Analysis of the determinants of the economic and environmental performance of Swiss dairy farms in the alpine area

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ABSTRACT

Improving the sustainability of the dairy food chain involves a reduction of the environmental impact of dairy farming, as a large part of the environmental impacts associated with dairy product consumption is generated in the agricultural phase of the milk life cycle. In this paper, we combine life cycle assessment and farm accountancy data to analyze the factors affecting the environmental performance, defined as the eco-efficiency of food production, and the economic performance of Swiss dairy farms in the alpine area. The results of the analysis show the existence of synergies in the enhancement of farm economic and environmental performance. Unfavorable natural production conditions (high altitudes and unfavorable topography) have a strong negative impact on both areas of performance. Conversely, organic farming, farm size, full-time farming and a high agricultural education level have a positive effect on the two dimensions of the sustainable performance of a farm.

Keywords: sustainability, dairy farming, economic performance, environmental performance, Switzerland

1. Introduction

Dairy products are of high relevance in terms of environmental sustainability of final consumption. According to a study conducted for the EU-25 by Tukker et al. (2006), dairy products are—within the food and drink consumption area—the second highest contributors[1] to the environmental impact of final consumption by private households and the public sector. Only a few studies have assessed the relative contribution of each phase in the life cycle of milk to milk's total environmental impact over its whole life cycle from production through consumption to disposal. Focusing on the milk production and processing phases, Hospido et al. (2003) showed for the Galician dairy sector that of these two phases the production phase (farming) was—for the impact categories (i) global warming potential, (ii) eutrophication potential and (iii) acidification potential—the main contributor to the total environmental impact generation (with a contribution to the total impacts of 80%, 74% and 58%, respectively). Performing a comprehensive life cycle assessment encompassing the farming, processing and consumption phases, Eide (2002) showed for Norwegian dairies that the agricultural phase was—for (i) the energy consumption, (ii) the acidification potential, (iii) the eutrophication potential and (iv) the global warming potential—the greatest contributor to the total environmental impact of the whole dairy supply chain. Assessing a very large sample of dairy farm operators from the United States and considering all phases in the dairy supply chain, Thoma et al. (2013) found that 72% of the greenhouse gas emissions associated with the consumption of fluid milk in the United States was accrued by the dairy farm gate. Analyzing—within a comparative study between Switzerland, Germany, France and Italy—the life cycle of cheese up to its point of sale, Bystricky et al (2014) found that the farming stage was responsible—for all environmental impact categories considered (demand for non-renewable energy resources, global warming potential, ozone formation potential, land use, eutrophication potential, acidification potential, terrestrial and aquatic ecotoxicity, and human toxicity) for more than 70% of the environmental impacts generated from the "cradle to the point of sale". These four studies provide evidence that, within the dairy supply chain, the "cradle-to-farm gate" link is for most environmental impact categories the most important contributor to the environmental impact of the full chain. A thorough understanding of the factors affecting the environmental impact generation at this level is therefore a pre-requisite if we want to improve the environmental sustainability of the dairy food chain and thus reduce its contribution to the environmental impacts related to the final consumption of products by private households and the public sector.

The present paper focuses on the Swiss dairy food chain of the alpine area, which is of particular importance for the Swiss agricultural sector (see Jan et al. 2012b). By using life cycle assessment (LCA) in combination

[1] The most important contributor is meat and meat products.

with farm accountancy data, we aim to identify the factors influencing the environmental and economic performance of Swiss dairy farms located in the hill and mountain region.

2. Materials and methods

The present work is based on the same data as those used in Jan et al. (2012a). Hence, we forgo a comprehensive description of this dataset and refer the reader to this publication for detailed information on the data and especially on the environmental impact assessment carried out.

2.1. Sample of farms

The investigation relied on a pooled[2] sample of specialized dairy farms located in the hill and mountain regions. The sample encompassed 56 farm observations. The hill and mountain regions included the hill zone as well as the mountain zones 1 to 4 as defined in FOAG (2008). The hill and mountain regions, also called alpine area in the present paper, can be defined roughly as the agricultural production area located between 500 and 1'500 meters above sea level. A specialized dairy farm was defined as a farm whose revenues from dairying generated at least 60% of total farm agricultural revenues without any direct payments. Farms with a proportion of revenues from para-agricultural activities above 20% of total farm revenues as well as farms whose revenues from forestry activities generated more than 10% of total farm agricultural revenues were excluded from the analysis to ensure that the observations were homogeneous in terms of production activities.

The data were collected within the framework of a broader project, the LCA-FADN (Life Cycle Assessment–Farm Accountancy Data Network) project, aiming at conducting a joint economic and environmental assessment of Swiss agriculture at the farm level (see Hersener et al. 2011). The farms of the sample were not selected according to a random procedure. The participation in the project occurred on a voluntary basis due to the complexity and comprehensiveness of the environmental data collection.

2.2. Environmental impact assessment using the SALCA approach

For each farm, a precise and comprehensive environmental impact assessment was conducted by using the SALCA (Swiss Agricultural Life Cycle Assessment) approach (see Baumgartner et al. 2011). The system investigated was made up of the agricultural production system defined in a narrow sense (see Jan et al. 2012a). The assessment covered the agricultural stage, that is, the "cradle-to-farm gate" link, of the milk life cycle. All agricultural inputs, production processes and outputs were taken into account. The environmental impacts were quantified based on very precise and detailed production inventories collected at the farm level. The following eight impact categories were quantified (the impact assessment method used being given in parentheses): (i) demand for non-renewable energy resources (ecoinvent method, Frischknecht et al. 2004), (ii) global warming potential over 100 years (IPCC method, IPCC 2007), (iii) eutrophication potential (EDIP97 method, Hauschild and Wenzel 1998), (iv) acidification potential (EDIP97 method, Hauschild and Wenzel 1998), (v) aquatic ecotoxicity (CML01 method, Guinée et al. 2001), (vi) terrestrial ecotoxicity (CML01 method, Guinée et al. 2001), (vii) human toxicity (CML01 method, Guinée et al. 2001) and (viii) land use (CML01 method, Guinée et al. 2001).

2.3. Analysis level

In the present work, the analysis was carried out at the whole-farm level and not at the level of the product "milk." This choice was motivated by the high degree of specialization in dairying of the farms investigated and by the associated homogeneity of their product mix (i.e., of their production activities). Choosing the farm unit instead of the product group "milk" as an analysis level furthermore enabled us to circumvent the typical problem of allocation of resources and emissions to different products (or product groups) encountered in life cycle assessment at product level in a multiple-product setting (e.g., Feitz et al. 2007, who showed—using a dairy manufacturing plant as a case study—how sensitive the product-level results of LCA studies were to the allocation approach used).

[2] The observations of a three-year period from 2006 to 2008 were pooled.

2.4. Economic performance

There exist many possible indicators to assess the economic performance of a farm. Basically, these indicators can be divided into two sub-groups: (i) the efficiency measures from the field of productive efficiency measurement and (ii) the classical profitability indicators commonly used in practice within the field of farm management. However, productive efficiency measures were shown to be inappropriate to assess the overall economic performance of an enterprise (Musshof et al. 2009). Hence, we used here a classical profitability indicator from the field of farm management, namely the work income per full-time family work unit. It assesses the farm income available per unpaid full-time family labor force after equity capital has been remunerated to its opportunity cost. This latter is defined as the interests that would be generated would the equity capital be remunerated to the interest rate on ten-year Swiss government bonds. The work income per annual full-time family work unit was derived from the accountancy data of the farms.

2.5. Environmental performance

Relying on the considerations of Halberg et al. (2005), Jan et al. (2012a) distinguished between the local and the global environmental performance of a farm. The local environmental performance of a farm was measured by means of a so-called area-based[3] indicator assessing the amount of environmental impact generated on-farm (i.e., at the level of the local ecosystem of the farm) per hectare farm area. The global environmental performance of a farm was quantified by means of an eco-efficiency indicator, eco-efficiency[4] being defined as the farm agricultural output per unit of environmental impact generated in the “cradle-to-farm gate” link of the food chain.

For the same reasons as those exposed in Jan et al. (2012a), the present work concentrated on the global environmental performance of a farm. Eco-efficiency was specified here as the amount of digestible energy (in MJ) produced by the dairy farm per unit of environmental impact. Specifically, nine eco-efficiency indicators were estimated: one for each of the eight environmental impact categories considered (this first type of indicator being called partial eco-efficiency indicator as it considered only one environmental impact category at a time) and an aggregate eco-efficiency indicator considering several impact categories at the same time and estimated according to the Data Envelopment Analysis–based approach described in Jan et al. (2012a). The aggregate eco-efficiency was expressed in percent and can be interpreted as the result of a benchmarking in which a farm is compared to its peers in terms of digestible energy production per aggregate environmental impact. Further details on the interpretation of this aggregate eco-efficiency are available in Jan et al. (2012a). To better understand the effect of the factors considered on each partial eco-efficiency indicator, partial eco-efficiency was decomposed into its sub-constituents, namely partial eco-efficiency at the input-group (e.g., energy carriers, fertilizers) level defined as the amount of digestible energy produced by the farm per unit of environmental impact attributable to this input group. To facilitate the analysis, the partial eco-efficiency indicators were converted into environmental-intensity indicators, environmental intensity being defined as the inverse of eco-efficiency (Verfaillie and Bidwell 2000). This conversion enabled us to separate per input group the environmental impact generation per MJ digestible energy produced[5,6].

2.6. Analysis of the factors affecting environmental and economic performance

As mentioned in the introduction, the objective of the present contribution was to analyze the factors affecting the environmental and economic performance of Swiss dairy farms located in the alpine area. Numerous fac-

[3] Term used by Halberg et al. (2005).

[4] Eco-efficiency is the inverse of environmental intensity, also called product-based indicator by Halberg et al. (2005).

[5] The use of eco-efficiency for this decomposition would have been associated with problems of additivity between the average eco-efficiency at whole-farm level and its constituents at input-group level. These problems result from the fact that eco-efficiency, like any ratio variable, is undefined if its denominator, in the present case the environmental impact generation, equals zero. Such a situation is met often at input-group level. This problem does not occur when environmental intensity is used.

[6] Eleven input groups were defined: (i) fertilizers and nutrients, (ii) energy carriers, (iii) purchased animal feed, (iv) buildings and equipments, (v) machinery, (vi) plant protection products, (vii) purchased seeds, (viii) purchased animals, (ix) on-farm emissions from animals (stable), (x) own animals not present on the farm (e.g., outsourcing of heifers rearing, summering of cattle) and (xi) other inputs.

tors[7] can impact farm economic and environmental performance. These factors can be classified into two groups: factors pertaining to the general environment of the farm and those related to the farm itself as economic agent (Jan et al. 2011). The first group can be split up into three major sub-groups: the legal/regulatory environment, the socio-economic environment and the natural environment. The second group encompasses three sub-groups: the structural factors, the management factors and the human factors. Taking into account the variable availability and the limited sample size, we focused in the present work on the following factors: natural production conditions, farm size, farm type (full-time or part-time farm), production form and agricultural education of the farm manager. The natural production conditions were represented by the categorical variable "agricultural production zone," this variable being made of three modalities: hill zone, mountain zones 1&2 and mountain zones 3&4. The agricultural zone classification was based on criteria regarding (i) the climatic conditions and especially the vegetation period length, (ii) the accessibility in terms of transport and (iii) the topography (FOAG 2008). Within the mountain region, the favorableness of the natural production conditions decreases from mountain zone 1 to 4. Farm size was measured in terms of food production quantity defined as the amount of digestible energy produced by the farm. Farm type was represented by a dummy variable (full-time *versus* part-time farming). Full-time farms were defined as farms whose household income originated from at least 90% agricultural income. Part-time farms were farms with at least 10% of their household income originating from non-agricultural activities. Production form had two categories: organic *versus* conventional farming. The variable related to the agricultural education of the farm manager considered two levels: (i) completed apprenticeship or lower agricultural education level and (ii) agricultural education level higher than a completed apprenticeship (e.g., master craftsman diploma or university degree).

Taking into account the limited sample size as well as the number of independent variables analyzed and considering the requirements in terms of number of observations for performing a multiple linear regression analysis[8], we had to reject this multivariate approach, which would have suited best for the purpose of the present work. Instead, we investigated separately the effect of each factor on each performance indicator considered. Owing to the limited size of the sample and to the fact that the assumptions (*inter alia* normal distribution assumption) required for performing parametric tests were not fulfilled, this effect was investigated by means of non-parametric statistical tools. If the determinant was interval-scaled, we used the non-parametric Spearman's rank correlation to assess the relationship between this determinant and the performance indicator considered. In the case of a categorical determinant, its effect on the performance indicator was analyzed by means of a Mann-Whitney U-test if the factor in question had two categories or of a Kruskal-Wallis test if the factor considered had more than two categories.

Based on this analysis, we could identify the factors presenting synergies (i.e., influencing both the economic and environmental performance in the same direction) and those showing trade-offs (i.e., affecting the two dimensions in an opposite direction) in the enhancement of farm economic and global environmental performance.

3. Results

The results of the analysis of the factors affecting the economic and global environmental performance of Swiss dairy farms in the alpine area are presented in the following five sub-sections[9]. Each sub-section is devoted to one of the factors presented previously in section 2. Due to the high correlation of the environmental intensity between terrestrial and aquatic toxicity (Spearman's rho=0.91, $p<0.001$) and for the sake of conciseness of the paper, the results regarding the aquatic toxicity are not presented here.

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[7] The terms "factor," "determinant," "independent variable" or "predictor" are used here as synonyms.

[8] Harrell (2001, p. 61) stated, as rule of thumb, that at least 10 to 20 observations should be available per predictor to obtain a reliable fitted-regression model. Applied to the present investigation, this rule would imply that at least 60 to 120 observations would be needed since the model encompassed six predictors and the categorical variable regarding the natural production conditions was transformed into two dummy variables.

[9] Owing to the paper length limit, we could not provide all detailed figures from the statistical analyses and tests carried out and had to focus on the most important results.

3.1. Effect of unfavorable natural production conditions

As obvious from Figure 1, the natural production conditions were shown to have a statistically significant effect on the aggregate eco-efficiency ($p<0.001$). Whereas farms located in the hill zone showed an average aggregate eco-efficiency of 86%, the average aggregate eco-efficiency of farms located in the mountain zones 1&2 and 3&4 was 68% and 36%, respectively[10]. With respect to the single environmental impact categories, we observed that the natural production conditions significantly influenced the environmental intensity regarding the demand for non-renewable energy resources ($p<0.001$), the global warming potential ($p<0.001$), the eutrophication potential ($p<0.001$), the terrestrial ecotoxicity ($p=0.06$), the human toxicity ($p<0.001$) and the land use ($p<0.001$). Farms located in the hill zone showed a significantly lower environmental intensity than those located in the mountain zones 1&2 and 3&4, the farms of the mountain zones 3&4 registering the highest environmental intensity for all impact categories considered. The environmental intensity differences between the three groups of zones were substantial and varied in their relative amplitude depending on the impact category considered. For example, the differences between the hill zone and the mountain zones 3&4 varied between a factor of 1.6 for the terrestrial ecotoxicity and 3.7 for the land use. A more detailed analysis at the input-group level showed that the differences were not due to a specific input group but concerned almost all input groups relevant for the impact category considered.

With respect to the economic performance, measured by the work income per family work unit, we observed significant differences between the three groups of zones considered ($p=0.07$, see Figure 2). The highest average income was observed for the hill zone (46'315 CHF per family work unit). The mountain zones 1&2 and 3&4 showed, compared to the hill zone, a lower work income per family work unit (29'930 and 34'550 CHF, respectively).

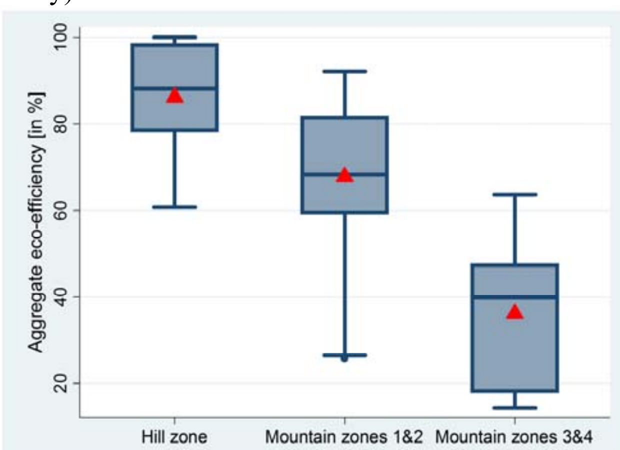

Figure 1. Effect of the natural production conditions on the aggregate eco-efficiency

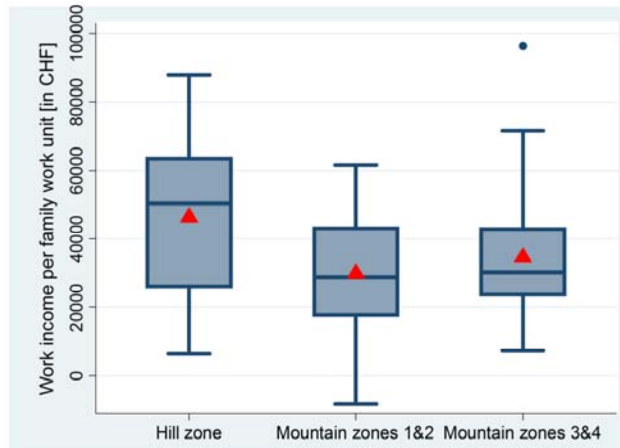

Figure 2. Effect of the natural production conditions on the work income per family work unit

3.2. Effect of farm size

The results of the non-parametric Spearman's rank correlation analysis showed the existence of a strong positive monotonic relationship between farm size, measured as farm digestible energy output, and farm aggregate eco-efficiency ($rho=+0.75$, $p<0.001$, see Figure 3).

The Spearman's rank correlation between farm size and environmental intensity was -0.73 ($p<0.001$) for the demand for non-renewable energy resources, -0.81 ($p<0.001$) for the global warming potential, -0.57 ($p<0.001$)

[10] All boxplot representations in this paper have to be interpreted as follows. The upper line of the box represents the upper quartile (Q75), the lower line of the box the lower quartile (Q25), the line subdividing the box the median (Q50). The lower whisker spans all data points within the range]Q25-1.5 IQR; Q25[(where IQR=interquartile range defined as Q75-Q25). The upper whisker spans all observations within the range]Q75; Q75+1.5 IQR[. Outliers (i.e., observations outside the whiskers) are marked as blue points. The red triangle represents the average.

for the eutrophication potential, -0.34 (p=0.01) for the terrestrial ecotoxicity, -0.70 (p<0.001) for the human toxicity and -0.80 (p<0.001) for the land use.

The negative correlation between farm size and environmental intensity proved to be related not to a particular input group but to the most important input groups for the environmental impact category considered.

A positive monotonic relationship was found between farm size and the work income per family work unit (rho=+0.37, p=0.005, see Figure 4).

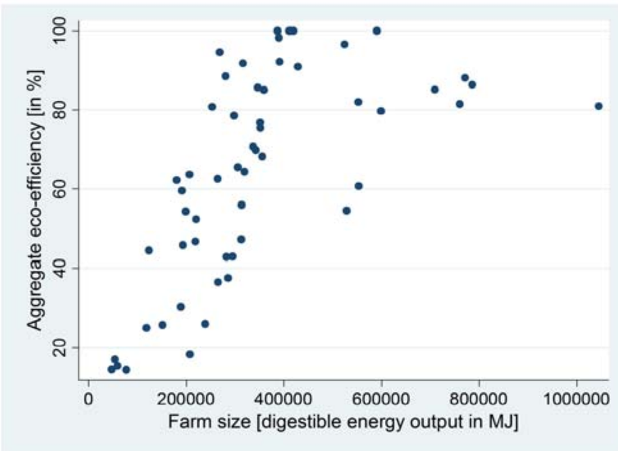

Figure 3. Effect of farm size on the aggregate eco-efficiency

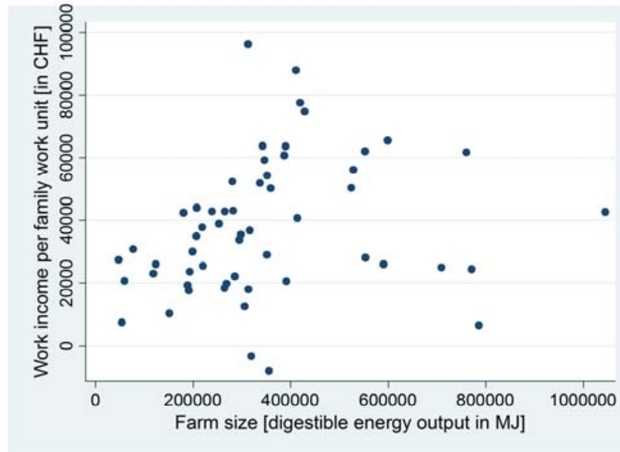

Figure 4. Effect of farm size on the work income per family work unit

3.3. Effect of farm type

Even if, based on a visual analysis of Figure 5, it would seem that full-time farms exhibited a higher aggregate eco-efficiency than part-time farms, the outcome of a Mann-Whitney U-test (p=0.15) showed that the differences were not significant at a 0.10 level. However, at the level of the environmental intensity for each single impact category, we observed some significant differences between these two groups of farms. Full-time farms tended to exhibit a lower environmental intensity than part-time farms regarding the demand for non-renewable energy resources (p=0.10), this being attributable to the input groups (i) purchased animal feed and (ii) buildings and equipments. With respect to the global warming potential, full-time farms also were characterized by a lower environmental intensity (p=0.04) being imputable to the input groups (i) purchased animal feed and (ii) buildings and equipments. In terms of eutrophication potential, full-time farms also showed a significantly lower environmental intensity than part-time farms (p=0.02). This better performance resulted from the input group fertilizers and nutrients. The lower environmental intensity of full-time farms compared to part-time farms observed for the impact category human toxicity (p=0.005) was ascribable to three input groups: (i) energy carriers, (ii) buildings and equipments and (iii) purchased animal feed.

In terms of economic performance, full-time farms significantly differed from part-time farms (p<0.001, see Figure 6). The average work income per family work unit was 51’614 CHF for full-time farms and 27’764 CHF for part-time farms.

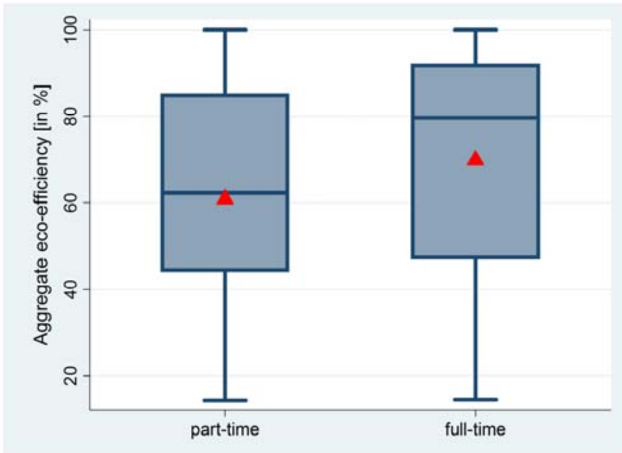

Figure 5. Effect of farm type on the aggregate eco-efficiency

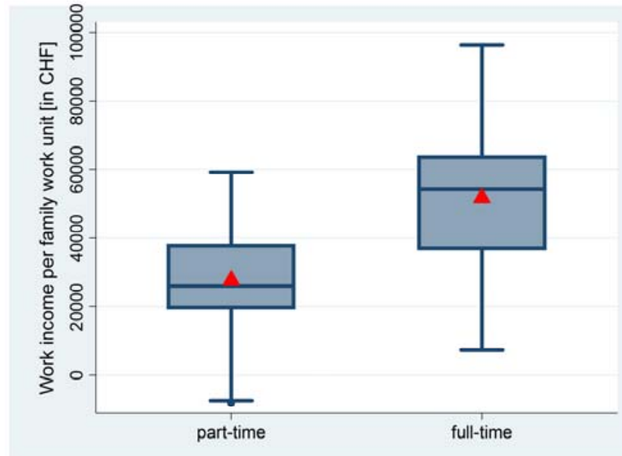

Figure 6. Effect of farm type on the work income per family work unit

3.4. Effect of production form

The boxplots of Figure 7 depict the variability of the aggregate eco-efficiency of the farms investigated for each production form (organic *versus* conventional farming). As apparent from this figure, organic farms showed a significantly higher aggregate eco-efficiency than conventional farms (p=0.06). The average aggregate eco-efficiency was 76% and 61% for the organic and conventional farms, respectively. A closer look at the environmental intensities revealed that—with the exception of the impact category land use—organic farms exhibited for all impact categories considered a significantly lower environmental intensity than conventional farms. Analyzing the environmental intensity at the input-group level, we found that the lower (p=0.09) environmental intensity regarding the demand for non-renewable energy resources was attributable to two input groups: (i) purchased animal feed and (ii) purchased animals. Two input groups accounted for the lower (p=0.06) environmental intensity regarding the global warming potential of organic farms: (i) purchased animal feed and (ii) fertilizers and nutrients. The better (p=0.02) environmental performance of organic farms in terms of eutrophication potential was found to result from their lower environmental intensity for the input groups (i) fertilizers and nutrients, (ii) purchased animal feed and (iii) purchased animals. With respect to the terrestrial ecotoxicity (p<0.001), the lower environmental intensity of organic farms could be ascribed to the input groups (i) purchased animal feed, (ii) plant protection products and (iii) purchased animals. Three input groups explained the better (p<0.001) performance of organic farms in terms of environmental intensity with respect to human toxicity: (i) energy carriers, (ii) purchased animal feed and (iii) purchased animals. Land use was the single impact category for which no significant differences in terms of environmental intensity was found between organic and conventional farming.

Compared to conventional farms, organic farms were characterized not only by a better environmental performance but also by a significantly better economic performance (p=0.01; see Figure 8). On average, the work income per family work unit was 53’712 CHF for organic farms compared to 32’676 CHF for conventional ones.

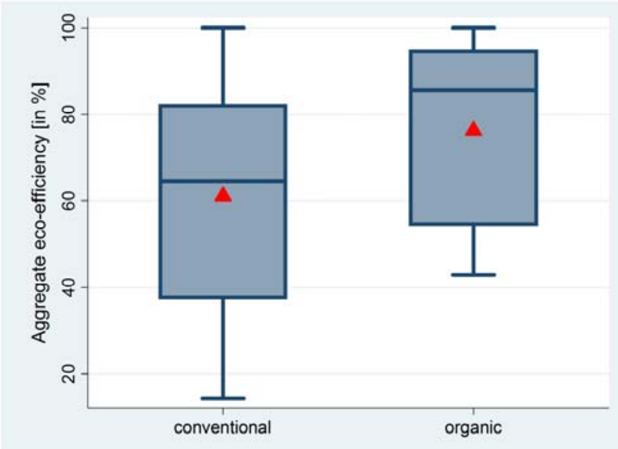

Figure 7. Effect of the production form on the aggregate eco-efficiency

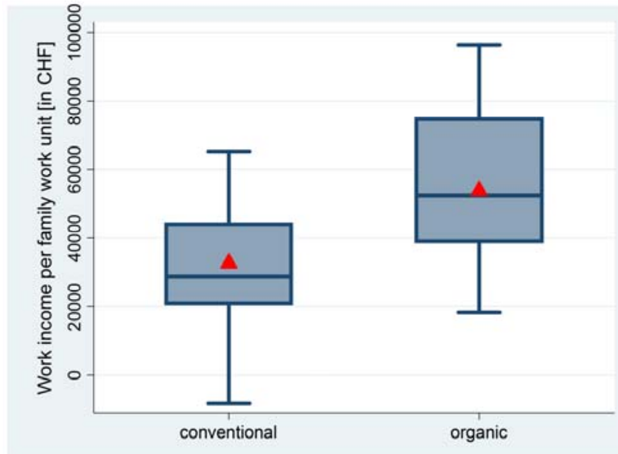

Figure 8. Effect of the production form on the work income per family work unit

3.5. Effect of agricultural education level

The effect of the agricultural education level on the aggregate eco-efficiency is depicted in Figure 9. A high agricultural education level was associated with a high aggregate eco-efficiency (p=0.009). The average aggregate eco-efficiency of farms whose managers had an agricultural education level higher than an apprenticeship was 77% compared to 57% for farms whose managers had an agricultural education level equivalent to or lower than an apprenticeship. A further analysis of the data revealed that a higher agricultural education involved a lower environmental intensity for all impact categories considered. This lower environmental intensity was not imputable to a particular input group but applied to almost all input groups relevant for the environmental impact category considered. A high agricultural education was revealed to be beneficial not only in terms of environmental performance but also in terms of economic performance (p=0.09, see Figure 10). The average work income per family work unit of a farm managed by a person with an agricultural education level higher than the apprenticeship was significantly higher than that of a farm managed by a person with an agricultural education level equivalent to or lower than the apprenticeship (44'439 CHF and 33'432 CHF, respectively).

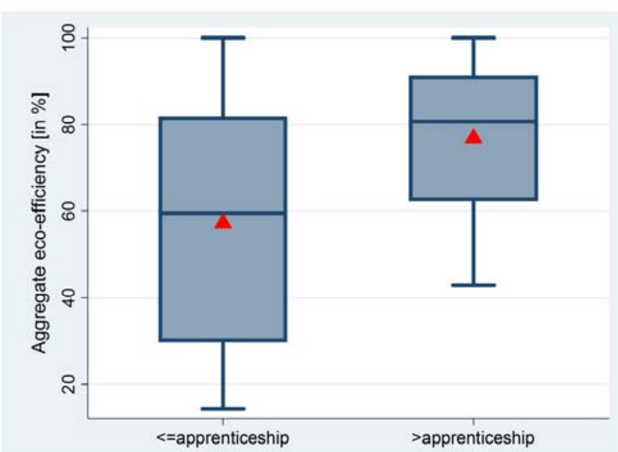

Figure 9. Effect of the agricultural education level on the aggregate eco-efficiency

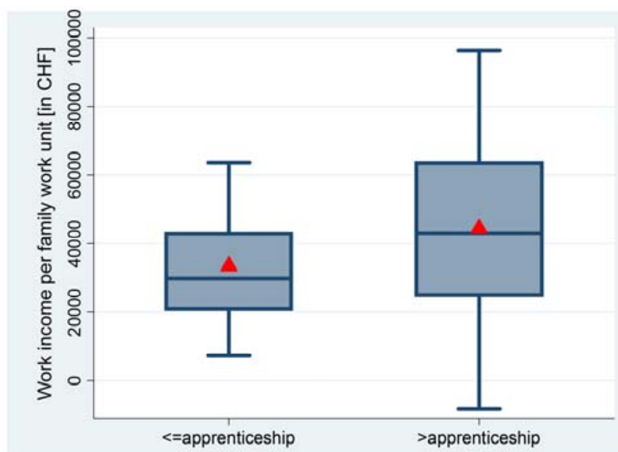

Figure 10. Effect of the agricultural education level on the work income per family work unit

4. Discussion

4.1. Main findings

The present work assessed the impact of selected factors on farm economic and environmental performance. Unfavorable natural production conditions were shown to strongly negatively influence both the global environmental and the economic performance of the farms investigated. The negative impact of unfavorable natural production conditions on farm eco-efficiency was not due to a specific input group but concerned all input groups. This finding highlights the systematic environmental but also economic competitive disadvantage of milk production under unfavorable natural production conditions. This finding also may question the appropriateness of milk production under such conditions. However, it should be considered here that dairy farms located in (unfavorable) mountain areas are characterized by their multifunctionality, that is, by their multiple functions going far beyond the simple food production function. The non-commodity outputs[11] that are associated with these additional functions and are by-products of the agricultural commodity outputs were not considered in the output variable used to assess eco-efficiency. This should be kept in mind when interpreting the results.

The result that farm size had a positive effect on the two considered dimensions of the sustainable performance of a farm emphasizes the substantial scale effects that exist in dairy farming regarding the use of not only economic but also environmental resources.

Compared to full-time farming, part-time farming, which was shown for Switzerland (see Jan et al. 2011; Roesch 2012) to be associated with a substantially lower economic performance, herein was also synonymous with a poorer global environmental performance. This seemed to result primarily from an inefficient use of purchased feed, of buildings and equipments and, in some cases, of fertilizers and energy carriers.

Whereas organic farming was shown in the literature to be associated with a—compared to conventional farming—higher eco-efficiency for some impact categories and with a lower one for others (see Tuomisto et al. 2012), in the present work it was associated with a higher eco-efficiency for all impact categories with the exception of land use, for which no significant differences were observed between organic and conventional farms. This higher eco-efficiency was attributable to the input groups purchased animal feed, fertilizers and nutrients and purchased animals[12], highlighting thus that this better performance resulted primarily from the feeding and fertilization strategies and practices of organic farming. This finding implies that—under the natural production conditions of the alpine area and the associated production restrictions and low forage yield potential—organic farming may be from both an environmental and an economic perspective a more appropriate technology than conventional farming for the dairy activity. Thus, a process of conversion from conventional to organic farming may be very likely to lead to economic and environmental benefits and to a substantial improvement of the sustainability of the dairy food chain in this region. This probably explains why the share of organic farms increases with the unfavorableness of the natural production conditions (e.g., in 2012, according to the Swiss Federal Statistical Office, the proportion of organic farms in the mountain zone 4 and in the plain zone was 35% and 5%, respectively).

Last but not least, agricultural education was shown to play an important role in terms of environmental and economic performance. A high agricultural education implied both high eco-efficiency and high work income per family work unit. All input groups were involved in this high eco-efficiency suggesting that better educated farm managers had better management capacities for the use of economic and environmental resources.

4.2. Limits of the study

For the interpretation and discussion of the results of the present investigation as well as their implications, attention should be paid to the following issues. Firstly, it should be noted that the investigation focused on only one of the two dimensions of the environmental performance of a farm, namely the so-called global environmental performance defined by Jan et al. (2012a) as the eco-efficiency of food production until the farm gate. The

[11] These non-commodity outputs, such as conservation of a mosaic rural landscape or contribution to the vitality of rural communities, are by-products of the agricultural commodity outputs.

[12] Some readers may be surprised that plant protection products are not mentioned here. This is because the present contribution focuses on farms located in the alpine area, a region in which the use of plant protection products in conventional farming is very limited and very often inexistent.

local environmental performance of a farm, which focuses on the environmental impact generation that occurs locally at the farm level and which is defined as the environmental pressure exerted by the farm on its local ecosystem, was not investigated in the present work. It is therefore necessary to remember that the findings of the present contribution regarding the factors affecting farm environmental performance apply to only the global dimension of farm environmental performance. Secondly, the sample was not selected at random due to the comprehensiveness and complexity of the data collection. This may have introduced a positive bias in the representativeness of the sample as it has to be expected that farm managers interested in environmental issues were more likely to participate in the project than those who did not feel concerned by such issues. Thirdly, an additional sample-related limitation of the investigation lies in the approach used to assess the effect of the selected factors on farm environmental and economic performance. As mentioned in section 2.6, due to the limited sample size, we had to refrain from applying multiple linear regression analysis and therefore investigated separately the effect of each factor on each performance indicator. Consequently, the effect measured for each factor is not a *ceteris paribus* one and may capture the effects of other factors correlated with the one investigated.

5. Conclusion

The present contribution provides initial evidence that the promotion of an economically viable alpine dairy farming sector as well as the enhancement of one with a high eco-efficiency are not antinomic but synergetic. By increasing farm size (i.e., through scale effects), by promoting organic farming as well as full-time farming and by raising the level of agricultural education among future farm managers, major enhancements in terms of economic and environmental performance could probably be achieved. Our work shows how valuable combined micro-level economic and environmental data are. Such data enable us to gain a better insight into the relationship between these two dimensions of sustainability. Such insight is a pre-requisite if we wish to improve sustainability. In order to gain a holistic understanding of the farm-level link between economic and environmental performance, our future studies will focus on the analysis of the link between (i) economic performance and local environmental performance and (ii) local and global environmental performance.

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