Effect of farming system changes on life cycle assessment indicators for dairy farms in the Italian Alps

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ABSTRACT

In some Alpine areas dairy farming is going through a process of intensification with significant changes in farming systems. The aim of this study was to investigate environmental performance of a sample of 31 dairy farms in an Alpine area of Lombardy with different levels of intensification. A cradle to farm gate life cycle assessment was performed including the following impact categories: land use, non-renewable energy use, climate change, acidification and eutrophication. From a cluster analysis it resulted that the group of farms with lowest environmental impacts were characterized by low stocking density and production intensity; farms that combined good environmental performances with medium gross margins were characterized also by high feed self-sufficiency and lowland availability. Environmental impacts of dairy farms in the mountain areas could be mitigated by the improvement of forage production and quality and by the practice of summer highland grazing, that significantly reduced eutrophication per kg of milk of the less self-sufficient farms.

Keywords: dairy farming systems, LCA, Italian Alps

1. Introduction

European agriculture in mountain areas is suffering from the increasing competitive economic pressure of plain agriculture, from the consumption of agricultural land in the valley floors caused by industrial and infrastructural uses, and from some peculiar social problems, like depopulation. During the last decades, Italian Alps were characterized by a very high rate of agricultural area abandonment, that mainly affected small farms with a maximum size of 5 ha (Streifeneder *et al.*, 2007). The remaining farms, especially in the dairy sector, showed an evolution trend towards increasing size and intensifying production, in order to increase competitiveness and sustain profitability. In the mountain areas of Lombardy annual milk yield per cow increased from 5871 kg in 2000 to 6798 kg in 2007 (AIA, 2008). This development was associated with marked changes in dairy farming systems: the switch from local to specialized dairy breeds (Holstein Friesian), the increase in purchased feeds (especially concentrates) to sustain higher milk yield, the sowing of maize for silage in substitution of permanent meadows in the valley fields, the growth of stocking density. The increasing nutrient burden resulting from the intensification process can affect the environmental sustainability of milk production in Alpine areas. Moreover farm intensification contributed to the decline of the traditional practice of summer pasturing of livestock in the highland, due to the problems of transferring large herds and to the high nutrient requirements of specialized breeds that overcome the supply from pastures.This is a further risk factor for the Alpine environment considering the central role of grazing livestock systems in preserving natural resources in mountain areas (Casasùs *et al.*, 2007).

The objective of this study was to assess the effects of farming system on the environmental impact potential of a group of dairy cattle farms located in the Italian Alps using the life cycle assessment (LCA) approach.

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2. Materials and methods

The study involved a sample of 31 dairy cattle farms situated on the floor of two Alpine valleys in the Central Italian Alps, selling their milk to a local cheese factory. All farmers were interviewed individually and part of the data came from the statistical database of agriculture in Lombardy (SIARL, 2006). A "cradle-to-farm-gate" life cycle assessment was performed for the reference year 2006. The functional unit (FU) was defined as 1 kg of fat-and-protein corrected milk (FPCM, 4.0% of fat content and 3.2% of protein content) leaving the farm gate or 1 hectare of farm valley land. The impact categories considered were: land use (m^2), non-renewable energy use (MJ), climate change (kg CO_2 eq.), acidification (kg SO_2 eq.) and eutrophication (kg NO_3 eq.). The characterisation factors for substances causing climate change, acidification and eutrophication were derived from IPCC (2007) and Guinée *et al.* (2002). We distinguished direct impacts (on-farm) that originate on the farm site from indirect impacts (off-farm) associated with the production and transport of inputs to the farm. Transports of materials and animals were included also in this study. Water use, farm buildings, machinery, seeds, medicines, mineral salts and washing detergents were not taken into account. For pesticides impacts associated with production and supply were considered only, while toxic effects associated with their use were not considered. Many farms bought heifers from Switzerland; as a consequence an LCA was performed on heifer production in Swiss farms. Allocation was based on the economic value of the products. An economic allocation was applied also for meat obtained as co-product of milk production (bull calves, old cows). The life cycle inventories (LCI) of diesel, fertilizers and pesticides production and use were derived from, respectively, Michaelis (1998), Davis and Haglund (1999) and Brand and Melman (1993). The main references used are summarized in Table 1.

Table 1: Main literature references for Life Cycle impacts

	Italy	**Switzerland**
Livestock rations	interviews	Agridea (2008)
Origin of feeds	Eurostat (2006)	Eidgenössisches Finanzdepartement EFD (2006)
Methane emissions	ERICA (Provolo, 2005) for cows and ISPRA (2008) for heifers. Estermann *et al.* (2001) during highland grazing	Switzerland GHG Inventory 1990-2005 (2007)
Nitrogen excretion	ERICA (Provolo, 2005) for cows, EMEP/EEA (2009) for heifers. Cornell-Penn-Miner (2004) during highland grazing	EMEP/EEA (2009)
Ammonia emissions	ERICA (Provolo, 2005) for cows, EMEP/EEA (2009) for heifers and during highland grazing	EMEP/EEA (2009)
Nitrous oxide emissions	ERICA (Provolo, 2005) for cows, EMEP/EEA (2009) for heifers. IPCC (2006) during highland grazing	EMEP/EEA (2009)
	On-farm	**Off-farm**
Ammonia emissions	Manure spreading: ERICA (Provolo, 2005). Artificial fertilizers: EMEP/CORINAIR (2002)	Manure spreading: Thomassen et al. (2008). Artificial fertilizers: EMEP/CORINAIR (2002)
Nitrous oxide emissions	Manure spreading: ERICA (Provolo, 2005). Artificial fertilizers: IPCC (2006)	Manure and artificial fertilizers spreading: IPCC (2006)
Leaching	Nitrates: Grignani and Zavattaro (2000) for grassland; Audsley (2000) for maize Phosphates: Nemececk and Kagi (2007)	Nitrates: IPCC (2006) or Italian literature. Phosphates: Nemececk and Kagi (2007)

A cluster analysis was performed to group the farms, based on the usual agglomerative hierarchical clustering and using centroid method (SAS, 2000).

Fixed effects were tested in a GLM analysis on dependent variables, using the model:

$Y_{ijklm} = \mu + PI_i + MP_j + HG_k + Z_l + e_{ijklm}$

Where Y_{ijklm}= dependent variables (impact categories); µ = overall mean; PI_i = effect of production intensity per ha (i=1 to 3; <8700, 8700-11500, >11500 kg FPCM/ha); MP_j = effect of milk production per cow (j=1 to 3; <4600, 4600-6200, >6200 kg of milk/cow); HG_k = effect of highland grazing of cows (k = 1 to 2; no or yes); Z_l = effect of feed self-sufficiency (l=1 to 3; <53, 53-72, >72% on DM basis) or percentage of lowland hectares used for maize silage production (l=1 to 3; 0, 0-22, >22%); e_{ijklm} = residual error.

3. Results and discussion

The main average farm characteristics are in table 2. The 13 farms that transferred their milking cows to highland during the summer produced on average 9.9 ± 2.0 kg FPCM/cow d^{-1} in the grazing period (92.1 ± 22.1 d/year), whereas in the lowland period milk yield in all farms averaged 16.5 ± 3.9 kg FPCM/cow d^{-1}.

Table 2: Main characteristics of the sample farms (n=31)

Parameter	**unit**	**mean ± SD**
Cows	n	51.9 ± 54.9
Livestock Units (LU)	n	76.0 ± 92.4
Valley land	ha	22.5 ± 24.0
Stocking density	LU/ha valley land	2.9 ± 1.4
Milk yield	kg FPCM/cow $year^{-1}$	5798 ± 1482
Milk/ha	kg FPCM/ha	13556 ± 8164

[a] FPCM = fat-and-protein corrected milk

On average, 62.9 ± 16.8% of the total dry matter (DM) of cow rations consisted of feed ingredients produced on the farm. All the concentrate feed was purchased, but also part of the forages were bought. No farms sold forages or exported manure.

The average results of the 31 sample farms for the five LCA categories per kg of FPCM were: 3.18 (± 1.87) m^2 for land use, 5.14 (± 2.02) MJ for energy use, 1.13 (± 0.27) kg CO_2-eq for climate change, 0.021 (± 0.006) kg SO_2-eq for Acidification and 0.075 (± 0.019) kg NO_3-eq for Eutrophication. The LCA categories per hectare of lowland were 326 (± 227) kg SO_2-eq and 1150 (± 894) kg NO_3-eq.

The high land use and acidification results per kg of milk were similar to the results from organic farms (Corson and van der Werf, 2008; Haas *et al.*, 2001). The high energy use per kg of milk was probably due to the marked land fragmentation in the valley floors.

The cluster analysis identified five main groups of farms (table 3) and one marginal farm not reported in the table. Characteristics of clusters 1 and 3 are: small herd size, low animal density and production intensity in the valley land, high farm pasturing rate (percentage of farms practicing summer highland grazing) and, respectively, high and low feed self-sufficiency. Farms in clusters 2 and 4 are medium sized and have medium gross margins. They differed in terms of production intensity (low and medium respectively), self-sufficiency (high and medium) and pasturing rate (medium and low). Cluster 5 collected the farms with large herd size, high milk yield per cow and production intensity, low self-sufficiency. Their average gross margin was about twice the ones of Clusters 2 and 4. Farms from Cluster 2 resulted in better environmental performances than farms from Clusters 4 and 5 for all the impact categories considered. In conclusion farms in Cluster 2 seem to show the best synthesis between environmental impact and gross margin, even if their gross margin per hectare and milk production per cow were low. In these farms the improvement of production and quality of self-produced forages, that was generally poor, can lead to better performances in terms of milk production and profitability, considering that in the Alpine environment successful forage conservation is crucial for milk production (Charmley, 2001).

Table 3. Mean values of farms from the different cluster groups (on-f= on farm, off-f= off farm)

	Cluster1	**Cluster2**	**Cluster3**	**Cluster4**	**Cluster5**
Farms (n)	5	8	5	6	6
Farms pasturing rate	0.60	0.37	0.60	0.16	0.33
Cows (n)	26.0	55.3	27.4	56.7	90.8
Valley land (ha)	16.1	32.7	12.8	24.5	23.2
Stocking density (LU/ha)	1.9	2.2	2.2	3.2	5.0
Milk yield (kg FPCM/cow)	5612	5446	5302	5848	6876
Production intensity (kg FPCM/ha)	8593	8901	9413	14124	24798
Feed self-sufficiency (%)	70.2	72.2	58.6	58.8	44.7
Gross margin (€)	60,038	123,059	47,938	133,345	211,150
Gross margin (€/ha)	3719	3769	3684	4918	8565
Land use off-f (ha/kg FPCM)	1.17	1.04	1.16	1.23	1.58
Energy use (MJ/kg FPCM)	4.31	4.85	4.59	4.95	5.36
Climate change (kgCO_2/kg FPCM)	1.05	1.09	1.08	1.11	1.15
Acidification (kg SO_2/kg FPCM)	0.018	0.021	0.018	0.023	0.026
Eutrophication (kg NO_3/kg FPCM)	0.063	0.073	0.065	0.078	0.095
Climate change on-f (kg CO_2/ha)	5213	6023	7171	8382	13157
Acidification on-f (kg SO_2/ha)	78.8	133	111	201	331
Eutrophication on-f (kg NO_3/ha)	194	380	267	555	949

From GLM analysis, it appeared that acidification was higher in farms with low feed self-supply in comparison with the other farms (0.025 *vs* 0.019 kg SO_2-eq/kg FPCM for feed self-sufficiency of <53 and ≥53% on DM, respectively; $P<0.05$) especially due to the higher off-farm acidification ($P<0.05$). Low self-sufficient farms had also higher off-farm land use and off-farm eutrophication compared to the high self-sufficient farms. These impacts are mainly related to the production and transport of feeds from the outside. Feed self-supply significantly affected gross margin per kg of milk (0.357 *vs* 0.451 €/kg FPCM, for low and high percentage of feed self-sufficiency, respectively; $P<0.05$): farms buying less external feed were more profitable. Feed self-supply was related to the percentage of maize land on the valley land that was 7.0, 14.6 and 29.2%, for farms with low, medium and high feed self-sufficiency ($P<0.05$). All off-farm impacts per kg of milk decreased with increasing maize land ($P<0.05$), but on-farm eutrophication significantly grew with increasing maize land (from 0.020 and 0.030 kg NO_3/kg FPCM with no maize and <22% maize land to 0.035 kg NO_3/kg FPCM with >22% maize land; $P<0.05$).

Acidification and eutrophication grew with production intensity of farms in terms of kg FPCM/ha: acidification was 0.019, 0.020 and 0.024 kg SO_2/kg FPCM per farms with <8700, 8700-11500 and >11500 kg FPCM/ha, respectively ($P<0.05$); eutrophication was 0.065, 0.067 and 0.084 kg NO_3/kg FPCM for the same classes of intensity ($P<0.05$). Farms with medium level of intensity (8700-11500 kg FPCM/ha) had the lowest values in all the impact categories and an acceptable gross margin. The intensification process of farming systems in the mountain areas has its worst consequences on a local scale. Acidification was 108, 129 and 255 kg SO_2/ha per farms with <8700, 8700-11500 and >11500 kg FPCM/ha, respectively ($P<0.05$); eutrophication was 280, 326 and 730 kg NO_3/ha for the same classes of intensity ($P<0.05$).

Production intensity was mainly related to stocking density (LU/ha; $P<0.05$) whereas milk production per cow was not statistically different among groups. Both feed self-sufficiency and production intensity are related to valley land availability. Since agricultural land on the valley floors is becoming a lacking resource, farmers could partly bridge the gap by using the forage resources of the highland during the summer period. Farms with low feed self-sufficiency (<53% DM) could improve their environmental sustainability by practicing summer grazing. Highland grazing decreased total eutrophication per kg of milk of farms with low self-sufficiency (from 0.092 to 0.070 kg NO_3/kg FPCM; $P=0.07$), thus offering a possibility to improve farm environmental performances without increasing maize land.

4. Conclusions

From the cluster analysis it resulted that the group of farms with lowest environmental impacts were characterized by low stocking density and production intensity; farms that combined good environmental performances with medium gross margins were characterized also by high feed self-sufficiency and lowland availability. In particular from GLM it resulted that farms with low feed self supply had significantly higher acidification, off-farm land use and off-farm eutrophication per kg of FPCM than the other ones, mainly due to the production and transport of feeds from the outside. At the same time farms with high level of production intensity, in terms of kg of milk per ha, had significantly higher acidification and eutrophication per kg of FPCM but also per ha, with the worst effects on a local scale.

There might be two scenarios of environmentally sustainable evolution for these farms: a process of extensification, by a decrease in the number of reared animals, or an increase of feed self-sufficiency by the improvement of the production and quality of self-produced forages. Finally, summer grazing in the highland could play an important role in both decreasing stocking density in the lowland and increasing self-sufficiency.

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