Huppes and Ishikawa (2005), an indicator of environmental intensity. The inverse of environmental intensity is the eco-efficiency ratio (Verfaillie and Bidwell 2000), also designated "environmental productivity" by Huppes and Ishikawa (2005). It is defined as the product or service value divided by the environmental impact in product or service creation (Verfaillie and Bidwell 2000) or, more concretely in the present case, as the amount of agricultural output per unit of environmental impact generated. The output can be measured in either monetary or physical terms (adapted from Verfaillie and Bidwell 2000). The "physical terms" group encompasses both physical units in a narrow sense (e.g. kilogram product) and functional units such as megajoule digestible energy (adapted from Verfaillie and Bidwell 2000). As in the case of an assessment of the environmental performance of a farm, we are primarily interested in the "physical" productivity of environmental impacts generation; a physical output is more appropriate.[6] The use of a monetary output might indeed be misleading as the *ceteris paribus*[7] increase in the market price of a given commodity (e.g. owing to marketing, labels or better market opportunities) would lead to better environmental performance and thus to a bias in the eco-efficiency indicator. Due to the fact that our investigation is carried out at farm level and that a farm can produce several outputs, we prefer the digestible energy content[8] as output measurement unit to any other physical units (such as kilogram dry matter). This unit is

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[4] Due to the limited size of the farm sample available for each year, the data were pooled over the 3 years.

[5] All raw data necessary for such a differentiation are available. However, as this differentiation has not been foreseen within the LCA–FADN project, estimating the on- and off-farm environmental impacts would require a consequent adaptation of the calculation processes and tools, which is not feasible in the short-run with the available resources.

[6] A physical output has also been used to assess eco-efficiency in similar farm level investigations (see e.g. Nevens et al. 2006; Meul et al. 2007).

[7] i.e. without any changes in environmental impact generation

[8] Estimated according to the approach developed by Rossier (1998)

indeed particularly well adapted, not only as it makes it possible to aggregate different outputs into a single homogeneous one but also because it refers to the primary function of agriculture of food provision. By proceeding in this way, we adopt, according to Huppes and Ishikawa (2009), a technologist's orientation as opposed to a business orientation. "Technologists define products in functional terms, as is also done in LCA, while a business orientation leads to 'value created' as the numeraire […]." (Huppes and Ishikawa 2009).

Two types of eco-efficiency indicators are calculated in the present work: partial eco-efficiency indicators, i.e. environmental productivity indicators in relation to each environmental issue considered, and an aggregate eco-efficiency indicator reflecting the overall farm environmental performance as regards all environmental issues considered. The aggregate eco-efficiency indicator is basically defined in a similar way to the partial eco-efficiency indicators. The central difference between these two types of indicator has to do only with their partial/aggregate nature, and with the method used to aggregate the environmental impact categories allowing the estimation of the aggregate eco-efficiency indicator. This method leads to an aggregate eco-efficiency indicator defined on a [0;1] scale, whilst the partial eco-efficiency indicators are defined on a [0;+∞) scale.

2.4.3 Partial eco-efficiency indicators

For each environmental issue considered, we assess for each farm investigated its eco-efficiency as regards this issue. Eco-efficiency is defined as the digestible energy output produced by a farm divided by the amount of environmental impacts it generates. Analogous to the productivity terminology used in economics, we refer to this type of eco-efficiency indicator as a "partial eco-efficiency indicator" as it takes into account only one environmental issue.

2.4.4 Measuring aggregate eco-efficiency using DEA[9]

Partial eco-efficiency indicators are very valuable tools for assessing the environmental performance of a firm. However, for policy-makers, an aggregate environmental performance indicator may be preferable as it avoids any risk of information overload by presenting the information "in a format tailored to decision-making" (Jollands et al. 2003). For this reason, we propose, in the present investigation, to additionally estimate an aggregate eco-efficiency indicator, which should summarize the information contained in the five separate partial eco-efficiency indicators defined previously. To assess the aggregate eco-efficiency of the farms investigated in their environmental impacts generation, we use the approach proposed by Kuosmanen and Kortelainen (2005). The major advantage of this approach is that it enables us to aggregate all environmental impact categories and, in the end, to obtain a single eco-efficiency indicator reflecting for each farm its overall efficiency in terms of its environmental impacts generation.

Eco-efficiency is defined as the ratio between the output produced by a firm (in the present case the digestible energy output) divided by an index of environmental damage that aggregates all environmental impact categories together and therefore reflects the overall environmental impacts generated by a firm. Formally, the eco-efficiency ratio is defined as follows (adapted from Kuosmanen and Kortelainen 2005):

$$\mathrm{EE}_n = \frac{v_n}{D(z_n)}$$

with:

EE_n eco-efficiency of unit n (n=1, … , N)
v_n output of unit n
z_n $M\times 1$ column vector representing the m environmental impact categories of unit n (m=1, …, M)
D damage function that aggregates the m environmental impacts into a single environmental damage index

The estimation of the environmental damage index requires aggregating its underlying environmental impact categories together. Ideally, as outlined by Telle (2006), the weight given to each impact should represent the costs to society of this impact. However, with a few exceptions, no market prices are available for these impact categories (Kuosmanen 2005). Furthermore, it is very difficult to quantify the costs to society of each environmental impact category (Telle 2006). Until now, two major approaches have been used to perform this aggregation. The first approach is a pragmatic and arbitrary one that consists in giving the same weight to each environmental impact category considered (Telle 2006). The second approach consists in estimating the value of each environmental impact on the basis of standard valuation approaches, such as the stated preference and the revealed preference approaches (Kuosmanen 2005; Kuosmanen and Kortelainen 2007). However, these conventional valuation methods have been heavily criticized by economists, ecologists and social scientists due to major deficiencies and problems (for a detailed review of the criticisms addressed to these two approaches, refer to Kuosmanen and Kortelainen 2007).

Kuosmanen and Kortelainen (2005) propose to tackle the aggregation challenge from another perspective by making use of Data Envelopment Analysis (DEA), a non-parametric approach used in the field of productive

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[9] Data Envelopment Analysis

efficiency measurement to assess technical efficiency. The DEA approach calculates for each unit weights that maximize its efficiency "subject to the condition that the similar ratios for every unit be less than or equal to unity" (Charnes et al. 1978). This maximization problem enables us to calculate the efficiency of any unit by endogenously determining the specific aggregation weights which can differ from units to units. This maximization problem can be formulated as follows (adapted from Kuosmanen and Kortelainen 2005):

$$\begin{array}{l}
\max\limits_{w} \mathrm{EE}_n = \dfrac{v_n}{D(z_n)} = \dfrac{v_n}{w_1 z_{n1}+w_2 z_{n2}+\ldots+w_M z_{nM}} \\
s.t. \\
\dfrac{v_1}{w_1 z_{11}+w_2 z_{12}+\ldots+w_M z_{1M}} \leq 1 \\
\dfrac{v_2}{w_1 z_{21}+w_2 z_{22}+\ldots+w_M z_{2M}} \leq 1 \\
\vdots \\
\dfrac{v_N}{w_1 z_{N1}+w_2 z_{N2}+\ldots+w_M z_{NM}} \leq 1 \\
w_1, w_2, \ldots, w_M \geq 0
\end{array}$$

with:

w_m	weight of environmental impact m for unit n (this weight is determined endogenously)
z_{nm}	environmental impact m generated by unit n

As outlined by Kuosmanen and Kortelainen (2005), this efficiency score has a compelling interpretation. Making use of mathematical programming methods and based on the decision making units[10] (DMUs) of the sample investigated, a piecewise production frontier is built over the data, the output being represented on the y axis and the environmental impact categories being represented as "inputs" on the x axes. Once the efficiency frontier is determined, it is possible to determine the relative efficiency of each DMU by calculating its relative distance from the production frontier. Where the inefficiency measurement is input-orientated, this distance measures "the maximum equiproportionate reduction potential in all inputs [in the present case environmental impacts] that is technically possible at the present level of […] activity v" (Kuosmanen and Kortelainen 2005).

2.5 Defining an indicator measuring farm's economic performance

For the present investigation, we employ a traditional profitability indicator used in Swiss agriculture to assess farm economic performance—the work income per family work unit (FWU). The use of this indicator to assess the economic dimension of the sustainable performance of a farm is stipulated by the Swiss legislator in the ordinance relating to the assessment of the sustainable performance of Swiss agriculture (S.R. 919.118). The work income per FWU measures the amount of value added generated, including direct payments, that is available for the remuneration of the family labour force after all other production factors (equity capital included[11]) have been remunerated. In this sense it reflects the ability of the farm to adequately remunerate all its production factors and thus to use its economic resources as efficiently as possible. By choosing this type of indicator, we are proceeding in a similar manner to Wagner (2005) who investigated the relationship between environmental and economic performance in the European paper industry using traditional profitability ratios to assess economic performance. This was also the approach adopted by Mouron et al. (2006) who investigated the relationship between environmental and income indicators for apple-growing in Switzerland using what they called "the net income per labour hour" as the central indicator of economic performance.

2.6 Analysis of the relationship between economic and global environmental performance

The objective of the present work is to analyze the relationship between economic and global environmental performance. This is done by performing a Spearman's rank correlation analysis (also called Spearman's rho) between the variable "work income per family labour unit" and each eco-efficiency indicator defined (both partial eco-efficiency indicators and the aggregate eco-efficiency indicator). The non-parametric Spearman's rank correlation coefficient is preferred to the parametric Pearson's correlation coefficient for the following reasons: whereas the Pearson's correlation coefficient only measures the strength of a linear relationship between two variables (Anderson et al. 2009), the Spearman's rank correlation coefficient measures the degree of monotonic association between two variables over rank values (Panik 2005). The tendency towards linearity emerges as a special case of the tendency towards monotonicity (Panik 2005). In our case, the Spearman's correlation coefficient is of greater interest than the Pearson's correlation coefficient as our primary aim is to investigate the monotonicity of the relationship between economic and global environmental performance. Furthermore, compared to the Pearson's correlation coefficient, the Spearman's correlation coefficient has the advantage of being less sensitive to outliers and more appropriate for a sample of small size (Blalock 1979).

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[10] In the field of Data Envelopment Analysis this term is used to refer to the entities analyzed.

[11] Equity capital is valued at its opportunity cost. The interest rate on 10-year Swiss government bonds is used as the remuneration rate for equity capital. It is taken from the official statistics of the Swiss National Bank.

3 Results

3.1 Descriptive statistics

The statistics relative to the work-income and the eco-efficiency indicators of the farms investigated are presented in Table 2.

In the following we present some descriptive statistics of the work-income per FWU and of the aggregate eco-efficiency indicator. The average work income per family work unit of the sample of farms investigated amounts to 37559 Swiss Francs. It exhibits a high range of variation, the minimum being equal to −8034 Swiss Francs and the maximum to 96363 Swiss Francs. The average aggregate eco-efficiency is equal to 64.5 %, and thus the eco-inefficiency amounts to 35.5 %. Similar to the economic performance indicator, a substantial variability can be observed for the aggregate eco-efficiency indicator. The lowest performing farm shows an eco-efficiency of 14.4 % as opposed to 100 % for the best-performing farms located on the frontier. Nine percent of the farms are located on the frontier and thus demonstrate an eco-efficiency equal to one.

3.2 Relationship between economic and global environmental performance

The results of the correlation analysis between the economic performance indicator and the partial and aggregate environmental performance indicators are shown in Table 3.

With the exception of the partial eco-efficiency indicator regarding the demand for non-renewable energy resources, for all other eco-efficiency indicators—the four other partial eco-efficiency indicators and the aggregate one—there exists a significant positive relationship between economic and environmental farm performance. The strength of the relationship is at its highest for the human toxicity issue and at its lowest for the terrestrial ecotoxicity issue. For the non-renewable energy resources issue, the positive relationship between economic and environmental performance is only significant with an alpha risk level of 12 % and should be thus interpreted with care.

These results provide initial evidence that the economic performance and global environmental performance of the farms investigated go hand in hand together. As is obvious from graphical representations, almost all combinations as regards joint economic and global environmental performance are possible. However, the probability that a farm will demonstrate a high eco-efficiency tends to be higher for a farm displaying a high work income per family work unit than for a farm which demonstrates a low one. This affirmation is briefly illustrated below for the aggregate eco-efficiency indicator. On the basis of the sample median value of the aggregate eco-efficiency and work-income per FWU, we classify the farms into four groups in terms of joint economic and global environmental performance. The distribution of the farms between the four groups defined is shown in Table 4. As is evident from this table, the proportion of farms in groups 1 and 4 is higher than the proportion of farms in groups 2 and 3. By performing a Chi-squared test between the two categorical variables described in Table 4, we can identify a strong dependence between these two variables ($p<0.001$).

4 Discussion

In the present section, we discuss the results of the investigation performed. In the first part, we summarize the main findings of our analysis. We then discuss these findings by comparing them with those of similar investigations found in the relevant literature. In the third sub-section, we discuss the DEA approach used to assess aggregate eco-efficiency, and more particularly compare this approach to similar approaches which implement both LCA and DEA techniques. In the last section, we address the limits of the present study.

Table 2 Descriptive statistics relating to the economic and environmental performance indicators of sample farms

	Mean	Median	SD	Min.	Max.
Work income per family work unit (in Swiss Francs)	37559	35208	21735	−8034	96363
Eco-efficiency as regards the demand for non-renewable energy resources (in MJ digestible energy per MJ non-renewable energy demand)	0.38	0.37	0.16	0.09	0.84
Eco-efficiency as regards eutrophication potential (in MJ digestible energy per kg N-eq)	163.1	167.2	68.2	26.0	321.0
Eco-efficiency as regards land use (in MJ digestible energy per m^2 land used)	1.06	1.15	0.52	0.15	2.26
Eco-efficiency as regards terrestrial ecotoxicity (in MJ digestible energy per terrestrial ecotoxicity point)	2466	1730	2022	508	9395
Eco-efficiency as regards human toxicity potential (in MJ digestible energy per human toxicity point)	10.4	10.2	5.5	1.6	26.2
Aggregate eco-efficiency (%)	64.5	66.9	26.3	14.4	100

Source: own calculations ($n=56$)

Table 3 Spearman's rank correlation analysis between the work income per family work unit and the six eco-efficiency indicators under consideration

	Spearman's rho	*p* Value
Eco-efficiency as regards the demand for non-renewable energy resources	0.21	0.12
Eco-efficiency as regards eutrophication potential	0.37	< 0.001
Eco-efficiency as regards terrestrial ecotoxicity	0.24	0.07
Eco-efficiency as regards human toxicity	0.41	0.002
Eco-efficiency as regards land use	0.36	0.006
Aggregate eco-efficiency	0.35	0.007

4.1 Main findings

This study highlights the substantial heterogeneity that exists among Swiss dairy farms in the hill and mountain regions in terms of both their economic and environmental performance. Whereas the existence of a high level of heterogeneity in terms of economic performance was already widely known prior to this study being conducted (refer for example to Lips 2010), the existence of a high level of variability in terms of environmental performance is a rather new finding. On average a farm could theoretically reduce its overall environmental impacts generation by 35.5 % without decreasing its digestible energy output if the farm were to adjust its performance towards the most efficient farms in the sample. At this stage we need to emphasize that this environmental impact reduction potential should be interpreted with care as it is of a theoretical nature. Whereas a proportion of this inefficiency may be attributable to farm management, another part may be due to factors that are beyond the control of the farm manager.

The second central finding of this empirical analysis is that a positive relationship exists between farm economic performance and farm global environmental performance, the latter being defined as the eco-efficiency of the environmental impacts generation of a farm. This positive relationship exists for all environmental issues considered, even if its strength substantially varies from one issue to another. Consequently, there is also a positive relationship between farm economic performance and the aggregate eco-efficiency indicator. In practice, this finding implies that, at the farm level, good economic performance and good global environmental performance are not antinomic but rather tend to go hand in hand. It is important at this stage to emphasize that this positive relationship is a statistical tendency and that there exist several exceptions to this rule. Some farms indeed perform well for one dimension and poorly for the other.

Table 4 Distribution of the farms in the four groups defined on the basis of the median value of the aggregate eco-efficiency and the work income per family work unit

		Global environmental performance	
		Low	High
Economic performance	Low	20 (35.7%) Group 1	8 (14.3%) Group 2
	High	8 (14.3%) Group 3	20 (35.7%) Group 4

Source: own calculations (n=56). The classification *low*/*high* has been made for both the economic and global environmental performance indicators on the basis of their respective median value. The figure outside the brackets represents the number of farms and the one inside the brackets the proportion of sample farms in the group under consideration

4.2 Discussion of the findings

Despite the omnipresence of the sustainability concept in the debate on agriculture, very few investigations on the relationship between economic and global environmental performance at farm level are to be found in the literature. This has to be attributed to the lack of appropriate accurate environmental data. To our knowledge, up to now, only three similar studies have been performed for European agriculture.

Using Life Cycle Assessments, Mouron et al. (2006) investigated the relationship between environmental and income indicators for apple growing farms in Switzerland. For this purpose, they analyzed the correlation between net income per labour hour and the environmental intensity[12] as regards energy use, ecotoxicity and eutrophication. They identified a strong negative correlation and therefore concluded that "mastering eco-efficiency as regards energy use, ecotoxicity and eutrophication is contingent to high income performance" (Mouron et al. 2006).

Thomassen et al. (2009) also performed a similar study to ours for the Dutch dairy sector on the basis of a sample of 119 specialized dairy farms. However, in comparison with our investigation, the Life Cycle Assessment has been performed solely on the basis of FADN data, which might have to some extent impaired the accuracy of the assessment.[13]

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[12] It is defined as the amount of environmental impacts generated per monetary unit of output (farm receipts). Environmental intensity is the inverse of eco-efficiency (Huppes and Ishikawa 2005).

[13] For instance, due to the limitations of the database used, they were unable to consider the environmental impacts associated with the use of machinery, buildings, medicines and seeds.

Furthermore, the two indicators they used for the measurement of economic performance—gross value added per kilogram fat-and-protein corrected milk (FPCM) and gross labour productivity defined as gross value added per total amount of labour—are partial economic performance indicators which therefore do not reflect the overall economic performance of a farm. For this reason, a comparison of our results with those of this study is of limited interpretability and therefore usefulness. Despite these methodological limitations, it is worth mentioning that Thomassen et al. (2009) found a negative relationship between labour productivity and environmental intensity as regards energy use, global warming potential and acidification potential, thus highlighting a certain positive relationship between economic and global environmental performance.

De Koeijer et al. (2002) examined the relationship between environmental efficiency and profit efficiency for Dutch sugar beet growers. They considered two environmental issues, the nitrogen surplus in kilogram N and the environmental impacts associated with the use of pesticides. Similar to our own investigation, they identified a positive correlation between environmental efficiency and profit efficiency.

From this literature overview, it emerges that our findings as regards the existence of a positive relationship between economic and global environmental performance are in line with the findings of previous studies also concerned with this research question for the agricultural sector.

4.3 Discussion of the DEA approach used to assess aggregate eco-efficiency

Although the joint implementation of DEA and LCA is fairly recent, there are already several studies combining both approaches (refer, for example, to Lozano et al. 2009, 2010; Vázquez-Rowe et al. 2010; Iribarren et al. 2010; Iribarren et al. 2011). Iribarren et al. (2010) distinguish in this regard two types of joint LCA+DEA applications: the five-step and the three-step approach. Below, we provide a brief description of these two approaches. We then explain how and to what extent our approach differs from these two approaches, and justify our choice.

The five-step approach consists in the following: (i) assessing the Life Cycle Inventory (LCI) of each DMU investigated; (ii) performing a Life Cycle Impact Assessment (LCIA) for each DMU on the basis of its LCI assessed in the previous step; (iii) assessing the operational efficiency and the efficiency targets (peers) of each DMU via DEA, considering the LCI data as inputs in the DEA model; (iv) performing an LCIA for each DMU on the basis of the LCI data of the target decision-making units (peers) arising from the DEA analysis; (v) quantifying for each DMU the environmental impact reduction from operational inefficiencies by comparing the environmental impacts of the virtual benchmark (peers) to those of the benchmarked firm (based on Iribarren et al. 2010).

The three-step approach consists of the aforementioned steps (i) and (ii), supplemented by a third step comprising a DEA analysis taking into account both the environmental impacts (determined in the second step) and the LCI data as inputs in the DEA model (based on Iribarren et al. 2010).

As is obvious from this description, these two types of joint LCA+DEA approaches basically differ in terms of the environmental variables considered as inputs in the DEA model. Whereas in the five-step approach the life cycle inventory data are considered as inputs in the DEA model, the input set in the three-step approach consists of both life cycle inventory data and environmental impacts.

In the present paper we follow neither of these two approaches. The input set of our DEA-based efficiency analysis encompasses environmental impacts only, as recommended by Kuosmanen and Kortelainen (2005). The justifications for this choice are given below. Basically, it is more appropriate to base the efficiency analysis on environmental impacts rather than on operational inputs (such as diesel or electricity) and/or undesirable environmental outputs (such as CO_2) from the LCI, as we are ultimately concerned with the environmental impacts rather than the amount of undesirable environmental outputs or operational inputs from the LCI (adapted from Kuosmanen and Kortelainen 2005). From our perspective, the main drawback of an operational efficiency indicator assessed on the basis of LCI data is that this indicator is only of a technical/operational nature[14] and does not capture what we might refer to as the “allocative environmental efficiency” defined for a given environmental impact as the ability of a firm to combine its operational inputs in the optimal proportions given their respective environmental impact generation. The efficiency figure we estimate in this article does not suffer from this drawback, as it relies on environmental impacts only. An additional major advantage of our approach is that the number of inputs to be included in the DEA model is much smaller than for a DEA analysis relying on LCI data. This results in the better discriminatory power of the efficiency analysis performed—an advantage which is of substantial importance in our case. Given that the farm level LCIA we have conducted is holistic, i.e. considers all farm operational inputs (including those related to infrastructure such as buildings), the implementation of the five-step or three-step approach would have been particularly challenging owing to a high number of operational inputs.

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[14] The environmental impacts generation (over the entire production chain up to the farm gate) associated with the use of one unit of each operational input is not taken into account when estimating these operational efficiency scores.

4.4 Limits of the present work

A major limitation of the present study lies in the fact that the sample is not selected at random with the associated possible consequences in terms of representativeness.

In addition to this sample-related limitation, it is necessary to emphasize that the results of the present investigation only apply to Swiss dairy farming in the alpine area and cannot be extrapolated either to other natural regions such as the plain region or to other countries.

It is also important to remember that the current analysis only focuses on the description of the relationship between economic and global environmental performance but does not investigate the mechanisms behind this relationship. Further investigations analyzing why this positive relationship exists for most farms and why it does not exist for some others are required to better understand the link between these two dimensions of the sustainable performance of a farm.

An additional major restriction of the present investigation is that it does not take into account qualitative environmental issues such as biodiversity, soil quality and soil erosion. This should be borne in mind when interpreting the results.

Probably the most important limiting factor in relation to the present work is that by using eco-efficiency—an indicator referred to by Halberg et al. (2005) as a "product-based" indicator—it considers only the global dimension of environmental performance and not its local one. As emphasized by Halberg et al. (2005), for environmental issues with regional or local targets (such as the eutrophication, acidification and ecotoxicity issues), both dimensions should be taken into account in an assessment of farm environmental performance. Whereas global performance should be measured by using product-based indicators reflecting the efficiency of environmental impacts generation over the whole production chain (i.e. at farm level but also in the upstream stages of farm inputs production), the local environmental performance should be assessed by means of area-based indicators. These area-based indicators should measure the quantity of environmental impacts generated at farm-level (upstream stages excluded) per unit of farm area. An area-based indicator enables an assessment to be made of the environmental pressure on the local ecosystem and to compare this pressure to the carrying capacity of this ecosystem, the carrying capacity being defined as "the maximum rates of environmental impacts generation that can be sustained indefinitely without progressively impairing the productivity and functional integrity of the ecosystem" (adapted from Rees 1996). In the present case, we are unable to assess the local environmental performance for the reasons given in "Section 2.4.1".

Last but not least, it is important to remind ourselves at this stage that the present work focuses only on two dimensions of sustainable performance—the economic and environmental dimensions—and ignores the social dimension. This should be kept in mind when deriving conclusions based on the results of the present investigation, since an improvement in both economic and environmental performance could imply a decline in farm performance regarding social issues, like the preservation of typical Swiss mountain rural scenery, the preservation of the cultural inheritance and traditions such as transhumance or the maintenance of livelihoods in the rural mountain territories.

5 Conclusions

Our analysis provides evidence of the existence of a positive relationship between economic performance—measured using the work income per family work unit—and global environmental performance—defined as the eco-efficiency of environmental impacts generation—of Swiss dairy farms located in the alpine area. This positive relationship exists in relation to all environmental issues considered—the demand for non-renewable energy resources, eutrophication, aquatic ecotoxicity, human toxicity and land use. Thus, there is no trade-off between economic and global environmental farm performance, and the positive relationship between economic and global environmental performance is also observed at aggregate level. This implies that, by improving their economic performance, farms also tend to increase the efficiency of their environmental impacts generation and vice versa. This conclusion is of central relevance for policy-makers as the diffusion of this finding should contribute towards improving the acceptance among farmers of the environmental objectives of Swiss agricultural policy in terms of an increase in environmental resource use productivity. In that sense it provides valuable insights for the enhancement of the sustainable performance of the Swiss dairy sector in the alpine area.

To our knowledge, the present study is the first to investigate the relationship between economic and global environmental performance in dairy farming to such a level of precision and completeness as regards the environmental assessment. In the agricultural sector precise economic micro-level data is traditionally readily available, as almost all European countries have at their disposal a Farm Accountancy Data Network which each year collects precise and detailed accountancy data for a sample of farms. Precise and comprehensive environmental data at farm level is very hard to come by. For this reason and due to the fact that the collection of farm level environmental data is very expensive, most of the empirical studies dealing with both the economic and environmental performance of a farm either use rough FADN proxies for the environmental variables required or carry out the environmental assessment solely on the basis of this FADN data making for that purpose numerous assumptions with the associated consequences in terms of assessment accuracy. As far as the present work is concerned, the environmental assessment has been performed using the LCA technique and by collecting all specific data required for the assessment on the farm. As a result, the assessment is very detailed and precise and takes into consideration a wide range of environmental impact categories, thus offering a unique opportunity to investigate the relationship between economic and environmental farm performance. By using a DEA-based approach to assess the aggregate eco-efficiency of a farm in terms of its environmental impacts generation, we have solved the problem of the aggregation of the different environmental impact categories in an objective manner, thus avoiding arbitrarily attributing an equal weight to each environmental impact category in order to derive an aggregate eco-efficiency indicator that is very useful for policy-makers. In this sense the analysis performed here using this LCA data and the DEA-based approach to assessing farm eco-efficiency provides new insights into the link between economic and global environmental farm performance for farmers, policy-makers and farm consultants.

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