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DEVELOPMENT VS EFFICIENCY OF POLISH FARMS – TRADE-OFF OR SYNERGY EFFECTS?

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ABSTRACT: The article aims to determine the nature of the relationship between farm development and its technical efficiency understood from the perspective of data envelopment analysis (DEA). The time scope of the analysis refers to the period 2004-2019. The empirical part of the article is based on the individual unpublished data for Polish farms conducting agricultural accounting according to Farm Accountancy Data Network (FADN). We employed a super-efficiency slack-based DEA model with variable returns to scale. This model enables us to compare and rank efficient farms as well as investigate the sources of farm (in)efficiency. We did not identify the substitution (trade-off) effect between farms` sustainability and efficiency. For mixed farms, there is some evidence for synergy effect since sustainable farms exhibit higher level of technical efficiency and these differences were statistically significant. The main policy recommendation that can be derived from these results is that agricultural policy should support both efficiency improvements and progress toward higher sustainability.

KEYWORDS: farms, slack-based model (SBM), technical efficiency, sustainability, FADN

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Introduction

Farm development has various facets. Currently, it is most often put together with the term “sustainable.” This concept is not clearly defined in terms of definition (Figiel, 2022), as well as semantics (Śleszyński, 2016). Consequently, there are very many definitions of the term, as well as there are very many proposals for the quantification of sustainable development at the farm level (Gaviglio et al., 2017; Valenti et al., 2018; Steinke et al., 2019). In the article, development is identified with the simultaneous realisation by the farm of selected assumptions (cf. methodological part) from the economic, environmental and social areas. Thus, it can be equated with sustainable development, although we are aware of some simplifications in this regard due to data limitations. The question may arise whether this type of development favours or limits farm efficiency?

In the literature on the subject, this problem is still not clearly resolved (Grzelak et al., 2022; Briner et al., 2013; Czekaj et al., 2020). The question is even more relevant because, on the one hand, the reduction of environmental pressures by farms is currently being promoted, and on the other hand, there is a need to maintain food security both at the national and global levels. This issue is related to the problem of complexity, which is particularly important for agriculture (Grzelak, 2015). The latter context is related to the war in Ukraine, as well as the growing demand for food in the world. From this point of view, the concept of sustainable intensification in agriculture seems interesting. As pointed out by Baulcombe et al. (2009), the idea is to increase agricultural productivity without increasing environmental pressure. In turn, A. Buckwell’s team defined sustainable intensification as increasing production efficiency while improving the environmental management of agricultural land (Buckwell et al., 2014). On the path of sustainable intensification, it is possible to increase agricultural production with limited pressure on the environment, which is particularly important for less developed countries (Pretty et al., 2011). As Staniszewski (2018) notes, for the EU15 member states, the concept of sustainable intensification primarily means increasing the environmental productivity of agriculture without reducing economic productivity. In contrast, in the new member states, the process has been more directed toward increasing economic efficiency. Our article, therefore, attempts to fill the research gap on whether it is possible in a country with a medium level of agricultural development (such as Poland) to focus on realising the social and environmental functions of agriculture with simultaneous improvements in technical efficiency.

The article aims to determine the nature of the relationship between farm development and farm efficiency understood from a data envelopment analysis (DEA) perspective. Its implementation was carried out by answering the research problems:

- Are farm sustainability and technical efficiency complementary or substitutable to each other?
- What are the sources of (in) efficiency of farms?

The time scope of the analysis refers to the period 2004-2019 and concerns, in the empirical part, farms from Poland. Our approach to the title question differs from the earlier ones in that we use a panel of farms 2,299 farms with continuous agricultural accounting in the period 2004-2019. In addition, we employed a super-efficiency slack-based DEA model with variable returns to scale, which enables us to compare and rank efficient farms. This model is of non-radial nature and makes it further possible to identify the so-called slacks – the room for potential improvement in the reduction of agricultural inputs and expansion of outputs. To the best of our knowledge, such an approach has not been previously used regarding the polish FADN panel.

The rest of the article is organised as follows. In the next section, we review the literature on links between sustainability and the efficiency of farms. In the third section, we provide a detailed methodology of this research. The fourth section is devoted to the analysis of results together with discussion, while the last part concludes.

Literature review

The analysed issues correspond in practical terms currently with a set of initiatives of the European Commission to achieve climate neutrality in Europe, the so-called European Green Deal (Dobbs et al., 2021). On the other hand, the need to ensure food security in a situation of war in Ukraine, broken supply chains, as well as growing global demand for food create pressure to increase food production. Thus the idea is to reduce the pressure from farms on the environment while not worsening the productivity of the used resources (Czyżewski et al., 2019). However, the support instruments of the CAP (Common Agricultural Policy) increasingly stimulate pro-environmental measures and limited productivity. Indeed, economic efficiency cannot be the only criterion for evaluating EU budget spending on agricultural policy due to the peculiarities of the land factor and the role that rural areas are supposed to play in society (Czyżewski & Polcyn, 2016; McDonagh et al., 2017). As indicated by studies conducted by (van Grinsven et al., 2019), agri-environmental subsidies contribute to the sustainable development of agriculture, and the increase in capital expenditures favours higher economic efficiency in agriculture. The research on the impact of factor intensity on sus-

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tainability and efficiency is dominated by the view that an increase in capital inputs favours high economic efficiency (Van Passel et al., 2007). However, there is fear that stimulating capital equipment under the CAP favours industrial agriculture and may lead to overinvestment (Van Passel et al., 2009).

At the farm level, not worsening the productivity of resources while reducing the pressure on the environment means that the relationship between sustainable development and efficiency should be strengthened. In practice, however, the objectives of farmers that are linked to economic and environmental spheres can be contradictory. Thus growing farm income is accompanied by greater pressure on the environment or increasing stratification of incomes and assets among farmers. For example, (Briner et al., 2013; Jaklič et al., 2014) affirmed the interchangeability between environmental and economic dimensions in the functioning of farms. (Ripoll-Bosch et al., 2012) underlined a clear trade-off between the economic and environmental goals based on investigating sheep farms (in different farming systems) in north-eastern Spain. The higher the economic sustainability, the lower the environmental sustainability. In turn, in Grzelak's (2020) study, the relationships between economic and environmental objectives on farms in Poland were found to be statistically insignificant. On the other hand, however, there was a cluster of farms in which these objectives were simultaneously highly ranked by respondents. This indicates the complexity of the phenomena studied. Špička et al. (2020), based on the experience of farms in the Czech Republic, underline that there is a trade-off between environmental sustainability and economic performance. Moreover, (Gomez-Limon & Sanchez-Fernandez, 2010; Picazo-Tadeo et. al., 2011; Bonfiglio et al., 2017) indicate that a balance between these dimensions is possible, and the relationship between economic and environmental objectives is positive. Different studies stress that larger units, and therefore those with more income, have a better chance of having a positive relationship between the economic and environmental spheres (Haileslassie et al., 2016; Grzelak, 2022b).

The problem of the relationship between efficiency (in the sense of DEA) and environmental sustainability is presented in the work of Guth et al. (2022). Based on the study of small-scale farms in Poland, Lithuania, Romania, Serbia, and Moldova stated that they are rather weak economically but environmentally friendly. Other conclusions come from the work of Gomes et al. (2009). They highlight, based on the performance of farms in Brazil, that the majority of the farmers increased their efficiency, which may support the existence of sustainability. Also, Czekaj et al. (2020) underline, based on the surveys of farms in Poland and Latvia, that economically strong individuals are more able to guarantee social and environmental sustainability. Grzelak et al. (2022) came to similar conclusions based on a survey of farms in Poland. They conclude that significant and positive relationships between the eco-

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nomic, social, and environmental dimensions could create synergies between them.

Methodology of research

In the analyses, the individual unpublished data for Polish farms conducting agricultural accounting according to Farm Accountancy Data Network (FADN) principles continuously during the period 2004–2019 were used. The data was deflated using price indices for products purchased or sold by farmers. In the analysed group, there were 2,299 farms of individuals.

FADN methodology for Poland distinguishes seven main types of farms. In Table 1, we provide the number of farms belonging to the given farm type in each year of analysis. Some farms have changed their type during the research period. The largest number of polish FADN farms can be classified as mixed, followed by field crops and dairy farms.

Table 1. Number of FADN farms in different types of farming in 2004-2019

Year	Fieldcrops	Horticul-ture	Permanent crops	Dairy	Grazing livestock	Granivores	Mixed	Total
2004	412	42	61	166	272	311	1032	2296
2005	419	42	60	190	285	338	964	2298
2006	404	61	57	181	308	377	911	2299
2007	413	64	66	187	309	360	900	2299
2008	456	63	71	199	345	306	856	2296
2009	471	64	74	204	352	312	817	2294
2010	342	75	67	533	85	359	814	2275
2011	368	69	66	540	100	347	803	2293
2012	390	71	70	535	116	337	763	2282
2013	534	63	68	525	62	194	832	2278
2014	556	61	70	519	66	198	787	2257
2015	578	58	69	482	61	189	770	2207
2016	616	59	70	536	90	187	723	2281
2017	643	61	71	535	88	171	708	2277
2018	672	58	73	502	95	167	686	2253
2019	727	61	70	516	119	156	621	2270
Total	8001	972	1083	6350	2753	4309	12987	36455
Unique units	923	84	92	705	660	524	1529	2299*

Source: author's work based on unpublished FADN data.

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Delimitation of farms into groups regarding sustainability farms was done based on economic, environmental, and social dimensions. The economic dimension was determined by estimating farm income per one full-time employed member of the farm family. If the level of these incomes exceeded the average level of net wages in the economy in Poland, then the farm met the condition of sustainability in the economic dimension. This was calculated for the surveyed farms based on the mean for the years 2004-2019. A similar approach was also used to estimate environmental and social sustainability.

Environmental sustainability was defined based on two sub-measures: the share of cereals in the crop structure and livestock density per 1 ha UAA. The choice of these measures was based on the fact that, in their case, it was possible to determine threshold values, which then set the critical values for the given sustainability areas (Wrzaszcz, 2013). In the case of the share of cereals in the sowing structure, the measure should not exceed 66%, while for animal stocking density, values in the range of 0.5–1.5 so-called large livestock units per 1 ha UAA are desirable, which is conducive to maintaining correct fertiliser management on the farm (Baum, 2011; Harasim, 2013). These two proposed metrics represent both agricultural production biodiversity and environmental pressure issues. It was assumed that sustainability in the environmental dimension takes place when the farm achieves it in each of these two sub-metrics.

Due to the microeconomic nature of the data, as well as the level of analysis, social sustainability was determined by the education and age of the farm manager. If the farm manager had at least a secondary agricultural education and was under 45 years old for the year under study, then the social sustainability condition was met. This results from the fact that in Poland, the age of 40 was adopted in the definition of a young farmer. It enables potential beneficiaries to benefit from additional forms of support under the CAP, e.g. the "Young farmer". However, such units would be very few among the studied farms because we use the average age of a farmer running a farm in the years 2004-2019. Therefore, the age of 45 was assumed. In the case of education, having at least a secondary education provides an adequate level of knowledge, which enables the farm's development. Younger farmers have a longer planning horizon and are less averse to risk than older farmers; they adopt new technology more readily and purchase newer equipment more often (Gale, 1994). Such an understanding of the social dimension, with some simplification, can also be applied to human capital.

In the second step of the study, the technical efficiency of the farms was calculated. There are two main approaches for efficiency calculation, namely DEA and stochastic frontier analysis (SFA). The key difference between these two is that the former provides higher flexibility in the structure of the pro-

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duction function while the latter enables noise separation (Bogetoft & Otto, 2011). In this research, the DEA-based model was chosen mainly because we deal with different farm types so the model flexibility is a big advantage. An important drawback of basic DEA models was, however, that they were radial so they assumed that inputs decrease or outputs expansion has to be proportional, while in reality, the potential to change the inputs (or outputs) level is very often not equal (Chen & Jia, 2017). This leads us to the use of the non-radial slack-based measure (SBM) model, first proposed by Tone (2001). In this model, one can assume that all inputs and outputs may change independently. The results of the model calculation show which inputs (or outputs) and in what proportion should be reduced (or increased). Furthermore, we prefer variable (VRS) rather than constant (CRS) returns to scale assumption because agriculture is recognised as a scale-sensitivity economic activity.

An important problem regarding basic DEA-based models, in particular with VRS assumption, is that they have weak discriminating power. In practice, it means that a large many decision-making units (DMUs) are usually found to be efficient (efficiency scores equal to 1) because they are situated on the efficiency frontier. However, it does not mean that these DMUs have exactly the same performance. To overcome this drawback, we use the super-efficiency model, first proposed by Andersen and Petersen (1993). In this approach for each of the efficient DMU an artificial frontier without a given DMU is designated and the distance between this DMU and a new frontier is calculated. The higher the distance the better positioned is the DMU and the higher efficiency score it obtains. Thanks to this approach, the comparison of efficient units becomes possible. From the perspective of this article, an advantage of the presented approach is that it enables to calculate median efficiencies more accurately.

Since 2004 polish farms have been subject of the EU common agricultural policy. The main feature of the policy from the farm perspective is that farmers receive subsidies for their current operations. However, the value of payments received is to large extent beyond the farmer's control. On the other hand, these subsidies create the economic environment for farming activities. Therefore, we include subsidies for current operations in the model as an uncontrollable input (Yang & Pollitt, 2009).

The super-efficiency SBM-DEA model is indicated as follows. Let the observed input data matrix be $X \in R_{+}^{m \times n}$, where n and m are the numbers of DMUs and inputs, respectively. The output data matrix is $Y^g \in R_{+}^{s \times n}$ where s is the number of good outputs.

For the specific DMU $(x_0, y_0) \in P$ the linear programming of the super-efficiency SBM-DEA model is described as follows:

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$$min \frac{1-\frac{1}{m}\sum_{i=1}^{M}\frac{s_i^-}{x_{ik}}}{1+\frac{1}{s}\sum_{r=1}^{S}\frac{s_r^+}{y_{rk}}}. \quad (1)$$

Subject to:

$$\sum_{j=1,\neq k}^{n} x_{ij}\,\lambda_j - s_i^- \leq x_{ik},\ i = 1,2,\dots,m, \quad (2)$$

$$\sum_{j=1,\neq k}^{n} x_{ij}\,\lambda_j + s_i^+ \geq x_{ik},\ r = 1,2,\dots,s, \quad (3)$$

$$\sum \lambda_j = 1\ , j = 1,2,\dots,n\ (j \neq k), s_i^- \geq 0, s_i^+ \geq 0,\ \lambda \geq 0,$$

where $\sum \lambda_j$ means that we assume variable returns to scale and $s_i^- \geq 0, s_i^+ \geq 0$, are the slack values for inputs, and outputs respectively. The slacks are defined as the DMU's potential to decrease of the input use or increase the level of output. Technically, the value of slack shows how much a given DMU should change its inputs or outputs level to become fully efficient (in the sense of strong efficiency).

The input/output mix differs between different farm types. In Table 2 we present mean values together with standard deviations for inputs and outputs used for the analysis for all seven farm types. If the value for the specific variable is not displayed, it means that this variable was not used or it was merged with another category. For example, a field crops farm can still have some livestock but the spending on feed is marginal, so this is included in the "other cost" category. Data in Table 2 shows that sample farms are highly diversified between main farm types but they also vary to a large extent within a given farm type (as demonstrated by standard deviations). Differences in the average level of inputs result from farm type specificity. When it comes to the level of production, it can be said that mixed farms, permanent crop and grazing livestock farms are, on average, smaller in economic terms in comparison to the other farm types. The highest level of current subsidies was noticed among field crops farms since the majority of support is organised in the form of direct payments related to farm areas.

Once efficiency scores are calculated for each farm every year, we calculate median scores for farms belonging to the given farm type and distinguish between 'sustainable' and 'unsustainable' farms, following the criteria described above. Since efficiency scores are not normally distributed we employ a non-parametric Wilcoxon rank sum-test to answer whether median efficiency scores for sustainable and unsustainable farms are significantly different.

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Table. 2. Mean values and standard deviation of variables used for technical efficiency analysis

Variable	Field crops		Horticulture		Permanent crops		Dairy		Grazing livestock		Granivores		Mixed farms	
	Av.	SD	Av.	SD	Av.	SD	Av.	SD	Av.	SD	Av.	SD	Av.	SD
production [PLN 1000]	229.5	257.1	379.6	422.2	168.1	183.7								
crop production [PLN 1000]							35.7	44.3	30.3	31.8	90.6	102.6	80.0	109.8
livestock production [PLN 1000]							212.8	270.5	124.5	135.2	358.9	576.5	89.4	115.7
labour [hrs/year]	4376	3063	8594	7644	6572	4725	4694	1570	4325	1385	4639	2642	4170	1689
Land [ha]	50	53	8	9	14	14	30	21	29	20	33	31	30	28
Livestock units							37	32	33	26	95	118	26	27
fertilizers [PLN 1000]	42.4	55.7	21.0	27.6	8.3	11.8								
pesticides [PLN 1000]	19.9	28.7	7.8	11.8	15.3	18.7								
Fertilizers & pesticides [PLN 1000]													23.3	36.3
Feed [PLN 1000]							58.6	89.4	34.6	40.7	223.4	355.1	49.1	67.7
Energy [PLN 1000]	22.1	25.5	71.2	109.0	13.6	17.3	18.4	20.5	12.0	10.8	21.5	27.3	13.4	16.2
depreciation [PLN 1000]	35.6	42.4	43.3	51.5	39.9	36.7	31.5	34.1	21.6	18.6	33.8	39.2	22.2	24.6
External costs [PLN 1000]					24.2	39.4								
other costs [PLN 1000]	66.3	85.4	148.1	233.9	22.5	40.2	72.1	82.7	47.8	50.3	85.6	112.1	32.8	48.7
Current subsidies [PLN 1000]	59.5	64.8	9.2	17.3	15.0	22.6	39.3	28.7	32.1	27.1	36.4	38.2	35.1	35.0

Source: author's work based on unpublished FADN data.

Results and discussion

To answer the first of our research questions, namely whether the sustainability and a higher level of efficiency can be treated as complementary or substitute objectives of the farm, the median efficiency scores for each farm type were calculated (cf. Table 3), distinguishing between sustainable (regarding given dimension) and unsustainable farms.

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Table 3. Median efficiency of sustainable and unsustainable farms under study in different types of farming

Sustainability dimension		Fieldcrops	Horticulture	Permanent crops	Dairy	Grazing livestock	Granivores	Mixed
Environmental	*Yes*	0.514	0.840	**0.735**	**0.688**	0.773	0.817	**0.649**
	No	*0.525*	0.840	0.678	0.679	*0.784*	*0.819*	0.617
Wilcoxon test value		1.054 (0.292)	-0.504 (0.614)	-1.109 (0.308)	0.496 (0.620)	-0.145 (0.885)	-0.173 (0.863)	-2.087** (0.037)
Economic & environmental	*Yes*	0.519	0.838	**0.725**	**0.688**	**0.790**	**0.826**	**0.656**
	No	*0.520*	*0.845*	0.678	0.680	0.780	0.819	0.615
Wilcoxon test value		0.357 (0.721)	-0.977 (0.328)	-0.464 (0.643)	0.245 (0.807)	-0.373 (0.709)	-0.630 (0.529)	-3.136*** (0.002)
Economic, social & environmental	*Yes*	0.510	0.839	**0.857**	0.660	0.778	**0.832**	**0.685**
	No	*0.520*	*0.906*	0.677	*0.680*	*0.781*	0.819	0.622
Wilcoxon test value		1.256 (0.209)	-0.557 (0.577)	-1.742* (0.082)	0.599 (0.549)	0.093 (0.926)	-0.592 (0.554)	-1.484 (0.138)

Note: nonparametric Wilcoxon rank-sum test is used; values are in italics when median efficiency of unsustainable farms is higher, bold stands for the opposite; ***,**,* stand for significance at 0.01, 0.05 and 0.1, respectively.
Source: author's work based on unpublished FADN data

In most of cases, the median scores for sustainable farms (in different dimensions) are not significantly different from the median for unsustainable farms. The difference is significant for permanent crops farms when economic, social and environmental dimensions of sustainability are simultaneously taken into account as well as for mixed farms when environmental or economic and environmental dimensions are considered. Interestingly, in all of these cases, the median value of efficiency was higher for farms classified as sustainable. In the rest of the cases, the differences were not significant but the general rule is that for crop farms the median efficiency scores were usually slightly lower for sustainable farms while for livestock farming it differs, depending on a particular type and sustainability dimension. However, taking all these results into account, we can say that we did not identify a trade-off effect between technical efficiency and sustainability of polish market-oriented farms. In the case of mixed farms, which constitute the largest share of the sample, we can even argue for the presence of a synergy effect.

Our results are in line with the findings of Adenuga et al. (2019; 2020), Peña et al. (2018), Urdiales et al. (2016), Wetteman and Latacz-Lohmann (2017), Guesmi and Serra (2015), or Hai and Speelman (2020). All these researchers advocate that it is possible to improve environmental aspects of

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farm functioning without deteriorating efficiency. For example, Wettemann and Latacz-Lohmann (2017) found that dairy farms in Germany can decrease their cost and GHG emission without depleting production level. Peña et al. (2018) found on the example of South America that economic effects can be improved by 20% with a simultaneous reduction of inputs and bad outputs by 20%. Based on the Irish example, Adenuga et al. (2019; 2020) concluded that analysed farms could increase production and reduce the nitrogen surplus at the same time. However, there are also contradictory findings in the literature. For example, Soteriades et al. (2015) have noted a negative correlation between dairy production efficiency and environmentally-friendly farm practices. According to Ullah et al. (2019) it is hard to achieve high economic efficiency and eco-efficiency at the same time. Huang et al. (2016) found, in turn, that relation between technical and environmental efficiency of farms depends on their size.

To answer the second research question we deal with the sources of farms` inefficiency for the farms with technical efficiency below one. More specifically, we analyse the average level of slacks on inputs and outputs to identify the most problematic areas of inefficient farms belonging to different farm types (Table 4). Elimination (or at least the decrease) of these slacks would increase farms` technical efficiency.

Table 4. The average level of slacks [in % of initial values] – an average of DMUs 2004-2019 means for studied farms

Variable/ Type of farming	Field-crops	Horticul-ture	Permanent crops	Dairy	Grazing live-stock	Grani-vores	Mixed
Production	70	15	38				
Crop production				110	80	27	36
Livestock production				8	10	12	62
Labour	-8	-10	-12	-11	-8	-10	-10
Land	-23	-24	-10	-8	-9	-9	-21
LSU				-9	-6	-7	-27
Fertilisers	-43	-24	-41				
Pesticides	-27	-24	-26				
Fertilisers & pesticides							-20
Feed				-8	-7	-3	-16
Energy	-18	-15	-19	-14	-11	-12	-16
Depreciation	-22	-13	-15	-14	-12	-15	-20
External costs			-24			-7	
Other costs	-13	-3	-13	-8	-4	-7	-8

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The key source of inefficiency among crop farms was fertiliser and pesticides use. Slack on fertilisers was particularly high for field crops and permanent crop farms. The values in Table 4 mean that, for example, inefficient field crop farms should decrease spending on fertilisers by 43%, on average. If we assume that all sample farms have access to the technological frontier (which seems to be a reliable assumption for FADN farms from a given type), then we can say that inefficient field crop farms have a large room for fertiliser decrease. The European Green Deal assumes reducing fertilisers use by 20% and pesticides by 50% by 2030 on the EU level. If we compare the results in Table 4 with these general objectives, then we can conclude that improving efficiency through the elimination of slacks would help significantly in the fulfilment of these goals.

For permanent crops farms, another important field of potential improvement is external costs which comprise hired labour, rents and interest paid. This type of farming is usually more dependent on external production factors (labour input, in particular) than others, but our results suggest that a decrease in spending for this type of cost is possible. Interestingly, among field crop and horticulture farms a relatively large slack on land input was observed. At the same time, the production level for all three crop farm types should be increased. It indicates an important problem with technical efficiency since slacks values suggest that inefficient farms could, on average, decrease their acreage but increase production simultaneously. In other words, many farms achieve too low production in relation to the current inputs used.

When it comes to livestock farming, the relative values of slacks are lower, meaning that the room for improvement is smaller in comparison to crop farming. However, the largest slacks are found concerning energy input and depreciation, while the latter represents the use of fixed capital. It shows that a transition to more energy-saving technologies is needed. The high value of slack on depreciation indicates that the use of fixed capital is too high for production. Therefore, it can be said that some livestock farms deal with the problem of overinvestment (Pawłowski et al., 2021).

Interestingly, there are some slacks on typical inputs for livestock production, such as feed costs, but they are relatively small. It is especially striking when compared with slacks on fertilisers and pesticides for crop farms. This result suggests that the use of main inputs is closer to optimal when it comes to livestock farms. Large slack in crop output for livestock farms results from the fact that many of them have very little crop production. Therefore, the relative slack values may be exaggerated.

Regarding inefficient mixed farms, it can be said that they struggle with the relatively large slacks on land and the number of livestock units and even larger slacks on production, especially livestock output. This suggests that

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the main problem of these farms is that their production level does not correspond to the degree of involvement of basic production factors, such as land or livestock units. It shows that there is significant room for improvement in terms of revenue, even without increasing the scale of operation.

Conclusions and recommendations

In this paper, we have used data from 2,299 commercial polish farms representing all seven main farm types for the 2004-2019 period to deal with two research questions, namely: whether there is a synergy or trade-off effect between technical efficiency and farm sustainability and what are the sources of farm inefficiency. To answer these questions, we have classified farms according to sustainability definitions and calculated median technical efficiencies for different groups of farms. Finally, we have performed the slack analysis to investigate the sources of farms` inefficiency.

Among the limitations of the research, one can mention the fact that sustainability and efficiency measurement employed in this paper is somehow subjective. However, the problem is that there is no consensus on how to measure these phenomena. A systematic approach proposed in this paper could add to the existing knowledge. The use of competitive approaches, such as stochastic frontier analysis, can be seen as a fruitful line for further research. Moreover, more environmental indicators should be gathered at the FADN level system in the European Union countries (Borychowski et al., 2022). This would allow an even more precise examination of farm development, taking into account the relationship between efficiency and environmental issues.

In the course of the analysis, we did not identify the substitution (trade-off) effect between farms` sustainability and efficiency. For mixed farms, there is some evidence of a synergy effect since sustainable farms exhibit a higher level of technical efficiency and these differences were statistically significant. The main policy recommendation that can be derived from these results is that agricultural policy should support both efficiency improvements and progress toward higher sustainability. These two policy objectives can be treated as complementary rather than opposite to each other.

The results also indirectly indicate that greater digressive of decoupled payments should take place, depending on the UAA (Grzelak, 2022a). The idea is to limit the impact of the rent-seeking phenomenon on-farm efficiency. The slack analysis has shown that major sources of inefficiency for crop farms are the excessive use of fertilisers and pesticides. For livestock farming, these were excessive energy consumption and inadequate level of fixed assets. Agricultural policy should stimulate a reduction in the use of fertil-

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isers and pesticides on crop farms, e.g. by promoting precision agriculture. In the case of livestock farms, it is necessary to take measures aimed at reducing the energy intensity of production and limiting the phenomenon of farm overinvestment. Among the most important problems of mixed farms is that they achieve a too low level of production with respect to their size. Production diversification, typical for mixed farms, provides some environmental benefits but it impedes the improvement of production results. The policy could provide some incentives for mixed farms to specialise in crop or livestock production. Alternatively, if higher diversity is seen as a public good, the policy should top-up incomes of mixed farms with specific subsidies. This postulate will be partially fulfilled through eco-schemes in the new common agricultural policy.

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The contribution of the authors

Conceptualization, A.G. and Ł.K.; methodology, A.G. and Ł.K.; obtaining data, A.G.; literature review, A.G.; estimation of models, Ł.K.; analysis and interpretation of data, Ł.K.; writing–original draft preparation, A.G. and Ł.K.; project administration, A.G.; funding acquisition, A.G. All authors have read and agreed to the published version of the manuscript.

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