Links between profitability, nitrogen surplus, greenhouse gas emissions, and energy intensity on organic and conventional dairy farms

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Abstract

This study examines the relationships between profitability, nitrogen (N) surplus, greenhouse gas emissions (GHG), and energy intensity and factors influencing these relationships in dairy farming. In-depth data from 10 conventional and 8 organic dairy farms in Western Norway were analyzed. Organic farms had lower N surplus per hectare (local, on-farm) and per unit output (global, cradle-to-farm-gate), and lower estimated GHG emissions and energy intensity per unit output, whereas labor input and farm profits did not differ. Higher profitability tended to be associated with improved performance of the environmental indicators examined. Intensification through increased use of concentrates tended to improve profit and reduce N surplus, GHG emissions and energy intensity per unit output within each farming system while N surplus per hectare could be negatively affected. To ensure a balanced representation of the environmental consequences of both organic and conventional farming systems, our results give support to extensive examination of both area- and product-based environmental performance indicators.

Keywords: Profit; organic farming; environment; life cycle assessment; sustainability

Running head: Profit and environmental performance in dairying

Introduction

Do environmental friendly practices of a business improve its economic performance? Traditionally, economists and managers have argued that environmental protection restricts options and imposes additional costs for firms, which may erode their profitability and competitiveness. Some analysts challenge this view, suggesting that pollution is often a waste of resources (materials, energy, etc.) and that well-designed environmental regulations can encourage innovations that may offset the costs of policy compliance (Porter and van der Linde 1995). Hart and Ahuja (1996) predicted that with increasing awareness of constraints imposed by the natural environment, pollution prevention, product stewardship, and sustainable development would increasingly be a source of competitive advantage. A firm can gain competitive advantages by pursuing a low-cost strategy or by increasing the perceived value of their products and services. For example, green products such as organic food and fibers create price premiums in the market.

Understanding whether good environmental performance has any financial benefit can have important policy implications. Environmental problems have traditionally been treated as inconsistencies between social and private benefits and been left mainly to government intervention to solve them. However, if green strategies are profitable, firms have incentives to reduce their externalization of environmental burdens, and environmental problems may be solved with less policy intervention, leading to “win–win” relationships between the interests of business and the protection of the environment (Iwata and Okada 2011).

Meta-analyses and reviews synthesizing the available empirical evidence suggest on average a small positive association between environmental and economic performance in corporate firms (Albertini 2013; Endrikat, Guenther, and Hoppe 2014), with an overall correlation coefficient of around 0.10. Some studies have also found a negative relationship or yielded insignificant results. The relationship between environmental and economic performance was, for example, stronger for proactive rather than reactive approaches to environmental sustainability, it was influenced positively by less financial risk, and the association was dependent on the operationalization of both constructs (Endrikat, Guenther, and Hoppe 2014). These results suggest to go beyond the question “Does it pay to be green?” by exploring when, where and how greening is paying off.

Ambec and Lanoie (2008) noted that farms may be less likely to benefit from better environmental performance than other firms because farms produce fairly homogeneous goods, are not on the stock market, and have few if any employees. Empirical studies in agricultural production have nevertheless found positive relationships between profitability and lower greenhouse gas (GHG) emissions (Jan et al. 2012; O’Brien et al. 2015; Repar et al. 2016; Thomassen et al. 2009), less use of energy (Jan et al. 2012; Repar et al. 2016; Thomassen et al. 2009), and a lower eutrophication potential (Jan et al. 2012; Repar et al. 2016), all indicators measured per physical unit of output produced by the farm. The indicators expressed per unit produced has a global focus and should preferably include emissions from production of farm inputs, as well as the inputs on the actual farm (Halberg et al. 2005), e.g., by use of life-cycle assessment (LCA).

Area-based indicators linked to environmental issues with a local or regional target should include emissions from the farm only (Halberg et al. 2005). Most direct relationships between profitability and area-based environmental indicators in farming, such as nitrogen (N) and phosphorus balances (Mihailescu et al. 2015) and eutrophication and acidification potential (Repar et al. 2016; Thomassen et al. 2009), have been found to be insignificant.

The intensification of dairy production in recent decades, achieved in part by increased use of fertilizers and concentrates, has generated concern about its environmental impacts (von Keyserlingk et al. 2013). These concerns include nutrient losses that may contribute to water and air quality impairment at local and global scales, GHG emissions, biodiversity, and use of non-renewable natural resources such as land and energy.

Links among production practices, profit, and environmental outcomes are in general complex, but to improve sustainability of farming systems, we need to understand how various factors influence farm profit and the environment. An Irish study found that increasing milk production per hectare from grazed grass mitigates GHG emissions and improves profit (O'Brien et al. 2015). Studies of Swiss dairy farms have found that factors such as larger farms, full-time farming, organic farming, agricultural education, and less use of concentrates promote both farm profit and environmental impacts, such as eutrophication potential, GHG emissions, and use of non-renewable energy, per unit produced (Jan, Lips, and Dumondel 2011; Jan et al. 2014; Repar et al. 2018), and also when measured per hectare (Repar et al. 2018).

Knowledge also is sparse about the relationship between product-based versus area-based environmental outcomes. One Swiss dairy study did find complex relationships between several product and area-based environmental indicators (Repar et al. 2016), suggesting that exclusively focusing on product-based indicators related to global environmental problems could deteriorate local environmental concerns.

This study had two main aims. The first was to analyze the relationships between profitability, N surplus, GHG emissions, and energy intensity of dairy farms in Western Norway. The second was to identify determinants that influence these relationships. Organic compared to conventional dairy production is of special interest in this study because organic farming is often assumed to improve environmental performance as a result of less agrochemical and nutrient inputs. Other determinants included herd size, concentrate feeding, and nitrogen in purchasedinputs.

Our contributions to the literature are as follows: Both local areas-based (N balance per ha) and global product-based (N balance, GHG emissions, and energy intensity per unit output) environmental issues are considered. Links between profitability and local as well as global environmental performance indicators are examined based on comprehensive farm–environmental data, and the study deepens understanding of the links between environmental performances and profitability and factors affecting these relationships in a dairy farming context.

Materials and methods

Study location

The study was carried out in the county of Møre og Romsdal in Western Norway (Figure 1). The county is in a coastal area around 62-63° N, and the climate is quite humid. The landscape is dominated by mountains, valleys, and fjords. The annual normal precipitation varies from 1000 to 2000 mm, fairly evenly distributed throughout the year, with the highest values near the coast (Koesling, Hansen, and Bleken 2017). The coldest monthly average temperature is 2°C near the coast and -5°C in the valleys, and the warmest average temperatures are 14°C and 15°C, respectively.

[Figure 1 around here]In the indoor season, cattle are mainly fed forages and purchased concentrates. On cultivated area, only grass and grass-clover leys are grown. Grain can be used as cover crop when establishing new swards and harvested as silage. The grazing period is usually not more than 3 months for dairy cows and 4 months for heifers. They graze on fully and surface-cultivated land, native grassland, and free rangeland.

Data collection

Ten conventional and 10 certified organic dairy farms in Møre og Romsdal were selected to participate in the project. These farms were selected in 2009, from among 1200 dairy farms in the county that year. The selected farms differed in herd size, milk yield and farm area per cow, fertilization, and concentrate feeding to represent the variation found in the county. Of 13 organic dairy farms in the county, 10 were willing to participate. The main criteria for the conventional farms were that they were about the same size and had similar soil conditions and climate as the organic farms and were recommended by local farm advisors. Participation in the project occurred on a voluntary basis because of the complexity and comprehensiveness of the data collection.

Data from the farms were collected for the calendar years 2010 to 2012. We used average figures of the 3 years for each farm rather than performance from the single years, which can be more random because of uncontrollable events (such as the weather). Two organic farms did not provide sufficient financial data for 3 years. Therefore, only the 18 farms with complete data sets were included in the current study.

Production and environmental data were collected together with financial data, offering a unique possibility to examine relationships between profitability, N surplus, GHG emissions, and energy intensity and factors influencing these performances. The system under consideration encompassed all agricultural outputs as well as all inputs and processes necessary for production of these outputs. Non-agricultural parts of the farm, such as forestry (timber production) and on-farm diversification, were not included in the analysis to ensure that the dairy farm activities were homogenous in terms of production activities and to ease the farm comparisons.

Financial data collected and analyzed within the framework of the Norwegian Farm Business Survey (NFBS) were made available for each farm. The NFBS is the Norwegian equivalent of the Farm Accountancy Data Network in the European Union. A description of the accounting principles in the NFBS is found in NIBIO (2017, 138-139).

For more detailed production and environmental data, each year, schemes were collected after spring cultivation, first and second cuts, and after the growing season. The information collected included farm area, livestock numbers, cultivation, yields and number of grazing days on different areas, sale and purchase of manure, amount and type of manure applied, method of application, and weather conditions. Farm visits were used to introduce schemes and to collect information on machinery and buildings and to prepare a farm map. The feed demand for all animals on the farm was calculated for each year as net energy demand for calves, heifers, bulls, dry cows, and milking cows. Feed demand was calculated for each group based on breed, condition, weight, and milking yield using specific values for Norway (Olesen, Strøm, and Lund 1999).

The net forage yields were calculated from the feed demand. We assumed that the amount eaten corresponded to the energy demand. The energy demand from forage harvested on farm was calculated as the total energy demand for the different cattle groups minus energy taken up from concentrates, purchased forages, free rangeland, and on-farm grazing for these groups. Based on the energy demand, the dry matter (DM) uptake for the different cattle groups was calculated by dividing the energy demand by the energy content of the different feed stuffs. For each farm, the energy content for on-farm forages was calculated from fodder analyses, and for concentrates, it was based on amount of purchased concentrates and the corresponding energy content. Grazing uptake from farm pasture and free rangeland was calculated by multiplying days for each group on area by estimated daily feed uptake based on their energy demand (Olesen, Strøm, and Lund 1999). More details are available in Koesling, Hansen, and Bleken (2017a).

The amount of N in purchased inputs was calculated as quantity of purchased inputs from accounting data multiplied by the N content. For the inputs containing N, we used the declaration of contents when available, or the standard nutrient content. The DM and N contents of concentrates were calculated from information on the formulations for the different types given by a Norwegian supply cooperative (Felleskjøpet Agri). The average values for the organic and conventional farms in the investigation were used as estimates for the N content in purchased silage.

Profitability

Calculations for each revenue and cost item were performed per livestock unit (LU); see the Supplemental material for a description of the 6 revenue and 10 cost items used in this study. The supplemental material includes an overview of the various government payment schemes paid to Norwegian dairy farmers in 2010-2012. The LU provides a single unit for total size of the livestock enterprises and allows each farm to be compared based on the resulting revenue or cost per LU. Total LUs on a farm were calculated as follows: 1 dairy cow (+ replacers) = 700 kg beef output (culled cows excluded, adjusted for livestock sales and purchases) = 10 winter-fed sheep. The ratios are based on forage feed requirements.

Both family farms and partnerships were included in the study. Often, the operator and the farm family provide a substantial amount of the labor resource unpaid in family farms. In partnership farms, operator labor payments may be included as a labor cost in the financial records. To achieve comparability between the different forms of business organizations represented, we used return to total labor (paid as well as unpaid) to assess the profitability of the farms. Return to labor is a remuneration for management and labor that is left after all other costs (including costs for total farm assets) are deducted from the total revenue. Farm asset value for the year was found by averaging the beginning and ending total asset values from the farm balance sheets. The interest claims for farm asset values were set equal to the charge of 3% per annum rate used in the NFBS.

When making comparisons across farms, it is useful to control for differences in their resource base. Comparisons often are made based on the factor that gives the highest profit per unit of the most limiting input. Labor is often a scare resource for farm businesses in Norway. We expressed return to labor in NOK/h of labor input recorded (€ 1 ≈ NOK 7.46 in 2012). All monetary measures are 3-year averages for 2010–2012 and presented in 2012 prices (all economic variables were uprated according to the Consumer Price Index).

Environmental accounting

A range of environmental accounting frameworks, tools, and methods have been developed, including LCA, emergy analysis, and ecological footprint (Patterson et al. 2017). LCA is a tool for evaluating environmental effects of a product, process or activity throughout its life cycle or lifetime. Emergy[1] analysis evaluates diverse flows of energy and materials through systems using common units (emjoules) to provide a broad view of the impact of management choices on sustainability. The ecological footprint measures human demand on nature, i.e., the amount of land required to provide for everything people use. The footprint can be compared at the individual, regional, national or global scale. These and other environmental accounting tools are further assessed in Patterson et al. (2017).

According to Sala et al. (2017), more sustainable production requires a holistic approach and life cycle thinking is increasingly seen as a key concept for supporting this aim. Three environmental indicators were examined in this analysis: N surplus, GHG emissions, and energy intensity. We followed a combined global–local framework to measure environmental

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[1] Emergy is defined as all the available energy that is used in the work of making a product expressed in units of one type of energy (Odum 1996).

impacts (Repar et al. 2017). Global indicators, measured per unit produced, were assessed based on a cradle-to-farm-gate life-cycle approach, considering the environmental impact of the production chain from extraction of raw materials to produce farm inputs, to manufacturing of these inputs, to all on-farm-processes. The impacts were decomposed to their on- and off-farm parts.

The local indicator was estimated as the environmental impact generated on-farm per unit of farmland. Local measures are required only for impact categories that are primarily influential at the local ecosystem scale (Repar et al. 2017), i.e., on-farm N surplus in this study. The global impacts were quantified by dividing the cradle-to-farm-gate environmental impacts by kilojoules of metabolic energy in milk and meat produced or per kilogram of protein in the output, providing a common denominator between the output of both milk and meat on dairy farms.

The indicators were as follows: local area-based impacts: N surplus; global product-based impacts: N surplus; GHG emissions expressed as global warming potential (GWP); and energy intensity expressed as energy-use. The choice of metabolic energy and protein output for the global impacts reflects the primary function of the dairy system, which is to provide humans with food by supplying food energy and edible high-value protein. To compare milk from the different farms based on its energy content, the amount of milk mass was standardized to a kilogram of energy-corrected milk (ECM) (Sjaunja et al. 1990), based on the fat and protein content for the different farms. The energy content of the carcass was set at 6.47 MJ/kg (Heseker and Heseker 2013). For cattle, on average, 2.4% of live weight was estimated to be N (Andrew, Waldo, and Erdman1994). This value was multiplied by 53% of live weight (Olesen, Strøm, and Lund 1999) to obtain an estimate of the amount of N in lean tissues in the carcass and edible byproducts, which we refer to as N in meat.

N surplus

The on-farm N surplus is N imported to the farm through purchased inputs (concentrates, forages, fertilizers, manure, livestock, sawdust, and straw), biological N fixation (BNF), and atmospheric deposition minus N exported (N in sold milk, meat gain, and manure). To estimate the amount of N from BNF, we first estimated the net roughage yields, which were calculated from the estimated feed uptake for each cattle group. The amount of N fixated per hectare was estimated from the share of clover in the yield, the N content in clover, and the share of N in clover plant assumed to be taken up by BNF; see Koesling, Hansen, and Bleken (2017) for a further description of the calculations.

GHG emissions

Calculations of GHG emissions were carried out with the FARM model (Flow Analysis and Resource Management); Schueler, Hansen, and Paulsen (2018). The material and energy flows were assessed in a whole farm model, and GHG emissions were calculated based on the interactions from it. The model mainly follows IPCC methodology (IPCC 2006). All GHG emissions were expressed as CO_2 equivalents (CO_2-eq) to account for the GWP for the respective gases in a 100-year perspective (IPCC 2006), where CH_4 and N_2O have, on a weight basis, a GWP of 25 and 298 times that of CO_2, respectively.

The following GHG sources were included: **cattle-derived emissions** (enteric CH_4, CH_4, and N_2O from animal excretes by grazing, indirect N_2O from NH_3 volatilization in the stable and during grazing); **emissions from storing manure** (CH_4, N_2O, and indirect N_2O from NH_3 volatilization); **forage production** (direct and indirect N_2O emissions from crop residues, fertilizer, and manure application; CO_2 emissions after liming; and CO_2, CH_4, and N_2O emissions from fuel combustion on farm); **feed import** (emissions from production of purchased concentrates and forage in CO_2-eq.); **supply chain** (emissions from production of fertilizers and lime (CO_2-eq), from production of electricity, silage foil, and pesticides, all in CO_2-eq); **transport to farm (**in CO_2-eq); **building materials** (in CO_2-eq) and **machinery materials** (in CO_2-eq). Estimates of GHG emissions from production of goods in the supply chain are CO_2-eq, given in the ecoinvent database (Frischknecht and Rebitzer 2005). Because of the large uncertainty in the estimates, soil C sequestration in grasslands or rangeland, CH_4 emissions from soil or CH_4 oxidation in soil, and CO_2, N_2O, and CH_4 from cultivation of peat soil were not included in GHG emission estimates given in the present paper.

Energy intensity

To describe the amount of primary energy used to produce the farm output, embodied energy from inputs were used. Embodied energy was calculated as the sum of all non-renewable and renewable energy resources from cradle-to-farm-gate, except manpower and solar radiation, for production of inputs from cradle-to-farm gate using an LCA approach; see Koesling, Hansen, and Schueler (2017) for a further description.

The use of agricultural area and amount of embodied energy (MJ kg^{-1}) of each ingredient in purchased concentrates was taken from Nemecek et al. (2011). The additional energy demand for transportation was calculated using ecoinvent v3.2 (Weidema et al. 2013) in regard to the quantity transported, distance from the country of origin to the reseller for the farmers in the project, and different types of transportation used. For all other purchased inputs, the embodied energy was calculated from the cumulative energy demand from ecoinvent v. 3.2.

For the different buildings, a 'bottom-up' approach was used to calculate the amount of embodied energy for the building materials in the envelope of the buildings, estimating a 50-year lifetime (Koesling et al. 2015). The building envelope is defined as materials used to construct and enclose the main external and internal building parts, such as the ground and intermediate floors, walls, building structure, roof framing, and roofing material. Embodied energy in technical equipment in the barns and in building materials was added.

For machinery, a record was prepared for each farm, including the type of machinery, brand, model, weight, and year of fabrication and purchasing. Machinery was categorized into the groups for agriculture according to ecoinvent V2.2 (Hischier and Weidema 2010) as follows: tillage machinery, slurry tanker, trailer, tractor, and other agricultural machinery. To calculate the amount of embodied energy per year, the amount of embodied energy was divided by the expected service life for the corresponding category (Koesling, Hansen, and Schueler 2017).

Factors influencing farm performance

Several factors influence farm performance. We examined decisions related to use of inputs and structural characteristics because such factors are of particular importance to gain insight into the link between profitability and environmental performance of dairy farms. The effects of the following factors were analyzed: farming system (organic or conventional), herd size (LUs), concentrate feeding (FUm/cow/y), and purchased N inputs (kg N/ha). The factors are defined in Table 1 (descriptive statistics).

Data analysis

Statistical analyses were carried out with SAS 9.3 (SAS Institute, Cary, NC, USA). To begin, we checked the distributional properties of the variables using PROC UNIVARIATE. Some of the variable distributions were skewed, asymmetrical, heavy-tailed, or with strong outlier observations. Non-parametric tests perform better when the data are not normally distributed, and these tests are particularly suitable for small sample sizes (Kitchen 2009). In normally distributed data, there is also little power loss associated with non-parametric tests. Non-parametric statistical procedures were therefore used in this study. Statistical significance is reported for $p < 0.10$, but small samples may result in too little statistical power for the test to identify significant results, the risk of making Type II errors (false-negative finding) increases, and several true relationships may not be discovered.

Descriptive statistics of production parameters, revenue and cost items, profitability, and environmental performance indicators were calculated for all farms and for the organically and conventionally managed herds presented as distinct groups. Descriptive analysis results are expressed as means, medians, and standard deviations for all farms and the two distinct groups, and the 10th and 90th percentiles are given for all farms. For measuring the relationships between profitability and the environmental indicators, we used the Spearman's rank correlation coefficient (r_S), which is a nonparametric measure of association based on the ranks of the data values.

Multivariate regression techniques are often used to simultaneously account for the myriad of factors that influence performance. Small samples (< 20 observations) are, however, appropriate for analysis only by regression with a single explanatory variable (Hair et al. 2006, 195). Therefore, we used bivariate analysis to determine the empirical relationship between each performance indicator and each explanatory variable considered. The Wilcoxon rank sum test within PROC NPAR1WAY was used to test if the two independent groups of conventional and organic farms differed with respect to the median values (Pappas and DePuy 2004). Exact tests were performed. To assess the relationships between continuous variables (use of inputs and herd size) and performance measures, we computed Spearman rank correlation coefficients.

Systematic differences in environmental impacts between organic and conventional systems can bias the correlation analyses (Mu et al. 2017), and we explored the correlations both for all farms and for the conventional and organic farms presented as distinct groups.

Results

Descriptive statistics

Table 1 shows descriptive statistics of the agricultural practices and financial and environmental profiles for all farms and for the conventional and organic farms presented as distinct groups. Descriptive details about percentiles for all farms and means and standard deviations for conventional and organic farms are found in Supplemental Table S.1.

[Table 1 around here]

Average performance indicates that herd size across all farms was 29.6 dairy cows, yielding 7213 kg ECM/cow/y, obtaining NOK 4.81/L, drawing upon 2214 FUm/cow/y of concentrates (Table 1). The average farmland-weighted value was 35.6 ha, yielding about 2900 kg DM/ha/y. Average beef output was 188 kg carcass weight (CW)/cow/y, obtaining NOK 37 to 38/kg CW. Total labor input was 3912 h/farm/y, or 143 h/LU/y. Total revenues averaged NOK 54881/LU/y, of which milk constituted 49%, government payments 35%, and calf and cattle 13%. Major cost groups were concentrates and machinery. Accounting for total costs of NOK 38019/LU/y left a return to labor of NOK 16862/LU/y, equating to NOK 120/h.

The average environmental performance were an N surplus of 156.5 kg N/ha or 7.69 kg N/kJ energy output, GHG emissions of 0.45 kg CO_2-eq/kJ energy output, and an energy intensity of 2.40 kJ input/kJ energy output (Table 1). Results per kilogram protein output are also shown in Table 1. The product-based indicators, either expressed per kilojoule energy output or per kilogram protein output, were generally highly correlated (Supplemental Table S.2), suggesting that the two specifications provided consistent results. The only exception was the energy intensity measures on organic farms ($r_s = 0.38$). For practical discussion, we focus on measures per kilojoule energy output, unless otherwise stated. Correlation results for measures per kilogram protein output are found in the Supplemental Tables S.2 and S.3.

Both profitability and environmental performance variables exhibited high ranges of variation between farms (Supplemental Table S.1). Return to labor ranged from NOK 59/h (P10) to 183/h (P90). The variation in environmental performance was particularly wide for local N surplus, with a range from 59 to 280 kg N/ha.

Comparing conventional and organic farms

Key differences emerged in the comparison of conventional and organic dairy farms. Not surprisingly, organic farms had lower purchased N inputs (kg N/ha) and used less concentrate/cow (Table 1). The lower input intensity of organic systems resulted in lower yields; median organic grass yield/ha was 85%, and median organic milk yield/cow was 74% of conventional yields, respectively; they filled less of their milk quota, and few organic farms kept and finished the dairy bull calves. Organic farms achieved significantly higher prices for their milk, but not for the sales value of cattle, and they received additional governmental payments through schemes to support maintenance of organic farming. On average for organic farms, these schemes constituted 15% of the government payments. Fewer inputs were used on the organic farms, and some of their variable costs (purchased feeds, forage variable costs, and veterinary and medicine) were significantly lower than for conventional farms. Labor input (in total or per LU) did not distinguish conventional from organic farms. In sum, there was no significance difference between the two groups in terms of profit measured as hourly return to labor, but with wide variations within the systems.

All environmental performance indicators differed significantly between the conventional and organic farms (Table 1). The median N surplus/ha of conventional farms was 2.6 times higher than for organic farms (199.1 vs. 77.3 kg N/ha; $p = 0.003$). Expressed per kilojoule of energy output, the median N surplus was still 2.5 times higher for conventional farms (10.6 vs. 4.22 kg N/kJ energy output; $p = 0.003$). Both median GHG emissions and energy intensity were around 1.3 times higher for conventional than organic farms ($p = 0.031$ for both).

Relationships between profitability, N surplus, GHG emissions, and energy intensity

The results of the correlations between profitability and the environmental performance indicators are shown in Table 2, for all farms and for the conventional and organic farms presented as distinct groups.

[Table 2 around here]

For all farms, there was a significant negative monotonic correlation between return to labor and GHG emissions ($r_s = - 0.40$; $p < 0.1$), i.e., financially successful farming was associated with lower GHG emissions. The coefficient in question was of the same magnitude for the separate conventional and organic groups, but the smaller samples made it more difficult to identify significant results. The other profit-environment relationships were insignificant, despite economically relevant strengths of the negative correlations (all $|r_s| > 0.20$) between profitability and the product-based indicators of N surplus and energy intensity. N surplus/ha showed weaker negative correlations ($|r_s| < 0.20$) with profitability for all farm groupings.

The analysis of the link between the environmental performance indicators showed high correlations between all global product-based indicators for all farms ($r_s > 0.70$; $p < 0.01$), as well as in the separate groups.

The only significant correlation between area and product-based indicators in the total sample was for the two N surplus measures ($r_s = 0.75$; $p < 0.01$). The significance and magnitude of this relationship vanished, however, for either conventional ($r_s = -0.07$) or organic farms ($r_s = 0.21$) considered separately. The reason is that organic farms performed better than conventional farms on both indicators, and the correlation would consequently be larger for the combined group than for either conventional or organic farms (Figure 2), cf. Mu et al. (2017). In the separate samples, N surplus/ha was negatively correlated with GHG emissions and energy intensity. The strength of the insignificant correlations was up to -0.50 for the link between N surplus/ha and energy intensity for organic farms.

[Figure 2 around here]

The performance parameters of each farm illustrated by the three categories (+, 0, −) are shown in Table 3. For N surplus/ha, the best conventional farm could not match the worst-performing organic farm (Figure 2). Therefore, no conventional farm could achieve ‘+’ on all parameters. The two most profitable organic farms performed well on all environmental parameters, showing that farms with low environmental impact can also be financially successful. The opposite was also found, with high environmental loads and low profitability, in particular for a few conventional farms. Some farms did also perform well (or worse) in economics but worse (better) in one or several of the environmental dimensions. Finally, some farms performed well in some environmental dimensions and poorly in others.

[Table 3 around here]

Determinants

The results of the analysis of the factors affecting profitability and the environmental performance indicators are shown in Table 4 (farming system effects are reported in Table 1).

[Table 4 around here]

When the impact of all farms was examined, the Spearman’s rank correlation analyses did not show any significant correlations between herd size and any of the profitability or environmental performance indicators. For conventional farms, however, increasing herd size was associated with a higher N surplus/ha ($r_s = 0.73$; $p < 0.05$). For organic farms, there was a much stronger association between larger farms and lower emissions of GHG/kg protein output ($r_s = -0.69$; $p < 0.10$) than GHG measured per energy output ($r_s = -0.19$; Supplemental Table S.3).

For all farms, more of purchased N inputs had a significantly negative impact on all environmental indicators except GHG emissions. We observed no significant correlation between N input and profitability. For the farming system groups considered separately, most of the significant effects vanished. The only significant relationship was between N input and N surplus/ha for conventional farms ($r_s = 0.94$; $p < 0.01$).

For all farms, more use of concentrates per cow significantly increased the N surplus per ha and per unit of output. No significant relationships were found for the other performance indicators. When examining the distinct groups, the significant correlation between concentrate feeding and N surpluses remained only for product-based N surplus for conventional farms. Several other significant associations emerged. For conventional farms and for organic farms, when measured per kg protein output, higher concentrate feeding was associated with lower energy intensity.

Few of the determinants (beyond farming system) demonstrated significant synergies or trade-offs with respect to the improvement of both profitability and the environmental performance. Only greater concentrate feeding in organic farms significantly reduced GHG emissions and increased farm profit.

Discussion

Discussion: conventional and organic farms

In the current work, organic farming was associated with lower environmental intensity than conventional farming for all impact categories assessed. The differences in environmental performance were driven by higher N application rates and more use of other N inputs on conventional than organic farms, leading to higher estimated GHG emissions stemming from production of fertilizers etc., and N_2O emissions from the soil. Higher N input per hectare resulted in a higher production of both forage and milk per hectare on conventional farms, but this increase could not outweigh a much higher N surplus on an area and product base. Because the production of fertilizers is energy demanding, the use of fertilizers also contributed to more use of embodied energy.

Production of milk and beef is closely linked. In the LCA in this study, as recommended by Cederberg and Stadig (2003), we used system expansion rather than allocation. Although less GHG was emitted per produced unit energy in milk and meat on organic than on conventional farms, there were no significant differences per unit produced milk when emissions were allocated between milk and meat (Schueler, Hansen, and Paulsen 2018), stemming from higher total GHG emissions per unit produced meat in conventional than organic farms.

A meta-analysis has shown that organic farming in Europe has generally lower environmental impacts per unit of production area than conventional farming, but because of lower animal and crop yields, this pattern is not always the case when expressed per unit of output (Tuomisto et al. 2012). In dairy production, the reviews by Tuomisto et al. (2012) and van Wagenberg et al. (2017) found lower energy use and N surpluses (or eutrophication potential) per unit of output in organic compared to conventional farms. GHG emissions were in most cases higher for organic milk in Tuomisto et al. (2012) because lower organic milk yields resulted in higher enteric methane emission per unit milk. Van Wagenberg et al. (2017) found, on average, the same GHG emissions per unit milk for organic and conventional systems. Other studies in mountainous dairy environments have found lower (or similar) GHG emissions for organic compared to conventional farms (Jan et al. 2014; Salvador et al. 2016).

It is widely assumed that organic farms require more work than conventional farms (Crowder and Reganold 2015). The current study could not, however, confirm an overall difference in labor use, supporting observations of similar or less labor input per hectare on organic dairy farms in England (Lobley, Butler, and Reed 2009). Organic profit matched conventional profit (on average 123 cf. 118 NOK/hour, respectively), taking organic price premiums and government payments into account. Other studies comparing the economics of organic with conventional milk production have also found that organic premiums cover the additional costs of organic production (McBride and Greene 2009) or that organic production is more profitable (Jan et al. 2014). Without additional government payments for organic farming, the mean profit in the organic system would be lowest (NOK 97/hour) in the current study. In fact, withdrawal of all government support payments would have resulted in a negative return to labor in both organic and conventional farms, showing that the survival of dairy farms in Norway depends on the agricultural support policy through the provision of public environmental and social benefits valued by the society.

Discussion: Relationships between profitability, N surplus, GHG emissions, and energy intensity

The only statistically significant profitability-environment relationship in the current study was between higher profitability and lower GHG emissions in the full sample. This finding is consistent with the general conclusion in the empirical “pay to be green” literature (Albertini 2013; Endrikat, Guenther, and Hoppe 2014) and studies in the farming sector (Fenollosa et al. 2014; Jan et al. 2012; O’Brien et al. 2015; Repar et al. 2016; Thomassen et al. 2009). This result supports the “win–win” hypothesis of a positive relationship between environmental and economic performance (Porter and van der Linde 1995). Our correlations between profitability and the other product-based indicators (N surplus and energy intensity) were statistically insignificant. The magnitude of the correlation coefficients also in the separate groups (r_s = 0.22 to 0.53) was higher than mean correlations (r = 0.09) observed in meta-studies (Albertini 2013; Endrikat, Guenther, and Hoppe 2014), however, and quite close to significant correlations (r_s = 0.24 to 0.33) between profitability and the same global environmental performance indicators as ours in a similar study of Swiss dairy farms (Repar et al. 2016). The statistical insignificance of many performance correlations in our study should be assessed in light of the small sample used in the analysis.

The relationship between profit and N surplus/ha in our study was weaker than for the global environmental performance indicators. Of interest, few significant correlations between profit and N surplus or eutrophication potential per hectare have been found in other dairy studies (Mihailescu et al. 2015; Repar et al. 2016; Thomassen et al. 2009).

We found strong and positive correlations among all of the global environmental performance indicators. Part of the strong global environmental performance relationships (for the conventional farms in particular) stems from higher use of N fertilizer, resulting in an increased N surplus, as well as increased energy intensity and GHG emissions during pre-farm and on-farm activities. This result indicates that improvements to one of the global environmental performance indicators would help to improve the general global environmental performance of a dairy farm. Similar findings of strong relationships between global environmental performance indicators in dairy farming have been reported in Battini et al. (2016), Guerci et al. (2013), and Mu et al. (2017).

The tendencies to negative relationships between N surplus per hectare and between GHG emissions and energy intensity are consistent with findings of trade-offs between global and local environmental impacts in studies of Swiss alpine dairy farms (Repar et al. 2016). Negative correlations between local and global environmental performance indicators imply that improvement in global environmental performance will worsen local environmental problems and vice versa. The complex relationships between global and local environmental performance indicators suggest that the multifaceted environmental pillar cannot be reduced to a single "one size fits all" indicator (Repar et al. 2017).

Even though positive relationships between profitability and (global) environmental performance should be established, some farms will not fit into a generalized pattern. Every farm is different, so generating widely applicable results and relationships can be hard. In the current study, the high variability among the farms in the ranking of the parameters (Table 3) illustrates these arguments.

Discussion: Determinants

Greater concentrate feeding (in the group of organic farms) was the only factor significantly associated with higher profitability and one environmental improvement (lower GHG emissions). Organic farming and less purchased N inputs (for all farms) had several desirable environmental effects but no significant effects on profitability. Our lack of synergies is in contrast with the findings of Jan, Lips, and Dumondel (2011), Jan et al. (2014), and Repar et al. (2018), who found synergies between profit and environmental performance indicators (including eutrophication potential, GHG emissions, and use of energy) by increasing herd size and by promoting organic farming.

Our analysis could not confirm that the most profitable farmers operate larger dairy herds, as identified in previous studies (e.g., McBride and Greene 2009; Repar et al. 2018). The current study rather suggests that size does not have an important effect on profit, but it should be noted that smaller herds in Norway receive more support per unit of output than the larger ones. The data also showed a wide spread in performance for small and larger herds, suggesting both that smaller farms can be top performers and that large size is not a guarantee of profitability. Our environmental findings support Potter and Lobley (1993) in that there is little evidence to suggest a functional relationship between farm size and environmental sensitivity. The exception was a link between larger herds and a higher N surplus per hectare in conventional farms.

Greater concentrate feeding involves additional costs but do also increase milk yield at a diminishing rate. This study found no adverse effect on profitability of the reported levels of concentrate feeding. In fact, for the organic sample, more use of supplementary feed was significantly associated with higher profitability. It may be that some organic farmers fed less concentrates than the economic optimum, related to limits of the use of concentrates in the feed ration by the organic legislation or for ethical reasons to reduce concentrate supplementation. Other European studies have found greater concentrate feeding to decrease profitability (Jan, Lips, and Dumondel 2011; O'Brien et al. 2015; Repar et al. 2018). For the separate conventional and organic samples, the global environmental impacts (N balance, GHG emissions, and energy intensity) tended to decrease as the use of concentrates increased, as also suggested by Battini et al. (2016) and Guerci et al. (2013), whereas N surplus/ha tended to increase. In contrast, Jan Lips, and Dumondel (2011), O'Brien et al. (2015) and Repar et al. (2018) found higher concentrate supplementation to increase environmental burdens.

High N input/ha was associated with higher N surplus/ha. One contribution to this particularly strong finding for conventional farms was a high positive correlation between input of N fertilizers and N surplus, whereas increased used of N fertilizers has not been found to be positively associated with increased forage yields (Koesling, Hansen, and Bleken 2017).

Limitations and future research

When interpreting the results of this study, several caveats need to be taken into account. The empirical evidence is local, derived from dairy farms in Western Norway in the years 2010–2012 using a specific research design. One should be careful in extrapolating the results to other regions or to other countries. The observations were not selected at random, with limitations regarding representativeness. The sample was necessarily small because of the extensive data collection from each farm, and the small sample size restricted analytical options and model specificity. Variation in performance is driven by a host of influences, so the bivariate analyses may be confounded by other factors that obscure the ‘real’ effect of a determinant on outcome.

Particularly, it is difficult to get comprehensive estimates of GHG emissions in such farm studies. The activity data and emission factors used have large uncertainties. The IPCC methodology are meant for national inventories and do not incorporate effects of agronomic practices such as grazing density, drainage conditions, pH, etc. (IPCC 2006). A Monte Carlo simulation for these farms within the uncertainty range given by IPCC (2006) showed that the estimated variations in CO_2 and N_2O emissions between the farms were larger than the uncertainty of the calculated results (Schueler et al. 2018). However, other factors that are not included in the present study like soil C sequestration, uptake and emissions of CH_4 from soil, and emissions of CO_2, N_2O and CH_4 from cultivation of peat soil, may alter the real net GHG emissions between the farms. Therefore, the results are valid for the GHG estimates included in this study, but not for real net GHG emission from these farms.

Numerous studies have suggested that profitability critically depends on the managerial ability (Nuthall 2009) and socio-demographic factors (Repar et al. 2018). Our study did not include any observations of managerial ability or socio-demographic information, which may also be determinants of environmental performance. One challenge associated with impacts of managerial ability is that there is no simple way to measure it. Although the main structure of the selected farms was the same, local environmental conditions will vary, such as distance to fields, angle of slopes, soil type, and local climate. These factors may also influence profitability and the environmental performance.

Our sample consisted of data from a 3-year period, and the duration may not be long enough to identify the long-run relationship between environmental performance and profitability. Longitudinal studies may be a promising future research approach.

Dairy farming has a multitude of environmental impacts beyond the environmental problems examined here, such as the value of landscapes, impact on biodiversity, use of land, pesticides, water, and plastic, soil quality, and potential environmental impacts of nutrients other than N. Studies into these and other environmental aspects at both the local and global scales are needed to assess relationships among a larger set of indicators. The current LCA method is however incomplete and does not comprehensively assess some environmental aspects that are critical for long-term sustainable food production, e.g., decreased soil quality and fertility, increased erosion, reduced ecosystem services due to intensification, and biodiversity loss (Sala et al. 2017). LCA modelling could therefore be complemented by knowledge coming from other approaches in order to gain a more complete picture of the environmental impacts of farming systems, e.g., by use of emergy analysis (Alfaro-Arguello et al. 2010). The economic pillar can be supplemented by measures dealing with liquidity and solvency (Zorn et al. 2018). Finally, our work omitted the third dimension of sustainability, namely social issues such as the well-being of farmers and rural communities, the quality of life of farm workers, and animal welfare. Improvements in both profitability and environmental performance might negatively influence farm performance regarding social issues. To improve the sustainability of dairy farming, the social factors affecting the sustainability of dairy farming systems must also be addressed. This issue is, however, a demanding one because there is no clear consensus on the measurement of social performance (Ambec and Lanoie 2008).

Conclusions

This study contributes to the understanding of how dairy farmers can find win–win solutions for both their farm profits and the environment. The results of the analysis of extensive data from 18 farms – 10 conventional and 8 organic – over a 3-year period found that organic farms performed better on the examined local (N surplus per hectare) and global environmental indicators (N surplus, GHG emissions, and energy intensity per unit output produced). For forage and milk yields, conventional farms outperformed organic farms, whereas farm profits did not differ.

We found that all the global environmental indicators, and to a lesser extent N surplus per hectare, tended to have a positive relationship with profitability. This relationship implies that by improving profitability, farmers will also improve their environmental performance and vice versa. As one example, the main factor that improved profitability and reduced GHG emissions, in particular for organic farms, was greater concentrate feeding per cow. This finding suggests a farm management strategy that provides a win–win solution, allowing farmers to improve their profitability while also mitigating GHG emissions (on the condition that the use of supplementary feed does not exceed the economic optimum). However, we also found that as farming systems intensified the use of inputs (N purchased/ha and concentrates/cow) and increased production per unit of land or livestock, they performed environmentally worse in N surplus per hectare.

Furthermore, our results showed strong positive correlations between the impacts of the global environmental performance indicators s. The relationships between the global indicators and N surplus per hectare were more complex, with several observations of no or negative relationships. These results suggest that exclusively focusing on either the global or local dimension of farm environmental performance can compromise the environmental evaluation of livestock systems because it will not account for potential negative effects on other environmental impacts. Systematic considerations of both local area-based and global product-based dimensions are needed to ensure a balanced representation of the environmental consequences.

This study did not consider all relevant aspects of sustainability, such as measures of social issues. Broader and more comprehensive approaches than in previous work are needed to include and combine the economic, social, and environmental aspects of sustainability of dairy farms and their determinants. Future studies of the overall sustainability of farms should also include socio-demographic information of the producers and assess what kind of managerial abilities farmers should have to improve several aspects of sustainability.

Supplemental material

Supplemental data for this article can be accessed here.

References

Albertini, E. 2013. Does environmental management improve financial performance? A meta-analytical review. *Organization & Environment* 26 (4):431–457. doi:10.1177/1086026613510301.

Ambec, S., and P. Lanoie. 2008. Does it pay to be green? A systematic overview. *Academy of Management Perspectives* 22 (4):45–62. doi:10.5465/AMP.2008.35590353.

Andrew, S. M., D. R. Waldo, and R. A. Erdman. 1994. Direct analysis of body composition of dairy cows at three physiological stages. *Journal of Dairy Science* 77 (10):3022–3033. doi:10.3168/jds.S0022-0302(94)77244-1.

Battini, F., A. Agostini, V. Tabaglio, and S. Amaducci. 2016. Environmental impacts of different dairy farming systems in the Po Valley. *Journal of Cleaner Production* 112 (1):91–102. doi:10.1016/j.jclepro.2015.09.062.

Cederberg, C., and M. Stadig. 2003. System expansion and allocation in life cycle assessment of milk and beef production. *The International Journal of Life Cycle Assessment* 8 (6):350–356. doi:10.1007/BF02978508.

Crowder, D. W., and J. P. Reganold. 2015. Financial competitiveness of organic agriculture on a global scale. *Proceedings of the National Academy of Sciences of the USA* 112 (24):7611–7616. doi:10.1073/pnas.1423674112.

Endrikat, J., E. Guenther, and H. Hoppe. 2014. Making sense of conflicting empirical findings: A meta-analytic review of the relationship between corporate environmental and financial performance. *European Management Journal* 32 (5):735–751. doi.org/10.1016/j.emj.2013.12.004.

Fenollosa, M. L., J. Ribal, A. Lidón, I. Bautista, R. Juraske, G. Clemente, and N. Sanjuan. 2014. Influence of management practices on economic and environmental performance of crops. A case study in Spanish horticulture. *Agroecology and Sustainable Food Systems* 38 (6):635–659. doi:10.1080/21683565.2014.896302.

Frischknecht, R., and G. Rebitzer. 2005. The ecoinvent database system: a comprehensive web-based LCA database. Journal of Cleaner Production 13 (13–14):1337–1343. doi:10.1016/j.jclepro.2005.05.002

Guerci, M., M. T. Knudsen, L. Bava, M. Zucali, P. Schönbach, and T. Kristensen. 2013. Parameters affecting the environmental impact of a range of dairy farming systems in Denmark, Germany and Italy. *Journal of Cleaner Production* 54:133–141. doi:10.1016/j.jclepro.2013.04.035

Hair, J. F. Jr., W. C. Black, B. J. Babin, R. E. Anderson, and R. L. Tatham. 2006. *Multivariate data analysis, 6th ed*. Upper Saddle River, NJ: Pearson Education.

Halberg, N., H. van der Werf, C. Basset-Mens, R. Dalgaard, and I. J .M. de Boer. 2005. Environmental assessment tools for the evaluation and improvement of European livestock production systems. *Livestock Production Science* 96 (1): 33–50. doi.org/10.1016/j.livprodsci.2005.05.013

Hart, S. L., and G. Ahuja. 1996. Does it pay to be green? An empirical examination of the relationship between emission reduction and firm performance. *Business Strategy and the Environment* 5 (1):30–37. doi:10.1002/(SICI)1099-0836(199603)5:1<30::AID-BSE38>3.0.CO;2-Q.

Heseker, B., and H. Heseker. 2013. Die Nährwerttabelle, 2. ed. Neuer Umschau Buchverlag, Taunus.

Hischier, R., and B. Weidema (Eds.). 2010. Implementation of life cycle impact assessment methods. Final Report Ecoinvent v2.2 No. 3. Swiss Centre for Life Cycle Inventories, Dübendorf.

IPCC, 2006. IPCC guidelines for national greenhouse gas inventories. In: Prepared by the National Greenhouse Gas Inventories Programme. IGES, Japan. Volume 4: Agriculture, Forestry and Other Land Use.

Iwata, H., and K. Okata. 2011. How does environmental performance affect financial performance? Evidence from Japanese manufacturing firms. Ecological Economics 70 (9):1691–1700. doi:10.1016/j.ecolecon.2011.05.010.

Jan, P., D. Dux, M. Lips, A. Alig, and M. Dumondel. 2012. On the link between economic and environmental performance of Swiss dairy farms of the alpine area. *International Journal of Life Cycle Assessment* 17 (6):706–719. doi:10.1007/s11367-012-0405-z.

Jan P., D. Dux, M. Lips M., M. Alig, and D. U. Baumgartner. 2014. Analysis of the determinants of the economic and environmental performance of Swiss dairy farms in the alpine area. Proceedings of the 9th International Conference LCA Food, 8-10 October 2014, San Francisco, USA, 595–605.

Jan, P., M. Lips, and M. Dumondel. 2011. Synergies and trade-offs in the promotion of the economic and environmental performance of Swiss dairy farms in the mountain area. *Yearbook of Socioeconomics in Agriculture* 4 (1):135–161.

Kitchen, C. M. R. 2009. Nonparametric versus parametric tests of location in biomedical research. *American Journal of Ophthalmology* 147 (4):571–572. doi:10.1016/j.ajo.2008.06.031.

Koesling, M., G. Ruge, G. Fystro, T. Torp, and S. Hansen. 2015. Embodied and operational energy in buildings on 20 Norwegian dairy farms - introducing the building construction approach to agriculture. *Energy and Buildings* 108C:330–45. doi:10.1016/j.enbuild.2015.09.012.

Koesling, M., S. Hansen, and M. A. Bleken. 2017. Variations in nitrogen utilisation on conventional and organic dairy farms in Norway. *Agricultural Systems* 157:11–21. doi:10.1016/j.agsy.2017.06.001.

Koesling, M., S. Hansen, and M Schueler. 2017. Variations of energy intensities and potential for improvements in energy utilisation on conventional and organic Norwegian dairy farms. *Journal of Cleaner Production* 164:301–314. doi:10.1016/j.jclepro.2017.06.124.

Lobley, M., A. Butler, and M. Reed. 2009. The contribution of organic farming to rural development: an exploration of the socio-economic linkages of organic and non-organic farms in England. *Land Use Policy* 26 (3):723–735. doi:10.1016/j.landusepol.2008.09.007.

McBride, W., and C. Greene. 2009. Costs of organic milk production on U.S. dairy farms. *Review of Agricultural Economics* 31 (4):793–813. doi:10.1111/j.1467-9353.2009.01467.x.

Mihailescu, E., W. Ryan, P. N. C. Murphy, I. A. Casey, and J. Humphreys. 2015. Economic impacts of nitrogen and phosphorus use efficiency on nineteen intensive grass-based dairy farms in the South of Ireland. *Agricultural Systems* 132:121–132. doi:10.1016/j.agsy.2014.09.008.

Mu, W., C. E. van Middelaar, J. M. Bloemhof, B. Engel, and I. J. M. de Boer. 2017. Benchmarking the environmental performance of specialized milk production systems: selection of a set of indicators. *Ecological Indicators* 72:91–98. doi:10.1016/j.ecolind.2016.08.009.

Nemecek, T., K. Weiler, K. Plassmann, and J, Schnetzer. 2011. Geographical extrapolation of environmental impact of crops by the MEXALCA method. Agroscope Reckenholz-Tänikon Research Station ART, Zürich.

NIBIO (Norsk institutt for bioøkonomi). 2017. Driftsgranskingar i jord- og skogbruk. Rekneskapsresultat 2016. Norsk institutt for bioøkonomi, Oslo.

Nuthall, P. 2009. Modelling the origins of managerial ability in agricultural production. *Australian Journal of Agricultural and Resource Economics* 53 (3):413–436. doi:10.1111/j.1467-8489.2009.00459.x.

O’Brien, D., T. Hennessy, B. Moran, and L. Shalloo. 2015. Relating the carbon footprint of milk from Irish dairy farms to economic performance. *Journal of Dairy Science* 98 (10):7394–7407. doi:10.3168/jds.2014-9222.

Odum, H. T. 1996. Environmental accounting: EMERGY and environmental decision making. New York: John Wiley.

Olesen, I., T. Strøm, and V. Lund. 1999. *Økologisk husdyrhald*. Oslo: Landbruksforlaget.

Pappas P. A., and V. DePuy. 2004. An overview of non-parametric tests in SAS: when, why, and how. SESUG 2004: The Proceedings of the SouthEast SAS Users Group, Nashville, TN 2004: TU04.

Patterson, M., G. McDonald, and D. Hardy. 2017. Is there more in common than we think? Convergence of ecological footprinting, emergy analysis, life cycle assessment and other methods of environmental accounting. *Ecological Modelling* 362:19–36. doi.org/10.1016/j.ecolmodel.2017.07.022

Porter, M. E., and C. van der Linde. 1995. Toward a new conception of the environment-competitiveness relationship. *Journal of Economic Perspectives* 9 (4):97–118. doi:10.1257/jep.9.4.97.

Potter, C., and M. Lobley. 1993. Helping small farms and keeping Europe beautiful: a critical review of the environmental case for supporting the small family farm. *Land Use Policy* 10 (4):267–279. doi:10.1016/0264-8377(93)90037-B.

Repar, N., P. Jan, T. Nemecek, D. Dux, M. A. Ceesay, and R. Doluschitz. 2016. Local versus global environmental performance of dairying and their link to economic performance: a case study of Swiss mountain farms. *Sustainability* 8 (12):1294. doi:10.3390/su8121294.

Repar, N., P. Jan, D. Dux, T. Nemecek, and R. Doluschitz. 2017. Implementing farm-level environmental sustainability in environmental performance indicators: A combined global-local approach. *Journal of Cleaner Production* 140 (2):692–704. doi:10.1016/j.jclepro.2016.07.022.

Repar, N., P. Jan, T. Nemecek, D. Dux, and R. Doluschitz. 2018. Factors affecting global versus local environmental and economic performance of dairying: a case study of Swiss mountain farms. *Sustainability* 10 (8):2940. doi.org/10.3390/su10082940.

Sala, S., A. Anton, S. J. McLaren, B. Notarnicola, E. Saouter, and U. Sonesson. 2017. In quest of reducing the environmental impacts of food production and consumption. *Journal of Cleaner Production* 140 (2): 387–398. doi.org/10.1016/j.jclepro.2016.09.054.

Salvador, S., M. Corazzin, E. Piasentier, and S. Bovolenta. 2016. Environmental assessment of small-scale dairy farms with multifunctionality in mountain areas. *Journal of Cleaner Production* 124:94–102. doi:10.1016/j.jclepro.2016.03.001.

Schueler, M., S. Hansen, and H.M. Paulsen. 2018. Discrimination of milk carbon footprints from different dairy farms when using IPCC Tier 1 methodology for calculation of GHG emissions from managed soils. *Journal of Cleaner Production* 177:899–907. doi:10.1016/j.jclepro.2017.12.227.

Sjaunja, L.-O., L. Bævre, L. Junkkarinen, J. Pedersen, and J. Setälä. 1990. A Nordic proposal for an energy corrected milk (ECM) formula. 27th session of the International Committee for recording the productivity of Milk Animals (ICRPMA), p. 156–157.

Thomassen, M. A., M. A. Dolman, K. J. van Calker, and I. J. M. de Boer. 2009. Relating life cycle assessment indicators to gross value added for Dutch dairy farms. *Ecological Economics* 68 (8-9):2278–2284. doi:10.1016/j.ecolecon.2009.02.011.

Tuomisto H. L., I. D. Hodge, P. Riordan, and D. W. Macdonald 2012. Does organic farming reduce environmental impacts?—A meta-analysis of European research. *Journal of Environmental Management* 112:309–320. doi:10.1016/j.jenvman.2012.08.018.

Van Wagenberg, C. P. A., Y. de Haas, H. Hogeveen, M. M. Van Krimpen, M. P. M. Meuwissen, C. E. Van Middelaar, and T. B. Rodenburg. 2017. Animal Board Invited Review: Comparing conventional and organic livestock production systems on different aspects of sustainability. *Animal* 11 (10):1839–1851. doi:10.1017/S175173111700115X.

von Keyserlingk, M. A. G., N. P. Martin, E. Kebreab, K. F. Knowlton, R. J. Grant, M. Stephenson, C. J. Sniffen, J. P. Harner III, A. D. Wright, and S. I. Smith. 2013. Invited review: Sustainability of the US dairy industry. *Journal of Dairy Science* 96 (9):5405–5425. doi:10.3168/jds.2012-6354.

Weidema, B. P., C. Bauer, R. Hirschier et al. 2013. Overview and Methodology. Data Quality Guideline for the Ecoinvent Database Version 3. Ecoinvent Report 1(v3). St. Gallen.

Zorn, A., M. Esteves, I. Baur, and M. Lips. 2018. Financial ratios as indicators of economics: A quantitative analysis for Swiss dairy farms. *Sustainability* 10 (8):2942. doi.org/10.3390/su10082942

Table 1

Descriptive statistics for all farms and for conventional and organic farms as distinct groups

Variable	All farms (N = 18)			Conv. (n = 10)	Organic (n = 8)	*p* value[a]
	Mean	Median	STD	Median	Median	
Farm characteristics						
Farmland (ha)[b]	35.6	26.8	24.6	28.1	24.1	0.515
Forage yield (kg DM[c]/ha)	2908	2825	836	3091	2631	0.043
N_{in}[d] (kg N/ha)	158.5	154.3	102.4	220.9	60.5	0.000
No. of dairy cows[e]	29.6	21.9	17.1	23.2	20.2	0.633
No. of livestock units (LU)	33.8	24.5	20.1	26.7	22.5	0.573
Milk production (kg ECM/cow)	7213	7773	1830	8258	6106	0.002
Milk quota (1000 L)	210.6	161.0	140.3	171.9	126.9	0.408
Milk quota fulfillment (%)	93.2	98.5	13.7	100.7	90.5	0.068
Concentrates (FUm[f]/cow)	2214	2361	775	2679	1451	0.002
Cow replacement rate (%)	38.8	39.7	9.3	41.0	38.8	0.264
Stocking rate (LU/ha)	1.02	0.97	0.33	0.99	0.92	0.515
Beef output (kg CW[g] per cow)	187.8	175.2	71.7	209	139	0.027
Milk price (NOK/L)	4.81	4.78	0.37	4.52	5.15	0.000
Price culled cows (NOK/kg CW)	37.12	37.90	2.51	38.29	37.42	1.000
Price other cattle (NOK/kg CW)	38.23	40.10	8.03	41.29	39.80	0.460
Total labor used (h)	3912	4009	658	4009	3822	0.633
Financial performance (NOK/LU)						
Total revenues	54881	55091	7397	56135	51837	0.315
Milk	26823	27675	6113	28034	24767	0.408
Calf and cattle	7346	6547	2543	8154	5732	0.012
Crops	722	429	1073	390	466	0.965
Government payments	17964	18771	5120	18105	19094	0.762
Organic government payments	1422	0	1662	0	3053	
Other incomes	605	575	1025	625	386	0.460
Total costs	38019	39626	8134	39626	38687	0.515
Concentrates	10006	10079	2469	10723	8371	0.203
Other purchased feeds	1461	620	2027	388	1368	0.033
Forage variable costs	1668	1543	1201	2510	309	0.002
Veterinary and medicine	1330	1396	383	1553	1022	0.002
Other variable costs	2298	2063	1052	2063	2142	0.762
Farm machinery	8375	8115	3242	9022	7099	0.762
Farm buildings	3976	3126	2652	4411	2032	0.146
General overheads	4745	4654	891	4382	4791	0.068
Land and milk quota	1573	1132	1425	1151	865	0.515
Interest	2586	2351	1374	2375	1975	0.515
Return to labor (NOK/LU)	16862	19424	7516	18748	19909	0.633
Total labor input (h/LU)	143	165	56	151	179	0.408
Return to labor (NOK/h)	120	118	46	107	118	0.965
Environmental performance						
N surplus (kg N/ha)	156.5	157.7	84.4	199.1	77.3	0.003
N surplus (kg N/kJ energy output)	7.69	8.40	3.35	10.6	4.22	0.003
GHG (kg CO_2-eq/kJ energy output)	0.450	0.447	0.066	0.500	0.385	0.031
Energy intensity (kJ input/kJ energy output)	2.40	2.23	0.46	2.70	2.03	0.031
N surplus (kg N/kg protein output)	0.671	0.693	0.298	0.908	0.358	0.003
GHG (kg CO_2-eq/ kg protein output)	39.23	39.78	6.508	44.12	31.90	0.044
Energy intensity (kJ input/ kg protein output)	209.4	191.0	43.15	236.6	178.4	0.026

[a] The difference between conventional and organic farms based on Wilcoxon rank-sum non-parametric test (two-sided) using the EXACT option within the PROC NPAR1WAY in SAS

[b] Weighted land area = fully cultivated land + 0.6 × surface cultivated land + 0.3 × native grassland, to compensate for the differences in the potential yield on these types of land

[c] DM (dry matter)

[d] N_{in} is the total amount of nitrogen in purchased inputs: concentrates, forages, fertilizers, manure, livestock, sawdust, and straw, expressed in kg N/ha/y

[e] Cow-years: each cow is included from the date of first calving until the date of culling.

[f] 1 FUm = 6900 kJ NE1, where NE1 is the net energy for lactation. FUm is equivalent to the net energy of 1 kg barley with 86% DM.

[g] CW (carcass weight)

Table 2
Spearman rank correlations between profitability and the environmental performance indicators

Variables	1	2	3	4	5
All farms (N = 18)					
1. Return to labor (NOK/h)	1.000				
2. N surplus (kg N/ha)	-0.152	1.000			
3. N surplus (kg N/kJ energy output)	-0.216	0.746^{***}	1.000		
4. GHG (kg CO$_2$-eq/kJ energy output)	-0.400^{*}	0.387	0.705^{***}	1.000	
5. Energy intensity (kJ/kJ energy output)	-0.321	0.395	0.787^{***}	0.831^{***}	1.000
Conventional farms (n = 10)					
1. Return to labor (NOK/h)	1.000				
2. N surplus (kg N/ha)	-0.188	1.000			
3. N surplus (kg N/kJ energy output)	-0.273	-0.067	1.000		
4. GHG (kg CO$_2$-eq/kJ energy output)	-0.527	-0.261	0.661^{**}	1.000	
5. Energy intensity (kJ/kJ energy output)	-0.455	-0.103	0.939^{***}	0.721^{**}	1.000
Organic farms (n = 8)					
1. Return to labor (NOK/h)	1.000				
2. N surplus (kg N/ha)	-0.191	1.000			
3. N surplus (kg N/kJ energy output)	-0.453	0.214	1.000		
4. GHG (kg CO$_2$-eq/kJ energy output)	-0.476	-0.071	0.595	1.000	
5. Energy intensity (kJ/kJ energy output)	-0.262	-0.500	0.571	0.333	1.000

Note. *$p < 0.10$; **$p < 0.05$; ***$p < 0.01$

Table 3
Profitability and environmental performance of the 18 individual farms. Ranked by declining return to labor.

	Profit per hour	Environment per hectare	per kJ of output		
Farm type	Return to labor	N surplus	N surplus	GHG emissions	Energy intensity
CONV	+	−	0	0	0
ORG	+	+	+	+	+
ORG	+	+	+	+	+
CONV	+	−	−	0	0
CONV	+	0	−	−	−
CONV	+	0	−	−	−
CONV	0	0	0	0	+
ORG	0	+	+	+	+
ORG	0	0	0	+	0
ORG	0	0	+	+	+
ORG	0	+	+	−	−
CONV	0	−	−	−	−
CONV	−	0	0	−	0
CONV	−	−	0	0	0
ORG	−	+	0	0	+
CONV	−	−	−	0	−
ORG	−	+	+	+	0
CONV	−	−	−	−	−

Note. ‘+’ favorable(best third); ‘0’ average (middle third); ‘−’ unfavorable (weakest third).

Table 4

Effect of herd size and use of inputs on profitability and the environmental performance indicators (Spearman rank correlation coefficients)

	Return to labor (NOK/h)	N surplus (kg/ha)	N surplus (kg/kJ energy output)	GHG (kg CO_2-eq/kJ energy output)	Energy intensity (kJ/kJ energy output)
All farms (N = 18)					
No. of livestock units (LU)	-0.028	0.379	0.315	-0.156	0.106
N_{in} (kg N/ha)[a]	-0.077	0.940^{***}	0.785^{***}	0.373	0.474^{**}
Concentrates (FUm/cow)	0.298	0.686^{***}	0.472^{**}	0.146	0.167
Conventional farms (n = 10)					
No. of livestock units (LU)	-0.248	0.733^{**}	0.200	-0.115	-0.139
N_{in} (kg N/ha)[a]	-0.127	0.939^{***}	-0.001	-0.212	-0.006
Concentrates (FUm/cow)	0.309	0.430	-0.588^{*}	-0.358	-0.685^{**}
Organic farms (n = 8)					
No. of livestock units (LU)	0.357	0.071	0.381	-0.381	0.238
N_{in} (kg N/ha)[a]	0.048	0.429	0.524	-0.262	0.143
Concentrates (FUm/cow)	0.786^{**}	0.191	-0.190	-0.691^{*}	-0.190

Note. $*p < 0.10$; $**p < 0.05$; $***p < 0.01$

[a] N_{in} is the total amount of nitrogen in purchased inputs: concentrates, forages, fertilizers, manure, livestock, sawdust, and straw, expressed in kg N/ha per year.

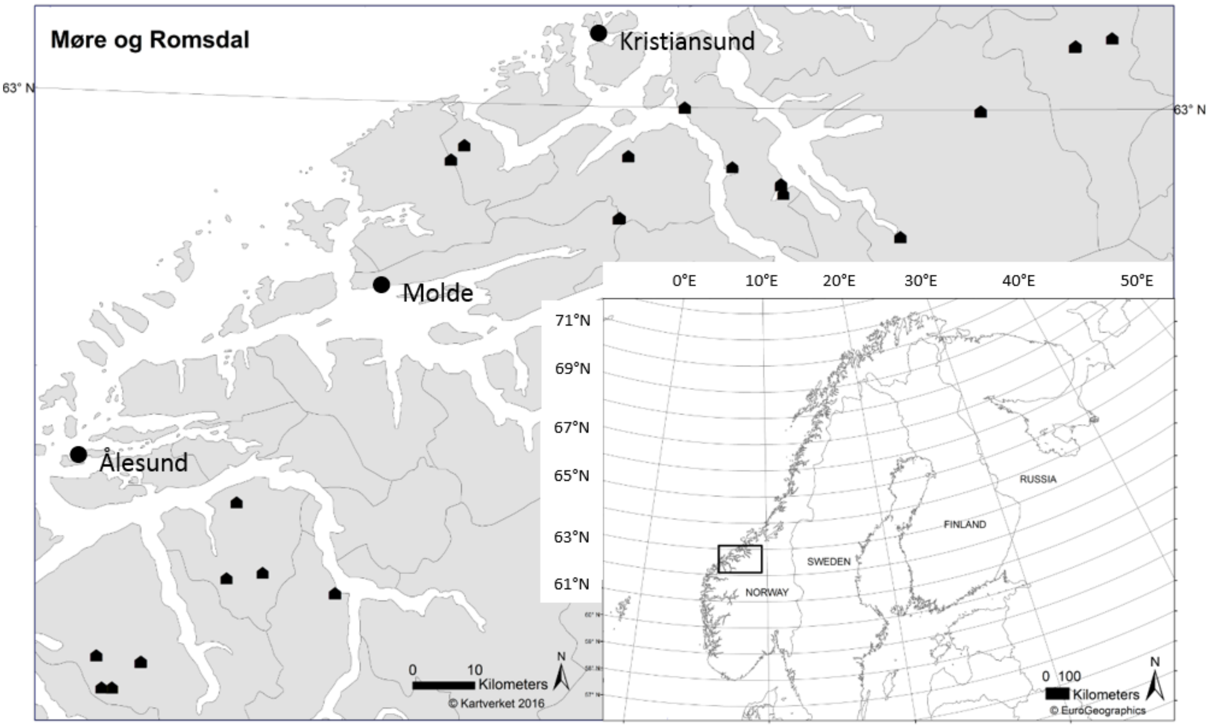

Figure 1.
Studied area: Map of Møre og Romsdal county and locations of the selected farms

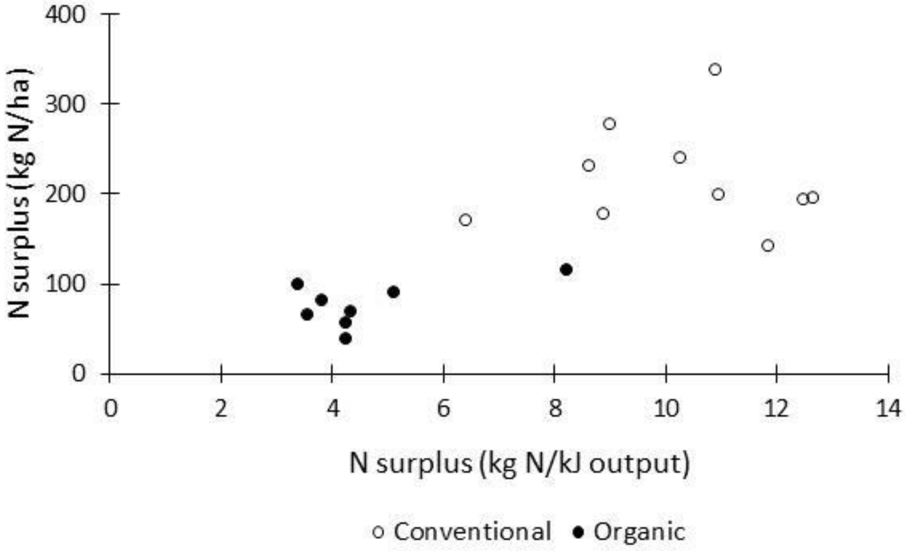

Figure 2.
Combining organic and conventional farms affects the correlation coefficient between N surplus per ha and per kJ energy output (r_{all} = 0.75; r_{conv} = -0.07; r_{org} = 0.21)