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Comparison of Greenhouse Gas Emissions, Nitrogen Intensity, Gross Margin, and Land Use Occupation between Conventional and Organic Dairy Farms

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In this study, 200 Norwegian dairy farms were analyzed over three years to compare greenhouse gas emissions, nitrogen (N) intensity, gross margin, and land use occupation between organically and conventionally managed farms. Conventionally managed farm groups were constructed based on propensity matching, selecting the closest counterparts to organically managed farms (n=15). These groups, each containing 15 farms, were differentiated by an increasing number of matching variables. The first group was matched based on geographical location, milk quota, and milking cow units. In the second match, the proportion of milking cows in the total cattle herd was added, and in the third, the ratio of milk delivered to milk produced and concentrate usage per dairy cow were included. The analysis showed that the conventionally managed farms (n=185) had higher greenhouse gas emissions (1.42 vs 0.98 kg CO2 per 2.78 MJ of edible energy from milk and meat, calculated as GWP100-AR4) and higher N intensity (6.9 vs 5.0 kg N input per kg N output) compared to the organic farms (N=15). When comparing emissions per kg of energy-corrected milk (ECM) delivered, conventional farms also emitted more CO2 (1.07 vs 0.8 kg CO2 per kg ECM). Furthermore, conventionally managed farms showed lower gross margins both in terms of NOK per 2.78 MJ edible energy delivered (5.8 vs 6.5 NOK) and per milking cow unit (30 100 vs 34 400 NOK), and they used less land (2.9 vs 3.6 m² per 2.78 MJ edible energy delivered) compared to organic farms. No differences were observed among the three conventionally managed groups in terms of emissions, N intensity, land use occupation, and gross margin.

Key words: propensity matching, life cycle assessment, norwegian dairy farms

Introduction

Greenhouse gas (GHG) emissions and other environmental impacts, as well as gross margin on dairy farms are influenced by various farming management practices, within both conventional and organic production (Asgedom and Kebreab 2011). The relative distribution between conventional and organic farms can be important because of potential differences in environmental impact between the two-farm managements. A better understanding of the impact of management form on GHG emissions from dairy farms could therefore be important in reducing the sector's overall GHG emissions, since dairy farming alone is calculated to contribute with 2.5% of the total annual anthropogenic GHG emissions (IPCC 2019b). According to Gerber et al. (2013), the livestock sector's GHG emissions are mainly caused by enteric methane emissions, which amounts to 46% of the sector's total GHG emissions. The second largest contribution of GHG emissions (36%) is from feed production. This includes emissions from pasture management, which are dominated by nitrous dioxide emissions from manure and mineral fertilizers.

Determining whether conventional or organic dairy farming has a better environmental and economic performance is challenging. There are categorical differences between the two farming systems, due to different production regulations, which in turn result in different farm structures (IFOAM 2006, Lovdata 2022). While most countries have regulations that apply to all farms, there are additional regulations for certified organic production. The organic standards prohibit certified organic farms to use synthetic pesticides and artificial fertilizers and place restrictions on the import of organic nutrients and feed, stocking density, and the proportion of concentrates in the feed ration (Lovdata 2022). In addition, the farm groups compared need to have similar environmental conditions, such as average temperature, precipitation, and soil characteristics. Secondly, the ratio between dairy

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cows and fattening animals can vary between farms, giving different environmental impacts. Thirdly, the need of replacement heifers may differ between the two groups. A lower share of replacement heifers needed gives a higher relative share of animals which can be used to produce meat. Producing more meat can affect the emissions and be measured when the environmental impact is divided on edible energy delivered. Further, the concentrate feeding intensity often differs between the two farming systems, based on goals of the organic farmers and the current organic regulation.

The assessment and comparison of greenhouse gas emissions per product unit on dairy farms has been a focus of many studies (e.g. Cederberg and Mattsson 2000, Haas et al. 2001, Kristensen et al. 2011). Some of these studies observed lower GHG emissions per produced unit on organic than on conventional farms (Cederberg and Mattsson 2000, Kassow et al. 2009, Frank et al. 2019) and some did not observe any difference between the two management per unit of energy corrected milk delivered (De Boer 2003, Thomassen et al. 2008, Kristensen et al. 2011, Pirlo and Lolli 2019). To further complicate matters, some studies observed higher emissions on organic farms when the authors did not use any allocation or when they applied economic allocation between meat and milk production (Kristensen et al. 2011, Flysjö et al. 2012). The differences in estimated GHG emissions may be influenced by the allocation rules, due to differences in milk yield and meat production between organic and conventional farms. When using biophysical allocation, the relationship between milk and meat-production and their associated net metabolic energy requirements for each is taken into consideration, by removing the associated emission from meat production.

To address these issues, some studies have employed matching techniques to minimize structural differences between the farming systems (Hansen et al. 2021, Lambotte et al. 2023). This allows for testing of isolated environmental and economic effects between organic and conventional production. Norwegian dairy farming is a multipurpose system, with production of both milk and meat for the market. This implies that the functional unit should either be based on allocation between milk and meat or expressed in a unit that both milk and meat contain, without any need for allocation. We present most results related to the functional unit 2.78 MJ edible energy in milk and meat delivered (2.78 MJMM). To ease comparability with other studies, we present some results related to one kg of energy corrected milk (kg ECM = 2.78 MJ edible energy). For this functional unit, the environmental impacts of milk and meat production were allocated based on net metabolic energy requirements for milk and meat production, as described in material and methods.

Nitrogen intensity (N intensity) is an important indicator of the general environmental performance. N intensity can be defined as the ratio between nitrogen used from all production inputs and nitrogen in milk and meat delivered. Earlier studies revealed that conventionally managed dairy farms often have higher N intensity or lower N efficiency (the inverse function) compared to organically managed farms (Olesen et al. 2006, Chmelíková et al. 2021). In a Norwegian study of dairy farms, Koesling et al. (2017a) found that the N-surplus per unit N-produced at farm level was 6.3 kg N per kg N in conventional farms versus 4.2 kg N per kg N in organic ones. The main nitrogen sources on organic farms are usually imported fodder, imported manure, or biological nitrogen fixation by legumes (Power and Doran 1984).

Conventional farms normally occupy less land than organic farms to produce the same amount of milk (van Wagenberg et al. 2017). This can be explained by higher forage yields and more use of purchased concentrates (Alvarez 2022). There are divergent findings for gross margin per produced unit between organic and conventional farms (Nicholas et al. 2004). Some of the contradicting results in economic performance have been found to be affected by sample selection, and differences between direct payments for organic farming between countries (Hansen et al. 2021).

The objective of this study was to evaluate the effect of organic and conventional dairy farms on environmental and economic indicators. Results for estimated GHG emissions are presented for two different functional units, one related to 2.78 MJ edible energy in milk and meat (2.78 MJ_{MM}) and the other related to one kg energy corrected milk (kg ECM = 2.78 MJ edible energy), with biophysical allocation between milk and meat. Other indicators are agricultural land use occupation (m^2 [2.78 MJ_{MM}]$^{-1}$), N intensity (kg N [kg N]$^{-1}$) and gross margin (NOK [2.78 MJ_{MM}]$^{-1}$). The impact of GHG emissions were calculated for $GWP_{100\text{-}AR4}$, based on the construction of comparable conventionally and organically managed groups of farms using propensity matching with nearest neighbours.

Materials and methods

Farms and production data

Data were collected from 345 dairy farms located in the two counties Møre og Romsdal and Trøndelag in central Norway. All farms participated in TINE Advisory Service's economic assessment (TAS), where data from the Norwegian Dairy Herd Recording System are combined with farm accountancy data. TAS is a voluntary service, accessible to all farmers who deliver milk to the cooperative dairy company TINE SA (cooperative dairy company). The system is meant to assist farmers in improving decision making for their production.

Criteria for inclusion of farms in this study were that the farms participated in all fiscal years from 2014 to 2016, and that there were no changes in cow housing (e.g., from tie stall to loose housing) or milking system (e.g., from conventional to automatic milking system) during the period. We ended up with records from a total of 200 farms. The removed farms (n=145) had a change in structure during the years 2014–2016. The remaining farms maintained a similar farm structure throughout the study. The climate in the region is humid, with annual precipitation ranging from 800 to 2000 mm. The precipitation is relatively evenly distributed throughout the year, with the highest annual precipitation in coastal regions. The region has an average temperature in July and August of about 15 degrees Celsius. The coldest month is February, with an average range in temperature from 0 degrees to –5 degrees Celsius (Dannevig 2019).

The mean and variation in herd size as numbers of dairy cows, milk yield per cow, farm area per cow, nitrogen fertilisation level, forage share in diet, and economic outcome of the study farms are presented in Table 4. Of the 200 farms, 15 were certified for organic production, while the remainder were conventionally managed. Seventy-eight farms had milking robots, while 122 farms had conventional milking systems, whereas 84 had tie-stall barns and 116 had loose housing. Of the 200 farms, 40 were joint venture farming operations while 160 were single farm enterprises. Milking cow units (MCU) were calculated from the total number of feeding days for cows in the herd divided by 365 (TAS 2011). MCU is standardised to an annual NEL requirement of 42 000 MJ (Animalia 2017). One MCU corresponds to the energy requirement of a cow with a liveweight of 600 kg, including foetal growth and the production of 8000 kg milk. Other animal groups are calculated with this as reference.

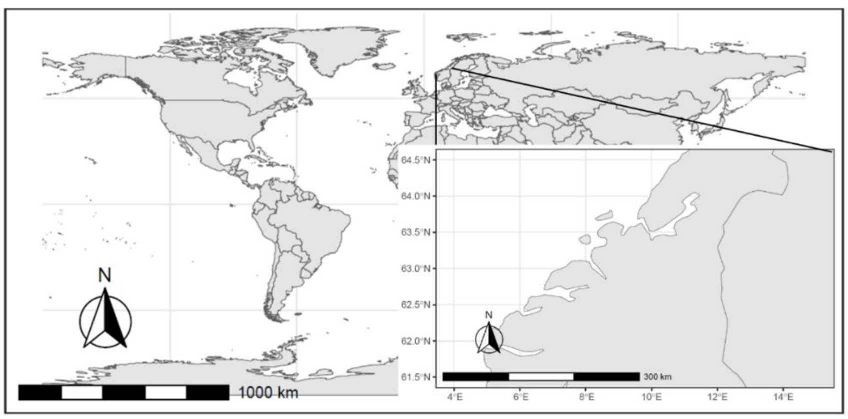

Fig. 1. Area in which the farms used in the dataset were located

Farm areas

Arable land and permanent pastures comprise the total farmed area of a dairy farm (DF). Free rangeland, consisting of native woodland or alpine vegetation, can solely be utlized by grazing livestock. Off-farm area refers to agricultural land used for producing forage or concentrate ingredients imported by the farms. Both off-farm and free rangeland areas supplement the dairy farm (DF) as shown in Figure 2, but the rangeland is not included in agricultural land use occupation. Land use occupation is defined as the sum of off-farm area, arable land, and permanent pasture on the dairy farm needed for milk and meat production (DS). Only products and inputs that were relevant for milk and meat production are included in the study.

In the region where the current study was performed, dairy cows typically graze for up to three months, while heifers can graze four months per year. The dairy cows and heifers graze on arable land (ley), permanent pasture, and free rangeland (Fig. 2), depending on each dairy farm's structure. During the indoor season, animals are fed preserved, farm-produced forage, mainly silage, and imported roughages and concentrates. On farm arable areas, grass and grass-clover leys are grown, and cereals are occasionally used as cover crop when establishing new leys and subsequently harvested as whole crop silage.

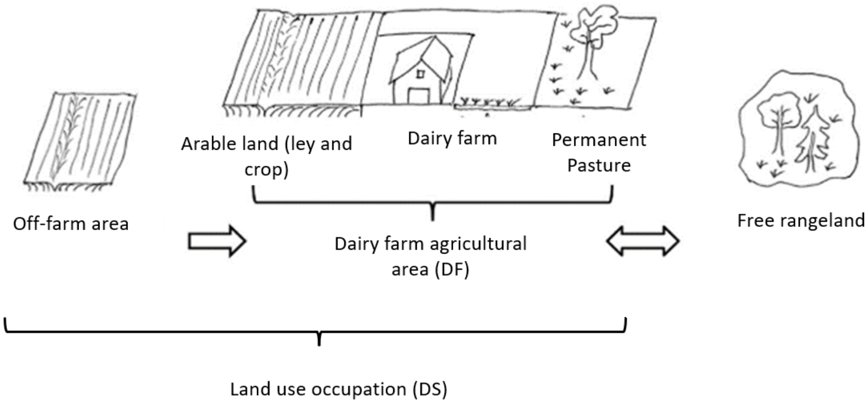

Fig. 2. The different categories of areas included in the calculation of land use occupation in this study

Purchased inputs

To convert the farm accountancy data for purchased products to physical quantities, we used annual agricultural prices, published by the Norwegian FADN (Norwegian account statistics for agriculture and forestry) (Hjukse 2017). The amount of the different ingredients in concentrates and their origin, was calculated based on information from the Norwegian Agricultural Purchasing and Marketing Co-operation (Felleskjøpet), for the region studied and the average product formulation over the three years. Based on this information, the amounts of concentrates for each conventionally and organically managed farm for the different ingredients from different origin were calculated as the basis for the LCA calculations. Data on the quantity and type of fertilisers sold during the project period were also acquired from the Norwegian Agricultural Purchasing and Marketing Co-operation and used in the calculation of purchased fertiliser for each conventional farm.

Calculating the environmental performance

The different indicators for the environmental performance for each of the 200 farms were calculated for delivered milk and meat at farm gate, using the FARMnor model (Schueler et al. 2019). FARMnor can be used to calculate a LCA from cradle to farm-gate and is modelled in line with ISO 14040 (ISO 2006a), ISO 14044 (ISO 2006b), and IPCC (IPCC 2021) as a framework. Inventory flows and emissions from external inputs to the farm are based upon mass flow, such as imported diesel, electricity, fertiliser, lime, silage foil, chemicals, building structure, and ingredients and origin of concentrate mixtures, derived from accounting data. The environmental impact of the purchased inputs, including transportation to the farm, was assessed by standard values using the ecoinvent© life cycle inventory (LCI) database (Frischknecht et al. 2005). In addition, supplementary information was provided by accounting data and transport distance to the farms (Schueler et al. 2018).

Methane emissions from on-farm digestion were calculated using a Tier 2 approach, with a fixed methane energy conversion factor based on daily dry matter intake as suggested by (Storlien et al. 2014). The methane emissions were calculated for each of the animal groups, i.e., dairy cows, suckling cows, calves, heifers, and bulls. The feed intake was estimated from average feed demand based on weight, weight gains and milk yield under Norwegian conditions for animals in each animal group (Olesen et al. 1999) (Table 1). Emissions from manure were calculated based on IPCC (2019).

Emission factor 1 (EF_1) for wet climates was used with an average value of 0.016 kg N_2O-N per kg N for N-inputs from synthetic fertiliser and with an average of 0.006 kg N_2O-N per kg N for other N inputs. Emission factor 3 (EF_3) was used for emissions from droppings during grazing under wet climate, on average 0.006 kg N_2O-N per kg N (IPPC 2019a, chapter 11 Table 11.1). Emissions related to feed production were derived from emissions related to diesel combustion, crop residues, and application of manure and fertilizers (Table 1). Harvested yields, in net energy per area, were calculated based on the energy demand for the animals in the different feeding groups for milk production (only dairy and suckler cows), maintenance, and meat production including net expected losses during harvest, and then subtracting the energy used from concentrates and imported roughages (Steinshamn et al. 2004). GHG emissions were calculated based on $GWP_{100\text{-}AR4}$.

Table 1. Emission factors used in FARMnor[1]

Flow	Factors and equations				Reference
Crop production					
N_2O	kg N_2O-N (kg N)$^{-1}$ = $EF_{1\text{-}synth}$ × Synthetic Fertilizer-N kg N_2O-N (kg N)$^{-1}$ = $EF_{1\text{-}other}$ × (Slurry-N + Crop residues-N) kg N_2O-N (kg N)$^{-1}$ = EF_3 × N from droppings during grazing				IPCC (2019a) in chapter 11, table 11.1
	Emission factor	Disaggregated	Default value	Uncertainty range	
	$EF_{1\text{-}synth}$	Synthetic fertiliser inputs in wet climates	0.016	0.013 – 0.019	
	$EF_{1\text{-}other}$	Other N inputs in wet climates	0.006	0.001 – 0.011	
	EF_3	Cattle, deposited by grazing in wet climates	0.006	0.000 – 0.026	
Crop Residue-N	Crop Residue-N = Above Ground-N + Below Ground-N Above Ground-N = AGDM × AGDM-N Below Ground-N = BGDM × BGDM-N				IPCC (2019a), in chapter 11 table 11.1a
	Grass-Clover Mixtures	Above-ground residues dry matter (AGDM)	Below-ground residues dry matter (BGDM)		
	N content	0.025 (± 75%)	0.016 (± 75%)		
	Ratio of residue dry matter to harvested yield	0.30	0.80 (± 50%)		
	Dry matter fraction of harvested product	0.90	0.90		
NH_3-N slurry	NH_3-N_{Slurry} = 0.4 × (TAN (spread with plate, cloudy weather) + 0.36 × TAN (spread with plate and extra water) + 0.3 × TAN (spread with trailing shoe))				Rösemann (2011)
Feed storage					
Dry matter loss	Concentrates	0.03			Steinshamn et al. (2004)
	Roughages	0.15			
Animal related					
CH_4	CH_4 (MJ per day) = (1.28 kg (± 0.16) DMI (kg per day) – 1.47 (± 3.04)				Storlien et al. (2014)
NH_3	N_{faeces} (kg N per day) = 0.001 × (40 × N_{intake} + (20 × DMI + 1.8 × DMI^2) × 6.25^{-1})) N_{urine} = X_{DE} × N_{feed} – N_{milk} – N_{meat} – N_{faeces} NH_3-N = N_{urine} × 0.197				Rösemann (2011)
Slurry	VS = DMI × (1-X_{DE}) × (1-X_{ash})				Rösemann (2011)
	TAN = N_{urine} × 0.803				Rösemann (2011)
Manure storage					
CH_4	CH_4 = VS × B_0 × MCF × 0.67 0.67 = conversion factor from m^3 CH_4 to kg CH_4				IPCC (2019a) Rodhe et al. (2012)
N_2O	N_2O-N = Slurry-N × EF_{mm}				IPCC (2019a)
NH_3	NH_3-N = Slurry-TAN × 0.045				Rodhe and Karlsson (2002)

[1]After inspiration form (Schueler et al. 2018); B0 = maximum methane-producing capacity of the manure; for dairy in Western Europe: 0.24 (m^3 CH_4 (kg VS)$^{-1}$); EFmm = Emission factor manure management (kg N_2O-N (kg Nexcreted)$^{-1}$); DM = Dry Matter (kg); DMI = Dry Matter Intake (kg day^{-1}); MCF = Methane conversion factor (g CH4 (kg VS)$^{-1}$); TAN - Total ammoniacal nitrogen (kg N); VS = Volatile solids (kg DM animal^{-1} day^{-1}); Xash = fraction of ash content in excretions (kg kg^{-1}); XDE = digestibility (MJ MJ^{-1})

Functional units

The functional (FU) unit for GHG emissions and energy use is the amount of 2.78 MJ edible energy from milk and meat (2.78 MJ_{MM}) delivered from the farm. This was calculated as the sum of edible energy in milk and meat delivered at the farmgate divided by the edible energy content in one kg milk, 2.78 MJ (Eq. 1) (Norwegian Food Safety Authority 2015). Milk from different farms was converted to energy corrected milk (ECM) (TAS 2011), based on the gross energy in milk. The edible energy content in one kg of carcass was set to 6.47 MJ per kg (Heseker 2013). The 2.78 MJ of edible energy therefore corresponded to the edible energy content of 1.0 kg of ECM, 0.42 kg of meat, or any combination of milk and meat amounting to 2.78 MJ of edible energy delivered at the farm gate (Koesling et al. 2017).

$$Number\ of\ FU\ (2.78\ \mathrm{MJ_{MM}}) = \frac{\left(\mathrm{ECM\ (kg\ delivered)} \times 2.78 \frac{\mathrm{MJ}}{\mathrm{kg}}\right) + \left(\mathrm{carcass\ (kg\ delivered)} \times\ 6.47 \frac{\mathrm{MJ}}{\mathrm{kg}}\right)}{2.78\ \mathrm{MJ}} \quad (1)$$

In Table 6, only the emissions allocated to milk production are presented. This allocation was done individually for each farm, based on the energy needed to produce milk and meat (biophysical allocation). This also makes comparisons with other studies easier and takes into account that the choice of allocation affects the reported results from the dairy farming system (Kristensen et al. 2011).

Economic calculations

Farm accounting data from TAS for the years 2014 to 2016 were used to calculate the gross margin in Norwegian kroner (NOK). The values presented in this paper are in NOK, with an average exchange rate of 8.7 NOK per Euro for the years 2014 to 2016. Gross margin was calculated based on the total revenues, including revenues from milk and meat, other revenues, and direct payments. The variable costs, including concentrate purchased, costs related to forage production, and other variable costs of production, were subtracted from the total revenue to arrive at the gross margin (Steinshamn et al. 2021). The gross margin was then calculated per kg 2.78 MJ_{MM} and per milking cow unit.

Nitrogen intensity

The nitrogen intensity was determined as the sum of nitrogen imported to the farm, biological nitrogen-fixation and atmospheric N-deposition divided by the amount of nitrogen in delivered milk and meat from the farm given by kg N per kg N. Biological nitrogen fixation (*BNF*) was calculated based on Equation 2.

$$BNF = (DM_{TAG} + DM_{BG}) \times CI\% \times N\% \times P_{fix}\% \quad (2)$$

Where DM_{TAG} = total above ground dry matter (DM), measured in (kg), DM_{BG} is below ground drymatter, *CI%* = precent of clover in herbage, *N%* = 3% herbage nitrogen content, and $P_{fix}\%$ = proportion of N fixed, assumed to be 95 % according to (Høgh-Jensen et al. 2004). The calculation of N intensity includes the import and purchase of fertilizers, live animals, manure, concentrates, and other feed. Also, the N-surplus from off-farm production of ingredients for concentrates and roughage as well as for purchased animals was included (embodied values) (Koesling et al. 2017a). Meat production included both live animals and animals for slaughter.

Statistical analysis

The statistical analysis was carried out using R (version 4.2.2), provided by the R core team (2022) in combination with R Studio (RStudio Team 2020). The aim of the statistical analysis was to select conventionally managed farms that matched the 15 organically managed farms, while being comparable in terms of the chosen factors. To achieve this, we used propensity matching with nearest neighbors. The propensity matching process was carried out for three scenarios, each selecting 15 conventionally managed farms, to ensure that statistical results are robust and to ensure similar population sizes in both selected groups (Randolph and Falbe 2014).

In the first matching (matching 1), we used the variables milk district ("milk district BC" and "milk district DE"), milk quota (in liters) and number of milking cow units per farm (Table 2). These factors all represent structural differences, unrelated to whether the farms were managed organically or conventionally. In the second matching (matching 2), we added the milking cow proportion of the total cattle herd to select conventionally managed farms with a herd structure comparable to organically managed farms, which tend to sell male calves earlier than the conventionally managed farms to produce more milk from on-farm feed, thus enabling them to fill their milk quota. In the third matching (matching 3), we also included the proportion of milk delivered of milk produced and the amount of concentrate used per dairy cow, measured as MJ $_{NEL}$ MCU_{dairy}^{-1}. The use of concentrates per dairy cow was included to assess the environmental impact of feeding intensity on organic farms compared to conventionally managed farms. All three matches were constructed without replacement and at a 1:1 ratio, following recommendations from Hansen et al. (2021), and Flubacher et al. (2015), for selecting matching variables. This means that one conventional farm was selected for each organic farm and the selected farms were only selected once. The total agricultural farm area was not used as a matching variable, as it was a response variable in the testing of farming system.

Table 2. Variables used in matching 1, matching 2 and matching 3

Variable	unit	Matching 1	Matching 2	Matching 3
Proportion of farms in district B + C	share	x	x	x
Proportion of farms in district D + E	share	x	x	x
Milk quota	1000 litre $farm^{-1}$	x	x	x
Milking cow units	MCUdairy $farm^{-1}$	x	x	x
Dairy cow proportion	MCUdairy $MCUall^{-1}$		x	x
Milk, delivered of produced	Kg ECM kg ECM^{-1}			x
Concentrate use, dairy cows	MJNEL $MCUdairy^{-1}$			x

To test the environmental impact and gross margin differences between conventionally and organically managed farm groups, we used a linear model (“lm”), comparing the effect of management factors on the response. The independent variable was the farm group (conventional or organic), and the dependent variables were GHG emissions according to different IPCC methodologies (kg CO_2-eq [2.78 $MJ_{MM}]^{-1}$), N intensity (kg N [kg N]$^{-1}$), gross margin (NOK per 2.78 MJ_{MM}^{-1}) and land use occupation (m^2 [2.78 $MJ_{MM}]^{-1}$). Tukey`s HSD (honest significance difference) was used to compare the effect of farm group on GHG emissions, N intensity, gross margin and land use occupation. We also tested the different conventionally managed farm groups against each other using a “lm” and conducted a Tukey’s HSD test. To ensure normal distribution in the model’s residuals, we transformed all response factors using Box-Cox or log transformations, based on the distribution of the residuals in the “lm”, to obtain normal distribution.

Results

Matching data

Matching reduced the differences between the three selected conventionally managed groups and the organically managed farm group, although the standard error increased between the three matched conventional groups compared to the total population of conventionally managed farms in the study (Table 3). As the matching groups progressed from 1 to 3, including increasingly more variables, the number of differing factors compared to the organically managed farm group was reduced (Table 3). Among the matched groups, group 3 exhibited the highest similarity to the organic farms, in the assessed variables (Tables 3 and 4). However, fertilizer import of nitrogen, and forage yield were notably higher in group 3 than for the organically managed farms. Group 1 differed from the organically managed farms in terms of lower dairy cow proportion and higher concentrate use, per dairy cow. In groups 1 and 2, fertilizer import of nitrogen, and concentrate use had higher values than the organically managed farms, while the forage share in the diet for cows was lower. For group 3, the fertilizer import of nitrogen and forage yield were the factors that were higher compared to the organic group (Table 3).

Table 3. Mean values of the matching variables for the different groups of dairy farms and the total population of conventional farms. SE represents the standard error of the mean.

		Organic		Matching 1		Matching 2		Matching 3		All conventional farms	
n		15		15		15		15		185	
	unit	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Proportion of farms in district B + C	share	0.73	0.44	**0.80**	0.49	**0.67**	0.47	**0.80**	0.47	0.49	0.50
Proportion of farms in district D + E	share	0.27	0.44	**0.27**	0.55	**0.40**	0.59	**0.20**	0.61	0.52	0.53
Milk quota	1000 litre $farm^{-1}$	253000	141000	**251000**	138000	**238000**	144000	**237000**	124000	281000	155000
Milking cow units	MCU_{dairy} $farm^{-1}$	35.4	19.06	**34.0**	17.3	**32.4**	18.48	**32.5**	16.1	36.6	18.8
Milk, delivered of produced	Kg ECM kg ECM^{-1}	0.93	0.04	0.93	0.08	**0.93**	0.08	**0.93**	0.06	0.95	0.04
Dairy cow proportion	MCU_{dairy} MCU_{all}^{-1}	0.72	0.04	0.66*	0.021	0.73	0.04	**0.72**	0.03	0.66*	0.09
Concentrate use, dairy cows	MJ_{NEL} MCU_{dairy}^{-1}	15400	2390	19800**	2260	18900*	3030	**15600**	2820	19100**	2720

SD = Standard Deviation of the mean; *, **, *** shows $p< 0.05$, $p< 0.01$ and $p< 0.001$, respectively, for comparison organic versus the groups of conventional managed farms; Bold numbers indicate variables included in the matching between organic and conventional farms.

Table 4. Characteristics of the different constructed groups, organic farms, matching 1, matching 2, and matching 3 of conventional farms and all conventional farms

		Organic		Matching 1		Matching 2		Matching 3		All conventional farms		All farms	
n		15		15		15		15		185		200	
Variable	Unit	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD		Mean
Milking Cow unit[1]	MCU_{dairy} $farm^{-1}$	35.4	19.1	34.0	17.3	32.4	18.5	32.5	16.1	36.5	18.8	36.5	18.7
All cattle[2]	MCU_{all} $farm^{-1}$	49.7	27.6	52.9	30.7	44.8	27.5	46.6	26.3	57.4	33.2	56.8	32.8
Non-dairy cattle[3]	MCU_{cattle} $farm^{-1}$	14.3	8.86	18.9	13.3	12.4	9.0	14.1	10.2	20.85	16.39	20.4	16.0
Dairy cow proportion	MCU_{dairy} MCU_{all}^{-1}	0.72	0.04	0.66*	0.08	0.73	0.08	0.72	0.06	0.66*	0.09	0.67	0.09
Concentrate use, dairy cows[4]	MJ_{NEL} MCU_{dairy}^{-1}	15400	2390	19800**	2260	18900**	3030	15600	2800	19200**	2720	18900	2870
Heifers	Number $farm^{-1}$	38.5	23.7	39.5	21.3	30.6	17.4	10.0	11.6	40.0	23.4	0.11	0.06
Bulls	number $farm^{-1}$	7.56	7.34	15.8	19.5	9.65	16.8	10.0	11.6	22.3*	25.4	0.06	0.07
Stocking density, cattle	MCU_{cattle} ha^{-1}	1.09	0.38	1.31	0.37	1.28	0.25	1.20	0.35	1.28	0.34	1.26	0.34
Animal health													
Age cows	Months	115	10.19	113	7.39	115	8.80	114	12.4	116	8.91	46.5	3.60
Age at first calving	Months	25.7	1.35	25.6	1.57	25.5	0.65	25.4	1.40	25.6	1.28	25.6	1.29
Calving interval	Months	12.3	0.88	12.2	0.37	12.2	0.48	12.4	0.68	12.3	0.63	12.3	0.7
Replacement rate	MCU_{dairy} MCU_{dairy}^{-1}	0.43	0.08	0.46	0.12	0.46	0.11	0.47	0.08	0.45	0.10	0.45	0.10
Milk somatic cell count	1000 $litre^{-1}$	124	25.92	122	30.04	119	26.93	128	33.93	127	27.64	127	27.47
Days from parturition to last insemination	Days	99.1	17.8	100	13.3	96.0	12.42	97.8	9.98	99.6	17.4	99.6	17.4
Feeding													
Concentrate use, all cattle	MJ_{NEL} MCU_{all}^{-1}	12800	1740	16600**	1770	16400**	2590	13700	2510	16400**	2170	18900	2900
Forage share in diet, cows	MJ_{forage} MJ_{total}^{-1}	0.65	0.05	0.53**	0.04	0.55**	0.05	0.61	0.08	0.56**	0.05	0.56	0.06
Pasture share in diet, all cattle	$MJ_{pasture}$ MJ_{total}^{-1}	0.21	0.07	0.17	0.09	0.21	0.07	0.18	0.11	0.16	0.08	0.17	0.08
Pasture share in diet, cows	$MJ_{pasture}$ MJ_{cows}^{-1}	0.11	0.05	0.08	0.06	0.10	0.05	0.09	0.07	0.07*	0.06	0.08	0.06
Concentrate use	MJ_{NEL} MCU_{dairy}^{-1}	199	23.0	244**	17.1	238**	31.6	206	39.5	236	26.8	233	28.2
Farm and feed production													
Diesel usage	litre ha^{-1}	117	29.0	120	41.4	121	67.9	120	55.3	134	54.7	133	53.4
Electricity per ECM	kWh kg ECM^{-1}	0.26	0.08	0.26	0.06	0.24	0.06	0.26	0.09	0.25	0.09	0.25	0.09
Farm agricultural area	ha $farm^{-1}$	46.5	25.9	42.4	25.3	35.9	21.5	37.8	13.3	46.2	26.8	46.2	26.6

Share of arable land	$ha_{arable}\ ha_{total}^{-1}$	0.86	0.08	0.92	0.06	0.87	0.12	0.86	0.18	0.89	0.12	0.89	0.12
Off-farm area	ha $farm^{-1}$	46.5	31.9	36.5	24.9	32.9	25.5	28.4	17.5	40.1	26.3	40.6	26.7
Fertilizer import, nitrogen[7]	kg N ha^{-1}	0.00	0.00	121**	43.3	129**	31.4	107**	29.9	126**	37.7	117	49
Forage yield	MJ ha_{DF}^{-1}	28800	5170	34900*	9330	34000**	7480	35300**	9200	34500*	7960	34100	7900
Production and economy													
Milk yield produced	kg ECM MCU_{dairy}^{-1}	7940	810	8470	810	8280	810	7850	820	8400	840	8360	850
Milk quota	1000 litre $farm^{-1}$	253000	141000	251000	137600	238000	144100	234000	124200	282000	154623	280000	153000
Milk delivered	kg $farm^{-1}$	252000	142900	255000	138100	239000	142700	223000	118800	276000	153781	274000	153000
Milk, delivered of produced	kg ECM kg ECM^{-1}	0.93	0.04	0.93	0.02	0.93	0.04	0.93	0.03	0.93	0.04	0.93	0.04
Regional deficiencpayment milk	NOK kg ECM^{-1}	0.24	0.12	0.27	0.14	0.28	0.15	0.25	0.13	0.31	0.13	0.31	0.13
Meat delivered	kg MCU_{all}^{-1}	103	28.4	123	47.0	99.7	33.3	110	30.0	140*	59.0	137	58.1
Regional deficiency payment meat	NOK kg $meat^{-1}$	3.82	2.09	3.65	2.49	4.35	1.44	4.21	1.99	4.47	1.60	4.42	1.65

[1] Milking Cow Unit (MCU) is standardised to an annual NEL requirement of 42 000 MJ. One MCU corresponds e.g. to the requirement of a cow with a life-weight of 600 kg, including foetal growth and the production of 8000 kg milk. Where other animal groups are referred as MCU, the values were calculated based on their energy-demand; [2] The whole herd on each farm is expressed as MCU equivalent; [3] Non milking cattle in herd expressed as MCU; [4] NEL is Net Energy Lactation in MJ; [5] Total concentrate usage divided on animal group; [6] Average price for farmers 2014-2016, (Hjukse 2017, 2016); [7]Mineral fertilizers import of nitrogen; SD = Standard Deviation of the mean; *, **, *** indicate $p< 0.05$, $p< 0.01$ and $p< 0.001$, respectively, for comparison organic versus the groups of conventional farms

Environmental impact and gross margin differences

Lower GHG emissions (GWP100-AR4) and N intensity were observed in organically managed farms compared to all conventionally managed farm groups (Table 5). Land use occupation and gross margin per unit milk and meat (2.78 MJmm) was higher for the organically managed farms compared to the conventionally managed ones (Table 5). This difference in profit between organic and all conventional farms was not persistent when expressed per farm agriculture area (26 000 NOK per ha vs 24 900 NOK per ha, respectively (*p*= 0.58)). However, all conventional farms and the three constructed conventionally managed farm groups were similar in in GHG emission, N intensity, land use occupation and gross margin.

The higher GHG emissions on conventional farms were associated with larger amounts of purchased concentrates and other inputs, and higher emissions in forage production to the organic farms (Tables 6 and 7). Total GHG emissions were also lower for the organically managed farm group compared to the mean of all conventionally managed farms. The constructed groups of conventionally managed farms did not differ from each other in terms of their response, neither did the matched groups and the total population of conventionally managed farms. The difference in environmental impact and gross margin between the organic managed farm group and the total population of conventional managed farms was persistent.

Table 5. Mean emissions, gross margin, land use occupation and N intensity for organic and conventional farms (matching 1, 2 and 3)

		Organic		Matching 1		Matching 2		Matching 3		All conventional farms	
n		15		15		15		15		185	
Variable	unit	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Gross margin	NOK MCU^{-1}	34400	4300	30000*	4420	30200**	4415	30800**	3860	30100**	3740
Gross margin	NOK $(2.78\ MJ_{MM})^{-1}$	6.5	0.79	5.79*	0.87	5.80**	0.87	5.54**	0.73	5.82**	0.83
$GWP_{100\text{-}AR4}$	kg CO_2-eq $(2.78\ MJ_{MM})^{-1}$	0.98	0.25	1.34**	0.20	1.28**	0.19	1.33**	0.19	1.42**	0.27
Land use occupation	$m^2\ (2.78\ MJ_{MM})^{-1}$	3.57	0.61	2.91**	0.38	2.88**	0.38	2.66**	0.56	2.92**	0.61
N intensity	kg N $(kg\ N)^{-1}$	5.04	1.57	6.87**	1.14	6.58**	1.14	6.57**	1.05	6.91**	1.28

SD = Standard Deviation of the mean; *, **, *** indicates *p*< 0.05, *p*< 0.01 and *p*< 0.001, respectively, for comparison organic versus the groups of conventional farms; Lettering states the different significance level at *p*< 0.05, between farms (matching 1, 2 and 3); Degrees of freedom 1 for all variables was 1, Degrees of freedom 2 was 28 for all responses in organic, matching 1, matching 2 and matching 3

Table 6. Contribution to GHG emissions from different sources on the dairy farms allocated to kg ECM

	Organic		Matching 1		Matching 2		Matching 3		All conventional farms	
n	15		15		15		15		185	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Import of silage	0.02	0.12	0.01	0.01	0.01	0.01	0.02	0.02	0.01**	0.02
Concentrate	0.09	0.04	0.16**	0.02	0.16**	0.03	0.15**	0.02	0.16**	0.03
Other purchased inputs	0.03	0.04	0.15**	0.05	0.16**	0.05	0.17**	0.07	0.15**	0.06
Infrastructure	0.07	0.08	0.07	0.02	0.07	0.02	0.08	0.02	0.07	0.02
Plant production	0.10	0.08	0.21**	0.06	0.23**	0.06	0.23**	0.06	0.22**	0.07
Grazing	0.03	0.08	0.01	0.01	0.02	0.02	0.04	0.04	0.02	0.03
Manure storage	0.04	0.08	0.03*	0.02	0.02*	0.02	0.03*	0.02	0.03	0.02
Animals in barn	0.42	0.08	0.39	0.04	0.39	0.04	0.41	0.06	0.40	0.05
Total emissions	0.80	0.14	1.04**	0.14	1.07**	0.16	1.11**	0.17	1.07**	0.17

Emission allocated to milk as kg CO_2-eq. $(kg\ ECM)^{-1}$ delivered, calculated as $GWP_{100\text{-}AR4}$; Forage production includes e.g. emissions from the use of fertilizer and spreading manure as well as diesel combustion; [3] Other purchased inputs include the emission from fertilizer and diesel production and transport to the farm; [4] Emissions from animals in the barn; *, **, *** shows *p*< 0.05, *p*< 0.01 and *p*< 0.001, respectively, for comparison organic versus the group of conventional farms; SD = Standard Deviation of the mean.

Table 7. Contribution to GHG emissions ($GWP_{100\text{-}AR4}$) from different sources on the dairy farms with the functional unit to 2.78 MJ_{MM} (amount of edible energy delivered in milk and meat)

	Organic		Matching 1		Matching 2		Matching 3		All conventional farms	
n	15		15		15		15		185	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Import silage	0.03	0.03	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.02
Import concentrate	0.11	0.01	0.21**	0.03	0.20**	0.04	0.21**	0.03	0.21**	0.04
Other purchased inputs	0.04	0.01	0.20**	0.08	0.20**	0.05	0.20**	0.07	0.21**	0.08
Infrastructure	0.09	0.02	0.09	0.03	0.09	0.02	0.10	0.03	0.10	0.03
Forage production[1]	0.13	0.02	0.27**	0.10	0.27**	0.07	0.27**	0.05	0.30**	0.08
Grazing[2]	0.05	0.03	0.04	0.02	0.05	0.03	0.06	0.04	0.04	0.03
Manure storage	0.05	0.02	0.03	0.02	0.03	0.03	0.03	0.03	0.04	0.03
Animals in barn[2]	0.49	0.09	0.48	0.06	0.45	0.06	0.48	0.09	0.5	0.08
Total emissions	0.98	0.16	1.34**	0.24	1.28**	0.20	1.33**	0.17	1.42**	0.25

[1]Forage production includes e.g. emissions from use of fertilizer and spreading manure as well as combustion of diesel; [2] Emissions from animals grazing and in the barn; *, **, *** shows $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively, for comparison organic versus the group of conventional farms; SD = Standard Deviation of the mean.

Discussion

Matching

The similarity in gross margin, GHG emissions, and N intensity across the three conventionally managed farm groups suggests that primary management traits such as geographical region (district), milk quota, dairy cow numbers, share of delivered milk (of produced milk) and concentrate usage by dairy cows had no essential effect on the environmental impact in the study. The similarities among these groups may be due to the farms being localized in different locations but similar agroclimatic conditions, thus giving an underlying similarity in farm structure (Borgen et al. 2012). A larger, more diverse population of farms prior to statistical matching would maybe have given a higher variation in the dataset prior to matching, and thus the potential for greater variation between matched and the unmatched farm group.

Differences in environmental performance and land use occupation

In our study, the higher GHG emissions from conventionally managed farms compared with organic managed farms are attributed to different production regimes of concentrates (off-farm), higher mineral N fertilization, and differences in on- and off-farm feed production (Table 7). This resulted in higher emissions from the categories imported concentrates, other purchased inputs, and forage production in the groups of conventionally managed farms compared to the organic ones. This is supported by the earlier works of Gerber et al. (2013), who found that variations in food production-related emissions are mainly caused by manure and mineral fertilizer application. In the study by Olesen et al. (2006), N efficiency was proven to be a good proxy for GHG emissions, with reduction of emissions related to increased N efficiency. The current study shows a similar effect per product unit, with higher emissions per product unit mainly related to increased import of N fertilizers.

Despite findings indicating that higher dietary concentrate:forage ratio can reduce enteric methane emissions per litre of milk produced (Beauchemin et al. 2008), the effects can be offset by on-farm feed production and purchased inputs (van Wyngaard et al. 2018). These factors give a higher total emission from production when increased use of concentrates does not result in higher milk yields per dairy cow on the dairy farms. In accordance with similar milk yield, the differences in GHG emissions between organic and conventional farms in this study is associated with higher emissions of nitrous dioxide and carbon dioxide in production of on- and off-farm feedstuff on conventionally managed farms. The small differences in milk yield across groups contradict the studies of Kristensen et al. (2011) and Thomassen et al. (2008) where the milk yield differed between the organically and conventionally managed farms, explaining why these studies did not obtain differences between organic and conventional management in GHG emissions per produced unit of milk.

The greater land use occupation on organically managed farms reflects a trade-off between reducing GHG emissions while increasing land use to produce milk and meat. This resonates with the findings of Meier et al. (2015), namely, that organic farming systems typically yield less in plant production (per area unit), hence requiring more land. We found that milk yields per cow were independent of total farm production of forage yields, but not of the total feed supply since conventional farms had higher concentrate usage but lower forage share in diet than organic farms. Increasing forage yield, and thus reducing the land use occupation within the group of organically managed farms is, however, more intricate than just applying more manure. To obtain higher forage yields on organic farms, factors such as weed-control, soil structure, supply of other nutrients than nitrogen, dependence on own manure as the main nitrogen source for grassland, and timing are more important than on conventional farms. In addition, improved use of grassland legumes, like white and red clover, is important, because of the strong correlation between legume proportion and grassland yields in organically managed grasslands (Steinshamn et al. 2016).

The lower N intensity on organically managed farms compared to conventionally managed farms (5.0 vs 6.9 kg N input per N kg output) can be explained by the restriction of mineral fertilizer use in organic farming and the limitations on the use of purchased concentrates. High N intensity can potentially increase the eutrophication potential if nitrogen is applied at levels above what the plants and the soil can utilise for plant growth and increasing soil organic matter. The average N intensity level on organic farms was higher than found for organic dairy farms in a previous study in the same region, which found 4.2 kg input per N kg output (Koesling et al. 2017a). The higher N intensity in the present study can be attributed to higher usage of concentrate compared to the study of Koesling et al. (2017a). Previous work has suggested to reduce N related emissions by introducing more extensive farming and by re-coupling crop and animal production (Bleken et al. 2005).

Our study showed similar levels of GHG emissions per kg ECM as those reported by Kristensen et al. (2011), when not accounting for meat production. The results show that the choice of functional unit results in different levels of GHG emissions per edible energy unit and emissions are lower when allocated to milk. Methane emissions from the digestion are directly proportional to the intake of dry matter. The feed conversion rate, computed as dry matter uptake per kg edible weight of milk and meat, is considerably higher for meat than for milk (Alexander et al. 2016). Consequently, the GHG emissions relative to edible energy are higher for meat than for milk. Therefore, when considering GHG emissions per MJ, emissions from milk and meat are greater than those from milk alone when the emissions are allocated between milk and meat. The GHG emissions associated with purchase of soya is lower nowadays than when this study was conducted for conventional farms, because the Norwegian Agricultural Purchasing and Marketing Co-operation (Felleskjøpet) now solely buys soya from certified areas in Brazil, thus resulting in lower emissions from land use change (Escobar et al. 2020). Changing the emission factor to the current situation would therefore reduce the estimated emissions from conventional farms in the present study.

Economic performance

The higher gross margin on the organically managed farms, compared to the conventionally managed farms suggests that conventionally managed farms have higher costs per produced unit without achieving a higher net income per product unit. The certified organic dairy farms received higher product prices for milk and meat, compared to conventional farms. These farms received an organic premium of 0.75 NOK kr per litre milk from TINE SA and 0.50 NOK per kg carcass weight for meat delivered to Nortura, a large cooperative in Norway operating slaughterhouses (LMD 2017). In addition, organic producers are receiving higher subsidies for grasslands and per cow in the dairy herd compared to conventional managed farms. The variable cost, however, of buying organic input factors such as concentrates and nutrients are higher than for conventionally managed farms.

In our study, a key driver of differences in gross margin between groups is the cost of purchased fertilizers per hectare, which the organically managed farms did not purchase. Specifically, an increase in input in conventional farming needs to result in higher feed production and increased milk or meat production to be economically efficient. In this study, it was found that such an increase of inputs did not affect the gross margin per 2.78 MJMM delivered. The results bear implications for farmers and regulators, showing the importance of reducing purchased inputs and improving the efficiency of purchased inputs. One potential regulation to mitigate climate impact from conventionally managed farms could be to improve efficiency of mineral N fertilizers, with for example precision agriculture (Bongiovanni and Lowenberg-Deboer 2004). The higher use of N fertilizers could be seen as an insurance for the conventional farmers to safeguard high yields, resulting in a lower land use occupation on conventional than on organic farms. The reason for higher land use occupation on organic farms is due to lower on farm grassland yields and lower yields of off-farm produced organic grains used in purchased concentrate. Higher arable land use requirement is important in a global food security perspective, as arable land for edible food production is a limited resource (Flachowsky et al. 2017). Increasing the proportion of organic produced food, the production needs to reduce food-competing feed. This reduction, will in turn, require lower animal numbers globally, and therefore less meat in the human diet (Muller et al. 2017).

Previous studies, such as Flaten et al. (2019), found no differences in profitability between the two management systems on Norwegian dairy farms when expressed as a return to labour. In addition, Flaten et al. (2019) found that the conventional farms had higher milk yields compared to the organic farms. This shows that the economic indicator used in this study with NOK $(2.78\ MJMM)^{-1}$ for assessing the differences between organically and conventionally managed dairy farms can have an impact on the observed differences. In a study by Hansen et al. (2021), who compared 177 conventional and 59 organic dairy farms on the basis of similar farms in Norway, found no difference in profitability was shown between organically and conventionally managed dairy farms after using matching to create similar farm groups, despite the higher profitability potential for the conventional farms.

Another study, conducted in France by Lambotte et al. (2023), found higher gross margin at the product level for organically managed farms. It is worth noting that the economic indicators' denominators seem to play a significant role. The obtained differences in gross margin between the management forms could become non-significant if expressed in other terms. The gross margin was not different when expressed per hectare on farm use, since the organic farms occupy more land compared to the conventional farms. The studies by Lambotte et al. (2023) and Flaten et al. (2019) suggest the importance of carefully selecting the right economic indicators and economic denominators for comparing the economic performance of different farming systems.

Limitations

When interpreting the results of this study, several factors call for consideration. Firstly, the findings are specific to the economic, environmental and climatic conditions of the farms studied. While the study featured a relatively large sample size compared to other Life Cycle Assessment (LCA) studies, the chosen farms decided themselves to participate in the Technical Advisory Service (TAS). This may favour farms that show best practice within the sector, potentially portraying farms with more focus on economic outcome and a lower environmental and climate impact than might be the case for the region's dairy farms in total. On the other hand, the reported accounting data can be seen as reliable, since they are also the official figures submitted to tax authorities by the individual farms. This pre-selection is a limitation affecting the study's matching process, which could have yielded different results if all dairy farms in the region had been included. Larger comparative groups could have strengthened the study's robustness.

This study does not incorporate labour costs in its gross margin calculations, thereby disregarding their influence on the gross margin differences. Differences in labour use between organically and conventionally managed farms have been discussed, with some studies suggesting higher labour requirements on organically managed farms due to weed control, increased crop or product diversity, and self-marketing strategies. However, this notion was not supported by a national survey of Norwegian farms (NIBIO 2015) and corroborated by Flaten et al. (2019) and Orsini et al. (2018) for dairy farms, implying that labour differences stem more from general farm structure adaptation than from the choice of organically versus conventionally managed dairy farm operations.

Calculating total farm-level GHG emissions is difficult due to the use of different models and estimates. The IPCC method considers national inventories but does not account for variations in agronomic practices such as, drainage conditions, and soil pH (IPCC 2021). Differences in soil carbon contents and carbon sequestration between organically and conventionally managed farms are not factored into total farm emissions in FARMnor, assuming that soil carbon is stable for dairy farms in this region. Having access to reliable data and including changes of soil carbon contents could have impacted the calculated differences.

The study's scope was limited to the number of both organically and conventionally managed farms, primarily due to access to farm data over a three-year period and the farms' geographical concentration. In particular, the number of organic farms was low, which represent a weakness of the study. The number of organically managed farm area is, however, limited in Norway, making up approximately 4.2% of Norwegian farms (SSB 2023). The study's dataset of organic farms has nearly twice that proportion. Conducting an LCA on commercial farms poses challenges due to data requirements and the time-consuming nature of data collection. There is however an inherent trade-off between the study's level of detail and the number of farms included, thus justifying the number of farms in the current study. Future studies could expand the number of organically managed farms to support the external validity of the results made in this study. Similarly, the inclusion of farms from different regions would also contribute to increased external validity.

Several impact categories are not taken into consideration in the present study, such as eutrophication potential, water and energy use. The first is linked to the assessed factor N intensity, the second is not assessed and is not a limiting factor under the current conditions in that region in Norway. Energy use is not assessed but is assumed to have positive correlation with GHG emissions. In addition, the inclusion of biodiversity in the two management systems, related to the different intensity and yield, could be of interest in future work.

Implications of the study

The findings in our study suggest that some of the conventionally managed farms could benefit from optimizing their on-farm resources. One measure could be to improve manure management and more efficient application of mineral nitrogen fertilizers. This could reduce GHG emissions, energy usage and N intensity, and potentially improve gross margin at their farms. However, if reducing the mineral N-fertilization and concentrate usage results in lower forage yields, these farms would likely need to increase the land use occupation to maintain the same production level. The differences in GHG emissions, land use occupation, N intensity and gross margin between organic and conventional farms suggest that the optimal management across environmental indicators should be weighted and optimized according to the most pressing environmental problems.

Conclusion

The greenhouse gas (GHG) emissions were on average lower on the organically managed farms compared to the conventional farms in sum of all evaluated GHG impact categories (0.98 vs 1.42 kg CO_2-eq [2.78 $MJ_{MM}]^{-1}$). The differences in GHG emission across groups were also present when we used kg ECM as the functional unit for GHG emissions. The organically managed farms had a lower nitrogen intensity compared to the conventional farms (5.0 vs 6.9 kg N kg input per N kg output). However, the gross margins (6.5 vs 5.8 NOK [2.78 $MJ_{MM}]^{-1}$) and land use occupation (3.6 vs 2.9 m^2 [2.78 $MJ_{MM}]^{-1}$) were higher in the organically managed dairy farm group compared to the corresponding conventionally managed farms per 2.78 MJ_{MM} delivered. When interpreting the gross margin results this difference should be considered. No notable difference was observed in calculated GHG emissions, nitrogen intensity, land use, and gross margin among the different conventional matched groups. However, when comparing the entire populations of conventionally managed farm with those managed organically, we did notice a similar difference in their environmental impacts, as observed between the constructed matched groups and the organic farms.

The findings suggest that reducing nitrogen use, at least, on the most intensive conventional farms, can contribute to reducing the GHG emissions and the nitrogen intensity at farm level. However, a significant reduction of nitrogen use will likely lead to an increase of land use occupation. As a side effect, the gross margin can increase by reducing the mineral N fertilization as long as yields can be maintained.

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