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COMPARING TECHNICAL-ECONOMIC AND ENVIRONMENTAL PERFORMANCE OF ECOLOGICAL DAIRY FARMING SYSTEMS FARMS IN AUSTRIA

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Abstract

In light of increasing environmental ambitions of the European Union and an associated ecological transition of its farming sector, it is crucial to assess, how such a transition affects in turn the economic viability of farms. In this context, the aim of the present study is thus to investigate and compare farm performance of a range of ecological farming systems, going beyond a comparison of only conventional and organic farms with broadly available European FADN data. Our study focusses on a FADN sample of specialized dairy farms in Austria (n = 1583) pooled over the years 2014 and 2015. Austrian agriculture and in particular its dairy sector is an ideal case for such an analysis, as it has already undergone a very dynamic ecological transition in the 1990s and ecological farms have since then further developed and diversified We identify four different farming systems in our sample (conventional farming, integrated/circular farming, organic farming and a combination of integrated/circular and organic farming), using a novel classification system, the LIFT farm typology. We further control for sample selection and production technology related bias in our comparison of farm performance between these groups. In terms of performance indicators, we use simpler indicators, such as partial productivity and profitability indicators or several environmental pressure indicators and additionally also estimate efficiency of farms with three different Data Envelopment Analysis (DEA) models. Our results indicate that adoption of the identified farming systems is strongly related to site conditions, which cannot be influenced by policies. Consequently, the economic viability of ecological farming systems depends also on public payments, compensating farms for natural disadvantages and the provision of public goods. However, in Austria these latter non-market outputs of ecological farming systems are also an asset, reflected in higher market prices for dairy products from farming systems with established brands and generally high consumer demand for more ecological products. Establishing markets for ecological products can thus reduce the dependency on public support and can be a further economic incentive for conventional farms to switch to a more ecological farming system.

Keywords

farm performance, ecological farming systems, matching, DEA, meta-frontier.

1 Introduction

In the context of the Green Deal and the accompanying strategies like the Biodiversity strategy and the Farm to Fork Strategy, the European Union (EU) is gearing up its efforts to achieve an ecological transition of its farming sector. These ambitious goals have – at least to some extent (PE'ER et al., 2020) – translated into the current reform of its Common Agricultural Policy (CAP). In this context it is crucial to assess, how such a transition, entailing the adoption of a variety of ecological farming practices by farms with associated potential environmental benefits, affects in turn the economic viability of and production of food, feed and fibre by farms within the EU.

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While a greater number of studies has investigated differences in economic and/or environmental performance between more well-established ecological classifications such as conventional and organic farming systems (see e.g. LAKNER and BREUSTEDT, 2017 for a recent overview) or other farming systems such as grazing and zero-grazing-based cattle farming systems (e.g. MEUL et al., 2012), a broader comparison of a variety of ecological farming systems is less common (FAO, 2019), in particular within a classification framework that is applicable on a European scale with readily available data (REGA et al., 2018).

The aim of the present study is thus to investigate and compare farm performance of a range of ecological farming systems, going beyond a comparison of only conventional and organic farms with broadly available European FADN data. Our study focusses on a FADN sample of specialized dairy farms in Austria (n = 1583) pooled over the years 2014 and 2015. Austrian agriculture and in particular its dairy sector is an ideal case for such an analysis, as it has already undergone a very dynamic ecological transition in the 1990s (VOGL and HESS, 1999) and ecological farms have since then further developed and diversified (FEDERAL MINISTRY of AGRICULTURE, REGIONS and TOURISM, 2020a). This allows to identify a broader range of ecological farming systems also within FADN data, where such ecological farms are otherwise often underrepresented (LAKNER and BREUSTEDT, 2017).

Methodologically we identify four different ecological dairy farming systems with the recently developed LIFT farm typology (REGA et al., 2019; THOMPSON et al., 2021). Secondly, we compare technical-economic and environmental farm performance of the identified systems. For this we use on the one hand simpler performance indicators, ranging from the calculation of partial productivity and profitability indicators as well as several environmental pressure indicators, to the estimation of farm efficiency with Data Envelopment Analysis (DEA). A crucial aspect in such comparisons, is the presence of certain biases, such as sample selection bias (BOGETOFT and KROMANN, 2018) or limitations of production possibilities of more extensive production technologies (KUMBHAKAR et al., 2009; BARÁTH et al., 2018). In order to alleviate such biases, we employ a matching procedure to control for selection bias and DEA based meta frontier of production possibilities to identify performance gaps between the farming systems. Both approaches have been used in the literature to compare performance of conventional and organic dairy farms before (MAYEN et al., 2010; ARAVINDAKSHAN et al., 2018).

Our results show potential synergies and trade-offs in terms of economic and environmental performance of the four identified farming systems (conventional farming, integrated/circular farming, organic farming and a combination of integrated/circular farming and organic farming) and of converting to a more ecological farming system.

The remainder of this article is structured as follows: in the next section we describe the case study region, before presenting our methodological approach as well as our empirical data. We then continue with the presentation of our results, before we provide concluding remarks.

2 Background of ecological farming in the Austrian dairy sector

With exception of the Danube valley and the north-eastern and south-eastern plains, Austria is dominated by mountains, making up roughly 64% of the total area. These areas are dominated by forests and permanent grasslands and farms have consequently specialized on grazing livestock husbandry. Dairy farms and more extensive grazing livestock farms, are the most common farm types in these regions. In total, specialist grazing livestock farms make up around 45% of all farms in Austria, of which roughly half (24%) deliver milk to dairies (FEDERAL MINISTRY of AGRICULTURE, REGIONS and TOURISM, 2020b). Dairy farms in Austria are mostly family farms with an average of around 22 dairy cows, a total number of livestock units of about 36 and roughly 33 ha of utilized agricultural area (UAA), which is mostly permanent grassland. Dual use breeds are dominating and the average milk yield is around 7,800 kg per dairy cow. These farms also often generate additional revenue from forestry and other gainful activities including for example the provision of (machinery) services or agro-tourism, additionally to dairy farming (LBG, 2020).

In terms of ecological transition of the farming sector, many dairy farms in Austria have already converted to organic farming as a more extensive form of agricultural production. Austria has the highest share of organic farms in the EU (18.3% in 2017) and the share of organic farms with milk delivery is even higher (25.5% in 2017) (FEDERAL MINISTRY of AGRICULTURE, REGIONS and TOURISM, 2020b). The organic farming sector in Austria experienced a very dynamic development in the 1990s, shortly before and after Austria joined the EU in 1995 with a growth from around 2,000 organic farms in 1992 to around 20,000 organic farms in 1998. This transition to organic farming was supported by government subsidies and a successful development of organic products and brands as well as their broad acceptance by large food chains and supermarkets (VOGL and HESS, 1999). After this period of huge growth, the number of organic farms developed less dynamically and reached around 24,000 farms in 2019. This is still considerable, if one takes into account structural change, characterised by a steady decline of the total number of farms from about 160,000 in 2000 to around 120,000 in 2019 (FEDERAL MINISTRY of AGRICULTURE, REGIONS and TOURISM, 2020b).

3 Method

Our methodological approach in this study consists of three steps: (i) identification of different ecological farming systems, (ii) calculation of performance indicators (iii) comparison of performance indicators between groups.

We identify different ecological farming systems, using the protocol for the LIFT farm typology (REGA et al., 2019; REGA et al., 2021) and a computer program to implement the protocol (THOMPSON et al., 2021). The LIFT farm typology allows to categorise farms into homogenous groups according to several ecological criteria. Specifically, the protocol allows to identify the following farming systems: (i) low input farms are characterized by a low level of use of environmentally detrimental inputs, (ii) integrated/circular farms are characterized by a high degree of circularity in their input use (e.g. own feed) and (iii) organic farms are either partially or fully certified as organic farms according to FADN data. While the classification of organic farms is straight forward, the classification of low input and integrated/circular systems requires the calculation of several indicators and total scores for each farming systems are then calculated based on a weighted average of the individual indicator scores. The methodology is designed in a way so that farms can belong to more than one farming system at the same time (e.g. low input, integrated/circular and organic). In contrast, conventional farms are those farms, which do not belong to any of the other farming systems.

A wide range of farm performance indicators are calculated in this analysis. In terms of technical-economic performance we investigate indicators related to profitability, partial productivity and efficiency, as well as two additional indicators, measuring the market orientation and financial stability of farms, respectively. With respect to environmental performance indicators, FADN data only provides limited information. We mainly use intensities of input use related to negative environmental externalities on the one hand and environmental subsidies as a proxy for the amount of public goods produced by farms. While this latter approach is far from accurate and does not consider any potential windfall effects of environmental payments, it is nevertheless a useful approximation for measuring the provision of public goods by farms.

Profitability indicators are calculated as revenue cost ratio (RCR). The advantage of using ratios is that they are easy to interpret and compare. A ratio greater than one means that a farm is profitable, while a ratio smaller than one indicates the opposite. Similar indicators have been also used in the literature (DAVIDOVA et al., 2002; BOJNEC and LATRUFFE, 2013). In terms of costs, we calculate RCRs once with main costs from financial accounting and once additionally considering opportunity costs of the three production factors land, labour and capital in order to be able to compare farms depending on structural differences in terms of ownership of the production factors (e.g. a farm, operating mainly on rented land vs. a farm operating mainly on own land). For the calculation of opportunity costs of land, we use farm-specific rental prices. In order to evaluate labour, we use a uniform wage of 15 EUR/hour, which is derived from average costs for outsourcing work to a machinery ring. For capital we use a uniform interest rate of 1%. Additionally, we calculate these RCRs with and without considering public payments to farms, resulting in a total of 4 RCRs.

Partial productivities are calculated as average products by dividing the total output of the farm by the individual inputs. Market orientation measures the share of subsidies of total output plus subsidies and is a measure of dependence from public payments. Finally, the equity ratio is calculated by dividing total liabilities through total assets and is an indicator for financial stability.

While partial productivity measures provide valuable insights into the use of individual inputs in the production process, they give, as the name suggests, only a partial picture. In order to assess overall productivity of farms, we therefore also calculate efficiency indicators, which consider all inputs and outputs jointly and additionally express productivity of farms as a relative measure, in comparison to benchmark farms. The two most common approaches to estimate efficiency are stochastic frontier analysis (SFA) and data envelopment analysis (DEA) (COELLI et al., 2005; BOGETOFT and OTTO, 2011). In this analysis we rely on DEA to estimate efficiency indicators. DEA is a non-parametric method and has been used for a long time to analyse technical-economic farm performance of dairy farms (FRASER and CORDINA, 1999; KIRNER et al., 2007). We consider an output-oriented DEA model, which is quite common in agriculture, as farmers have more control over their input use, meaning they try to maximise their output, based on their chosen input level (KARAGIANNIS, 2014). Also, we use the double bootstrap procedure of SIMAR and WILSON (2007), which considers the truncated nature of DEA efficiencies and has been used regularly in agricultural applications (e.g. LATRUFFE et al., 2008). Calculations are done in R (R DEVELOPMENT CORE TEAM, 2021) and the package {rDEA} (SIMM and BESSTREMYANNAYA, 2020). In order to ease interpretation, we calculated the inverse of output-oriented efficiencies, resulting in efficiency scores between 0 and 1, where 1 indicates a fully efficient farm

The size of our FADN sample allows us to use some further methods, aimed at addressing certain biases, when comparing farm performance of the different farming systems. Firstly, in order to address a possible sample selection bias, we use a matching procedure. A possible problem in this context is that farms, with for example different site conditions or other structural differences are more likely to have adopted certain farming systems than others. Matching allows to control for such structural differences between groups and thus to reduce or eliminate sample selection bias in such a comparison. The basic idea is to match farms based on observed factors in order to create a valid counterfactual and then compare performance of matched farms (HO et al., 2007). Matching is used widely in the empirical literature to compare economic and environmental performance of different farm groups or the response of farms to subsidies (MAYEN et al., 2010; BARÁTH et al., 2018). In this analysis, we use direct covariate matching (DCM), which is a non-parametric, straight-forward and flexible matching approach and has been applied in similar contexts (KIRCHWEGER et al., 2016). In DCM, matching is performed upon several covariates at the same time. As matching algorithm, we use nearest neighbour matching with replacement and set callipers for each variable, allowing us to control the sensitivity of the matching procedure. A statistical comparison of matching covariates before and after matching is then carried out in order to test, whether structural differences between the groups have been successfully eliminated. After matching, inference in terms of comparison of farm performance between groups is made by computing average treatment effects. Specifically, we calculate the average treatment effect on the treated (ATT).

Another possibly restrictive assumption is that farms in different farming systems all operate under the same production technology. If this is not the case, part of the estimated inefficiency might be related to performance gaps, related to technological constraints or regulations associated with individual farming systems and not actual inefficiency. We therefore further use the metafrontier framework of O'DONNELL et al. (2008), which has also been widely applied (e.g. ARAVINDAKSHAN et al., 2018). Firstly, we estimate efficiency of farms based on separate frontiers for each farming system. Then, we estimate efficiencies for all farms, assuming one common technology, resulting in a metafrontier of production possibilities. Comparing farming system specific efficiencies with efficiencies based on the metafrontier, allows to split up efficiency into a part which is related to differences in technology, the so-called metatechnology ratio (MTR), and a second part which is due to actual inefficiency. MTRs also show which farming system has the most productive technology.

4 Data

Our FADN dataset consists of an unbalanced panel of specialized dairy farms (TF14 = 45). Upon inspecting the data, we removed some observations with very unusual input-output combinations. Our panel dataset then contains 1,583 observations and 853 farms over both years as well as 796 in 2014 and 787 farms in 2015.

We use the five inputs land, labour, capital, intermediate expenses and herd size in all three estimated DEA models, with similar input specifications being quite common for dairy farms (KELLERMANN and SALHOFER, 2014). Land is expressed in ha UAA. Labour is given in annual working units (AWU), where a value of one denotes full-time equivalent employment of one person and includes unpaid family labour as well as hired labour. Intermediate expenses are expressed in Euros and include regular expenses for e.g. feed, energy, plant protection or machinery services, among others. Herd size is measured in livestock Units (LSU), which makes it possible to aggregate different types of animals into one measure. Lastly, our capital input is based on the end of year values of the assets of farms minus the value of agricultural land and livestock, as these two are already included as separate inputs.

The output specification differs between the three models. In the first model we use the aggregated market revenues of farms as output, measured in Euro, excluding subsidies (output 1). In order to better reflect the technical aspect of the production process and investigate efficiency without the consideration of different milk prices between farming systems, in the second model we provide another output definition consisting of 2 separate outputs, namely milk quantity, measured in kg and other output, comprising all other market revenues, measured in Euro (output 2).

Finally, in the third model output consists of the aggregated revenues of farms, but this time including agri-evnironmental payments and payments for organic farming. In the empirical literature, analysing the productivity and efficiency of farms, subsidies are usually not considered as part of the output, as they are not a physical output generated through the production technology (MINVIEL and LATRUFFE, 2017). This is in particular the case for direct payments from pillar one and LFA payments. However, recent research suggests that farms may be rationally inefficient (HANSSON et al., 2018), meaning that they derive non-use values from e.g. the provision of public goods like enhanced animal welfare or farmland biodiversity. In this context, we follow RENNER et al. (2021), arguing that ecological payments, based on voluntary agri-environmental measures reflect the monetary compensation for the provision of non-marketable goods by farmers like for example animal welfare or farmland biodiversity and are accompanied by adjustments of input levels of farmers. However, we do not include direct payments and payments for less favoured areas (LFA) in the output, as for these payments a potential link with an adjustment of input levels is less clear. Based on this approach, a comparison of efficiency measures derived from model 1 with those calculated based on model 3, allows us to assess, whether payments for the provision of public goods are high enough to offset potential efficiency losses attributable to the participation in agri-environmental measures and the associated regulations.

5 Results

5.1 Descriptive statistics

Table 1 provides an overview of the variables used for the DEA and additional variables, describing our sample. Arithmetic means as well as coefficients of variation (CV were calculated for the whole sample and the 4 farming systems.

Looking at the in- and outputs it becomes evident, that conventional farms are on average the largest, while integrated/circular farms are by far the smallest. For organic and integrated/circular organic farms there is a similar trend. While both groups are smaller in terms of inputs and outputs compared to conventional farms, they are still bigger than integrated/circular farms and integrated/circular organic farms are not that much smaller compared to organic farms. These differences in size also manifest in the degree of specialisation of the farms, reflected in the share of dairy output from total output. Regarding milk yield, organic and both integrated/circular farming groups have a more extensive dairy husbandry system. With milk prices it is the other way around. A similar trend can be seen for subsidies.

Table 1. Descriptive statistics of DEA variables and selected additional variables

Variable	Whole sample (n = 1,583)	Conventional (n = 871)	Int./circular (n=274)	Organic (n=258)	Int./circular-Organic (n=180)
Output(s) and inputs of DEA models					
Total output excl. AE subsidies (TEUR)	100.04 (0.63)	118.10 (0.56)	57.72 (0.61)	99.50 (0.57)	77.80 (0.53)
Milk (t)	162.12 (0.75)	206.06 (0.65)	83.41 (0.58)	142.27 (0.65)	97.81 (0.58)
Other output (TEUR)	42.55 (0.68)	47.99 (0.62)	30.36 (0.83)	40.63 (0.68)	37.56 (0.65)
Total output incl. AE subsidies (TEUR)	106.39 (0.61)	122.98 (0.55)	62.19 (0.60)	109.85 (0.55)	88.44 (0.52)
Land (ha UAA)	31.02 (0.70)	31.94 (0.58)	24.99 (0.82)	30.37 (0.80)	36.68 (0.84)
Labour (AWU)	1.95 (0.33)	2.04 (0.31)	1.71 (0.35)	1.93 (0.34)	1.95 (0.34)
Capital (TEUR)	536.44 (0.54)	574.06 (0.52)	413.52 (0.65)	559.86 (0.50)	507.94 (0.51)
Intermediate expenses (TEUR)	55.50(0.62)	67.10 (0.55)	31.31 (0.49)	54.71 (0.52)	37.28 (0.46)
Herd size (LU)	39.05 (0.59)	45.96 (0.54)	25.99 (0.47)	36.03 (0.54)	29.83 (0.54)
Additional variables					
Share of dairy output from total output	0.56 (0.27)	0.58 (0.24)	0.49 (0.29)	0.58 (0.26)	0.52 (0.31)
Milk yield (t/cow)	6.55 (0.23)	7.25 (0.19)	5.51 (0.21)	6.09 (0.21)	5.36 (0.17)
Milk price (EUR/kg)	0.36 (0.17)	0.34 (0.12)	0.33 (0.09)	0.41 (0.12)	0.40 (0.22)
Total operational subsidies (TEUR)	21.43 (0.55)	21.30 (0.54)	15.63 (0.53)	25.55 (0.49)	24.95 (0.52)
Decoupled subsidies (EUR/LSU)	226.10 (0.33)	225.99 (0.31)	240.42 (0.36)	202.08 (0.26)	239.25 (0.42)
LFA subsidies (EUR/LSU)	152.96 (0.91)	117.90 (0.91)	170.30 (0.75)	202.21 (0.86)	225.65 (0.78)
RD subs. excl. LFA and inv. (EUR/LSU)	191.30 (0.75)	120.80 (0.77)	186.36 (0.63)	305.61 (0.40)	376.10 (0.37)
Share of dairy cows from total LSU	0.60 (0.17)	0.60 (0.17)	0.57 (0.19)	0.62 (0.16)	0.61 (0.18)
Share of rented land from total land	0.30 (0.83)	0.34 (0.74)	0.22 (0.91)	0.28 (0.86)	0.25 (1.00)
Debt ratio	0.12 (1.83)	0.15 (1.67)	0.07 (2.00)	0.13 (1.46)	0.09 (2.22)
Share of permanent grassland	0.89 (0.17)	0.87 (0.18)	0.86 (0.17)	0.96 (0.08)	0.91 (0.15)
Share of farms above 600 m	0.57	0.49	0.56	0.76	0.66

Source: own calculations. Note: Values denote means, values in parenthesis denote coefficients of variation (CV)

5.2 Technical-economic and environmental performance

As a simple comparison of means might be biased, we focus directly on ATTs of performance indicators after matching. For matching, structural differences between the groups were considered in terms of farm size (measured by standard output), site conditions (proxied by LFA payments per LSU and the share of permanent grassland) and a dummy for the year 2014 (matched farms had to be from the same year). Results are depicted in Table 3. In the upper part of the table, means of the matching variables before and after matching are shown. After matching, none of the variables are statistically different anymore. However, this comes at a cost, as at the same time the number of matched farms decreased significantly. One may say this reduction in sample size is problematic as it introduces attrition bias to our matched sample, but at the same time this allows us to compare farms of the different farming systems of similar size and facing similar site conditions. ATTs were calculated by comparing each of the groups pairwise to one another, whereby the less ecological farming system was always defined as the control group and the more ecological farming system the treated group. This results in a total of 6 comparisons, namely (a) conventional → integrated/circular, (b) conventional → organic, (c) conventional → integrated/circular organic, (d) integrated/circular → organic, (e) integrated/circular → integrated/circular organic and (f) organic → integrated/circular organic. These comparisons allow to identify performance gaps between the different farming systems for the respective performance indicators.

Comparing conventional and integrated/circular farms shows that the latter systems performs largely worse in terms of technical-economic performance and better in terms of environmental performance, indicated by the respective ATTs.

Analysing the differences between conventional and organic farms, shows that organic farms are able to compete with the matched sample of conventional farms in terms of profitability. In particular the three FADN farm income indicators have a positive ATT, indicating that their income per AWU is between around 3,000 and 5,000 EUR higher, compared to conventional farms. However, for the profitability indicator, where public payments are not considered and opportunity costs of production factors are included, there is no difference. This indicates that this advantage in terms of profitability is mostly due to public payments, as at the same time partial productivities tend to be lower, except for productivity in relation to intermediary expenses. Finally, efficiency estimates from model 2 are significantly lower for organic farms. In terms of environmental performance organic farms perform again better than conventional farms. In terms of efficiency, when subsidies, associated with the provision of public goods by agriculture are considered, organic farms have a positive ATT.

When comparing conventional farms with integrated/circular organic farms, the trend is overall very similar to the previous comparison of conventional and organic farms. However, there are also some interesting details to note. Firstly, the higher subsidies this farming system receives on average, contribute to a further increase in the ATTs of profitability indicators, where subsidies are included. On the other hand, partial productivities of land, labour and capital decrease further, while partial productivity in relation to intermediate consumption has an even higher ATT. Coming to environmental performance, ATTs indicate that integrated/circular organic farms perform far better than conventional farms according to the investigated indicators.

Table 2. Comparison of matching variables and ATT of performance indicators between groups

	Means Conv|Int	**Sig.**	**Means Conv|Org**	**Sig.**	**Means Conv|Int_Org**	**Sig.**	**Means Int→Org**	**Sig.**	**Means Int|Int_Org**	**Sig.**	**Means Org|int_Org**	**Sig.**
Standard output (TEUR) before matching	88.6|50.6	***	88.6|70.4	***	88.6|60.4	***	50.6|70.4	***	50.6|60.4	***	70.4|60.4	**
Standard output (TEUR) after matching	49.6|49.8	.	55.7|55.8		49.8|50.2		44.2|44.1		40.5|40.5		44.3|44.6	
LFA subsidies (TEUR) before matching	4.1|3.8	**	4.15|5.6	***	4.1|5.6	***	3.8|5.6		3.8|5.6	***	5.6|5.6	
LFA subsidies (TEUR) after matching	4.2|4.2		4.92|4.9		4.8|4.8		5.0|5.0		4.9|5.0		5.2|5.2	
Share of perm. grassland before matching	0.87|0.86	*	0.87|0.96	***	0.87|0.91	***	0.86|0.96	***	0.86|0.91	***	0.96|0.91	***
Share of perm. grassland after matching	0.96|0.96		0.99|0.99		0.99|0.99		0.99|0.99		0.98|0.98		0.99|0.99	
Number of farms in each group	871|274		871|258		871|180		274|258		274|180		258|180	
Number of matched farms	76		103		60		39		29		42	
Performance indicators	**ATT** Conv→Int	Sig.	**ATT** Conv→Org	Sig.	**ATT** Conv→Org_Int	Sig.	**ATT** Int →Org	Sig.	**ATT** Int→Int_Org	Sig.	**ATT** Org→int_Org	Sig.
Technical-economic performance indicators												
Private RCR excluding opp. costs	0.11	***	0.04	*	0.18	***	-0.08	***	0.07	***	0.16	***
Public RCR excluding opp. costs	0.20	***	0.12	***	0.37	***	-0.06	***	0.16	***	0.24	***
Private RCR including opp. costs	-0.03	***	0.00		0.00		0.01		0.03	***	-0.01	
Public RCR including opp. costs	-0.02	.	0.04	***	0.06	***	0.02	***	0.06	***	0.00	
Market orientation	-0.03	***	-0.04	***	-0.07	***	-0.02	***	-0.03	***	-0.02	***
Equity ratio	0.02	**	0.00		0.01		-0.03	***	-0.03	***	0.09	***
Output (EUR) per ha of UAA	-1,046	***	-555	***	-1,745	***	626	***	-359	***	-1,079	***
Output (EUR) per AWU	-6,962	***	-253		-1,744	.	3,079	***	3,613	***	-5,823	***
Output (EUR) in relation to assets	-0.03	***	-0.01	.	-0.02	***	0.03	***	0.01	**	-0.01	***
Output (EUR) in relation to interm. exp.	0.24	***	0.10	***	0.38	***	-0.16	***	0.23	***	0.34	***
Output (EUR/LSU)	-243	***	-45		-117	*	144	***	216	***	-82	
Gross farm income (EUR/AWU)	-512		4,846	***	8,686	***	860	*	6,677	***	231	
Farm net value added (EUR/AWU)	470		4,353	***	8,723	***	215		5,839	***	1,095	
Farm net income (EUR/AWU)	1,154	.	2,980	***	9,068	***	438		6,099	***	998	
TE vrs1 (output in EUR)	0.00		0.01		0.02	***	-0.02	***	0.03	***	0.03	***
TE vrs2 (kg milk and other output in EUR)	-0.03	***	-0.07	***	-0.07	***	-0.02	***	-0.01	*	0.03	***
Environmental performance indicators												
Stocking density (LSU/ha)	-0.31	***	-0.21	***	-0.63	***	0.14	***	-0.25	***	-0.33	***
Veterinary expenses (EUR / cow)	-39	***	-33	***	-67	***	39	***	-24	***	-13	***
Fertiliser costs EUR/ha)	-20	***	-4.85	**	-20	***	-0.42		-5.91	***	-6.63	***
Crop protection costs EUR/ha)	0.85		-3.72	***	-2.90	***	-3.73	***	-2.48	***	-0.12	***
Concentrate feed costs (EUR/ha)	-201	***	-11		-285	***	196	***	-65	***	-212	***
RD subsidies (excl. LFA and Inv.) (EUR/ha)	66	***	158	***	254	***	95	***	169	***	89	***
Eff. vrs3 (output incl. RD subsidies in EUR)	0.00		0.03	***	0.07	***	0.00		0.06	***	0.05	***

Source: own calculations. Note: sig. indicates a statistically significant difference of ATT with ***, **, *, and . indicating significance at the 0.1%, 1%, 5% and 10% level.

A comparison between integrated/circular farms and organic as well as integrated/circular organic farms shows some potential for an improvement in terms of economic performance, in particular with respect to profitability and productivity and partially also efficiency (only for model 1), if they would switch to integrated/circular organic farming systems. For the organic farming system, results are interestingly not that clear, in contrast to the simple mean comparison without matching. With regard to environmental performance, results are mixed. If integrated/circular farms would switch to the organic farming system, their environmental performance would decrease based on some indicators and increase based on others, whereas it would further increase, if they would switch to the integrated/circular organic farming system.

Finally, if organic farms were to switch to the integrated/circular organic farming system, this would result on average in no notable change in terms of profitability, but only if subsidies are considered. Partial productivity of land, labour and capital would decrease, but would increase with respect to intermediate expenses and also as regards efficiency estimates of models 1 and 2. At the same time, environmental farm performance would increase based on virtually all indicators.

Up until now, we have assumed that all farms operate under the same production technology, when comparing efficiencies between the groups. Table 3 shows efficiency results, if we instead assume different production technologies for each group. For conventional farms, most of the inefficiency is due to inefficiency within their respective groups, and the MTRs are consequently very high for all 3 models, indicating that conventional farming is overall the most productive production technology. For the other farming systems, more inefficiency is attributable to a potential technology gap, as is visible by the lower MTRs. Only in model 3, which considers agri-environmental and organic payments additionally in its output, the other production systems can keep up to some extent with conventional farming.

Table 3. Comparison of group-, metafrontier-efficiency and metatechnology ratio

Efficiency measure	Conventional (n = 871)	Integrated/circular (n=274)	Organic (n=258)	Integrated/circular-Organic (n=180)
Efficiency with respect to group frontier				
TE vrs1 (output in EUR)	0.65	0.60	0.68	0.66
TE vrs2 (kg milk and other output in EUR)	0.73	0.72	0.75	0.77
Eff. vrs3 (output incl. RD subsidies in EUR)	0.66	0.62	0.69	0.69
Metatechnology ratio (MTR)				
TE vrs1 (output in EUR)	0.96	0.92	0.86	0.89
TE vrs2 (kg milk and other output in EUR)	0.98	0.88	0.83	0.81
Eff. vrs3 (output incl. RD subsidies in EUR)	0.94	0.90	0.90	0.92
Efficiency with respect to metafrontier				
TE vrs1 (output in EUR)	0,62	0,55	0,59	0,59
TE vrs2 (kg milk and other output in EUR)	0,71	0,63	0,62	0,62
Eff. vrs3 (output incl. RD subsidies in EUR)	0,62	0,56	0,62	0,63

Source: own calculations.

6 Discussion and conclusions

The aim of the present study was to investigate and compare farm performance of different farming systems, going beyond a comparison of only conventional and organic farms with broadly available European FADN data. Our methodological approach consists of three steps:

(i) identification of different ecological farming systems with the LIFT farm typology, (ii) calculation of performance indicators, measuring technical-economic and environmental farm performance and (iii) comparison of performance indicators between groups, which was done with simple mean comparisons, matching and a metafrontier of production possibilities. Our analysis is based on a dataset of specialized Austrian dairy farms, pooled over the years 2014 and 2015.

In terms of the data source, we want to point out two issues. Firstly, FADN data provides only limited data on environmental performance of farms and we thus relied on proxies. In the near future, more such data should be available, when the FADN is convertet into a Farm Sustainability Network (FSDN). It would be very beneficial to add more environmental data in FSDN, which are already collected for other purposes (e.g. in the IACS), such as data allowing for a better differentiation of grassland in terms of its intensity of use (e.g. number of cuts).

A second issue is that the land variable in our analysis, measured as hectare of UAA is problematic, when farms have large shares of their land in disadvantaged mountainous areas (e.g. alpine pastures, or other very extensive grasslands). In Austrian FADN data, such areas are multiplied with a reduction factor smaller than one, leading to a reduced measure of farm size in terms of land, which better reflects the biophysical production possibilities. Direct payments are also based on this reduced land measure. Adding a similarly adapted land variable to the European FADN data would certainly also be beneficial for future analyses of farm performance with FADN data.

Overall, our results reveal potential synergies and trade-offs in terms of economic and environmental performance of the identified farming systems and of switching to a more ecological farming system. In general, both integrated/circular farming systems identified can be seen as more extensive forms of production, compared to conventional farms and organic farming systems, respectively. However, the conventional integrated/circular farming system performs overall worse compared to the other groups. While this farming system performs better in terms of environmental performance compared to the conventional system, it performs worse, when looking at technical-economic performance. In contrast, organic and integrated/circular organic farming systems can compete with conventional farms in terms of profitability, especially, if subsidies are included, a result which is not always found in similar literature (KUMBHAKAR et al., 2009; MAYEN et al., 2010). At the same time, these farming systems also perform better in terms of environmental performance than the conventional system and also than the integrated/circular system. Switching from organic to an integrated/circular organic farming system does not lead to further economic drawbacks. Profitability stays roughly the same, while overall efficiency even increases slightly and environmental performance also increases further.

Based on these findings we can draw some first conclusions in terms of policy recommendations: Our results indicate that adoption of the identified farming systems is strongly related to site conditions (only a small number of farms remained for matching, when controlling for site conditions and time), which cannot be influenced by policies. Consequently, the economic viability of more ecological farming systems depends also on public payments, compensating farms for natural disadvantages and the provision of public goods. However, in Austria these latter non-market outputs of ecological farming systems are also an asset, reflected in higher market prices and generally high consumer demand. Establishing markets for ecological products can thus reduce the dependency on public support and can be a further incentive for conventional farms to switch to a more ecological farming system.

In a next step, the present analysis could be expanded to include also a second-stage analysis of potential drivers of inefficiency, to control for further structural differences between the farming systems. However, as noted by BOGETOFT and KROMANN (2018) a second stage regression on efficiencies focuses on the combined effect of a frontier shift and catch-up, while the matching approach allows to separate these two effects.

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