## INTERPRETIVE SUMMARY

In recent decades, the dairy farming sector has been characterized by progressive intensification process; the effects of this process on the environment are the focus of many resources but they are not clarified yet. The study assesses the environmental impacts of dairy production, expressed as global warming potential, acidification, eutrophication potentials and non-renewable source consumption (energy and land use), starting from detailed data of 28 Italian dairy farms, in a life cycle approach. The analysis identifies relations between farming intensity and environmental impacts per milk unit and per land unit.

**RUNNING TITLE: ENVIRONMENTAL IMPACT OF MILK PRODUCTION**

# HOW FARMING INTENSIFICATION CAN AFFECT THE ENVIRONMENTAL IMPACT OF MILK PRODUCTION?

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## ABSTRACT

The intensification process of the livestock sector has been characterized in recent decades by increasing output of product per hectare, increasing stocking rate, including more concentrate feed in the diet and improving the genetic merit of the breeds. In dairy farming the effects of intensification on the environmental impact of milk production are not completely clarified. The aim of the study was to assess the environmental impacts of dairy production in a life cycle approach and to identify relations between farming intensity and environmental performances expressed on milk unit and land unit. A group of 28 dairy farms located in Northern Italy was involved in the study; data collected during personal interviews of farmers were analyzed in order to estimate emissions (global warming potential, acidification and eutrophication potentials) and non-renewable source consumption (energy and land use). The environmental impacts of milk production obtained from the Life Cycle Assessment were similar to those of other recent studies and showed high variability among the farms. From a cluster analysis three groups of farms were identified, characterized by different levels of production intensity. Clusters of farms showed similar environmental performances on product basis, despite important differences in terms of intensification level, management and structural characteristics. The study pointed out that, from a product perspective, the most environmentally friendly way to produce milk is not clearly identifiable. However the Principal Components Analysis showed that some characteristics related to farming intensification, such as milk production per cow, dairy efficiency and stocking density, were negatively related to the impacts per kg of product, suggesting a role of these factors in the mitigation strategy of environmental burden of milk production on a global scale. Considering the environmental burden on a local perspective, the impacts per hectare were positively associated with the intensification level.

**Key Words:** milk production, intensive farming, environmental impact, Life Cycle Assessment

## INTRODUCTION

During ~~the~~ recent decades the European livestock sector has shown a general trend towards enlarging farm size and increasing intensification in terms of output per hectare. The intensification of production is generally characterized by increasing stocking rate, including more concentrate feed in the diet and improving the genetic merit of the breeds (Alvarez et al., 2008). Such evolution has also affected the Italian dairy sector, which has shown a strong decrease in the total number of dairy cows over the last 30 years (from 2.6 million in 1980 to 1.6 million at present) and an increase in the number of cows per farm from 7.9 to 31.8 in the same period (ISTAT, 2012). Furthermore, in Northern Italy favorable climatic and infrastructural conditions have led to a very high livestock concentration with a consequent intensive utilization of natural resources (i.e. land, air, water) and high environmental pressure. Intensification of livestock production systems is generally considered detrimental from an environmental point of view. A study from New Zealand (Basset-Mens et al., 2009) showed that increasing the number of cows per land unit (with higher N-fertilization and more land used to grow maize for silage instead of permanent grass) reduced dairy farm eco-efficiency in terms of both milk production and land use functions. Penati et al. (2011), assessing environmental sustainability of a group of alpine dairy farms, found that the best environmental performances were obtained by the farms characterized by low stocking density, low production intensity, high feed self-sufficiency and large land availability in the valley floor. But other results from the literature showed some positive effects of intensification of livestock production in terms of environmental impact mitigation. A review study of Crosson et al. (2011) concluded that increased output per ha obtained through intensification can reduce emissions per kg of product. Kristensen et al. (2011) identified “herd efficiency” and “farming intensity” as relevant strategies for environmental impact reduction. Yan et al. (2013) found that, as milk production increases, a mitigation of environmental impact is observed. Casey and Holden (2005) suggested that, to improve the environmental efficiency of dairy farms, a move toward fewer cows producing more milk at lower stocking rates is required. This represents an extensification in terms of area but an intensification in terms of animal husbandry systems.

Life Cycle Assessment (**LCA**) is a generally accepted method for estimating the environmental impact of agricultural products on a global perspective. The main environmental effects quantified in LCA studies on dairy systems are: the acidifying and eutrophic effects on watercourses, the global warming effect and the utilization of resources such as land and non-renewable energy during the production of milk (O'Brien et al., 2012).

Even if climate change is a global issue, for environmental aspects with a local connotation (especially acidification and eutrophication), environmental impact should be evaluated not only per unit of product but also per hectare of land. In particular, eutrophication pertains directly to the leaching and run-off of nitrate and phosphate to the ground and surface water; therefore this parameter contains a local aspect (Oudshoorn et al., 2011). Many authors showed significantly worse environmental performances of the intensive livestock systems when the impacts were expressed in terms of land unit (Casey and Holden, 2005; Haas et al., 2001).

The first objective of the study was to analyze the environmental performances of a sample of dairy farms, both on a global and on a local perspective, through an LCA approach. The second objective was to identify the relation between environmental impacts and main farm characteristics, focusing in particular on farming intensity.

## MATERIALS AND METHODS

### *System description and data collection*

A group of 28 dairy cattle farms were involved in the study. All the farms were located in Northern Italy and they were members of a cheese factory producing Grana Padano O.P.D. All cows were Italian Holstein, kept in permanent confinement, without pasture. This rearing system is the most commonly used in the North of Italy.

Data were collected through personal interviews of farmers. Questions were addressed to obtain precise information about: cropping systems and field operations, fuel consumption, number of animals and housing systems, manure storage and animal rations. Moreover, data regarding all the inputs entering the farms were acquired: amount of purchased feeds (both roughages and concentrates), fertilizers and pesticides, bedding materials, number and origin of purchased replacing animals.

In each farm, forages (hays and silages) and Total Mixed Ration were sampled and analyzed for the content of dry matter (**DM**), ash, crude protein (**CP**), ether extract and crude fibre with AOAC (1995) and starch with AOAC (1998) methods; neutral detergent fibre was analyzed following Mertens (2002), acid detergent fibre and acid detergent lignine with the method of Van Soest et al. (1991). Data obtained from the analyses were used for the estimation of digestibility of the feeding rations. The amount of milk produced by each farm was provided by the cheese factory, whereas the amount of meat (as animal live weight) was estimated on the basis of the number of animals sold for slaughter and their live weight declared by the farmers.

Composition of concentrate feed was estimated on the basis of the raw materials reported on the commercial labels using CPM-Dairy Ratio Analyzer Beta V3 software (Cornell-Penn-Miner, 2004).

Table 1 summarizes the inventory of the most important data used for impact assessment. All the data are expressed as the average value of the 28 dairy farms.

The income over feed cost (**IOFC**) was used as economic indicator of farm profitability as proposed by Hutjens (2007) and it was calculated as the income from milk minus feeding costs (self-produced and purchased feed) per cow per day.

### *Emission estimation*

***Greenhouse gas emissions on-farm.*** Table 2 shows the models used for on-farm Greenhouse Gas Emission (**GHG**) estimation. Methane ($CH_4$) emissions from livestock enteric fermentations were estimated using the equation (equation [8d] $R^2$ = 0.63) from Ellis et al. (2007). To convert the energy of enteric methane in kilograms of methane emitted the factor 55.65 MJ/kg $CH_4$ (IPCC 2006a) was used. Methane emissions from manure management were estimated using the Tier 2 method suggested by IPCC (2006a). Volatile solid excretion was estimated considering:

- Gross Energy of the diets (kj / kg DM) evaluated using Ewan equation (1989);
- Digestibility of the feed estimated using a calculation model developed for each type of forage and concentrate feed on the basis of the equation proposed by INRA (2007). Feed nutritional characteristics were obtained from the laboratory analyses.

In this study, animal nitrogen excretion was estimated as proposed by the IPCC (2006a) Tier 2 method considering the nitrogen intake (on the basis of CP% of the diet) minus the nitrogen retained by the animals and excreted with milk. Nitrous oxide ($N_2O$) emissions from manure storages occurred in direct and indirect forms and in both cases they were estimated using the Tier 2 method from IPCC (2006a). Direct and indirect $N_2O$ losses from fertilizers application were respectively estimated following the Tier 2 and Tier 1 methods suggested by IPCC (2006b): the amount of nitrogen applied to the soils from synthetic fertilizers and from manure (slurry and solid) plus the nitrogen from crop residues were accounted in the estimation.

Carbon dioxide ($CO_2$) emissions from fuel combustion were estimated on the basis of fuel consumption of each farm. Emissions occurring during field operations (i.e. plowing, harrowing, sowing, harvesting, etc.) were estimated using the processes of the Ecoinvent (2007) database, whereas for the other fuel consumptions (i.e. use for feeding mixer) the emission factor used was 3.12 kg of $CO_2$ $kg^{-1}$ of diesel as proposed by Nemecek and Kägi (2007). Emissions from livestock respiration and the variation in soil carbon stocks were not accounted.

***Other emissions on-farm.*** Table 3 reports the models used for the estimation of acidifying and eutrophic substances emitted on-farm.

Ammonia ($NH_3$) and nitrogen oxide emissions (NOx) that occur during animal housing, manure storages and spreading were estimated following the method proposed by EAA (2009a,b) on the basis of the total amount of nitrogen excreted by the animals. The Tier 2 used a mass flow approach based on the concept of a flow of Total Ammonia Nitrogen (**TAN**) through the manure management systems. $NH_3$-N and NOx emission factors, as proportion of TAN, were specific for each manure types (slurry or solid) and each step in manure handling (EAA 2009a). $NH_3$ and NOx emitted during manure spreading and application of synthetic fertilizers were estimated following EAA guidelines (2009b). The amount of nitrogen leached was estimated following the IPCC (2006b) model (Table 2). To estimate emissions of $PO_4^{3-}$ the amount of phosphorus lost in dissolved form to surface water (run-off) and leached was considered as proposed by Nemecek and Kägi (2007).

***Off-farm processes.*** The emissions related to off-farm activities were calculated using LCA software, Simapro PhD 7.3.3 (PRé Consultants, 2012) and were modeled using the databases reported in Table 4. The following processes were considered: the production chain of commercial feed (from crop growing to feed factory processing), production of purchased forages and bedding material, rearing of purchased replacing heifers, production of chemical fertilizers and pesticides and of diesel and electricity used in the farms. Transportation was accounted only for the feed, bedding materials and purchased replacing animals.

Since farms bought a quota of their replacing heifers, a simplified LCA was performed to assess the impacts associated to heifer rearing, considering animals sold at 24 months of age, an average feed intake, an average diet composition, standard housing conditions and manure management.

***Impact assessment***

The environmental impact of milk production in each dairy farm was evaluated through a detailed ‘‘cradle-to-farm-gate’’ LCA (Belflower et al., 2012). The system boundaries included all the on-farm processes plus the off-farm activities linked to the production of external inputs (Figure 1).

The selected environmental impact categories were: global warming, acidification, eutrophication, non-renewable energy use and land use (O'Brien et al., 2012). The impact assessment was performed with the EPD 1.03 (2008) method, updated with IPCC 2007 GWP conversion factors (100 year time horizon). Land use was estimated on the basis of total area (on- and off-farm land).

On a global perspective the functional unit (**FU**) was established as 1 kg fat and protein corrected milk (**FPCM**) leaving the farm gate (Thomassen et al., 2008) estimated using the formula: FPCM (kg) = raw milk (kg) x (0.337 + 0.116 x % fat + 0.060 x % protein), from Gerber et al. (2010). The biological allocation method developed by IDF (2010) for dairy farming system was ~~used~~ calculated using the following formula:

AF = 1 - 5.7717 * R

where AF= allocation factor for milk; R = M meat / M milk; M meat = sum of live weight of all animals sold including bull calves and culled mature animals; M milk = sum of milk sold FPCM.

The environmental impacts were also estimated from a local point of view assuming 1 ha of farm land as functional unit.

***Statistical analysis***

Statistical analysis was performed using SAS 9.2 software (SAS, 2001) and was carried out in 3 steps. The first step was performed through a Principal Component Analysis (PCA, proc PRINCOMP) to study the relationships among total environmental impacts per kg of milk and per hectare (ha), their on-farm contributions and a number of quantitative variables related to farming intensity: production level (kg FPCM cow$^{-1}$ day$^{-1}$), dairy efficiency (kg FPCM kg$^{-1}$ dry matter intake), number of dairy cows, stocking rate as Livestock Units (**LU** ha$^{-1}$), total farm land (ha), shares of maize land for silage and grassland on total farm land and Income Over Feed Cost (€ $cow^{-1}$ $d^{-1}$). In the second step farms were grouped through a CLUSTER procedure (using average linkage method) considering the following variables: total farm land (ha), number of dairy cows, stocking rate (LU $ha^{-1}$), production level (kg FPCM $cow^{-1}$ $day^{-1}$), percentage of grass hay and maize silage on dry matter intake, percentage of maize land for silage on farm land, dairy efficiency (kg FPCM $kg^{-1}$ dry matter intake), feed self-sufficiency expressed as the ratio between the DM produced on farm and the total DM used for animal feeding. For each cluster average farm characteristics and environmental impacts on a global (FU = 1 kg of FPCM) and local (FU = 1 ha of farm land) scale were computed. Moreover a Pearson Correlation Analysis was used to identify the relation between farms characteristics and each environmental impact expressed per ha of farm land.

## RESULTS

### *Environmental impacts of milk unit*

Table 5 reports the average results of the environmental impact assessment of milk production in the farms under consideration expressed per milk unit. The on-farm percentage of greenhouse gas emissions was much higher compared to the off-farm one. The most important contributor to global warming was enteric and manure storage emission (52.9 ± 4.40%), followed by emissions related to the production of concentrate feed (19.9 ± 6.78%). Almost all the acidification was due to on-farm activities and the main role was played by farm crop production (39.1 ± 8.54%), animal housing (22.7 ± 2.63%) and manure storages (22.5 ± 5.25%). Also for eutrophication on-farm contribution was the most important factor; in particular farm crop production was the major driver (51.6 ± 7.89%), while in the off-farm processes the production of concentrate feed accounted for 21.2 ± 7.66 % of total eutrophication potential. In non-renewable energy use the on- and off-farm contributions were similar; the production of concentrate feed covered alone the 46.6 ± 13.9% of the total energy consumption. Similarly to energy consumption, land use did not show any important difference between on- and off-farm shares; crop production for purchased concentrate feed contributed alone ~~for~~ 33.0 ± 10.8% of total impact, followed by growing of purchased forages (5.82 ± 7.58%).

Figure 2 shows the average contributions of different substances to Global Warming Potential (**GWP**), acidification and eutrophication.

Overall, methane was responsible for 49.9 ± 3.64% of total greenhouse gas emission, followed by carbon dioxide and nitrous oxide, which had similar weights (25.4 ± 2.59% and 24.5 ± 3.25% respectively). Enteric fermentation was the most important source of $CH_4$: 74.3 ± 8.87% of total methane was produced in the gastrointestinal tract of the animals.

Ammonia emission accounted for 88.8 ± 2.34% of acidification potential. Ammonia volatilized mainly during application of manure on farm soils (41.4 ± 9.36% of total ammonia emission) and during animal housing and manure storages (respectively 25.6 ± 2.87% and 25.1 ± 5.66% of total ammonia emission). Nitrate leaching was the main contributor to eutrophication potential (47.8 ± 4.01%) followed by volatilized $NH_3$ (40.3 ± 4.61%), while the role of phosphate losses was less important (only 6.13 ± 1.43%). The percentage of nitrate leached during on-farm crop production was higher than the fraction related to purchased feed (concentrates and forages): 67.1% ± 10.4 and 29.6% ± 10.9 of total nitrogen leached, respectively.

***Interaction between farm characteristics and environmental impact***

The results obtained from the Principal Components Analysis are plotted in Figures 3 and 4 and the eigenvectors are reported in Tables 6 and 7. Figure 3 shows the multivariate correlation between farm characteristics and environmental impacts per kg FPCM. The first dimension explains 38.7% of the total variance while the second dimension explains 20.1%. Total impacts (GWtot, LANDtot, and ENERGYtot) and their on-farm quotas, expressed in terms of kg of milk produced, are in the same area and highly correlated with each other and with feed self-sufficiency. On-farm land use and on-farm energy use are strongly related to feed self-sufficiency because higher the quota of feed produced on farm, higher their impacts. Total and on-farm acidification and eutrophication are very close to the percentage of land used for maize silage production, which needs high nitrogen fertilization.

The farm characteristics enclosed in the upper-left area are inversely related to the total impacts per kg of milk. The distance between the variables on the first dimension of the graph means that improving milk production and dairy efficiency, on one hand, and increasing stocking density and the share of grassland on farm land, on the other hand, may result in a reduction of all the impacts per kg of product. Dairy efficiency is one of the parameters which mainly influence the profitability, expressed as IOFC, of a dairy farm; in fact they are in the same area. Stocking density and feed self-sufficiency are in the opposite sides of the graph and inversely related as a consequence of the higher amount of feeds generally bought from the market in the high stocking density farms. Figure 4 shows the multivariate correlation between farm characteristics and environmental impacts per ~~hectare~~ ha of land. All environmental impact categories are close to each other, to the percentage of land for maize silage and to the stocking density. On the first dimension (prin 1), which explains 50.8% of the variance, all impact categories, expressed on unit of land, are inversely related to feed self-sufficiency.

The Pearson correlation analysis identified stocking density and feed self-sufficiency as the major drivers of environmental burden per ha of farm land for all the impact categories: in particular global warming (kg $CO_2$-eq. $ha^{-1}$ farm land) showed a strong positive correlation with stocking density ($r = 0.91$; $P < 0.001$) and a negative correlation with feed self-sufficiency ($r = - 0.71$; $P < 0.001$). Significant positive correlations were shown between the percentage of land used to grow maize for silage and all on-farm impact categories, especially acidification and eutrophication (0.55; $P < 0.01$ and 0.58; $P < 0.01$, respectively).

Figure 5 shows the relationship between stocking density and eutrophication expressed both per kg of FPCM and per ha of farm land: the number of LU per ha did not affect the emission per kg of milk, while it is a key point when the impact is expressed on land unit.

***Farming intensity and environmental performances***

The cluster analysis clearly identified three groups of farms differing in terms of intensity level (Table 8). The first one (HIGH) included 10 farms characterized by high level of intensification: high milk production per ha, high percentage of arable land on total land, large land area sowed with maize for silage, high stocking density, high milk yield per cow, high dairy efficiency, high use of concentrate and maize silage in the cow rations instead of grass hay. The second cluster (MEDIUM) consisted of 7 farms less intensive in comparison with the farms of first cluster. The third group (LOW) included 11 farms identified as the least intensive on the basis of their characteristics.

Total farm land was different among the three groups, with the highest value in the MEDIUM cluster and lower values in the others. The percentage of arable land of the LOW group was lower compared to the other two groups; HIGH had the higher quota of land used to grow maize for silage in comparison with the LOW group. The number of livestock units showed the same trend among the groups observed for the farm land. Stocking rate was generally high; in the HIGH group it was particularly elevated compared with the other groups. The milk production levels of HIGH and MEDIUM were higher compared to LOW; similarly the dairy efficiency, which is strongly related to the level of productivity, showed better results in HIGH and MEDIUM farms. HIGH farms had lower feed self-sufficiency compared to the other groups which had similar values. Considering the economic performances, no differences were observed between the average IOFC of the three clusters.

Analyzing the environmental impacts on the product basis, only few differences were observed among the groups and overall they should be considered similar (Table 9). LOW farms showed higher on-farm energy use compared to the HIGH ones. Farms belonging to HIGH had lower on-farm land use impact compared to the other two groups, while LOW had lower off-farm land use than HIGH and MEDIUM.

The results change widely if the environmental impacts are evaluated on land unit, as shown in Table 10.

HIGH had higher total environmental impacts per ha of farm land for all the categories in comparison to the other two groups which were similar to each other. A similar trend was observed for on-farm GWP, acidification and eutrophication which were higher in HIGH than in MEDIUM and LOW. No differences were found regarding on-farm energy use.

## DISCUSSION

### *Environmental impacts of milk unit*

The estimated GWP for the production of 1 kg of FPCM was comparable to the value found by Guerci et al. (2013) and in agreement with Castanheira et al. (2010) who similarly obtained a higher contribution of on-farm activities to GHG emission compared to off-farm activities. The acidification and the eutrophication potentials were similar to Castanheira et al. (2010), but higher compared to findings reported by O'Brien et al. (2012) and Basset-Mens et al. (2009). Total non-renewable energy use was consistent with the result reported by Thomassen et al. (2008) for conventional Dutch dairy farms. Considering land use, the total impact and on-farm contribution were similar to O'Brien et al. (2012) and Basset-Mens et al. (2009). The contributions of the different substances to GWP were comparable with Castanheira et al. (2010). Similarly several other studies reported $CH_4$ to be the predominant contributor to the total climate change emissions (Flysjö et al., 2011; Kristensen et al., 2011; O'Brien et al., 2012), whereas Thomassen et al. (2008) found a methane contribution to total climate change of only 34% in the conventional system and of 43% in the organic system. Enteric methane is generally recognized as the major driver of greenhouse gas emissions of milk production and the abatement of enterically derived $CH_4$ is considered one of the most promising strategies for the reduction of GHG emissions from the dairy sector (Mc Geough et al., 2012).

The main contribution of ammonia to total acidification potential was found also by Thomassen et al. (2008) and Castanheira et al. (2010) who observed that $NH_3$ emissions have a strong impact on the total acidification potential, whereas $SO_2$ and NOx play a minor role. Castanheira et al. (2010) reported $NH_3$ and $NO_3$ as the major contributors to total eutrophication potential while Thomassen et al. (2008) found phosphate to be more important in terms of impact on eutrophication. In the study of O'Brien et al. (2012) nitrate losses occurring on-farm were around 90% for the seasonal grass-based dairy system but only about 30% for the confinement dairy system.

***Interaction between farm characteristics and environmental impact***

The negative relationships shown by the PCA between total environmental impacts per milk unit, on one side, and dairy efficiency and milk production level, on the other, are in agreement with numerous results from the literature. In fact, feed conversion efficiency of the animals is known to be an effective strategy in mitigating the environmental impact per unit of product (Hermansen and Kristensen, 2011; Yan et al., 2013); according to Capper et al. (2008) a general increase in productivity might positively affect the environmental sustainability of milk. Guerci et al. (2013) showed that farming strategies based on high production intensity and high dairy efficiency could mitigate environmental impacts per kg of milk. The mitigation effect of enhancing dairy efficiency is based on the dilution of environmental costs associated with maintenance. Moreover high producing cows usually receive low fibre rations reducing their methane emission per kg milk.

The negative correlation between stocking density and total impacts (per kg of FPCM) is a little surprising, especially if eutrophication and acidification potentials are considered. But farms with high stocking density were also at the same time characterized by high production levels and high dairy efficiency.

Grassland instead of arable land seemed to have a positive effect on the environmental impact, but its role was not so clear due to the opposite effects of many factors. Generally grassland needs less fertilization than arable land with positive effect on GWP, eutrophication and acidification, but arable crops (for instance maize silage) have higher yield per ha and require less field operations and less energy compared to grass hay production (Rotz et al., 2010).

Profitability, expressed as IOFC, shows a negative relationship with total environmental impacts per kg of FPCM. Farms with cows more efficient in converting feed to milk have higher income per cow and lower impacts per milk unit.

Regarding environmental impacts per ha of land, the PCA showed that the farm management characteristics mostly related to the different impact categories were stocking density and percentage of land for maize silage production. High LU per ha means high quantity of organic nitrogen on soil and low feed self-sufficiency. With respect to percentage of land for maize silage production, its positive relationship with environmental impact per ha depends mainly on the high demand of maize in terms of nitrogen application (organic and chemical), which is positively related to environmental impact per unit of land as found by Casey and Holden (2005).

***Farming intensity and environmental performances***

The study did not show any difference between the environmental impact per milk unit of the three clusters of farms, despite important differences among the groups in terms of farm characteristics and farming intensity. On the contrary, when the functional unit was the hectare of farm land, most of the impacts were much higher in the group of farms with high intensity level. In general intensification, defined as increased output per ha, invariably led to increased emissions when expressed on an area basis; however, the result was less obvious when expressed on a product basis (Crosson et al., 2011). Basset-Mens et al. (2009) highlighted better environmental performances for the low input dairy systems compared to the more intensive ones from both product and local perspective; similar results were obtained by O'Brien et al. (2012) for a grass based farm vs. a confinement system. Van der Werf et al. (2009) observed no difference in terms of environmental impact between conventional and organic dairy systems when milk sold was considered as functional unit; however, on land basis the conventional systems showed a significantly higher environmental burden compared to the organic ones. Similar results were found by Haas et al. (2001), who reported significantly worse environmental performances in the intensive system than in the extensive one when the impact was expressed on land unit. Casey and Holden (2005) found a significant positive linear correlation between stocking rate and the amount of $CO_2$-eq. $ha^{-1}$ but no relationship between stocking rate and GHG emissions $kg^{-1}$ milk. Similarly Oudshoorn et al. (2011) found that no correlation between N-surplus per ha and emission of GHG per kg ECM existed.

As a consequence, when the environmental impacts related to the product unit are considered, the identification of the more sustainable production strategy seems to be difficult. Several studies compared organic vs. conventional farms or grass based vs. confined farms: some authors attributed better environmental performances to the low input systems (Belflower et al., 2012; O'Brien et al., 2012), others associated the more intensive systems with a potential reduction of the environmental pressure (Kristensen et al., 2011; Thomassen et al., 2008); other researchers reported different results depending on the impact category considered (Cederberg and Mattsson, 2000).

## CONCLUSIONS

The results of the study showed that, when assessing the environmental impact per milk unit, it is difficult to clearly identify the relation between farming intensity and environmental performances, despite important differences in terms of farm intensification level, management and structural characteristics. However, the Principal Components Analysis showed that some characteristics related to farming intensification, particularly milk production per cow, dairy efficiency and stocking density, were negatively related to the impacts per kg of product; this suggests a role of these factors in the mitigation strategy of environmental impact of milk production on a global scale.

Besides an important role in global environmental impact (i.e. climate change), livestock systems are often responsible for local and not less important impacts (i.e. eutrophication of soils and water). Considering the environmental burden on a local perspective, the impacts were positively associated with the intensification level.

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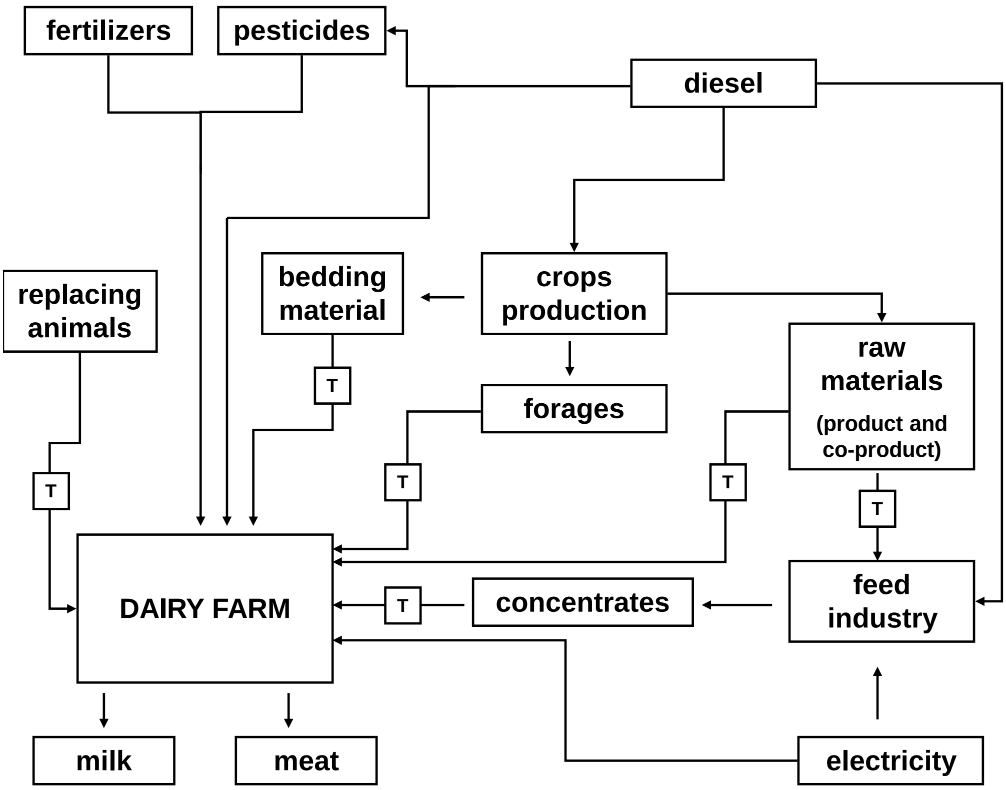
Bava **Figure 1**



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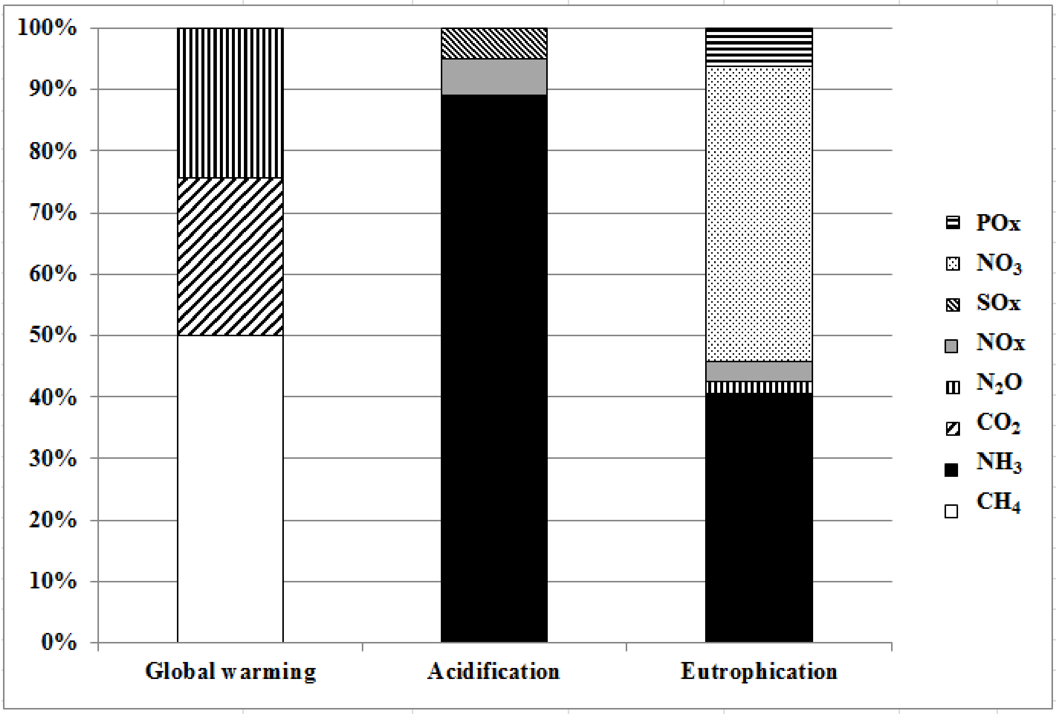

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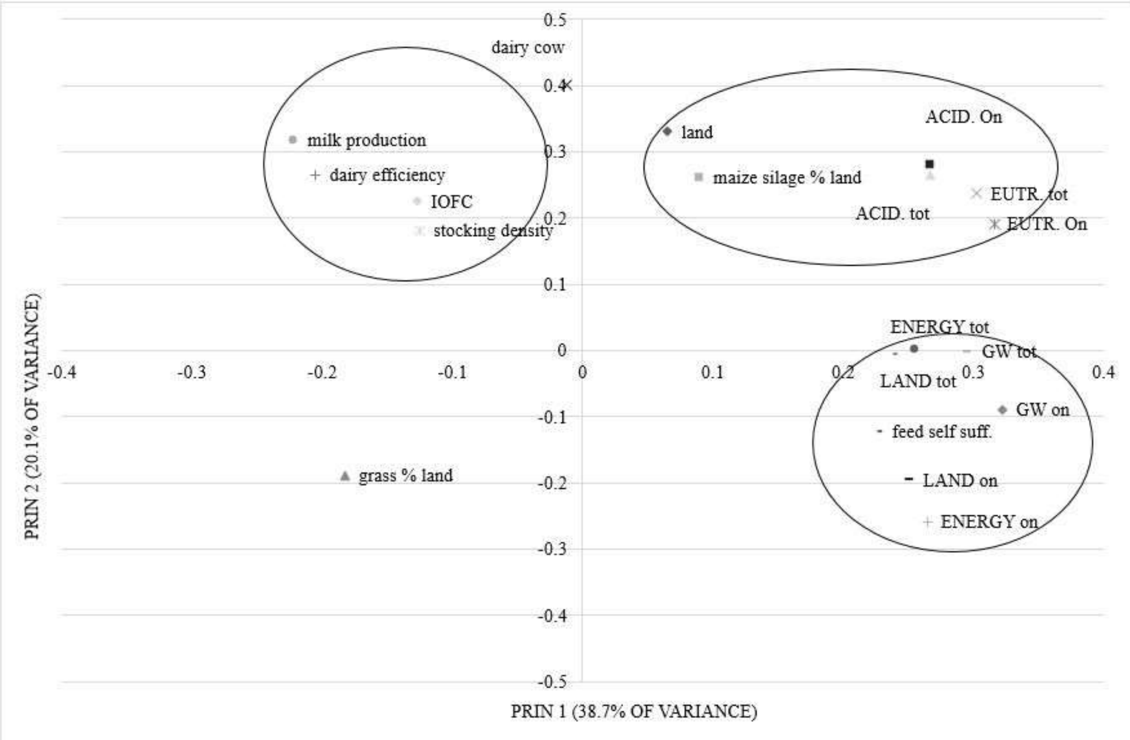

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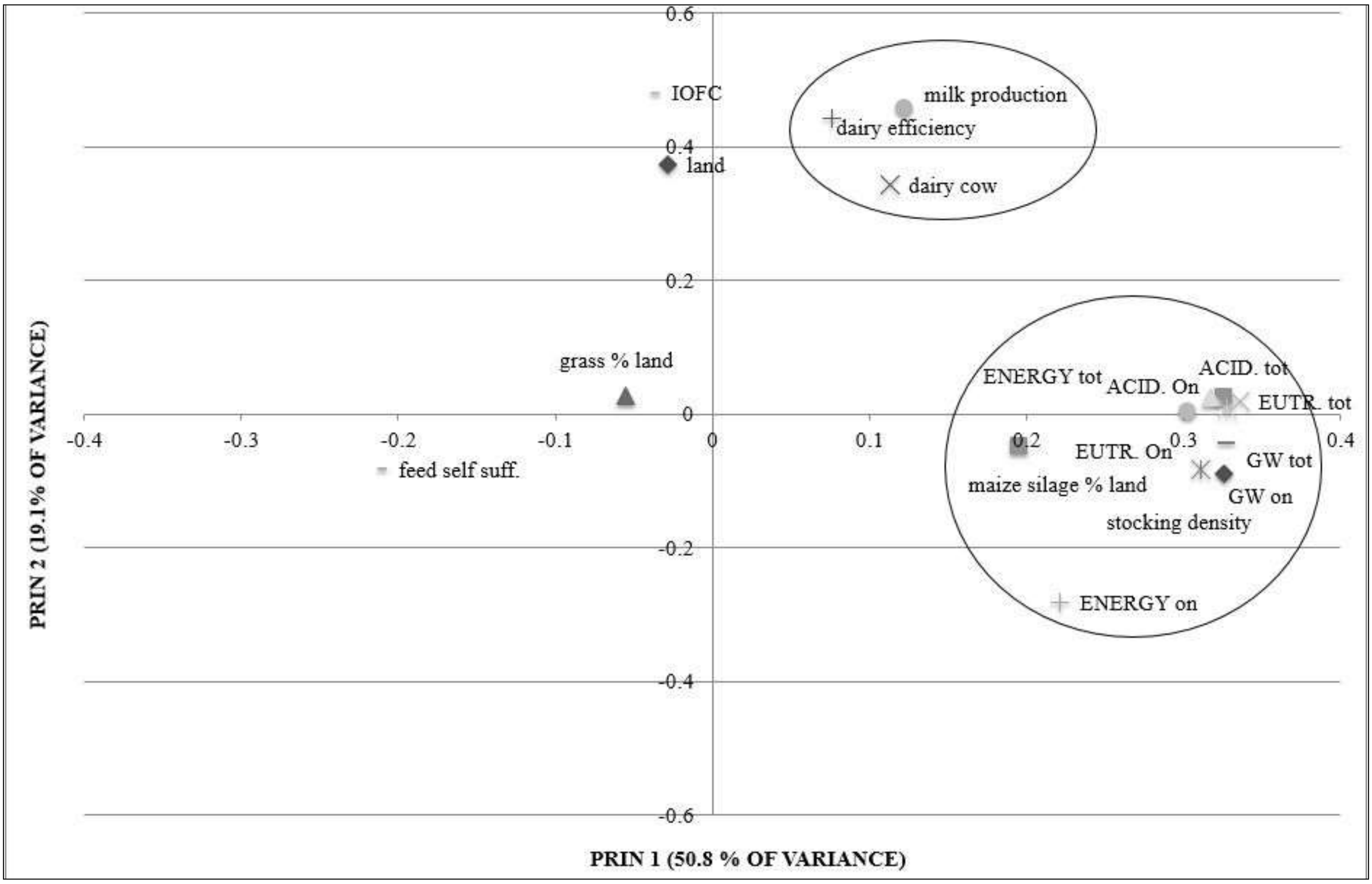

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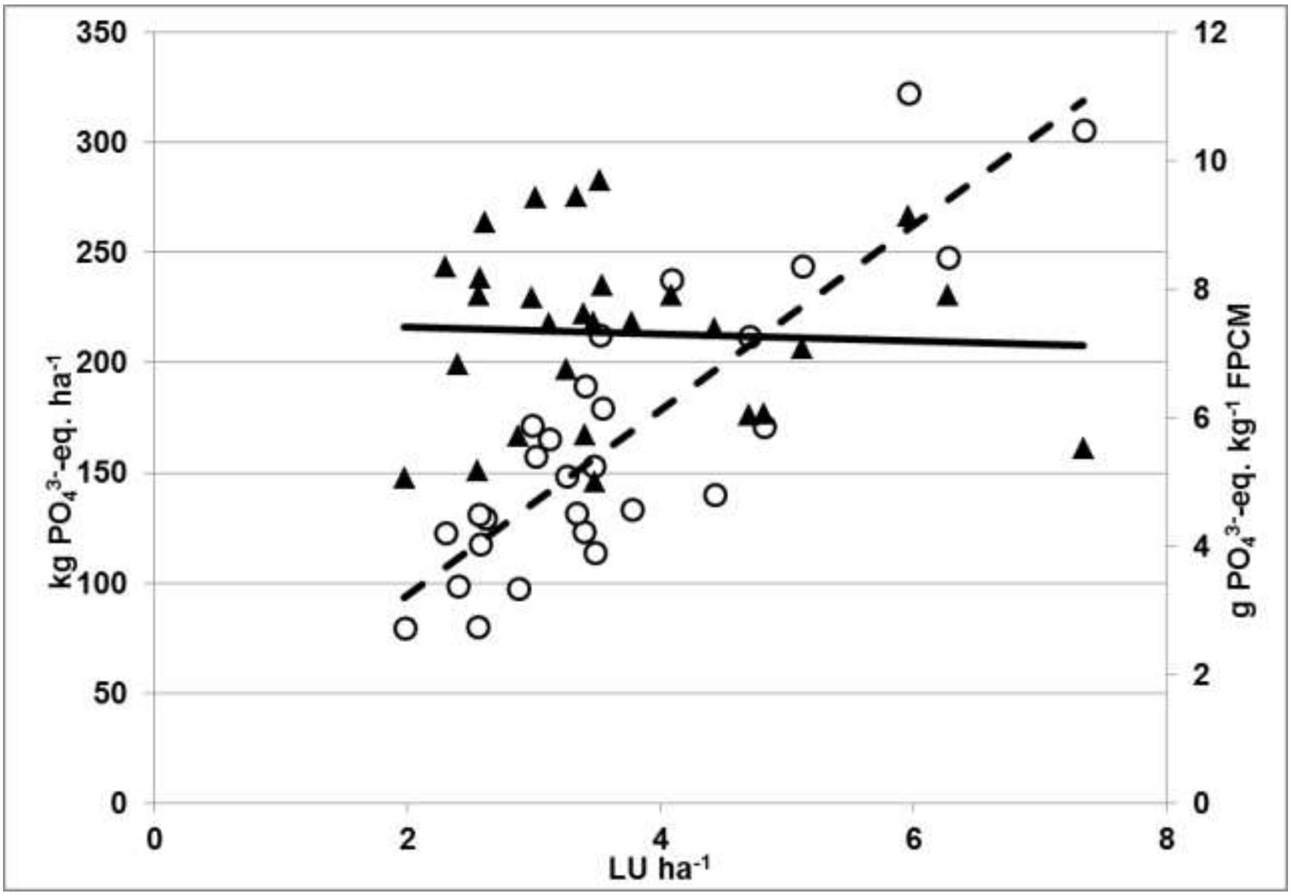

**Figure 1.** System boundaries (T = transportation)

**Figure 2.** Contribution of different substances to the impact categories

**Figure 3.** PCA (environmental impacts expressed per kg FPCM)

**Figure 4.** PCA (environmental impacts expressed per ha farm land)

**Figure 5.** Relation between stocking density and eutrophication expressed per kg of FPCM and per ha of farm land. ° eutrophication/ha and stocking density: $y = 42.025x + 10.561$; $R^2 = 0.7379$.

▲ eutrophication/kg FPCM and stocking density: $y = -0.0543x + 7.5317$; $R^2 = 0.0025$

Table 1. Inventory data (average of the 28 farms)

| | Unit | Mean | S.D. | Minimum | Maximum |
|---|---|---|---|---|---|
| LAND | | | | | |
| Farm land | ha | 40.7 | 27.8 | 8.5 | 120 |
| Permanent grassland | % land | 52.1 | 23.8 | 12.9 | 100 |
| Maize land for silage | % land | 36.5 | 20.3 | 0.0 | 87.1 |
| NEl yield[a] | MJ $ha^{-1}$ | 74965 | 20924 | 34901 | 134248 |
| Nitrogen yield | kg $ha^{-1}$ | 180 | 38.2 | 103 | 238 |
| N synthetic fertilizers | kg $ha^{-1}$ | 84.3 | 51.1 | 0.0 | 202 |
| Pesticides (a.s.)[b] | g $ha^{-1}$ | 791 | 614 | 0.0 | 1849 |
| HERD | | | | | |
| Dairy cows | n. | 90.3 | 52.0 | 17.0 | 195 |
| Livestock Unit | n. | 143 | 86.7 | 25.7 | 308 |
| Milk production | kg FPCM $cow^{-1}day^{-1}$ | 27.1 | 4.3 | 18.1 | 35.4 |
| Production intensity | kg FPCM $ha^{-1}$ | 19764 | 7955 | 12005 | 46455 |
| Meat production[c] | kg $farm^{-1}$ $year^{-1}$ | 130 | 45.6 | 53.1 | 223 |
| MANURE TYPE | | | | | |
| Solid manure | % | 40.3 | 38.0 | 0.0 | 100.0 |
| Liquid slurry | % | 59.7 | 38.0 | 0.0 | 100.0 |
| FEED | | | | | |
| Feed produced on-farm | t DM $LU^{-1}$ $year^{-1}$ | 3.8 | 1.2 | 1.6 | 6.5 |
| Purchased forages | t DM $LU^{-1}$ $year^{-1}$ | 0.3 | 0.4 | 0.0 | 1.4 |
| Purchased concentrates | t DM $LU^{-1}$ $year^{-1}$ | 1.7 | 0.7 | 0.4 | 3.0 |
| ENERGY | | | | | |
| Diesel use | kg $LU^{-1}$ $year^{-1}$ | 88.6 | 21.3 | 54.0 | 141 |
| Electricity use | kwh $LU^{-1}$ $year^{-1}$ | 211 | 79.9 | 52.3 | 336 |

[a] net energy for lactation
[b] active substances
[c] live weight sold

**Table 2.** Models and emission factors (EF) used for the estimation of GHG emissions on-farm

| Pollutant | Source | Amount | Reference |
|---|---|---|---|
| $CH_4$ | enteric | $CH_4$ (MJ) = 2.16 (± 1.62) + 0.493 (± 0.192) • DMI (kg) − 1.36 (± 0.631) • ADF (kg) + 1.97 (± 0.561) • NDF (kg) | Ellis et al. (2007) |
| | manure storage | $CH_4$ = VS x $B_0$ • 0.67 • MCF/100 • MS | Eq. 10.23 - IPCC (2006a) |
| | | VS = [GE • (1-DE/100)+(UE • GE)] • [(1-Ash)/18.45] | Eq. 10.24 - IPCC (2006a) |
| | | GE (kj) = 17350 + (234.46 •EE%) + (62.8 • CP%) - (184.22 • Ash%) | Ewan (1989) |
| | | DE: feed digestibility | INRA. 2007 |
| | | MCF solid storage: 4 | IPCC (2006a) |
| | | MCF liquid slurry: 17 | |
| | | MCF pit storage: 27 | |
| $N_2O$ direct | manure storage | $N_2O$ = Nex • MS • EF • 44/28 | Eq. 10.25 - IPCC (2006a) |
| | | Nex = Nintake • (1− Nretention) | Eq. 10.31 - IPCC (2006a) |
| | | N intake: DMI • (CP%/100/6.25) | |
| | | N retention: N retained per animal with milk and weight gain | Eq. 10.33 - IPCC (2006a) |
| | | EF solid storage: 0.005 (0.0027 - 0.01) | Tab. 10.21 - IPCC (2006a) |
| | | EF liquid slurry: 0.005 | |
| | | EF pit storage: 0.002 | |
| | field | $N_2O$ = (Nsn + Non + Ncr) • EF • 44/28 | Eq. 11.2 - IPCC (2006b) |
| | | Non: annual amount of N from managed animal manure applied to soil (Nex - Frac_loss + N bedding) | Eq. 10.34 - IPCC (2006a) |
| | | Frac_loss solid storage: 40% (10 – 65) | Tab. 10.23 - IPCC (2006a) |
| | | Frac_loss liquid slurry: 40% (15 – 45) | |
| | | Frac_loss pit storage: 28% (10 – 40) | |
| | | EF: 0.01 (0.003 - 0.03) | Tab. 11.1 - IPCC (2006b) |
| $N_2O$ indirect | manure storage | $N_2O_G$= Nvolatilization • EF • 44/28 | Eq. 10.27 - IPCC (2006a) |
| | | Nvolatilization: Nex • MS • Frac_GasMS/100 | |
| | | Frac_GasMS solid storage: 30 (10 – 40) | Tab. 10.22 - IPCC (2006a) |
| | | Frac_GasMS liquid slurry: 40 (15 – 45) | |
| | | Frac_GasMS pit storage: 28 (10 – 40) | |
| | | EF: 0.01 (0.002 - 0.05) | Tab. 11.3 - IPCC (2006b) |
| | field | $N_2O_{(ATDN)}$ = [(Nsn • Frac_GasF) + (Non • Frac_GasM)] • EF • 44/28 | Eq. 11.9 - IPCC (2006b) |

| | | | |
|---|---|---|---|
| | | Frac_GasF: 0.1 (0.03 - 0.3) | Tab. 11.3 - IPCC (2006b) |
| | | Frac_GasM: 0.2 (0.05 - 0.5) | Tab. 11.3 - IPCC (2006b) |
| | | EF: 0.01 (0.002 - 0.05) | Tab. 11.3 - IPCC (2006b) |
| | | $N_2O_{(L)}$ = (Nsn + Non) • Frac_Leach • EF • 44/28 | Eq. 11.10 - IPCC (2006b) |
| | | Frac_Leach: 0.3 (0.1 - 0.8) | |
| | | EF: 0.0075 (0.0005 - 0.025) | Tab. 11.3 - IPCC (2006b) |
| $CO_2$ | field operations diesel combustion[a] | $CO_2$ = kg diesel • EF | Econivent (2007) Nemecek and Kägi (2007) |
| | | EF: 3.12 kg of $CO_2$ $kg^{-1}$ of diesel | |

[a] excluding the quota used during field operations

**Table 3.** Models and emission factors (EF) for the estimation of ammonia. nitric oxide and phosphate emissions on-farm

| Pollutant | Source | Amount | Reference |
|---|---|---|---|
| $NH_3$ | housing | TAN = Nex • EF_TAN | Eq. 10 - EEA (2009a) |
| | | EF_TAN: 0.6 | Tab. 3-8 - EEA (2009a) |
| | | $NH_3$build_slurry = TANbuild_slurry • EFbuild_slurry • 17/14 | Eq. 15 - EEA (2009a) |
| | | EFbuild_slurry: 0.2 | Tab. 3-8 - EEA (2009a) |
| | | $NH_3$build_solid = TANbuild_solid • EFbuild_solid • 17/14 | Eq. 16 - EEA (2009a) |
| | | EFbuild_solid: 0.19 | Tab. 3-8 - EEA (2009a) |
| | manure storage | $NH_3$storage_solid = TANstorage_slurry • EFstorage_slurry • 17/14 | Eq. 29 - EEA (2009a) |
| | | EFstorage_slurry: 0.20 | Tab. 3-8 - EEA (2009a) |
| | | $NH_3$storage_solid = TANstorage_solid • EFstorage_solid • 17/14 | Eq. 30 - EEA (2009a) |
| | | EFstorage_solid: 0.27 | Tab. 3-8 - EEA (2009a) |
| | field | $NH_3$applic_slurry = TANslurry_applic • EFapplic_slurry • 17/14 | Eq. 35 - EEA (2009a) |
| | | EFapplic_slurry: 0.55 | Tab. 3-8 - EEA (2009a) |
| | | $NH_3$applic_solid = TANsolid_applic • EFapplic_solid • 17/14 | Eq. 36 - EEA (2009a) |
| | | EFapplic_solid: 0.79 | Tab. 3-8 - EEA (2009a) |
| | | $NH_3$applic_fert =Nfert_applic • EFfert_type | Eq. 3 - EEA (2009b) |
| | | EFurea: 0.1067 + 0.0035 • Ts | Tab. 3-2 - EEA (2009b) |
| | | EFamm.nitr. and NPK: 0.0080 + 0.0001 • Ts | |
| NOx | manure storage | NOxstorage_solid = TANstorage_slurry • EFstorage_slurry • 17/14 | Eq. 29 - EEA (2009a) |
| | | EFstorage_slurry: 0.0001 | Tab. 3-9 - EEA (2009a) |
| | | NOxstorage_solid = TANstorage_solid • EFstorage_solid • 17/14 | Eq. 30 - EEA (2009a) |
| | | EFstorage_solid: 0.01 | Tab. 3-9 - EEA (2009a) |
| | field | NOxapplic_tot= (Nslurry_applic + Nsolid_applic + Nfert_applic) • EFapplic | |
| | | EFapplic: 0.026 | Tab. 3-1 - EEA (2009b) |
| $PO^{3-}_4$ | field | $P_{gw}$ (leached to ground water) = $P_{gwl}$ • $F_{gw}$ | Par. 4.4.3 - Nemecek et al. (2007) |
| | | $P_{gwl}$ arable land: 0.07 | |
| | | $P_{gwl}$ permanent pasture and meadow: 0.06 | |
| | | $F_{gw}$: 1+0.2/80 • $P_2O_5$slurry | |
| | | $P_{ro}$ (P lost through run-off to rivers) = $P_{rol}$ • $F_{ro}$ | |
| | | $P_{rol}$ open arable land: 0.175 | |
| | | $P_{rol}$ extensive meadow: 0.25 | |
| | | $F_{ro}$fert: 0.2/80 • $P_2O_5$fert | |
| | | $F_{ro}$slurry: 0.7/80 • $P_2O_5$slurry | |
| | | $F_{ro}$manure: 0.4/80 • $P_2O_5$manure | |

**Table 4.** Inventory of off-farm processes

| Process | References |
|---|---|
| Feed production | |
| *Crops* | Ecoinvent, 2007; Baldoni e Giardini, 2002; Ribaudo, 2002; data from this study |
| *Milk powder* | LCA food DK, 2007 |
| *Feed processing* | LCA food DK, 2007 |
| Forage production | Ecoinvent, 2007; Baldoni e Giardini, 2002; Ribaudo, 2002; data from this study |
| Bedding material production | Ecoinvent, 2007 |
| Rearing animals | data from this study |
| Fertilizer production | Patyk and Reinhardt, 1997; Ecoinvent, 2007 |
| Pesticide production | Ecoinvent, 2007 |
| Energy production | Ecoinvent, 2007 |
| Transportation | Ecoinvent, 2007 |

**Table 5.** Total environmental impacts expressed per kg of fat and protein corrected milk (FPCM) for the 28 dairy farms and on-farm contributions

| Environmental impact | Location | Mean | S.D. | Minimum | Maximum |
|---|---|---|---|---|---|
| Global warming, kg $CO_2$-eq. | Total | 1.26 | 0.17 | 0.90 | 1.56 |
| | On-farm % | 74.3 | 7.05 | 61.1 | 87.8 |
| Acidification, g $SO_2$-eq. | Total | 15.2 | 3.34 | 8.63 | 21.7 |
| | On-farm % | 86.6 | 5.60 | 70.1 | 94.9 |
| Eutrophication, g $PO_4$-eq. | Total | 7.33 | 1.39 | 5.00 | 9.69 |
| | On-farm % | 74.6 | 8.10 | 59.5 | 90.3 |
| Energy use, MJ | Total | 5.47 | 0.89 | 2.85 | 7.33 |
| | On-farm % | 43.3 | 12.5 | 22.9 | 72.1 |
| Land use, $m^2$ | Total | 0.95 | 0.16 | 0.59 | 1.24 |
| | On-farm % | 58.1 | 12.4 | 40.1 | 83.1 |

**Table 6**. Eigenvectors corresponding to the principal components retained for the 28 dairy farms (impacts expressed per kg of fat and protein corrected milk). The first 5 principal components had eigenvalues greater than 1

| | | **Prin 1** | **Prin 2** | **Prin 3** | **Prin 4** | **Prin 5** |
|---|---|---|---|---|---|---|
| Farm Land | ha | 0.07 | 0.33 | 0.29 | 0.00 | -0.52 |
| Maize land for silage | % land | 0.09 | 0.26 | -0.29 | -0.25 | 0.07 |
| Permanent grassland | % land | -0.18 | -0.19 | 0.05 | 0.44 | -0.07 |
| Dairy cows | n | -0.01 | 0.40 | 0.08 | -0.02 | -0.55 |
| Stocking density | n | -0.13 | 0.18 | -0.48 | -0.03 | -0.06 |
| Milk production | kg FPCM $cow^{-1}d^{-1}$ | -0.22 | 0.32 | 0.17 | 0.12 | 0.27 |
| Dairy efficiency | kg milk $kg^{-1}$ DMI | -0.20 | 0.27 | 0.23 | -0.01 | 0.33 |
| Feed self sufficiency | % total feed | 0.23 | -0.12 | 0.26 | -0.42 | 0.00 |
| Global warming total | kg $CO_2$-eq. | 0.30 | 0.00 | -0.14 | 0.35 | -0.06 |
| Global warming on-farm | kg $CO_2$-eq. | 0.32 | -0.09 | -0.14 | -0.03 | -0.10 |
| Acidification total | g $SO_2$-eq. | 0.27 | 0.28 | -0.08 | 0.07 | 0.17 |
| Acidification on-farm | g $SO_2$-eq. | 0.27 | 0.27 | -0.08 | -0.04 | 0.15 |
| Eutrophication total | g $PO_4$-eq. | 0.30 | 0.24 | -0.06 | 0.16 | 0.15 |
| Eutrophication on-farm | g $PO_4$-eq. | 0.32 | 0.19 | -0.04 | -0.13 | 0.10 |
| Energy use total | MJ | 0.25 | 0.00 | 0.09 | 0.38 | 0.24 |
| Energy use on-farm | MJ | 0.26 | -0.26 | 0.05 | -0.28 | 0.04 |
| Land use total | $m^2$ | 0.24 | -0.01 | 0.30 | 0.35 | -0.09 |
| Land use on-farm | $m^2$ | 0.25 | -0.20 | 0.34 | -0.06 | -0.03 |
| IOFC[1] | € $cow^{-1}d^{-1}$ | -0.13 | 0.23 | 0.42 | -0.16 | 0.23 |

[1]IOFC: Income Over Feed Cost

**Table 7.** Eigenvectors corresponding to the principal components retained for the 28 dairy farms (impacts expressed per ha). The first 4 principal components had eigenvalues greater than 1

| | | **Prin 1** | **Prin 2** | **Prin 3** | **Prin 4** |
|---|---|---|---|---|---|
| Farm Land | ha | -0.03 | 0.37 | 0.35 | -0.47 |
| Maize land for silage | % land | 0.20 | -0.05 | 0.40 | 0.15 |
| Permanent grassland | % land | -0.06 | 0.03 | -0.58 | -0.32 |
| Dairy cows | n | 0.11 | 0.34 | 0.30 | -0.49 |
| Stocking density | n | 0.31 | -0.08 | -0.08 | -0.10 |
| Milk production | kg FPCM $cow^{-1}d^{-1}$ | 0.12 | 0.46 | -0.20 | 0.17 |
| Dairy efficiency | kg milk $kg^{-1}$ DMI | 0.08 | 0.44 | -0.16 | 0.35 |
| Feed self sufficiency | % total feed | -0.21 | -0.08 | 0.41 | 0.25 |
| Global warming total | kg $CO_2$-eq. | 0.33 | -0.04 | -0.10 | -0.09 |
| Global warming on-farm | kg $CO_2$-eq. | 0.33 | -0.09 | -0.04 | -0.08 |
| Acidification total | g $SO_2$-eq. | 0.33 | 0.03 | 0.03 | 0.05 |
| Acidification on-farm | g $SO_2$-eq. | 0.32 | 0.02 | 0.06 | 0.06 |
| Eutrophication total | g $PO_4$-eq. | 0.34 | 0.02 | 0.02 | 0.01 |
| Eutrophication on-farm | g $PO_4$-eq. | 0.33 | 0.01 | 0.11 | 0.05 |
| Energy use total | MJ | 0.30 | 0.00 | -0.11 | 0.03 |
| Energy use on-farm | MJ | 0.22 | -0.28 | 0.10 | 0.18 |
| IOFC[1] | € $cow^{-1}d^{-1}$ | -0.04 | 0.48 | 0.02 | 0.37 |

**Table 8.** Characteristic of the clusters

| | | INTESITY LEVEL | | | | | |
|---|---|---|---|---|---|---|---|
| | | HIGH | | MEDIUM | | LOW | |
| | | Means | SD | Means | SD | Means | SD |
| Farm | | 10 | | 7 | | 11 | |
| Farm land | ha | 34.9 | 8.17 | 81.4 | 21 | 20 | 9.84 |
| Arable crops | % of total land | 54.1 | 17.4 | 61.7 | 20.2 | 34.5 | 25.6 |
| Maize for silage | % of total land | 45.7 | 18.6 | 38.5 | 13.3 | 26.9 | 22.5 |
| Livestock Unit | n | 157 | 37.1 | 258 | 36.1 | 55 | 21.5 |
| Stocking density | LU/ha | 4.71 | 1.44 | 3.31 | 0.8 | 2.97 | 0.67 |
| Daily milk production | kg FPCM $cow^{-1}$ | 28.9 | 2.03 | 28.1 | 2.29 | 24.7 | 5.66 |
| Production intensity | kg FPCM $ha^{-1}$ | 25917 | 9043 | 17771 | 4875 | 15439 | 4668 |
| Dry matter intake | kg $cow^{-1}d^{-1}$ | 21.22 | 1.3 | 21.2 | 1.92 | 12.0 | 2.12 |
| Dairy efficiency | kg milk $kg^{-1}$ DMI | 1.36 | 0.16 | 1.33 | 0.07 | 1.22 | 0.18 |
| Forage concentrate ratio | | 1.33 | 0.33 | 1.37 | 0.58 | 2.21 | 1.56 |
| Maize silage intake | % DMI | 30.41 | 6.84 | 34.7 | 3.04 | 22.75 | 17.3 |
| Grass hay intake | % DMI | 15.64 | 11.5 | 17.9 | 9.23 | 27.47 | 14.4 |
| Feed self sufficiency | % total feed | 54.63 | 10.4 | 69.2 | 12.5 | 71.72 | 14.4 |
| IOFC | € $cow^{-1}d^{-1}$ | 5.96 | 1.23 | 6.76 | 0.82 | 5.78 | 1.27 |

[1]IOFC: Income Over Feed Cost

**Table 9.** Environmental impacts expressed per kg of fat and protein corrected milk corresponding to each cluster of farms

| | | INTENSITY LEVEL | | | | | |
|---|---|---|---|---|---|---|---|
| | | HIGH | | MEDIUM | | LOW | |
| | | Mean | SD | Mean | SD | Mean | SD |
| Global warming. kg $CO_2$-eq. | Total | 1.26 | 0.17 | 1.27 | 0.13 | 1.25 | 0.21 |
| | On-farm | 0.90 | 0.13 | 0.95 | 0.09 | 0.96 | 0.21 |
| | Off-farm | 0.36 | 0.09 | 0.32 | 0.08 | 0.29 | 0.13 |
| Acidification. g $SO_2$-eq. | Total | 16.0 | 3.07 | 16.2 | 4.05 | 13.9 | 2.91 |
| | On-farm | 13.9 | 2.79 | 14.3 | 4.24 | 12.0 | 2.89 |
| | Off-farm | 2.13 | 0.51 | 1.94 | 0.48 | 1.86 | 1.09 |
| Eutrophication. g $PO_4$-eq. | Total | 7.59 | 1.24 | 7.71 | 1.10 | 6.86 | 1.63 |
| | On-farm | 5.45 | 0.82 | 5.96 | 1.38 | 5.23 | 1.65 |
| | Off-farm | 2.14 | 0.56 | 1.75 | 0.51 | 1.63 | 0.74 |
| Energy use. MJ | Total | 5.44 | 1.17 | 5.44 | 0.66 | 5.51 | 0.8 |
| | On-farm | 2.00 | 0.42 | 2.19 | 0.38 | 2.77 | 0.91 |
| | Off-farm | 3.44 | 0.98 | 3.25 | 0.54 | 2.74 | 1.01 |
| Land use. $m^2$ | Total | 0.89 | 0.16 | 1.02 | 0.18 | 0.97 | 0.14 |
| | On-farm | 0.44 | 0.13 | 0.59 | 0.14 | 0.64 | 0.14 |
| | Off-farm | 0.45 | 0.09 | 0.43 | 0.11 | 0.32 | 0.13 |

**Table 10.** Environmental impacts expressed per hectare corresponding to each cluster of farms

| | | INTENSITY LEVEL | | | | | |
|---|---|---|---|---|---|---|---|
| | | HIGH | | MEDIUM | | LOW | |
| | | Mean | SD | Mean | SD | Mean | SD |
| Global warming, kg $CO_2$-eq. | Total | 36269 | 10026 | 26094 | 8130 | 22475 | 5907 |
| | On-farm | 25992 | 7500 | 19384 | 5542 | 16935 | 3618 |
| | Off-farm | 10277 | 3088 | 6711 | 2845 | 5540 | 3442 |
| Acidification, g $SO_2$-eq. | Total | 464 | 154 | 316 | 56 | 252 | 85.5 |
| | On-farm | 404 | 141 | 276 | 63.5 | 216 | 66.6 |
| | Off-farm | 60.0 | 17.8 | 40.2 | 18.2 | 36.2 | 28.6 |
| Eutrophication, g $PO_4$-eq. | Total | 218 | 65.6 | 155 | 31.6 | 123 | 35.0 |
| | On-farm | 158 | 51.7 | 118 | 22.6 | 92.0 | 24.5 |
| | Off-farm | 60.3 | 18.2 | 37.1 | 19.8 | 30.7 | 18.3 |
| Energy use, MJ | Total | 152327 | 36184 | 111278 | 32997 | 99317 | 26930 |
| | On-farm | 56063 | 12714 | 43844 | 8653 | 47436 | 10663 |
| | Off-farm | 96264 | 28116 | 67434 | 26867 | 51881 | 30655 |