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Factors Affecting Global versus Local Environmental and Economic Performance of Dairying: A Case Study of Swiss Mountain Farms

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Abstract: Improving the sustainability of the dairy food chain requires a simultaneous improvement in global and local environmental performance, as well as in the economic performance of dairy farms. We investigated the effect of different structural, farm management, socio-demographic, technological and natural-environment-related factors on the economic and environmental performance of dairying. Our analysis relied on a case study of 56 Swiss alpine dairy farm observations, for which cradle-to-farm gate life cycle assessments and farm accountancy data were combined. The data refer to the years 2006 to 2008. The effect of the selected factors on farms' economic and environmental performance was analysed by means of non-parametric statistical approaches. The results revealed the existence of some factors presenting synergies and several factors showing trade-offs in the enhancement of farm global environmental, local environmental and economic performance. More generally, the promotion of farm global environmental performance and farm economic performance was shown to be synergetic whereas the enhancement of farm global and local environmental performance turned out to be mostly antinomic. However, some factors, namely organic farming, higher agricultural education, silage-free milk production, and also, to a weaker extent, full-time farming, larger farm size and lower intensity of cattle concentrates use, showed a potential to bring simultaneous improvements in the global and local environmental performance as well as the economic performance of dairy farming. Policy-makers should be aware of the complexity of the joint improvement of farm economic and environmental performance and only promote factors capable of synergistically enhancing the environmental and economic performance of dairy farming.

Keywords: sustainable agriculture; dairy farming; environmental performance; economic 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. [1], dairy products were—within the food and drink consumption area—the second-highest contributors (the most important contributor was meat and meat products) 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 (see, e.g., Hospido et al. [2], Eide [3], Thoma et al. [4] and Bystricky et al. [5]). Though differing regarding their investigation scope, the countries analysed, the environmental impact categories considered, and the environmental impact assessment methods used, these four studies provide evidence that, within the dairy supply chain, the "cradle-to-farm gate" link is for most environmental impact categories the main contributor to the environmental impact of the full chain. More specifically, the farming stage was shown to be the most important contributor for the impact categories (i) global warming potential; (ii) eutrophication potential and (iii) acidification potential across different studies ([2,3,5]). It was also responsible for 72% of greenhouse gas emissions associated with the consumption of fluid milk in the United States [4]. More generally, these findings go hand in hand with the results of Kuisma and Kahiluoto [6], who showed that agricultural production presents the greatest potential for increasing the biotic resource efficiency of the entire agrifood system. A thorough understanding of the factors affecting the environmental impact of farming is therefore a prerequisite if we wish to improve the environmental sustainability of the dairy food chain and thus reduce its contribution to the environmental impacts generation related to the final consumption of products by private households and the public sector.

Farm environmental sustainability requires complying with the ecosystem's carrying capacity constraints at both local and global ecosystem levels [7]. In terms of farm environmental performance assessment, this implies the separate implementation of local and global environmental performance indicators [7]. Improvement of farm environmental sustainability requires improvement of both global and local environmental performance dimensions [7]. The empirical implementation of both global and local environmental performance indicators in a case study of Swiss dairy farms revealed—depending on the environmental impact category considered—both synergies and trade-offs between the two environmental performance dimensions, with trade-offs predominating over synergies [8]. It also highlighted the existence of synergies between global environmental and economic performance and mostly non-significant relationships between local environmental and economic performance [8]. Improving our knowledge of the relationship between environmental and economic performance is important "when the dual objective of high environmental quality and good economic performance is pursued" [9], as is the case in Swiss agriculture. To avoid an improvement in both environmental performance dimensions happening at the expense of farm economic performance, the factors potentially influencing farm environmental performance should also be investigated for their effects on farm economic performance.

Until now, most LCA-based studies investigating the potential factors of environmental performance in dairy farming have focused on the analysis of the effect of production form (organic vs. conventional, e.g., [10–13]) or of production intensity (see, for example, [11,14–17]) on farm environmental performance. When investigating the effects of different factors on farm environmental performance, none of these studies distinguished between the global and local environmental performance of a farm as defined by Repar et al. [7]. With a few exceptions, the environmental focus of these studies was—due to their LCA perspective—mostly on what Repar et al. [7] defined as farm global environmental performance, since the LCA approach by definition does not separately assess the farm local environmental performance dimension, as defined by Repar et al. [7]. Investigations simultaneously analysing the factors potentially affecting the global and local environmental, as well as economic performance of dairying are still lacking.

The present article aims to extend the LCA-approach and related farm global environmental performance perspective by complementing it with the local dimension of farm environmental performance in order to gain a more comprehensive picture of environmental sustainability. For Swiss dairy farms located in the hill and mountain region, it analyses the link between selected farm characteristics and (i) global environmental performance, (ii) local environmental performance, and (iii) economic performance. Structural, managerial, socio-demographic, natural-environment and production-technology-related characteristics are thereby considered. The analysis relies on a unique dataset combining life cycle assessments (LCAs) and farm accountancy data. The final purpose of this analysis is to highlight the factors that have the potential to simultaneously improve or worsen all three investigated performance dimensions, i.e., that present a synergy (either positive or negative) in the enhancement of farm environmental and economic performance. At the same time, we are interested in identifying the factors that influence at least two performance dimensions in a different direction, i.e., that show a trade-off in terms of promotion of the sustainable performance dimensions considered.

2. Materials and Methods

The present work was based on the same data as those used in Repar et al. [8]. Hence, we limit the description of the dataset to essential aspects and refer the reader to that publication for detailed information on the data, especially on the environmental impact assessment carried out.

2.1. Data Source and Sample

The investigation relied on an unbalanced pooled sample of specialised dairy farms located in the hill and mountain regions of Switzerland from the years 2006, 2007 and 2008. The sample encompassed 56 farm observations with very detailed environmental and economic data. The hill and mountain regions included the hill zone as well as mountain zones 1 to 4, as defined in FOAG (Swiss Federal Office for Agriculture) [18]. The hill and mountain regions, also referred to as alpine area in the present paper, can be roughly defined as the agricultural production area located between 500 and 1500 m above sea level. As in Jan et al. [19], a specialised 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 called the LCA-FADN (Life Cycle Assessment–Farm Accountancy Data Network) project, which conducted a joint economic and environmental assessment of Swiss agriculture at farm level (see [20]). The farms in the sample were not selected according to a random procedure. Participation in the project was voluntary due to the complexity and comprehensiveness of the environmental data collection. Due to the very small sample size and the non-random sampling procedure, no specific weighting system was implemented, implying that all observations were weighted equally. Further details on the data source can be found in Jan et al. [19] and Repar et al. [8].

The dataset our investigation relied on is—despite the fact that it dates back to the years 2006 to 2008—unique in three regards. First, it combines comprehensive and detailed economic as well as environmental farm-level data. Secondly, the size of our sample is—for an LCA-based investigation in the agricultural field—quite substantial. Thirdly, the cradle-to-farm gate LCAs were based on very comprehensive and detailed data collected at farm level in the form of production inventories with the help of a specific farm management software adapted and extended for that purpose (see Hersener et al. [20] and Jan et al. [19]). Due to these features, this dataset offers a unique opportunity for a comprehensive analysis of the factors affecting farm environmental and economic performance.

2.2. Environmental Impact Assessment Using the SALCA Approach

For each farm, a comprehensive environmental impact assessment was conducted using the SALCA (Swiss Agricultural Life Cycle Assessment) approach (see [21,22]). The system investigated was made up of the agricultural production system defined in a narrow sense, i.e., without any forestry and para-agricultural activities (see [19]). The assessment covered the agricultural stage, i.e., 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 detailed production inventories collected at farm level. Due to the update of the SALCA approach since the original data collection, the life cycle impact assessments (LCIAs) for the sample farms were reassessed (see [8]).

The cradle-to-farm gate environmental impacts were quantified for the following environmental impact categories: demand for non-renewable energy, ozone depletion, P-resource demand, K-resource demand, deforestation, global warming potential, land competition, human toxicity, aquatic ecotoxicity, terrestrial ecotoxicity, ozone formation, acidification, terrestrial eutrophication, aquatic N-eutrophication and aquatic P-eutrophication. In the second step, due to the requirements of the quantification of farm local environmental performance indicators, the quantified cradle-to-farm-gate environmental impacts were decomposed into their off- and on-farm parts [8]. Only the on-farm environmental impacts were considered for the quantification of farm local environmental performance, whereas both on-farm and off-farm impacts were accounted for when quantifying farm global environmental performance [7,8]. For a list of the models used for (i) the estimation of direct field and farm emissions and (ii) the environmental impact assessment, refer to Repar et al. [8].

2.3. Farm Global vs. Local Environmental Performance

Following the framework developed by Repar et al. [7] for environmental performance assessment at farm level, we distinguished between farm global and local environmental performance. This distinction relied on theoretical considerations on how to implement the environmental sustainability concept at farm level [7]. More precisely, it was derived from the rule according to which the compliance with the carrying capacity of both local and global ecosystems is a prerequisite to ensure environmental sustainability [7]. This distinction was also proposed by other authors, who called for the use of different environmental performance indicator types (area-based versus product-based) depending on the scale of environmental relevance (local versus global) of the environmental issue considered (e.g., Haas et al. [23]; Van der Werf and Petit [24]; De Boer [25]; Halberg et al. [26]; Payraudeau and Van der Werf [27]; Blonk et al. [28]; Jan et al. [19]).

2.3.1. Farm Global Environmental Performance

Following Repar et al. [8], we quantified global environmental performance by means of an eco-efficiency indicator, this indicator being the inverse of environmental intensity [29]. Global environmental performance is defined as the MJ digestible energy available for humans produced by the farm divided by the global (i.e., on- and off-farm) environmental impacts generated in the cradle-to-farm-gate link of the food chain [7,8]. Specifically, a global environmental performance indicator was calculated for each of the fifteen environmental impact categories assessed.

2.3.2. Farm Local Environmental Performance

Local environmental performance was calculated as farm usable agricultural area (UAA) in hectares divided by the local (i.e., on-farm) environmental impacts [7,8]. A local environmental performance indicator was quantified for each of the following eight environmental impact categories of local relevance: human toxicity, aquatic ecotoxicity, terrestrial ecotoxicity, ozone formation, acidification, terrestrial eutrophication, aquatic N-eutrophication and aquatic P-eutrophication.

2.4. Farm Economic Performance

Many possible indicators exist to assess the economic performance of a farm. Basically, these indicators can be divided into two sub-groups: (i) efficiency measures from the field of productive efficiency measurement and (ii) 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 [30]. Hence, we proceeded similarly to Repar et al. [8] and investigated three profitability indicators from the field of farm management;

namely, work income per full-time family work unit, return on equity and output/input ratio. All three indicators enable a comprehensive assessment of farm economic performance because they take all production factors into account. However, these three indicators differ regarding the procedure (opportunity cost versus residual value) followed for the remuneration of own production factors (equity capital and unpaid family labour) (for further details refer to [8]). All three economic performance indicators were derived from the accountancy data of the investigated farms.

2.5. Factors of Global Environmental, Local Environmental and Economic Performance

As mentioned in the introduction, the objective of the present contribution was to analyse various factors potentially affecting the global and local environmental performance as well as the economic performance of Swiss dairy farms located in the alpine area. We considered a factor in a broader sense as any farm characteristic that may potentially directly or indirectly (i.e., not ceteris paribus) contribute to the enhancement or deterioration of farm environmental and economic performance. Numerous factors can impact farm environmental and economic performance. Relying on the classification of potential factors of farm performance proposed by Jan et al. [31], we can distinguish between two major groups of factors: those pertaining to the general environment of the farm, and those related to the farm itself as an economic agent. 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 four sub-groups: structural factors, farm management factors, technological factors and socio-demographic factors.

Taking into account the variable availability, limited sample size and the fact that the investigated farms operated under the same regulatory environment and a—at least to a certain extent—quite similar socio-economic environment, the present work focused mostly on the factors belonging to the aforementioned second group. Given the explorative objectives of our investigation, a broad selection of factors was considered. In total, seventeen factors, which may potentially affect farm environmental and economic performance were considered. These factors are listed, defined and categorised in Table 1. Five of the investigated factors were categorical in nature, while twelve of them were numeric. An overview of descriptive statistics for the investigated factors is available in Table 2 for the categorical factors and in Table 3 for the numeric factors.

Table 1. Overview and specification of investigated factors of farm global and local environmental and economic performance.

Factor Group	Factor	Factor Type	Factor Specification	Measurement Unit
Environment	Agricultural production zone	Categorical, ordinal	The natural production conditions were represented by the ordinal variable "agricultural production zone", this variable consisting of three modalities: (1) hill zone; (2) mountain zones 1&2 and (3) mountain zones 3&4. The agricultural zone classification is based on criteria regarding (i) climatic conditions and especially vegetation period length; (ii) accessibility in terms of transport and (iii) topography [18]. Within the mountain region, the favourableness of the natural production conditions decreases from mountain zone 1 to 4.	n.a.
Structure	Farm size	Numeric, interval scaled	Farm size was measured in terms of usable agricultural area (UAA).	ha UAA
Structure and socio-economic environment	Farming type	Categorical, ordinal	Farming type encompassed two modalities: (1) part-time farming and (2) full-time farming. Full-time farms were defined as farms whose household income was made of at least 90% agricultural income. Part-time farms were farms with at least 10% of their household income originating from non-agricultural activities.	n.a.
Output composition	Share of crops in the farm digestible energy output	Numeric, ratio scaled	Share of digestible energy (DE) from crops in the total digestible energy output of the farm (both in MJ).	%
Output composition	Share of non-dairy cattle in the farm digestible energy output	Numeric, ratio scaled	Share of DE from other cattle (cattle not used for dairy production) in the total digestible energy output of the farm (both in MJ).	%
Dairy production technology	Production form	Categorical, nominal	The production form encompasses two modalities: (1) proof of ecological performance (PEP) versus (2) organic farming. The PEP requirements are equivalent to those of the former Swiss integrated production label, which was in force until 1998. Since farms have to comply with the PEP requirements to receive direct payments, conventional farming (i.e., farming without PEP) hardly exists any more [32].	n.a.
Dairy production technology	Milk utilisation and associated feeding system	Categorical, nominal	In Switzerland, farms producing milk used to make raw-milk cheese are not allowed to feed silage to their cows. For this reason, we differentiate between the following two dairy production systems: (1) dairy production with silage, called here "silage milk" (the milk is used to produce dairy products other than raw-milk cheese and silage is fed to the cows) versus (2) dairy production without silage, referred to here as "silage-free milk" (the milk is used for raw-milk cheese production and no silage is fed to the cows).	n.a.
Milk production, grassland management and fertilisation intensity	Milk production intensity	Numeric, interval scaled	Milk production intensity was defined as the farm annual milk production output (in kg) per unit (ha) forage area.	kg milk/ha forage area
Milk production, grassland management and fertilisation intensity	Stocking rate	Numeric, interval scaled	Defined as the total number of livestock units (LUs) present on the farm per unit farm UAA.	LU/ha UAA
Milk production, grassland management and fertilisation intensity	Grassland share	Numeric, ratio scaled	Share of grassland area in the total farm UAA.	%

Table 1. *Cont.*

Factor Group	Factor	Factor Type	Factor Specification	Measurement Unit
Milk production, grassland management and fertilisation intensity	Grassland yield	Numeric, interval scaled	Farm grassland yield (in dT dry matter) divided by the farm UAA (in ha).	deciton dry matter /ha UAA
Milk production, grassland management and fertilisation intensity	N-fertiliser applied	Numeric, interval scaled	Total quantity of nitrogen (N) fertiliser applied on the farm in a year per unit farm UAA. It encompassed the nitrogen from manure, other organic fertiliser and mineral fertiliser.	kg N/ha UAA
Milk production, grassland management and fertilisation intensity	P-fertiliser applied	Numeric, interval scaled	Total quantity of phosphorus (P) fertiliser applied on the farm in a year per unit farm UAA. It encompassed the phosphorus from manure, other organic fertiliser and mineral fertiliser.	kg P/ha UAA
Herd management	Milk yield per cow	Numeric, interval scaled	Expressed as the farm yearly milk production in kg per dairy cow and year.	kg milk/cow/year
Herd management	Concentrates use intensity	Numeric, ratio scaled	Concentrates use intensity was defined as the share of concentrates in the total cattle feed, this share being estimated on a dry matter basis.	%
Socio-demographic characteristics of farm manager	Age	Numeric, interval scaled	Expressed as the age of farm manager in years.	years
Socio-demographic characteristics of farm manager	Agricultural education level	Categorical, ordinal	The agricultural education level of the farm manager comprises of two categories: (1) completed apprenticeship or lower agricultural education level, (2) agricultural education level higher than a completed apprenticeship (e.g., master craftsman diploma or university degree).	n.a.

Table 2. Descriptive statistics of the investigated categorical factors of farm global environmental, local environmental and economic performance.

Categorical Factor	Percentage of Farms in the Sample (%)
Agricultural production zone	
Hill zones	37.5
Mountain zones 1 and 2	30.4
Mountain zones 3 and 4	32.1
Farming type	
Full-time farming	41.1
Part-time farming	58.9
Production form	
Organic farming	23.2
Proof of ecological performance	76.8
Milk utilisation and associated feeding system	
Silage-free milk	33.9
Silage milk	66.1
Agricultural education level of the farm manager	
Higher than an apprenticeship	37.5
Completed apprenticeship or lower agricultural education level	62.5

Source: Own calculations based on the sample of specialised hill and mountain dairy farms from the LCA-FADN project [20].

Table 3. Descriptive statistics of the investigated numeric factors of farm global environmental, local environmental and economic performance (DE = digestible energy).

Factor [Unit in Square Brackets]	Minimum	Maximum	Mean	Std. Deviation	Coefficient of Variation (%)
Farm size [ha]	7.98	40.60	22.49	9.06	40.28
DE share crops [in %]	0.00	58.20	8.18	13.96	170.66
DE share other cattle [in %]	0.08	65.80	8.49	12.21	143.82
Milk production intensity [in kg milk per ha forage area]	1943.09	14,661.59	5382.88	2568.69	47.72
Stocking rate [in Livestock Units per ha]	0.45	2.00	1.18	0.34	28.81
Grassland share [%]	54.55	100.00	91.22	11.92	13.07
Grassland yield [dT/ha]	35.30	113.48	65.08	15.45	23.74
N-fertiliser applied [kg N/ha]	11.02	208.02	100.38	41.99	41.83
P-fertiliser applied [kg P/ha]	2.17	25.02	9.13	4.03	44.14
Milk yield per cow [in kg per cow and year]	2858	12,167	6027	1524	25
Share of concentrates [%]	0.75	17.28	8.12	4.32	53.20
Age of the farm manager [years]	24	65	44.38	9.76	21.99

Source: Own calculations based on the sample of specialised hill and mountain dairy farms from the LCA-FADN project [20].

2.6. Analysis of the Factors Affecting Global Environmental, Local Environmental and Economic Performance

Taking into account the limited sample size as well as the number of independent variables analysed and considering the requirements in terms of number of observations for performing a multiple linear regression analysis (Harrell [33] stated, as a rule of thumb, that at least 10 to 20 observations should be available per factor to obtain a reliable fitted-regression model. Applied to the present investigation, this rule would imply that at least 170 to 340 observations would be needed, since the model encompassed 17 factors), we had to reject this approach, which would have been best suited for the purpose of the present work. Instead, we investigated the effect of each factor on each performance indicator considered separately. Because of the limited sample size and the fact that the assumptions (inter alia, the normal distribution assumption) required for performing parametric tests were not fulfilled, this effect was investigated by means of non-parametric statistical tools. If the factor was interval-scaled, we used the non-parametric Spearman's rank correlation to assess the relationship between this factor and the performance indicator considered. In the case of a categorical factor, its effect on the performance indicator was analysed with the Mann-Whitney U test if the factor in question had two categories, or the Kruskal-Wallis test if the factor considered had more than two categories.

3. Results

The results of the Spearman's rank correlation analysis between the numeric factors and each performance indicator investigated are presented in Table 4. Table 5 provides the results of the non-parametric tests (Kruskal-Wallis test/Mann-Whitney U test) investigating the relationship between the categorical factors and each performance indicator investigated. The median and average values of each performance indicator for each factor category/group are available in Appendix A.

Based on the results of the analysis conducted, we can classify the investigated factors into two different groups/types depending on their relationship with farm global environmental, local environmental and economic performance.

3.1. Factors Influencing the Three Performance Dimensions in the Same Direction

Organic farming, higher agricultural education level, silage-free milk production, farm size, concentrates use intensity and part-time farming belong to the first group of factors defined as those that simultaneously influenced all three performance dimensions in the same direction.

Depending on the direction (positive versus negative) of the effect, we can distinguish two subgroups within this first group.

Organic farming, higher agricultural education level and silage-free milk synergistically positively influenced farm global and local environmental as well as economic performance. They had a clear positive correlation with many global environmental performance indicators, some local environmental performance indicators and all economic performance indicators investigated (see Table 5). Farm size also belongs to this subgroup of factors that synergistically positively influenced farm global and local environmental as well as economic performance (Table 4). However, the positive effect of larger farm size on global environmental performance was quite weak and only concerned few indicators, i.e., environmental impact categories.

Conversely, as can be seen in Table 4, the share of concentrates in the cattle feed was negatively correlated with several global and local environmental performance indicators and with one economic performance indicator, revealing the existence of a negative synergetic effect of this factor on global and local environmental performance and also, but to a lesser extent, on economic performance. Part-time farming also belongs to the factors that synergistically negatively influenced farm global and local environmental as well as economic performance. As can be seen in Table 5, however, its negative effect on farm environmental performance is limited to a very few global and local environmental performance indicators.

3.2. Factors Influencing the Two Environmental Performance Dimensions in Different Directions

Eleven further factors affected the two environmental performance dimensions considered in different directions. The first subgroup that can be distinguished within this group consists of the factors that prevailingly positively influenced farm global environmental performance and negatively affected farm local environmental performance. This first subgroup encompasses the following eight factors: crop share in the farm digestible energy output, milk production intensity, stocking rate, grassland yield, N-fertiliser applied per ha, P-fertiliser applied per ha, milk yield per cow and year, and age of the farm manager (Table 4). Most of the factors in this first subgroup did not show any significant relationship with farm economic performance, with the exception of milk production intensity and milk yield per cow, both of which positively correlated with two farm economic performance indicators (work-income per family work unit and output/input ratio) (see Table 4). The second subgroup consists of the factors that correlated prevailingly negatively with farm global environmental performance and positively with farm local environmental performance. This second subgroup consists of three factors, namely unfavourable natural production conditions, non-dairy cattle share in the farm digestible energy output, and grassland share. As can be seen in Tables 4 and 5, each of these three factors correlated negatively with at least one economic performance indicator.

Table 4. Spearman's rank correlation analysis between the numeric factors and the performance indicators.

	Farm Global Environmental Performance: Eco-Efficiency (MJ Digestible Energy (DE) for Humans/On- and Off-Farm Environmental Impact)															Farm Local Environmental Performance (ha Farm Usable Agricultural Area/On-Farm Environmental Impact)								Farm Economic Performance		
Numeric factor	**Demand For non- Renewable Energy**	**Ozone Depletion**	**P-resources Demand**	**K-resources Demand**	**Deforestation**	**Global Warming Potential**	**Land Competition**	**Human Toxicity**	**Aquatic Ecotoxicity**	**Terrestrial Ecotoxicity**	**Ozone Formation**	**Acidification**	**Terrestrial Eutrophication**	**Aquatic N-Eutrophication**	**Aquatic P-Eutrophication**	**Human Toxicity**	**Aquatic Ecotoxicity**	**Terrestrial Ecotoxicity**	**Ozone Formation**	**Acidification**	**Terrestrial Eutrophication**	**Aquatic N-Eutrophication**	**Aquatic P-Eutrophication**	**Work Income Per Family Work Unit**	**Return on Equity**	**Output/Input Ratio**
Farm size	+0.23 *	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	+0.25 *	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	+0.30 *	n.s.	n.s.	+0.38 **	+0.37 **	+0.36 **	n.s.	n.s.	n.s.	+0.30 *	+0.33 *
Share of crops in the farm DE output	+0.51 ***	+0.44 ***	+0.24 *	n.s.	n.s.	+0.51 ***	+0.49 ***	+0.42 **	n.s.	n.s.	+0.48 ***	+0.52 ***	+0.50 ***	n.s.	+0.38 **	n.s.	−0.47 ***	−0.45 ***	n.s.	n.s.	n.s.	−0.54 ***	n.s.	n.s.	n.s.	n.s.
Share of non-dairy cattle in the farm DE output	−0.53 ***	−0.54 ***	−0.44 ***	−0.33 *	−0.52 ***	−0.59 ***	−0.60 ***	−0.51 ***	−0.31 *	n.s.	−0.59 ***	−0.57 ***	−0.56 ***	−0.53 ***	−0.52 ***	n.s.	+0.25 *	+0.28 *	+0.23 *	n.s.	n.s.	n.s.	n.s.	n.s.	−0.24 *	n.s.
Milk production intensity	+0.52 ***	+0.52 ***	+0.30 *	n.s.	+0.24 *	+0.62 ***	+0.80 ***	+0.60 ***	n.s.	n.s.	+0.65 ***	+0.55 ***	+0.55 ***	+0.44 ***	+0.69 ***	n.s.	−0.34 **	−0.49 ***	−0.50 ***	−0.38 **	−0.38 **	−0.31 *	+0.27 *	+0.33 *	n.s.	+0.33 *
Stocking rate	n.s.	+0.24 *	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	−0.32 *	n.s.	n.s.	−0.69 ***	−0.62 ***	−0.61 ***	−0.23 *	−0.25 *	n.s.	n.s.	n.s.
Grassland share	−0.70 ***	−0.63 ***	−0.37 **	n.s.	−0.32 *	−0.71 ***	−0.72 ***	−0.61 ***	n.s.	n.s.	−0.68 ***	−0.72 ***	−0.71 ***	−0.33 *	−0.66 ***	n.s.	+0.53 ***	+0.58 ***	+0.26 *	n.s.	n.s.	+0.54 ***	−0.31 *	n.s.	n.s.	−0.25 *
Grassland yield	+0.24 *	+0.28 *	+0.32 *	+0.30 *	+0.39 **	n.s.	+0.38 **	+0.36 **	+0.37 **	+0.25 *	n.s.	n.s.	n.s.	+0.52 ***	+0.43 **	n.s.	n.s.	n.s.	−0.61 ***	−0.56 ***	−0.56 ***	n.s.	n.s.	n.s.	n.s.	n.s.
N-fertiliser applied	+0.41 **	+0.43 ***	n.s.	n.s.	n.s.	+0.51 ***	+0.57 ***	+0.27 *	n.s.	n.s.	+0.51 ***	+0.44 ***	+0.43 ***	+0.25 *	+0.46 ***	−0.30 *	−0.42 **	−0.62 ***	−0.74 ***	−0.59 ***	−0.58 ***	−0.53 ***	n.s.	n.s.	n.s.	n.s.
P-fertiliser applied	+0.32 *	+0.37 **	n.s.	n.s.	n.s.	+0.37 **	+0.43 **	n.s.	n.s.	n.s.	+0.39 **	+0.28 *	+0.28 *	+0.30 *	+0.29 *	−0.29 *	−0.24 *	−0.42 **	−0.74 ***	−0.68 ***	−0.68 ***	−0.35 **	n.s.	n.s.	n.s.	n.s.
Milk yield per cow	+0.27 *	n.s.	n.s.	n.s.	n.s.	+0.43 **	+0.47 ***	+0.38 **	n.s.	−0.23 *	+0.46 ***	+0.50 ***	+0.51 ***	n.s.	+0.47 ***	n.s.	−0.33 *	−0.47 ***	n.s.	n.s.	n.s.	n.s.	+0.42 **	+0.29 *	n.s.	+0.32 *
Concentrates use intensity	n.s.	n.s.	−0.42 **	−0.48 ***	−0.50 ***	n.s.	n.s.	n.s.	−0.51 ***	−0.54 ***	n.s.	n.s.	n.s.	−0.33 *	n.s.	n.s.	−0.58 ***	−0.63 ***	n.s.	n.s.	n.s.	−0.46 ***	n.s.	n.s.	−0.27 *	n.s.
Age	n.s.	n.s.	n.s.	+0.27 *	n.s.	n.s.	n.s.	+0.24 *	n.s.	+0.24 *	n.s.	n.s.	n.s.	+0.23 *	n.s.	+0.35 **	n.s.	n.s.	n.s.	−0.23 *	−0.23 *	n.s.	−0.30 *	n.s.	n.s.	n.s.

Notes: Significant Spearman's rhos are given in the table; statistical significance level: * $p < 0.1$; ** $p < 0.01$; *** $p < 0.001$; n.s. = not significant; Shading in red indicates significant negative correlation; Shading in green indicates significant positive correlation. Shading intensity reflects the strength of the correlation. Source: Own calculations based on the sample of specialised hill and mountain dairy farms from the LCA-FADN project [20].

Table 5. Results of the non-parametric tests (Kruskal-Wallis test and Mann-Whitney U test) investigating the relationship between the categorical factors and performance indicators.

Categorical factor	Farm Global Environmental Performance: Eco-Efficiency (MJ Digestible Energy for Humans/On- and Off-Farm Environmental Impact)																Farm Local Environmental Performance (ha Farm Usable Agricultural Area/On-Farm Environmental Impact)							Farm Economic Performance		
	Demand For non- Renewable Energy	Ozone Depletion	P-Resources Demand	K-Resources Demand	Deforestation	Global Warming Potential	Land Competition	Human Toxicity	Aquatic Ecotoxicity	Terrestrial Ecotoxicity	Ozone Formation	Acidification	Terrestrial Eutrophication	Aquatic N-Eutrophication	Aquatic P-Eutrophication	Human Toxicity	Aquatic Ecotoxicity	Terrestrial Ecotoxicity	Ozone Formation	Acidification	Terrestrial Eutrophication	Aquatic N-Eutrophication	Aquatic P-Eutrophication	Work Income per Family Work Unit	Return on Equity	Output/Input Ratio
Unfavoura-ble natural production conditions	− ***	− ***	− **	− *	− **	− ***	− ***	− ***	− *	n.s.	− ***	− ***	− ***	− ***	− ***	− **	+ **	+ **	+ ***	+ *	+ *	+ ***	n.s.	− *	n.s.	− *
Part-time farming	− *	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	− **	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	− **	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	− ***	− ***	− ***
Higher agricultural education level of farm manager	+ **	+ **	n.s.	+ **	+ ***	+ **	+ *	+ ***	+ *	n.s.	+ **	+ ***	+ ***	+ *	+ *	+ *	n.s.	n.s.	n.s.	+ *	+ *	n.s.	n.s.	+ *	+ **	+ *
Organic farming	+ *	+ *	+ ***	+ ***	+ ***	+ *	n.s.	+ ***	+ ***	+ ***	n.s.	+ *	+ *	+ **	+ *	+ **	+ *	+ **	n.s.	n.s.	n.s.	+ *	n.s.	+ *	+ **	+ **
Silage-free milk	n.s.	n.s.	+ **	+ **	+ **	n.s.	n.s.	+ **	+ *	n.s.	n.s.	n.s.	n.s.	+ *	+ *	+ **	n.s.	n.s.	n.s.	n.s.	n.s.	+ *	n.s.	+ ***	+ **	+ ***

Notes: Results of non-parametric tests are given in the table; statistical significance level: * $p < 0.1$; ** $p < 0.01$; *** $p < 0.001$; n.s. = not significant; Shading in red indicates significant negative correlation; Shading in green indicates significant positive correlation. Source: Own calculations based on the sample of specialised hill and mountain dairy farms from the LCA-FADN project [20].

4. Discussion

4.1. Main Findings

Our findings revealed that six of the investigated factors (organic farming, higher agricultural education level, silage-free milk, farm size, share of concentrates in the cattle feed and part-time farming) were synergetic in their effect on global and local environmental and economic performance, as they influenced all three performance dimensions in the same direction. For four of these factors (organic farming, higher agricultural education, silage-free milk and farm size), the synergy was positive. In contrast, the two other factors (share of concentrates in the cattle feed and part-time farming) showed a negative synergy. The remaining eleven factors did not show this synergetic effect but rather presented trade-offs in their effects on different performance dimensions and, more particularly, on farm local and global environmental performance.

We also observed that most factors analysed influenced global environmental performance and economic performance in the same direction, which highlights the synergies that exist in the promotion of these two dimensions of the sustainability performance of a farm. Contrariwise, for the majority of factors, the enhancement of local environmental performance frequently presented trade-offs with the improvement in global environmental performance.

4.2. Discussion of the Main Findings

The following subsection discusses two out of six factors that synergistically influenced all performance dimensions investigated, namely organic farming and concentrates use intensity, by comparing our results with those of similar studies found in the literature. For the other four factors (farm manager's agricultural education, silage-free milk, farm size and part-time farming), no similar LCA-based studies could be found in the literature.

Regarding dairy production technology, organic farming was shown in a review conducted by Tuomisto et al. [34] to be associated with—compared to conventional farming—higher eco-efficiencies (i.e., global environmental performance) for one impact category (energy use) and lower ones for a couple of others (land use, eutrophication potential and acidification potential). In terms of local environmental performance, Thomassen et al. [13] found, for Dutch dairy farms, a lower N and P_2O_5 surplus per ha for organic farming. Jan et al. [35] also reported, for Swiss farms, a lower nitrogen surplus per ha for organic farming. Regarding farm economic performance, organic farming was shown to have a positive effect on work income per family work unit of the Swiss mountain farms [31]. In the present work, organic farming was associated not only with higher local environmental performance regarding most of the impact categories considered, but also with higher global environmental performance for most impact categories, and higher economic performance regardless of the chosen profitability indicator. 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 is likely to be, in terms of local and global environmental performance, as well as economic performance, a more appropriate technology than conventional farming for dairy activity. Thus, a process of conversion from conventional to organic farming is likely to lead to overall environmental and economic benefits and consequentially to a substantial improvement in the sustainability of the dairy food chain in this region. This probably explains why the share of organic farms in Switzerland increases with the unfavourableness of the natural production conditions (e.g., in 2012, according to Bio Suisse [36], the proportion of the usable agricultural area cultivated under organic farming in the mountain and in the plain region was 19.6% and 6.5% respectively).

Concerning the effect of concentrates use intensity on the environmental performance of dairying, LCA-based studies have shown that decreasing the use of concentrates in the feed may lead to improvement in farm global and local environmental performance. Thomassen et al. [13] showed, for Dutch dairy farms, that decreasing the use of concentrates per kg of milk has the potential to improve farm global environmental performance, for both organic and conventional dairy farming.

They furthermore showed that the N and P_2O_5 surplus per ha was higher for conventional than for organic farms. This finding had to do with higher concentrate input on conventional farms, showing the negative effect of concentrates use intensity on local environmental performance [13]. The results found by Arsenault at al. [37] for Canadian dairy farms in Nova Scotia province also suggested that a decrease in the use of concentrates had the potential to improve the global environmental performance of dairy farming. The present study confirmed these findings in the context of Swiss mountain dairy farming as it showed that a lower share of concentrates in cattle feed has the potential to produce positive effects on both global and local environmental performance. Furthermore, it also revealed the existence of positive effects of lower concentrates use intensity on farm economic performance. Similar findings regarding the positive influence of decreased concentrates use intensity on farm profitability (measured as work income per family work unit) have already been revealed for the Swiss alpine dairy farms in the study by Jan et al. [31].

Using the same dataset as in the present work and based on a correlation analysis, Repar et al. [8] found that farm global environmental performance goes hand in hand with farm economic performance, while it is often negatively correlated with farm local environmental performance. The present analysis of the factors affecting farm global and local environmental performance came to a similar finding. Specifically, it showed that several factors affect farm global environmental and farm economic performance in the same direction and several other factors influence farm global and local environmental performance in the opposite direction. In that sense, our work highlights (i) the synergies that exist in the promotion of farm global environmental and economic performance and (ii) the trade-offs that are present in the enhancement of farm global and local environmental performance. Our findings regarding the trade-offs between local and global environmental performance are in line with those of Guerci et al. [38] and Battini et al. [16], who stressed for Italian dairy farms the potential trade-offs that may exist between global and local environmental impacts.

As identified in the present work, six factors have a synergetic effect on all three performance dimensions investigated, and can therefore be used as a lever for the simultaneous improvement of the environmental and economic sustainability of dairy farming in the alpine region. Nevertheless, for most of the factors investigated in this work, the direction of their effect on the three investigated performance dimensions diverged, which highlights the high complexity of the farm sustainable performance maximisation.

4.3. Limits of the Study and Future Research Needs

For an interpretation and discussion of the results of the present investigation, as well as their implications, attention should be paid to the following issues.

Firstly, 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.

Secondly, as already discussed by Repar et al. [7] and Repar et al. [8], the indicators implemented in this work for the measurement of farm environmental performance present through their definition a major limitation, namely that they assess relative rather than absolute environmental sustainability [39]. This implies that there is no guarantee of achieving an absolute sustainable state at global and local ecosystem level [7]. Implementing the absolute environmental sustainability concept in the farm environmental performance indicators would imply the highly challenging introduction of the ecosystem carrying capacity constraint into each environmental performance indicator as conceptually exposed in the discussion by Repar et al. [7].

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. Since we had a limited sample size at our disposal, we had to refrain from applying multiple linear regression analysis. Consequently, the measured relationship between one factor and one performance indicator is not a ceteris paribus effect and may capture the effects of other factors correlated with the one investigated.

To the best of our knowledge, the small sample size problem and its related limitations in terms of statistical approach occur in all existing similar LCA-based investigations, most of which rely on fewer than 30 (and even quite often fewer than 10) observations (see for instance Cedeberg et al. [10], Haas et al. [11], Thomassen et al. [13], Bava et al. [15], Battini et al. [16]). We are fully aware that such sample sizes are suboptimal from a statistical point of view. However, due to the complexity and high costliness of performing detailed and comprehensive Life Cycle Assessments at farm level, it has, up until now, not been feasible to collect LCA-data for a substantially higher number of farms. Current developments in the information and communication technology field, especially those related to big data processing and smart farming, should, however, make it possible in the future to substantially increase the sample size of farm-level LCA-based investigations. Indeed, they should make it possible (i) to substantially improve the efficiency and quality of LCA data collection, and (ii) to reduce the 'data collection burden' for farmers and LCA practitioners, which is a prerequisite for a broad implementation of the LCA-technique and the local–global farm environmental performance indicators framework proposed by Repar et al. [7].

Another limitation is that our results should not be generalized to a broader context. We can only generalize the findings to mountain dairy farms from the European Alpine region showing similar dairy production systems and production intensity ranges, and operating under similar natural production conditions and agri-environmental regulations. Other production systems, farm types (for example arable cropping) or regions (for example lowlands) could yield very different results in terms of factors affecting farm environmental and economic performance.

An additional limitation of our investigation was that it did not cover the social dimension of sustainability. Further investigations on the effect of different factors on the social sustainability performance of alpine dairy farms are required, especially when considering the important socio-economic relevance of dairy farming for the local economies of the mountainous regions, which are less populated and not easily accessible [40].

Finally, the complexity of the relationships found between the factors and performance indicators investigated and especially the numerous trade-offs observed in this study reveal that a synergistic improvement in the global and local environmental performance of dairy farming is highly challenging.

In that sense, our work indirectly suggests that improving the environmental sustainability of food chains may require more than an environmental performance improvement in the cradle-to-farm gate link of the food chain. Without questioning and changing consumption patterns towards goods and services with a much lower environmental impact, the challenge of reducing the ecological footprints of humanity within the planet's boundaries will very likely be difficult to meet. This was also argued by Godfray and Garnett [41], who called for action throughout the food system on multiple fronts and especially for a moderation of demand, a reduction in waste, an improvement in governance and the production of more food with less environmental impacts.

4.4. General Implications and Related Recommendations for Stakeholders

The environmental sustainability challenges faced by agriculture are so extensive that they urgently require action at farm level. Action can only be effective in reaching sustainability goals if it relies on theoretically founded indicators and on facts, i.e., on accurate data from a representative sample of farms. Assessing farm local and global environmental performance according to the framework developed by Repar et al. [8] and implemented in the present empirical application is a prerequisite for a theoretically founded and fact-based improvement in the environmental sustainability of the agricultural sector. The implementation of this framework requires conducting cradle-to-farm gate LCAs. These are—due to their very expansive and detailed data requirements—very time consuming, which impedes the broad implementation of the local–global environmental performance assessment framework. As explained in Section 4.3, current developments in the information and communication technology field should strongly facilitate the diffusion of the LCA technique, which is a prerequisite for a broad implementation of the local–global farm environmental performance indicators proposed by Repar et al. [8]. Based on these considerations, we call for a coordinated action plan at national level, aiming to provide the legal, technical, organisational and financial conditions (i) to promote the dissemination and use of the LCA technique in the agricultural sector (including the education), and (ii) to enable a LCA-based agri-environmental monitoring providing accurate estimates of the local and global environmental performance of a sizeable sample of representative farms. Policy-makers should consider this as a priority in their political agenda and especially in future agricultural policy reforms.

Our findings on the existence of trade-offs between local and global environmental performance represents a serious challenge not only for the improvement of environmental sustainability in agriculture in itself, but also in terms of transfer of this knowledge to stakeholders and especially consumers, who might feel overwhelmed by the complexity of the local/global environmental performance concept. It is, therefore, important to put substantial efforts on the translation of this concept into practice. Consumers are, to some extent, aware of possible trade-offs between the environmental and economic sustainability of farming. They should also be informed (i) that environmental performance is made of two dimensions, the local and the global one; and (ii) that the factors promoting global environmental performance do not necessarily enhance local environmental performance. This additional trade-off, which occurs within the environmental dimension of sustainability, could make the consumers' decision-making process while purchasing food even more complex.

5. Conclusions

Our work provides initial evidence that the promotion of an economically viable alpine dairy farming sector, as well as the enhancement of one with a high global environmental performance, are not antinomic but synergetic. Contrariwise, the enhancement of farm local and global environmental performance turns out to be in many cases antinomic. Policy-makers should be aware of the trade-offs that exist in the enhancement of farm sustainable performance and stimulate only those factors that are capable of synergistically enhancing the global environmental, local environmental and economic performance of farming. Last but not least, our work demonstrates the value of combined micro-level economic and environmental data. Such data enable us to gain a better insight into the relationship between different dimensions of sustainability, which is a pre-requisite if we wish to improve sustainability.

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Appendix A.

Table A1. Median and average values of farm global environmental performance indicators for the investigated categorical factors: Part 1.

		Farm Global Environmental Performance: Eco-Efficiency (MJ Digestible Energy for Humans/On- and Off-Farm Environmental Impact)													
		Demand for Non-Renewable Energy [1]		Ozone Depletion [2]		P-Resources Demand [3]		K-Resources Demand [4]		Deforestation [5]		Global Warming Potential [6]		Land Competition [7]	
		Median	Average	Median	Average	Median	Average	Median	Average	Median	Average	Median	Average	Median	Average
Natural production conditions	Hill	0.51	0.53	8.43×10^7	8.69×10^7	4825	17,102	3400	9083	2054	17,608	1.80	1.82	1.44	1.41
	Mountain 1&2	0.38	0.37	5.95×10^7	6.06×10^7	2837	10,547	1777	7013	1767	15,928	1.55	1.51	1.09	1.08
	Mountain 3&4	0.24	0.23	3.37×10^7	3.65×10^7	2073	2704	1707	2344	574	978	0.76	0.82	0.49	0.45
Farm type	Part-time	0.34	0.35	5.57×10^7	5.58×10^7	3022	7407	1798	5283	956	8857	1.33	1.34	0.92	0.93
	Full-time	0.48	0.44	7.30×10^7	7.27×10^7	3800	14,899	2951	7730	2054	15,908	1.58	1.50	1.34	1.10
Agricultural education level	Lower	0.34	0.32	5.21×10^7	5.24×10^7	2645	5039	1692	4151	846	5658	1.23	1.21	0.87	0.87
	Higher	0.48	0.48	7.56×10^7	7.99×10^7	6483	19,559	5391	9850	2189	21,911	1.77	1.72	1.33	1.22
Production form	PEP	0.36	0.35	5.57×10^7	5.57×10^7	2668	3502	1657	2372	890	3138	1.37	1.33	1.02	0.95
	Organic	0.44	0.49	7.91×10^7	8.61×10^7	24,618	33,578	18,773	19,242	13,697	40,249	1.73	1.66	1.34	1.16
Feeding system	Silage	0.39	0.37	5.89×10^7	5.82×10^7	2800	7721	1777	4311	890	9339	1.31	1.32	0.92	0.92
	Silage-free	0.35	0.42	5.50×10^7	7.15×10^7	5405	15,865	4023	10,138	2158	16,453	1.52	1.57	1.31	1.15

Source. Own calculations based on the sample of specialised hill and mountain dairy farms from the LCA-FADN project [20]. [1] in MJ DE per MJ eq.; [2] in MJ DE per kg CFC11 eq.; [3] in MJ DE per kg P; [4] in MJ DE per kg K; [5] in MJ DE per m^2; [6] in MJ DE per kg CO_2 eq.; [7] in MJ DE per m^2a.

Table A2. Median and average values of farm global environmental performance indicators for the investigated categorical factors: Part 2.

		Farm Global Environmental Performance: Eco-Efficiency (MJ Digestible Energy for Humans/On- and Off-Farm Environmental Impact)															
		Human Toxicity [8]		Aquatic Ecotoxicity [9]		Terrestrial Ecotoxicity [10]		Ozone Formation [11]		Acidification [12]		Terrestrial Eutrophication [13]		Aquatic N-Eutrophication [14]		Aquatic P-Eutrophication [15]	
		Median	Average	Median	Average	Median	Average	Median	Average	Median	Average	Median	Average	Median	Average	Median	Average.
Natural production conditions	Hill	10.79	10.91	94	233	2598	4768	0.21	0.21	7.95	8.54	0.87	0.94	567	662	18,772	18,567
	Mountain 1&2	6.14	6.46	118	221	3375	4557	0.18	0.18	6.93	6.71	0.77	0.74	654	852	13,322	13,762
	Mountain 3&4	4.17	4.20	78	84	2479	2453	0.09	0.10	3.44	3.58	0.37	0.39	344	329	3961	5919
Farm type	Part-time	5.84	6.17	99	160	2598	3483	0.15	0.15	5.83	5.97	0.63	0.66	496	622	12,478	11,859
	Full-time	8.33	9.17	108	213	3117	4644	0.19	0.17	7.46	7.00	0.81	0.77	567	599	13,502	14,741
Agricultural education level	Lower	5.15	5.85	94	135	2372	2954	0.14	0.14	5.16	5.33	0.57	0.59	484	537	11,689	11,233
	Higher	8.33	9.99	135	259	3355	5637	0.19	0.19	7.95	8.16	0.86	0.90	627	738	14,573	16,059
Production form	PEP	6.08	6.28	85	102	2145	2422	0.16	0.15	5.83	6.06	0.64	0.67	496	510	12,784	11,979
	Organic	10.95	11.10	435	445	9622	9046	0.19	0.19	6.31	7.48	0.69	0.82	828	952	17,211	16,561
Feeding system	Silage	5.84	6.54	94	144	2592	3348	0.14	0.15	5.83	5.90	0.63	0.65	496	545	12,322	11,486
	Silage-free	8.11	9.07	167	254	3355	5152	0.18	0.18	6.93	7.35	0.76	0.81	595	746	16,941	16,075

Source: Own calculations based on the sample of specialised hill and mountain dairy farms from the LCA-FADN project [20]. [8] in MJ DE per kg 1,4-DB eq.; [9] in MJ DE per kg 1,4-DB eq.; [10] in MJ DE per kg 1,4-DB eq.; [11] in MJ DE per m^2.ppm.h; [12] in MJ DE per m^2; [13] in MJ DE per m^2; [14] in MJ DE per kg N; [15] in MJ DE per kg P.

Table A3. Median and average values of farm local environmental performance indicators for the investigated categorical factors.

		Farm Local Environmental Performance (ha Farm Usable Agricultural Area/On-Farm Environmental Impact)															
		Human Toxicity [1]		**Aquatic Ecotoxicity** [2]		**Terrestrial Ecotoxicity** [3]		**Ozone Formation** [4]		**Acidification** [5]		**Terrestrial Eutrophication** [6]		**Aquatic N-Eutrophication** [7]		**Aquatic P-Eutrophication** [8]	
		Median	**Average**	**Median**	**Average**	**Median**	**Average**	**Median**	**Average**	**Median**	**Average**	**Median**	**Average**	**Median**	**Average**	**Median**	**Average**
Natural production conditions	Hill	7.63×10^3	8.77×10^3	0.03	0.05	0.28	8.82	1.38×10^5	1.37×10^5	5.55×10^4	5.36×10^4	5.90×10^5	5.68×10^5	0.06	0.05	1.96	1.84
	Mountain 1&2	1.18×10^3	2.16×10^3	0.08	0.12	2.02	4.67	1.42×10^5	1.45×10^5	4.43×10^4	5.38×10^4	4.67×10^5	5.69×10^5	0.11	0.11	1.38	1.54
	Mountain 3&4	2.76×10^3	7.24×10^3	0.09	0.10	4.78	23.89	1.87×10^5	1.91×10^5	6.83×10^4	6.85×10^4	7.22×10^5	7.23×10^5	0.13	0.12	1.42	1.56
Farm type	Part-time	1.49×10^3	5.61×10^3	0.08	0.09	2.29	13.94	1.43×10^5	1.54×10^5	5.29×10^4	5.72×10^4	5.61×10^5	6.05×10^5	0.10	0.10	1.39	1.60
	Full-time	5.43×10^3	7.21×10^3	0.06	0.08	2.08	10.20	1.49×10^5	1.60×10^5	6.07×10^4	6.02×10^4	6.38×10^5	6.37 × 105	0.07	0.08	1.62	1.74
Agricultural education level	Lower	1.90×10^3	5.55×10^3	0.08	0.09	2.29	13.38	1.42×10^5	1.52×10^5	5.35×10^4	5.35×10^4	5.61×10^5	5.65×10^5	0.08	0.10	1.39	1.66
	Higher	6.22×10^3	7.43×10^3	0.04	0.09	2.08	10.78	1.49×10^5	1.64×10^5	6.29×10^4	6.66×10^4	6.65×10^5	7.06×10^5	0.07	0.09	1.52	1.66
Production form	PEP	1.79×10^3	5.64×10^3	0.06	0.07	1.64	10.75	1.43×10^5	1.52×10^5	5.35×10^4	5.55×10^4	5.61×10^5	5.88×10^5	0.08	0.09	1.49	1.69
	Organic	6.30×10^3	8.35×10^3	0.15	0.15	4.95	17.88	1.49×10^5	1.73×10^5	6.29×10^4	6.79×10^4	6.65×10^5	7.19×10^5	0.13	0.12	1.48	1.56
Feeding system	Silage	1.79×10^3	6.45×10^3	0.06	0.08	2.02	15.96	1.43×10^5	1.55×10^5	5.29×10^4	5.66×10^4	5.61×10^5	5.99×10^5	0.07	0.09	1.49	1.67
	Silage-free	6.09×10^3	5.91×10^3	0.07	0.10	2.40	5.47	1.49×10^5	1.61×10^5	6.07×10^4	6.19×10^4	6.38×10^5	6.55×10^5	0.08	0.10	1.48	1.65

Source: Own calculations based on the sample of specialised hill and mountain dairy farms from the LCA-FADN project [20]. [1] in ha per kg 1,4-DB eq.; [2] in ha per kg 1,4-DB eq.; [3] in ha per kg 1,4-DB eq.; [4] in ha per m^2.ppm.h; [5] in ha per m^2; [6] in ha per m^2; [7] in ha per kg N; [8] in ha per kg P.

Table A4. Median and average values of farm economic performance indicators for the investigated categorical factors.

		Farm Economic Performance					
		Work Income per Family Work Unit (in Swiss Francs)		Return on Equity (in %)		Output/Input Ratio	
		Median	Average	Median	Average	Median	Average
Natural production conditions	Hill	50,272	46,315	−4.54	−14.14	0.93	0.92
	Mountain 1&2	28,872	29,930	−6.56	−6.66	0.84	0.83
	Mountain 3&4	30,309	34,549	−8.50	−18.18	0.84	0.85
Farm type	Part-time	25,951	27,764	−11.87	−16.10	0.84	0.82
	Full-time	54,213	51,614	−0.42	−8.95	0.93	0.93
Agricultural education level	Lower	29,914	33,432	−11.87	−19.07	0.84	0.84
	Higher	43,018	44,437	0.75	−3.33	0.92	0.92
Production form	PEP	28,872	32,676	−10.24	−16.93	0.84	0.85
	Organic	52,270	53,712	0.76	−0.74	0.94	0.94
Milk production	Silage	25,382	28,677	−12.29	−16.55	0.83	0.83
	Silage-free	52,270	54,855	0.75	−6.58	0.94	0.96

Source: Own calculations based on the sample of specialised hill and mountain dairy farms from the LCA-FADN project [20].

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