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Farm outcomes based on cluster analysis of compound farm evaluation

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Abstract: The purpose of this paper is to examine the internal structure of Czech agricultural holdings based on a multicriteria evaluation of the five dimensions representing the main functions of agriculture including production, economic factors, financial stability, environmental, and social and other factors. A cluster analysis was performed to identify two clusters of farms. The first cluster consists of smaller holdings that specialize in livestock production and achieve poorer financial results compared to the second cluster, which includes a larger share of large holdings that focus on crop production. The first cluster exhibited better performance as regards environmental protection and financial stability. In contrast, the second cluster achieved better scores regarding production and economic factors. However, an evaluation of all dimensions showed that the second cluster of farms obtained slightly better ratings (2.7% above the overall average) then the first cluster (3.1% below the overall average score). It is up to policy makers to decide which group of farmers, is more approaching the aim of the new agricultural policy. Policy makers can consider the results of this study to find the areas where the sustainability rate should be increased and purposefully promote that by specific measures to achieve balanced farming system.

Keywords: classification statistics; farm accountancy data network; multidimensional assessment; multifunctional farming; sustainability

Agriculture as such does not have a single objective, specifically the production of foodstuffs. Rather, agriculture has a set of diverse functions. According to the European Commission (EC) (1999), agriculture has multipurpose nature and its three main functions include producing foodstuffs, feedstuffs, and fibres, conserving rural areas and landscape, and contributing to the viability of rural areas and to balanced territorial development. This definition is supported by the Food and Agriculture Organization of the United Nations (FAO) (1999), which ascribes four dimensions to multifunctional agriculture: (*i*) the production of foodstuffs (food security), (*ii*) the social function (quality of life in rural areas), (*iii*) the economic function (agriculture is an important factor for national economic growth, which is conditional on market development and institutional development), and (*iv*) the environmental function (this function is correlated to such global issues as biological diversity, climate change, transformation of fertile land into deserts, water quality and availability, and air pollution).

In 2017, EC communicated its vision of the future of food and farming stressing the need of smarter, modern and sustainable Common Agricultural Policy (CAP). In 2019, the "Green Deal" have been introduced to the public by EC having specific impacts also on the European agricultural sector. One of the practical proposals is to convert farm accountancy data net-

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work (FADN) into the farm sustainability data network to obtain data on Farm to Fork strategy as well as environmental and climate sustainability enriching existing economic and production source of data (EC 2020). A variety of research viewpoints and approaches to multifunctional agriculture have been compiled, sorted, and analysed by Renting et al. (2009). In their work, the researchers present a broad review that classifies approaches to research into market regulation, land use, factors concerning stakeholders (farmers), and public regulation. In addition, they bring attention to factors that currently restrict research, encouraging the creation of an integrative interdisciplinary framework. A systematic review on the definition and the content of sustainable agriculture have been published by Velten et al. (2015) suggesting developing ambiguous terms instead of precise concepts supporting multivalent and flexible meanings.

A sizeable number of original works examine the non-production functions of agriculture with a focus on defining environmental and social benefits, on determining their value (Thomassen et al. 2009; Mészáros et al. 2015), and on examining the effect of agriculture on certain selected areas (Van der Werf et al. 2009). Numerous studies into agriculture and into environmental protection in relation to agriculture use multidimensional methods to incorporate findings obtained in various other fields (Dolman et al. 2012). Detailed summary of the methodological approaches has been compiled by De Luca et al. (2017) confirming that scientists use mainly multi-criteria decision analysis, life cycle methodologies and its combinations analysing agricultural sustainability.

The OECD (2008), in partnership with the Joint Research Centre of the European Commission, has created a procedure for compiling a composite indicator using data from various fields. A similar procedure is employed in compiling, for example, the Environmental Performance Index (Joint Research Centre 2014), which can be used to compare performance of countries as regards the protection of ecosystems and human health.

The aim of this research is to analyse inner structure of farms reflecting their agricultural sustainability ratings and to provide relevant evidence for policy makers to better target measures within new direction of agricultural policy. At the same time, this can serve as a source of information for individual farmers to uncover strengths and weaknesses in their farming.

Particular methodology used in this study is described in the section materials and methods following by the chapter introducing results and discussion. Last section summaries main findings and suggested conclusions.

MATERIAL AND METHODS

This paper examines the five basic functions of agriculture. The functions are divided into five dimensions within the framework of a multicriteria assessment. The dimensions include production, economic factors, financial stability, environmental factors, and social and other factors.

A study into data pertaining to the sustainability of multifunctional agriculture has been performed by Latruffe et al. (2016a). However, the necessity to use of a broad range of data is hindered by their limited availability. This work is based on data available in the database maintained by the Czech Farm Accountancy Data Network (FADN). FADN is data source enabling various analysis of farm sustainability on farm level (Wrzaszcz 2014; Sulewski and Kloczko-Gajewska 2018).

The production dimension has been assessed using data on four areas, specifically (*i*) crop yield (sales per hectare where crop yield cannot be determined), (*ii*) weight increase, (*iii*) livestock yield (milk, eggs, honey), and (*iv*) livestock mortality.

The economic dimension consists of six evaluation criteria, specifically (*i*) farm net value added/annual work unit (FNVA/AWU), (*ii*) labour productivity, (*iii*) crop production per hectare or livestock production per livestock unit, (*iv*) direct crop costs per hectare or direct livestock costs per livestock unit, (*v*) intermediate consumption productivity, and (*vi*) return on equity (ROE).

The financial stability dimension comprises six indicators, specifically (*i*) quick ratio liquidity, (*ii*) cash-flow liquidity, (*iii*) total debt to total assets, (*iv*) maturity of receivables, (*v*) net working capital index, and (*vi*) investment without subsidies.

The environmental dimension was assessed using 10 indicators, including (*i*) organic manure use, (*ii*) mineral fertilizers, (*iii*) crop protection, (*iv*) share of legumes, (*v*) stocking density, (*vi*) share of grassing, (*vii*) greening, (*viii*) energy productivity, (*ix*) share of soil-improving crops, and (*x*) renewable energy production.

The dimension consisting of social and other factors includes eight indicators, specifically (*i*) gender of owner or farm manager, (*ii*) young farmer indications, (*iii*) number of employees, (*iv*) education of owner or farm manager, (*v*) land ownership, (*vi*) protection of origin (PDO/PGI), (*vii*) wages, and (*viii*) diversification.

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An overall score was awarded based on ratings assigned to individual indicators. The overall score for a given dimension is equal to the sum of ratings given to specific indicators. This methodology was employed to calculate the total score for the evaluated holdings, using a weighted average of scores awarded to the individual dimensions. An advantage and novelty of this approach is especially in the comprehensive valuation of a larger range of dimensions than it is common in the current research. The focus is not only on the environmental sustainability, but within this study the complex long-term sustainability of farms is evaluated to ensure both business operations and food production, care for the countryside, rural life and other agricultural functions. Another great advantage is the use of a representative sample of business data, which allows the practical application of the proposed measures for the needs of agricultural policy.

The data used in the assessment were obtained from statistical surveys of agricultural holdings conducted by the FADN in 2016 (FADN CZ 2019). The analysed sample comprises 1 351 agricultural holdings.

This paper employs the typology of agricultural holdings used by the European Union. The typology is used to classify agricultural holdings according to their production specialization and economic size.

Data used in this study include the average score awarded to each of the five dimensions for every holding in the assessed sample, and the average outcome for indicators describing these holdings and the nature of their operations. The objective was to determine whether holdings can be classified into clusters based on the similarity of the outcome of a multicriteria assessment, and to subsequently describe thus ascertained clusters of agricultural holdings. For this purpose, a cluster analysis was performed, a method used to analyse multidimensional subjects and to classify them into clusters. First, a hierarchical cluster analysis was carried out to determine the number of clusters. Subsequently, the *k*-means non-hierarchical vector quantization method was employed.

The number of clusters was determined using the unweighted pair-group method that relies on arithmetic averages to calculate the average distance between all subjects in one cluster and all subjects in another cluster. This method eliminates the effect of extreme values because the existence of a cluster depends on the parameters of all of the subjects constituting such a cluster.

The classification of agricultural holdings into clusters was carried out using the *k*-means vector quantization method. This method requires the number of clusters to be established in advance. The *k*-means method can be used to determine the number of different clusters by minimizing the between-cluster sum of squares. An iterative calculation technique is used to determine the cluster centres by relocating subjects from one cluster to another without reducing the sum of squares (Hartigan and Wong 1979).

The correlations between the individual dimensions in the sample and the clusters existing within the sample were determined using a correlation analysis. Correlations between variables were measured using Pearson's correlation coefficient, which ranges between the values <–1, 1>. The higher the value of the coefficient, the greater the correlation. A negative value indicates negative correlation and *vice versa*.

Data were processed using the MS Office software suite (version 16) and the Statistica software (version 13).

RESULTS AND DISCUSSION

Using a cluster analysis, the sample of 1 351 holdings was divided into two clusters. Cluster 1 includes 627 agricultural holdings and cluster 2 includes 724 holdings. That corresponds to 46% and 54% of the total sample of 1 351 holdings, respectively.

The first detected cluster contains 37% of small, 40% of medium, 7% of large, and 16% of largest holdings. The second detected cluster contains 10% of small, 47% of medium, 12% of large, and 30% of largest holdings.

Considering the production specialization of holdings, it was ascertained that in cluster 1, 15% of holdings specialize in field crops, 37% in cattle farming, 16% in milk production, 28% in mixed production, 2% in pig and poultry farming, 2% in perennial crops.

In contrast, field crops play an important role in the second cluster of holdings (50%). Holdings specializing in cattle farming and milk production account for only 2% and 13%, respectively. A similar proportion was found to exist among holdings specializing in mixed production (26%), pig and poultry farming (2%), and perennial crops (7%).

A comparison of scores awarded to the two clusters during an evaluation of individual dimensions showed that holdings in cluster 1 are oriented toward ecology and have a higher level of financial stability, i.e. lower debt. Holdings in cluster 2 received higher scores for the production and economic dimensions. It means that these holdings record higher yield and perform better, which translates into better financial results.

The overall sustainability rating, which includes all of the dimensions, for cluster 1 was 3.1% below

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average for the entire sample. In contrast, the rating awarded to cluster 2 was 2.7% above the overall average. A basic description of both clusters including comparison of scores of dimensions is provided in Table 1. A comparison of the share of individual dimensions in the total score awarded to both clusters is shown in Figure 1. These results can be compared to findings of Špička et al. (2020) where the sustainability was measured according to type of farming and economic size of farms (based on European agricultural typology). Their final ratings are analogous to ours as the average of economic performance of field crops is high (1.33) and environmental sustainability score is lower (0.811) similarly to our results of cluster 2. Cluster 1 is closer to type of farming focused on grazing livestock rearing, where average score of economic performance is 0.831 and environmental sustainability score is 1.351. Cluster 1 corresponds more to small farms and cluster 2 consists rather from larger companies.

Table 2 shows correlation coefficients between individual dimensions for the entire sample as well as for the two examined clusters. Most of the correlations that were found to exist between individual dimensions are weak. In the entire sample, no correlation was confirmed between the production dimension and dimension consisting of social and other factors, and between the environmental dimension and the dimension consisting of social and other factors. The strongest, albeit indirect, correlation was identified between the economic and environmental dimensions. The interdependencies between dimensions were studied by Sulewski et al. (2018a) using data from 601 Polish FADN survey farms. One of their conclusions suggest that the farms reaching high level of rating in one dimension has difficulties to obtain such a good result in other dimensions. Otherwise farms with balanced results of more dimensions reach only medium level of total sustainability.

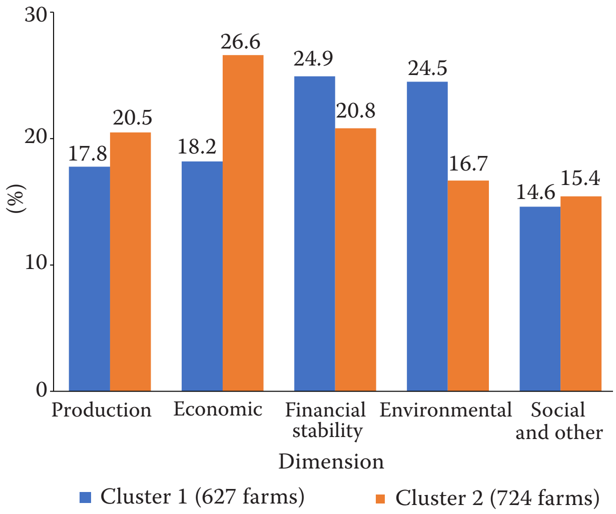

Figure 1. Share of the dimensions in the overall score

Source: Author's own elaboration based on FADN CZ 2016 data (FADN CZ 2019)

In cluster 1, the strongest positive correlation was found to exist between the economic and social dimensions. It can be therefore concluded that the higher the score given to the economic dimension, the higher the score attributed to the dimension of social and other factors. No correlation was found to exist between the financial stability and environmental dimensions and between the environmental dimension and the dimension of social and other factors.

In cluster 2, the strongest positive correlation was found between the economic and financial stability dimensions. The assessment of this cluster did not confirm the importance of three of the correlations, specifically the correlations between the production and economic dimensions, between the production and financial stability dimensions, and between the environmental and financial stability dimensions.

An average holding from cluster 1 employs 12 annual labour units (AWU) and operates on 409 hectares

Table 1. Description of cluster dimensions based on rating

Dimension	Cluster 1 = 627 farms			Cluster 2 = 724 farms		
	average rate	SD	variance	average rate	SD	variance
Production	0.8778	0.2562	0.0656	1.0715	0.2865	0.0821
Economic	0.8982	0.2473	0.0611	1.3918	0.2299	0.0529
Financial stability	1.2308	0.2941	0.0865	1.0898	0.2385	0.0569
Environmental	1.2096	0.2488	0.0619	0.8724	0.2262	0.0512
Social and other	0.7214	0.2246	0.0505	0.8070	0.2388	0.0570

The Euclidean distance between the clusters amounts to 0.290503; the Euclidean distance between cluster squares amounts to 0.084392

Source: Author's own calculation based on FADN CZ 2016 data (FADN CZ 2019)

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Table 2. Five-dimensional correlation analysis

Dimension	Dimension				
	production	economic	financial stability	environmental	social and other
Total sample (1 351 farms)					
Production.	1	0.191***	–0.053**	–0.155***	–0.024
Economic	0.191***	1	–0.158***	–0.340***	0.186***
Financial stability	–0.053***	–0.158***	1	0.151***	–0.179***
Environmental	–0.155***	–0.340***	0.151***	1	–0.022
Social and other	–0.024	0.186***	–0.179***	–0.022	1
Cluster 1 (627 farms)					
Production	1	–0.122***	0.108***	0.192***	–0.112***
Economic	–0.122***	1	–0.112***	0.148***	0.300***
Financial stability	0.108***	–0.112***	1	0.040	–0.214***
Environmental	0.192***	0.148***	0.040	1	–0.009
Social and other	-0.112***	0.300***	–0.214***	–0.009	1
Cluster 2 (724 farms)					
Production	1	–0.033	–0.034	–0.071*	–0.076**
Economic	–0.033	1	0.209***	0.117***	–0.107***
Financial stability	–0.034	0.209***	1	–0.037	–0.068*
Environmental	–0.071*	0.117***	–0.037	1	0.202***
Social and other	–0.076**	–0.107***	–0.068*	0.202***	1

Statistically significant correlations are marked *for $P < 0.1$, **for $P < 0.05$, and ***for $P < 0.01$
Source: Author's own elaboration based on FADN CZ (2019) database

of farming land, 60% of which is leased. Even though the average number of livestock units per holding was lower in cluster 1 compared to cluster 2, the intensity of livestock production was higher (the livestock per hectare indicator amounts to 0.77 DJ/ha).

An average holding from cluster 2 is bigger as regards both the extent of labour and the size of cultivated land (690 hectares). In contrast, the share of unpaid labour and livestock per unit of land is lower but share of rented land is higher (82%). The upper 25% of holdings in cluster 2 employ twice as many workers and farm on land with a size nearly twice as large than its counterpart. The general parameters of agricultural holdings in the entire sample and in the clusters of comparable holdings are specified in Table 3.

As far as social factors, it was ascertained that cluster 1 comprises 11% of holdings managed by women and 16% holdings managed by persons below the age of 40 years. In cluster 2, the proportion of women was 3% lower, but the number of managers below the age of 40 years was 2% higher.

More farmers possess university education in the field of agriculture in cluster 2 (51%) than in cluster 1 (41%). A comparable number of workers in management positions possess complete secondary education in the field of agriculture in both cluster 1 and cluster 2 (38% and 39%, respectively). There were fewer farmers with no formal secondary or tertiary education and with hands-on experience with agriculture only in cluster 2 (10%) than in cluster 1 (22%).

Data describing business conducted by holdings in the two clusters are provided in Table 4. In this respect, it needs to be pointed out that the simple arithmetic mean used in the description of the sample differs from the global ratio indicators used for the calculation and publication of average values by the FADN scheme.

Most of the holdings constituting cluster 2 specialize in crop production. Only 17% of total production accounts for livestock production and 7% for other production. In contrast, the production structure in cluster 1 is more balanced (crop production: 50%, livestock production: 42%). These figures are reflected in a considerably higher efficiency of crop production per hectare achieved by holdings in cluster 2, which includes a higher share of enterprises specializing in high-volume flower production. In addition, cluster 2 exhibits twice as high average farm net value added/annual work unit (FNVA/AWU). The top 25% of holdings in cluster 2 record more than one million crowns per AWU. The total production result per AWU, which is one million crowns

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Table 3. Structural description and statistical data

Indicator	Mean	Lower quartile (25%)	Upper quartile (75%)	Coefficient of variation
Total sample				
Annual work unit	15.07	1.83	17.94	159.382
Unpaid work unit	1.13	0.00	1.93	98.775
Utilized agricultural area	560.00	46.00	829.00	147.434
Rented area	452.00	22.00	687.00	154.459
Livestock units	239.00	0.00	248.00	205.876
Cluster 1				
Annual work unit	12.21	1.53	12.41	174.696
Unpaid work unit	1.23	0.00	1.96	88.460
Utilized agricultural area	409.00	41.00	571.00	157.403
Rented area	323.00	17.00	461.00	169.904
Livestock units	228.00	15.00	225.00	194.481
Cluster 2				
Annual work unit	17.54	2.06	23.35	147.528
Unpaid work unit	1.04	0.00	1.89	108.665
Utilized agricultural area	690.00	60.00	1 061.00	135.563
Rented area	563.00	31.00	858.00	139.990
Livestock units	249.00	0.00	273.00	213.525

Source: Author's own elaboration based on FADN CZ (2019) database

higher on average in cluster 2 than in cluster 1, reflects the structure of holdings in the two clusters.

Most of the holdings in cluster 1 are more specialized in extensive livestock production and organic farming than in cluster 2, and their agricultural role overlaps to a larger extent to environmental considerations. Those farms are more dependent on subsidies, even farms in upper quartile receive 3% more subsidies than is a value of their own production.

This fact can also be observed in the farm net value added/annual work unit (FNVA/AWU), which is 50% lower than in cluster 1. The bottom 25% of these holdings records no more than EUR 16 566 per AWU. Most holdings in cluster 1 use short-term, as opposed to long-term, loans, which results in higher scores for the financial stability dimension in the multicriteria assessment. Environmental indicators are more favourable in cluster 1. All indicators pertaining to good land cultivation are better in cluster 1 compared to cluster 2. Another factor testifying to extensive approach to cultivation is a low input of mineral fertilizers in soil.

A study comparing economic, environmental, and social sustainability (Latruffe et al. 2016b), which was one of the outputs of the international project "Farm Level Indicators for New Topics in Policy Evaluation", used the cluster analysis to classify agricultural holdings. The authors employed the hierarchical method to identify clusters, and the number of clusters was determined using their expertise. In contrast to this paper, three clusters were identified for each production specialization.

The results confirmed that the cluster of holdings that record better economic results also receive higher multicriteria scores. This finding is consistent with conclusions drawn by Polish researcher Wrzaszcz (2014), who also found that results are strongly correlated to the size of holdings and their production specialization.

Wrzaszcz's work confirmed that a positive correlation exists between the economic and environmental dimensions, particularly in respect of certain production specializations. An analysis of the results of her work did not extend to a detailed examination of individual classes according to production specialization; however, a statistically significant correlation was found between the economic and environmental dimensions in the entire sample as well as in the detected clusters. The correlation is indirect throughout the sample; a weaker direct correlation can be observed in clusters 1 and 2.

Studies carried out by Irish researchers (Dillon et al. 2016) have established that large holdings that register the best economic results ultimately produce less air pollution compared to farmers with less intensive agricultural production. On the contrary, intensively operating holdings place greater burden on soil due to

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Table 4. Selected indicators

Indicator	Unit	Total sample			Cluster 1			Cluster 2		
		mean	quartile		mean	quartile		mean	quartile	
			lower	upper		lower	upper		lower	upper
Production structure and efficiency										
Share of crop production on total	%	64	40	96	50	31	66	76	55	100
Share of livestock production on total	%	29	0	49	42	25	60	17	0	32
Share of other production on total	%	8	0	10	8	0	11	7	0	9
Direct livestock costs /livestock production	%	86	54	99	91	58	109	78	51	85
Direct crop costs /crop production	%	33	22	43	31	16	43	35	27	43
Crop production/ha	EUR/ha	2 969	403	1 063	586	183	623	5 058	770	1 319
Livestock production/LU	EUR/LU	916	440	1 283	770	403	1 063	1 136	660	1 466
Direct crop costs/ha	EUR/ha	880	110	403	183	37	257	1 466	257	476
Direct livestock cost/LU	EUR/LU	623	403	806	550	367	733	733	476	953
Subsidies use										
Production + subsidies /total costs	%	131	105	146	127	102	143	134	106	150
Subsidies/production	%	49	21	49	78	29	103	24	17	29
Assets structure										
Liabilities/assets	%	22	2	32	20	1	31	23	4	34
Current assets/current liabilities	%	63	3	21	78	3	21	49	3	21
Economic results										
Farm net value added /AWU	EUR/AWU	21 734	10 775	28 734	14 330	6 854	19 681	28 147	16 566	35 734
Production/AWU	EUR/AWU	49 954	23 566	66 154	30 566	16 383	39 949	66 777	42 881	83 159
Environmental indicators										
Share of legumes	%	8	0	10	12	0	16	5	0	8
Share of grassing	%	29	0	52	51	18	91	10	0	13
Stocking density	%	168	0	3	265	1	1 000	82	0	1
Quantity of nitrogen	kg/ha	77	18	127	41	0	70	108	58	153
Quantity of phosphorus	kg/ha	18	0	30	8	0	10	27	9	37
Quantity of potassium	kg/ha	25	0	30	6	0	5	41	5	56

LU – livestock units; AWU – annual work unit
Source: Author's own elaboration based on FADN CZ (2019) database

a higher amount of excess nitrogen per hectare. This finding is confirmed by the outcome of this paper with regard to Czech farmers. Likewise, the positive correlation between the economic and social dimensions is consistent with findings collected in the examined sample of Czech holdings and cluster 2.

CONCLUSION

The objective of this study was to examine the internal structure of a sample of agricultural holdings using the outcome of an assessment of five dimensions that correspond to the main functions of agriculture. A cluster analysis was used to identify two clusters

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of holdings that are similar within the clusters, where the two clusters differ from one another. Holdings in cluster 1 are marked by higher use of livestock production and lower economic results compared to cluster 2, which includes a larger number of large holdings specializing in crop production. Holdings in cluster 1 received higher scores for the environmental and financial stability dimensions. Conversely, cluster 2 received better scores for the economic and production dimensions. Scores awarded for the social dimension were similar in both clusters; however, cluster 2, which included larger holdings, recorded better results. The correlation analysis confirmed weak correlations between most of the dimensions, both in the entire sample and in the individual examined clusters. Well balanced sustainability across various dimensions should be the aim of the CAP as all dimensions analysed are important for the sustainability (Sulewski et al. 2018a).

For the future agricultural sustainability, it is important to achieve balanced production system providing sufficient amount of high-quality food, protecting nature and nature sources, minimalizing economic risk for farmers and supporting social life in the rural area. It is up to policy makers to decide which group of farmers, either those in cluster 1 or cluster 2, is more approaching the aim of the new agricultural policy. Policy makers can take into account the results of this study to find the areas where the sustainability rate should be increased and purposefully promote that by specific measures. On the other hand, it has been confirmed (Wrzaszcz 2014; Sulewski and Kloczko-Gajewska 2018; Špička et al. 2020) that the agricultural dimensions have a relationship between themselves and can positively or negatively affect each other which should be taken into consideration. The future research could focus on modulation of the selected policy measures and its impact on the farm results and multidimensional evaluation. In order to achieve this goal satisfactorily, it is necessary to deal with the modelling of structural changes resulting from the analysed measure.

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