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Can a Pursuit of Productivity Be Reconciled with Sustainable Practices in Small-Scale Farming? – Evidence from central and eastern Europe?[1]

Abstract: Small farms constitute the vast majority of agricultural holdings in the world. Therefore, there are the questions of how the small farm sector should evolve and whether economic and environmental goals can be pursued simultaneously. The main objective of this article is to identify potential improvements (a non-radial inefficiency slack) in small farms in central and eastern Europe with different types of farming under an environmentally adjusted production function. Based on this, potential development pathways for small farms are assumed. A hybrid data envelopment analysis meta-frontier super-efficiency model with environmental proxies reflecting biodiversity (i.e. crops diversity, grassland, orchards, vineyards) and undesirable outputs (such as soil organic matter loss and GHG sources) and an uncontrollable policy input is used on a country-representative sample of 2320 small farms in four countries: Poland, Romania, Serbia, and Moldova. We found that the more technically efficient small farms are also usually more sustainable when socially desirable criteria were considered. Crops small farms can evolve in two directions: "landscape guardians" and "artisanal (traditional) framers." Livestock farms could either maintain the status quo or choose an exit pathway. Mixed farms are likely to become landscape guardians, while a sustainable intensification path is open for 20% of farms that specialize in permanent crops.

Keywords: development of agriculture, public goods; eco-efficiency; small farms; sustainable agriculture, agricultural policy

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1. Introduction

While there is no clear definition of a small farm, an approximate estimate is that there are 570 million farms worldwide of which about 4% are in highly developed countries, 59% in China and India, and the remaining 37% in other low or middle-income countries. As many as 85% of farms (i.e. 480 million) have 2 hectares or less (Lowder et al., 2016). Viewed in this way, small farms occupy about 12% of global agricultural land, but the rural areas of which they are an integral part are where nearly 50% of the world's population lives and works.

The understanding of the small farm and associated land use varies by region of the world. In East Asia and the Pacific, South Asia and sub-Saharan Africa, more than 50% of farms are smaller than 1 hectare, and more than 90% are smaller than 5 hectares. These farms occupy a relatively large share of the agricultural area - more than 60% (Lowder et al., 2016).

In Europe and central Asia, as well as in the Middle East and North Africa, the land use structure is markedly different than in developing countries. Small farms, understood as entities of less than 5 hectares, also constitute the majority of farms there - more than 80%, but their share of agricultural land is only about 30%. This percentage, however, is not negligible in terms of absolute values (FAO, 2014; Lowder et al., 2016; Stępień & Maican, 2020).

According to Eurostat, in 2019, there were 10 million farms in Europe, providing 9.48 million full-time jobs in the agricultural sector. On these farms, there were as many as 1.9 million workers in Romania and 1.5 million in Poland (these two countries clearly diverge from the other member states). They were followed by Italy, which had only about 0.9 million employed in agriculture (European Parliament (EP), 2021). In terms of persons, 22 million people worked regularly in agriculture in the EU-28, the vast majority of them (over 80%) worked on small farms (EUROSTAT, 2022).

In the case of small-scale farming, the key is the broader context of their operations boiling down, first, to maintaining the territorial cohesion of rural areas. If only large farms dominated, then traditional villages would change dramatically and more people need to move to the cities. Second, small farms can play different roles in rural areas, far beyond food provision only. Therefore, they create a complex network of rural multifunctionality, and they provide environmental benefits that are unrelated to the scale of agricultural production but build farm value for society. This is what Vecchio et al. (2021, p.78) called "the protagonism of small farms in the construction of multifunctional business styles." Third, small farms, including those in Europe, contribute to food and nutrition security (FNS) through their ability to self-supply food and supplement regional and local food systems (Toma et al., 2021). Fourth, they provide a buffer against poverty, social exclusion, and low household income in rural areas from a sociological perspective (Davidova et al., 2012), and they avoid, to some extent, the price-cost squeeze in the context of the economic theory of the market treadmill (Czyżewski et al., 2019). Fifth, they are custodians of cultural heritage, which supports the sustainability of rural communities (Davidova et al., 2013).

However, small farms encounter many development barriers and gain relatively little from agricultural policies due to i) direct exclusion of small farms from the benefits of rural development measures through threshold criteria (Dwyer, 2014; Toma et al., 2021); ii) administrative difficulties and relatively high transaction costs including cognitive burdens (European Parliament, 2014; Vigani & Dwyer, 2020); iii) path dependency in post-socialist countries (Gorton et al., 2009; Żmija & Żmija, 2018); iv) the limited number of policy measures dedicated to small farms in the EU and the EU's associated countries compared to other regions of the world (Stępień & Maican, 2020; IPC-IG, 2019). The answer to this problem could be to some extent the new delivery model (NDM) of the EU CAP, starting in 2023. Among other things, its aim is to provide more targeted support for smaller farms and allow EU countries greater flexibility in adapting measures to local conditions.

Nevertheless, effective agricultural policies for small farms depend on a proper diagnosis of the problems which is difficult to formulate due to the hardly accessible data from this sector. We argue that an efficiency analysis can be a diagnostic tool as it reveals the best feasible performance in a given contex (i.e. technological frontier). Furthermore, the inefficiency slack with regard to individual inputs/outputs is particularly useful as it suggests aspects on which public policies shall focus.

Nevertheless, there are two possible paths to using the results of efficiency analysis to provide recommendations for policymakers. Many studies estimate inefficiency levels and regress them with various independent variables (e.g. age, education, access to information – Bonfiglio et al., 2017; Stępień et al., 2021). This is an approach that identifies sources of inefficiency and allows us to formulate long-term recommendations that can be compared to the prevention of disease treatment. We think, however, that prophylaxis alone is not enough for the moment, given the increasing environmental issues – it is necessary to simultaneously "try to remove the current symptoms of the disease, otherwise the patient may not survive"; and for this comes the concept of inefficiency slack defined as non-proportionate (non-radial) movement, i.e. such a change in a particular input/output that does not involve a change in any other input/output. Such perceived slack can also apply to fully efficient decision making units (DMUs) (which are at the frontier). In their case, it is also often possible to have a shift along the frontier that results in an improvement of a particular input/output without affecting the others. Inefficiency can also be in the form of proportionate movement, that is, a change in all inputs/outputs by the same percentage. However, this version of inefficiency (sometimes called 'radial slack') is difficult to combat in practice, because proportionally reducing all inputs simultaneously seems unrealistic. Therefore, in this article we focus exclusively on non-radial slack (calling it 'slack movement' or 'real slack'). In economic reality, slack movement is a certain anomaly that occurs when, for example, a farm could reduce fertilizer use without a decrease in production or adjustments in other inputs. If a farmer does not do so, he/she is therefore acting irrationally usually due to some cognitive limitations. In this situation, agricultural policy can try to directly encourage the farmer to reduce fertilizer use, rather than looking for long-term measures such as raising the level of farmer awareness through education and training. The eco-schemes in EU CAP after 2023 fit into such a reasoning - they focus on removing symptoms, i.e. unfavorable farming practices, rather than looking for their causes.

Therefore, **the research questions of this article are as follows**:

RQ1. Is there a trade-off or synergy between technical efficiency and eco-efficiency? How does the distribution of efficiency of small farms change when environmental criteria and public policies are introduced into the microeconomic production function?

RQ2. What are the potential improvements, so called “inefficiency slack”, in small farms’ resources allocation based on the evidence from central and eastern Europe (CEE)? How can agricultural policies create context-specific levers for small-scale farmers that promote eco-efficiency?

To answer these questions, we employ the concept of non-radial inefficiency slack under the hybrid DEA approach. We assume that only those changes in individual inputs and outputs could a farmer accept that do not generate trade-offs relative to other inputs/outputs. For example, a farm might be willing to reduce a fertilizer input in response to certain policy measures, provided no significant change in utilized land, labor, or yields is involved. Hence, one has to distinguish between proportionate movement (sometime called the “radial slack”) and non-radial slack movement. The latter seems relatively easy to remove in practice, as it does not imply changes in the remaining inputs/outputs (no trade-offs), unlike proportionate movement, which assumes, for example, a simultaneous decrease in all inputs and an increase in all outputs by the same percentage (non-oriented approach). Let us add that even a fully effective decision making unit (DMU) can face a slack, i.e. the possibility of a move along the frontier resulting in a decrease/increase in a given input/output, ceteris paribus.

With reference to the above research problems, **the main objective of this article is to identify potential improvements, i.e. an efficiency non-radial slack on small farms in four eastern European countries and different types of farming (TF) under conditions of a modified production function by introducing socially desirable criteria, including environmental objectives, and policy measures.** This approach helps to identify realistic directions for the development of small farms and the types of policy tools that could stimulate this development. We also address the topical issue of whether the increase in the economic efficiency of small farms comes at the expense of their environmental performance (Guth et al., 2022).

This analysis is based on a review of a representative sample of 2320 small farms (precisely defined in the methods section) from the two CEE countries with the largest numbers of small farm workers in Europe: Poland and Romania and the two EU-associated countries, Serbia and Moldova, with a highly fragmented agriculture. Introducing the latter gives insight into small-scale farming in CEE countries that are not members of the EU and do not participate in CAP.

A hybrid data envelopment analysis (DEA) meta-frontier super efficiency model with desirable and undesirable outputs and uncontrollable policy input is used to assess efficiency and calculate slack. To the best of our knowledge, hybrid efficiency measures with undesirable outputs within an environmentally adjusted production function followed by an extended slack analysis have not been applied, especially with regard to small farms from CEE. Moreover, our selection of socially desirable and undesirable outputs involved a precise measurement of the loss of soil organic balance and an index of crop diversity that did not appear in efficiency analyses.

The rest of this article is organized as follows: in the next section, we review the issues of potential paths of development of small farms to date and farms eco-efficiency recent studies. The third section describes the data and methods used. In the fourth section, we present our results, focusing on the two research questions. The final section concludes and provides policy recommendations.

2. Literature overview

2.1 Potential developmental paths for small farms

In this section, we discuss the question of what pathways are possible for the development of small farms, how to stimulate them with agricultural policy? The literature has developed two alternative directions for the development of small farms and several subtypes in each of them (Stringer et al., 2020). The first is development through growth in efficiency, and the second is development through the provision of public goods.

Within the first path, there are two subtypes:

- *Sustainable intensification* for small holders who are already market oriented (Staniszewski 2018). This group is theoretically the most important for global food and nutrition security (FNS). Nevertheless, many authors are skeptical about the possibility of substantial increases in yield from small-scale farming (Thornton et al., 2018; Poulton et al., 2010). Indeed, there is some concern about whether a small-scale farm can become entirely commercial without access to a larger land resource. Land concentration, therefore, requires a very specific institutional framework—preferential loans, payments to stimulate the transfer of land to young successors, reasonable regulation of the land market, and schemes to retrain those leaving agriculture.

- *Collective actions of small holders* that include, for example, cooperative grazing or land rental (Lesorogol, 2008). Implementing this strategy can also involve the joint use of buildings and equipment and the joint organization of crop sales and the purchase of inputs, such as in the form of agricultural producer groups. However, such strategies do not have sufficient support in the CAP, and support for producer groups ends after a five-year period. In addition, they are quite risky for the environment because of “a tragedy of commons” if they are not carefully managed (Sklenicka et al., 2014).

Within the second developmental path, there are three subtypes:

- *Landscape/land cohesion guardians* is an option for traditional extensive small farms. In this case, the role of agricultural policy is crucial, and it should compensate extensive small holders for opportunity costs and identify the best ways to protect public goods. However, as Stringer et al. (2020) say, area-based payments for environmental services entail very high transaction costs, and they are often inefficient. Hence, the search for result-oriented solutions in this area (Hasund et al., 2013; Allen et al., 2014) or quasi-market valuing of public goods (PG). Therefore, a hybrid solution should be sought, for instance agri-environmental subsidies could be integrated with support for agritourism development. At the same time, the state should develop road infrastructure and “smart villages” (Cambra-Fierro & Pérez, 2022) in areas of extensive agriculture to facilitate access for tourists to the offer of small farms.
- *The small farm as a side job:* This is an option often included in the previous one, and we will further identify it with “landscape guardians.” Stringer et al. (2020) considered these farms to be the most reasonable and sustainable “low-cost and low-risk” social system. It is pointed out, however, that in this system, both environmental and production issues often recede into the background, and the effect of non-targeted direct payments is to shape a

group of social farms that subsist mainly on state support (pensions, retirement, child subsidies), maintaining fallow land and pastures of little production and environmental value just to meet the minimum requirements for receiving area payments.

- *Artisanal farmers* in a multifunctional model: Such a model is successfully developing in Italy or Croatia regarding new member states (NMS), and it is considered by many agricultural economists as a target model for small-scale farming (Vecchio et al., 2021). However, it is difficult to assess whether this can be the target path in all conditions. Its primary advantages are building intangible farm equity and sustaining the cohesion of rural areas. Its essence lies in shortening food distribution channels (“from farm to fork”) and building innovative business solutions that create added value through premium prices and high quality while addressing slow food movement (Goodman, 2012; Marsden et al., 2018). At the same time, small holders can avoid the market treadmill, which causes a prize-cost squeeze.

This option also requires an appropriate institutional framework, e.g., flexible hygiene regulation for small holders including agritourism services, authorized public processing points (e.g., mobile slaughterhouses), VAT exemptions, and advice about finding lucrative market niches.

However, there is a third option: the *exit pathway.* Leaving agriculture is very often the only possible alternative for small holders who are facing declining income and have neither a side job opportunity nor the ability to improve efficiency. In CEE countries, agriculture is also a reservoir of free labor that protects small towns from rising unemployment.

The key policy issue is to determine which of the three paths is feasible in a given regional and local context without requiring a radical change in the farming system. Only then can effective policy measures be designed (Bartolini et al., 2021). A slack analysis may address the above issue by indicating the non-radial inefficiencies that theoretically could be easily removed by farmers if they were aware of them and willing to do it.

Hence, the pathway of sustainable intensification may be available in the conditions of:

- potential to increase the output value (positive slack on production);
- no potential to increase the provision of PG (non-positive slack on any PG); and
- potential to decrease bad outputs.

The landscape guardian's pathway can be associated with**:**

- no potential to increase the output value (non-positive slack on production);
- potential to increase the provision of PG (positive slack on at least one PG); and
- potential to decrease bad outputs.

The artisanal farming implies**:**

- potential to increase the output value (positive slack on production);
- potential to increase the provision of PG (positive slack on at least one PG);
- potential to decrease bad outputs;

The exit pathway concerns inefficient farms that are not classified in any of the three main pathways mentioned above; the status quo pathway – efficient farms that are not classified in any of the three pathways mentioned.

We use the above classification later on to determine what percentage of farms in each TF would be likely to follow a given path.

2.2 Eco-efficiency in farming

In recent years, many authors have attempted to calculate eco-efficiency in farming using different variants of the DEA or a stochastic frontier analysis (SFA) model and taking into account the adjusted production function (Huang et al., 2016; Dakpo et al., 2017; Song & Chen, 2019). A hybrid approach has been however rarely adopted although it combines the advantages of slack-based approach and radial models and avoids arbitrary initial assumptions about the type of inefficiency slack for particular outputs/inputs.

The authors mainly focused on environmental issues, such as greenhouse gas emissions, water quality, nitrogen balance (Dakpo et al., 2017; Song & Chen, 2019), or polluting inputs (Huang et al., 2016). The most common research question answered by the authors was whether additional environmental/social conditions conflicted with the farm's economic goals.

The prevailing view in the literature, especially for developed countries, is that improving eco-efficiency or reducing environmental pressures can be done without compromising the economic performance of farms (Beltrán-Esteve et al., 2017; Urdiales et al., 2016; Wettemann & Latacz-Lohmann, 2017; Bonfiglio et al., 2017) or even while improving the latter (Pena et al., 2018; Adenuga et al., 2019, 2020; Guesmi & Serra, 2015; Hai & Speelman, 2020). Nevertheless, there are also results to the contrary, indicating that in some cases, there may be a contradiction between economic and environmental goals (Ghali et al., 2016; Ullah et al., 2016; Lakner & Breusted, 2017). Moreover, only one study was dedicated to the small farm sector in CEE (Guth et al., 2022). On the other hand, Huang et al. (2016), in the Chinese context, showed that the relationships in question can be more complicated. Those authors found that there is a positive relationship between technical efficiency (TE) and environmental efficiency (EE) for farms with lower-than-average levels of TE. However, if we focus on the most efficient farms, the relationship takes the shape of an inverted U. That is, the most economically efficient farms become less eco-efficient.

However, the world literature lacks such studies of the small farm sector in CEE. In addition, we think that with the long experience with the EU CAP, the informational potential of slack in Europe could be much better used as a guide for removing inefficiencies.

3. Data and methods

3.1 Definition of small farms

The perception of what a small farm varies among countries of CEE. Toma et al. (2021) proposed a common criterion that a small farm in CEE is an entity less than 5 ha of utilized agricultural area (UAA) or 8 economic standard units (ESUs). However, different CEE countries use various definitions based on four criteria: i) area of agricultural land, ii) workload, iii) economic size (ES) expressed in standard output (SO), and iv) subsistence level.

As for the criterion of area, especially in Poland and Romania, there is no consensus. Some authors claim that a very small farm has an area of up to 5 ha and that this approach is dominant (Stępień &Maican, 2020). Others state that a small farm covers 5 to 30 ha (Zmija et al., 2013), or up to 10 ha or 19 ha in the case of a so-called "relatively small farm" (Gruchelski & Niemczyk, 2016). The area approach is sometimes combined with the subsistence level, adding the condition that the small holder is also a semi-subsistence farm, using at least 50% of the output for self-provision (Toma et al., 2021).

In terms of workload, it is most often assumed that a small farm requires a relatively high level of effort per 1 ha and uses 0.5-1.5 annual work unit (AWU) per year (Stępień &Maican, 2020), but the specificity of the type of farming should be taken into account in this case, and comparisons of labor-consuming directions, e.g., horticulture, should be approached with caution.

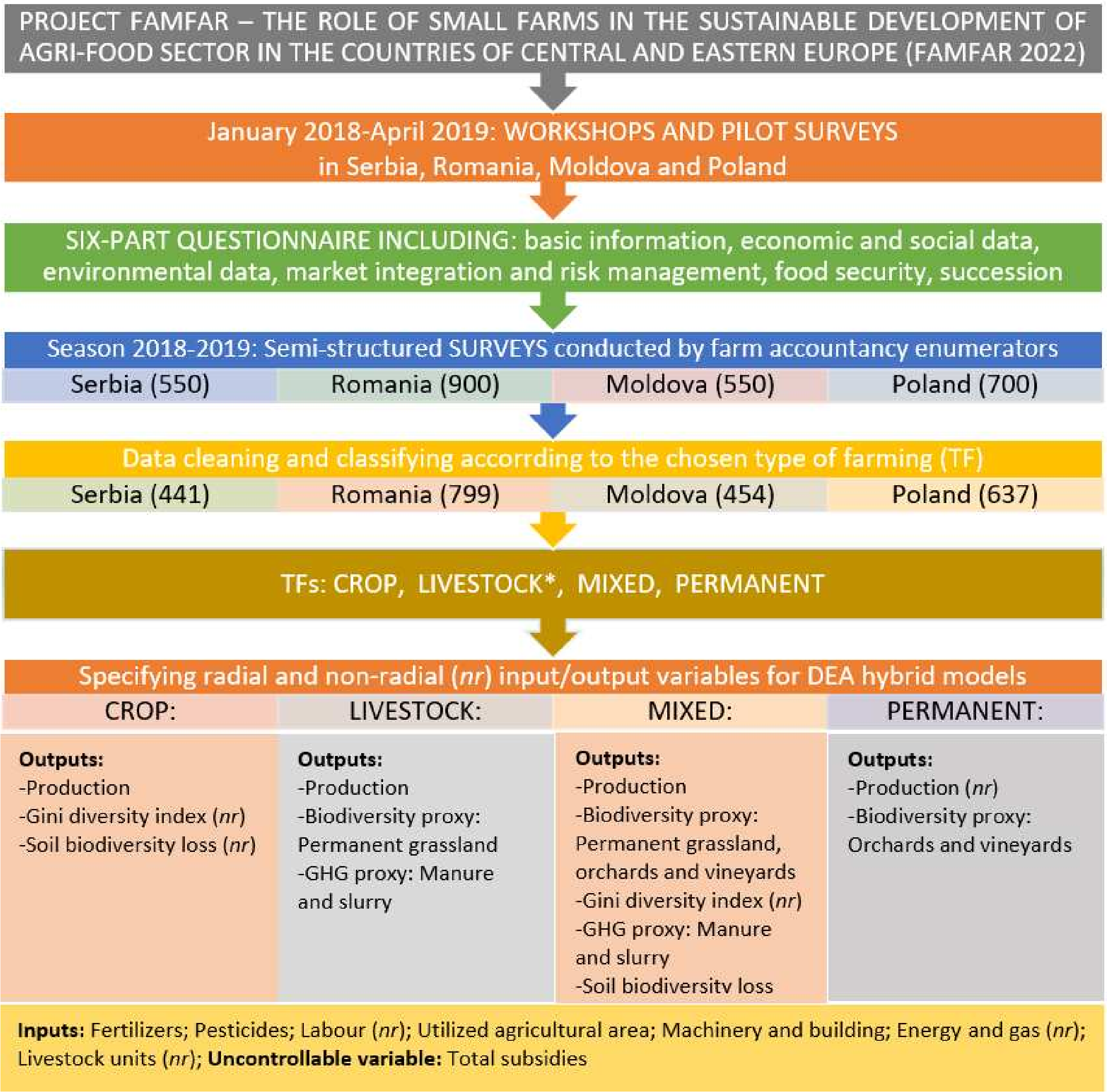
The approach used in the dataset of the EU FADN—that is, the criterion of economic size (ES14) expressed in SO that covers farms with a threshold of SO 2000–15,000 € yearly, seems the most widely used of all. The disadvantage of this approach is that it excludes units smaller than 2000 SO, which count as small farms according to all other definitions. In addition, SO classification may include cases of farms with a very large area of land (owned and rented) that is not cultivated in accordance with its economic potential, as indicated at the regional SO average.

Therefore, in this article, we focused on the economic size approach as it most general and can be applied to different types of farm. FADN logic to define small farms by SO seems to be the best option in Europe as it enables replicability of our research in other European countries where small-scale farming sector is also significant. Moreover, it is usually more suitable than hectare criterion if permanent crops are taken into account as they might have small area but high economic potential. Hence, we defined a unit as a small farms if it has standard output up to 15,000 EUR. However, to avoid analyzing farms with large production potential (even if their actual level of standard output falls within the indicated range) we exclude farms with more than 50 ha of UAA.

3.2 Dataset

Data were collected in 2019 under the FAMFAR project funded by the Polish National Agency for Academic Exchange (FAMFAR, 2022; Figure 1). Farmers were asked by professional farm accountancy enumerators about several aspects of their farm functioning (see Figure 1). After a careful data cleaning procedure and distinguishing different types of farming, our sample database consisted of data from 2320 small farms distributed among the four countries (Table 1).

We recall that data was obtained, therefore, before the pandemic and Russia's war against Ukraine. These two events have the impact on agricultural sector in CEE countries and their consequences will also be observed in the future. However, DEA methods are sensitive to outliers so we assume that it is better to run calculations in more stable environment. What is more, in this paper we deal rather with relative positioning of the farm in relation to frontier and we assume that this position does not change dramatically from year to year.



* Small livestock farms in Serbia need to be excluded since they were so scarce that the criterion of minimum number of DMUs for DEA would not be fulfilled.

Figure 1. Research flowchart

Table 1. Distribution of sample farms among countries and farm types

Country	Crop (1)	Livestock (2)*	Mixed (3)	Permanent (4)	*Total*
Serbia (1)	226	-	164	51	*441*
Romania (2)	328	121	273	66	*799*
Moldova (3)	170	41	63	180	*454*
Poland (4)	225	119	245	48	*637*
Total	*949*	*281*	*745*	*345*	***2320***

* There were too few livestock farms in Serbia and we needed to exclude them since otherwise the criterion of minimum number of DMUs for DEA calculation would not be fulfilled.

We divided our sample into four main TF, based on the production structure. Farms were classified as "crop" or "livestock" if at least 75% of the farm output value came from the respective TF. Farms that did not meet this criterion were classified as "mixed." From the "crop" subsample, we excluded farms that were focused mainly on permanent crops (including wine and horticulture production). Following FADN rules, we treated them as a separate subsample. Table 1. shows the number of farms in each type in each country under study.

3.3 Model specification for computing efficiency scores and slack

For this paper, we employed a DEA-based model to compute efficiency scores. The main advantage of DEA is that it does not require any a priori form of the production function. Basic DEA models were radial, but in the real world, it is clear that the savings potential of inputs (or expansion potential of outputs) is very often not equal between variables (Chen & Jia, 2017). Tone (2001) has proposed a fully non-radial, slack-based measure (SBM) DEA model in which each input and output can change in different proportions. However, there might be some agricultural production variables that are strongly related (i.e., total farming area and fertilizer use in crop production) and variables without a clear connection (i.e., pesticides and the number of work units). This led us to use a hybrid model (Tone, 2004) in which it was possible to distinguish between radial and non-radial variables. We treated a variable as radial if the Spearman rank correlation coefficient between that variable and any other variable was statistically significant and higher than 0.5 (Chiu et al., 2013; Wang et al., 2019). Table 2 contains a detailed list of the variables used for the models, together with descriptive statistics.

Table 2. Descriptive statistics for the variables used in modelling (annual values)

TYPE	VARIABLE	CROP				LIVESTOCK				MIXED				PERMANENT			
		Mean	Sd.	Min	Max	Mean	Sd.	Min	Max	Mean	Sd.	Min	Max	Mean	Sd.	Min	Max
Standard output	production value in EUR 1000	8.62	7.2	0.33	44.65	10.48	8.06	0.15	46.7	9.43	7.03	0.36	49.78	*10.29*	*8.97*	*0.11*	*46.05*
PG Output 1	Gini diversity index	*0.193*	*0.138*	*0*	*1*	-	-	-	-	*0.217*	*0.180*	*0.1*	*1*	-	-	-	-
PG output 2	permanent grassland, orchards and	-	-	-	-	-	-	-	-	2.92	5.18	0.00	50.00	-	-	-	-

	vineyards in ha																
PG output 3	permanent grassland in ha	-	-	-	-	4.66	6.05	0.00	36.49	-	-	-	-	-	-	-	-
PG output 4	orchards and vineyards in ha	-	-	-	-	-	-	-	-	-	-	-	-	2.53	4.06	0.00	48.80
Bad output 1	stable manure and slurry use in tonnes	-	-	-	-	95.91	179.97	0.00	1350.00	42.34	89.05	0.00	1250.00	-	-	-	-
Bad output 2	soil biodiversity loss t/ha (based on soil organic matter balance)	*0.38*	*0.71*	*-6.74*	*2.27*	-	-	-	-	-0.07	0.96	-13.53	2.21	-	-	-	-
Input 1	Fertilizers use in EUR	947	1221	0	8335	551	775	0	5817	702	886	0	13916	633	876	0	9143
Input 2	Pesticides use in EUR	578	1272	0	30478	202	633	0	9143	327	531	0	6096	1246	2024	0	13514
Input 3	labour in AWU	*1.43*	*0.71*	*0.14*	*5.61*	*1.69*	*0.76*	*0.16*	*3.81*	*1.67*	*0.70*	*0.12*	*7.14*	*1.63*	*0.78*	*0.33*	*4.52*
Input 4	utilized agricultural area in ha	9.48	8.54	0.09	50.00	9.29	7.82	0.05	47.69	9.02	7.01	0.10	50.00	4.97	4.48	0.10	50.00
Input 5	machinery and building value in EUR	19699	23389	0	509111	21232	19774	0	250774	22065	18407	0	250313	23477	34052	0	507967
Input 6	energy and gas spending in EUR	*719*	*1033*	*61*	*9773*	*741*	*933*	*71*	*9382*	*724*	*1078*	*49*	*10052*	*704*	*1077*	*76*	*9885*
Input 7	Number of livestock unit	*1.39*	*2.57*	*0.00*	*22.94*	*14.63*	*14.66*	*0*	*105.90*	*8.71*	*8.91*	*0*	*91.08*	*0.68*	*1.29*	*0*	*8.80*
Uncontrollable input	total subsidies value in EUR 1000	2.05	4.97	0	108.99	2.59	3.87	0	45.63	1.93	3.05	0	33.65	1.78	4.77	0	40.75

Note: PG - public good; non-radial variables highlighted in italics; country averages for soil biodiversity loss and crops diversity are in Tables 6-9. Zero values regarding Input 7 for livestock farms are due to the fact that they apply to beekiping farms. Zero values due to the degree of wear and age of the equipment, farmers sometimes declared zero market value, and in the case of the building, the cost of demolition exceeded the value of the land on which the building stands.

Since agriculture is typically a scale-sensitive activity, we employed variable returns to scale (VRS). Considering that small farms should add to the improvement of the quality of the natural environment by reducing environmental pressure, but that they also must produce PG and a decent amount of food, we treated the reduction of inputs and the expansion of outputs as equally important, so the non-oriented model was used.

We are aware that even farms of the same production type, but from different countries, may not have access to the same technology, so calculations under a common technological frontier may be biased. Therefore, we introduced a meta-frontier model (Long et al., 2018) in which farms are assigned to a country cluster.

Another issue related to the analysis of efficiency using DEA is that basic DEA models have weak discriminating power, and many DMUs are found to lie on the frontier. This results in the fact that all these DMUs have efficiency scores equal to 1, so they cannot be compared (Yang et al., 2015; Long et al., 2018). In this paper, we used the so-called super efficiency model first introduced by Andersen and Petersen (1993) and more recently used by Wang et al. (2019), among others. This model produces different scores for efficient DMUs that are 1 or higher, and the higher the score, the better positioned the DMU.

A small farm can deliver PG or decrease environmental pressure in a specific production context triggered by public policies. A farm has, however, a very limited impact on subsidies received because their level is agreed through political negotiations between countries. Therefore, in extended models, we included the total value of subsidies received by the farms not as a standard input but rather as an **uncontrollable input** (Bankey & Morey, 1986; Yang & Pollit, 2009).

To sum up, our model may be called **a hybrid DEA meta-frontier super-efficiency model with undesirable output and uncontrollable input and assuming variable returns to scale.**

Technically, the model can be described 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. This input data matrix can be decomposed into radial ($X^R \in R_+^{m_1 \times n}$) and non-radial parts ($X^{NR} \in R_+^{m_2 \times n}$). The total number of inputs is equal to $m = m_1 + m_2$. Similarly, we have a good (desirable) output and a bad (undesirable) output data matrix: $Y^g \in R_+^{s \times n}$ and $Y^b \in R_+^{z \times n}$, where s and z are the numbers of good outputs and bad outputs, respectively. Similarly, for inputs, these two matrices can also be decomposed into radial and non-radial parts: for good outputs $Y^{gR} \in R_+^{s_1 \times n}$ and $Y^{gNR} \in R_+^{s_2 \times n}$; for bad outputs $Y^{bR} \in R_+^{z_1 \times n}$ and $Y^{bNR} \in R_+^{z_2 \times n}$. All the DMUs are divided into C clusters.

For the specific DMU $(x_0, y_0) = (x_0^R, x_0^{NR}, y_0^{gR}, y_0^{gNR}, y_0^{bR}, y_0^{bNR}) \in P$ the linear programming of hybrid super efficiency DEA model under meta frontier is described as follows:

$$min \frac{1-\frac{m_1}{m}(1-\theta)-\frac{1}{m}\sum_{i=1}^{m_2}\frac{s_i^{NR-}}{x_{ik}^{NR}}}{1+\frac{s_1}{s}(\phi-1)+\frac{1}{s}\sum_{r=1}^{s_2}\frac{s_r^{NR+}}{y_{rk}^{gNR}}+\frac{z_1}{z}(\omega-1)+\frac{1}{z}\sum_{t=1}^{z_2}\frac{s_t^{NR-}}{y_{tk}^{bNR}}} \qquad (1)$$

s.t.

$\sum_{c=1}^{C}\sum_{j=1,\neq k}^{n} x_{ij}^{R}\,\lambda_j \leq \theta x_{ik}^{R}$, $i = 1,2,\dots,m_1$

$\sum_{c=1}^{C}\sum_{j=1,\neq k}^{n} x_{ij}^{NR}\,\lambda_j - s_i^{NR-} \leq x_{ik}^{NR}$, $i = 1,2,\dots,m_2$

$\sum_{c=1}^{C}\sum_{j=1,\neq k}^{n} y_{rj}^{gR}\,\lambda_j \geq \phi y_{rk}^{gR}$, $r = 1,2,\dots,s_1$

$\sum_{c=1}^{C}\sum_{j=1,\neq k}^{n} y_{rj}^{gNR}\,\lambda_j + s_r^{NR+} \geq y_{rk}^{gNR}$, $r = 1,2,\dots,s_2$

$\sum_{c=1}^{C}\sum_{j=1,\neq k}^{n} y_{tj}^{bR}\,\lambda_j \leq \omega y_{tk}^{bR}$, $t = 1,2,\dots,z_1$

$\sum_{c=1}^{C}\sum_{j=1,\neq k}^{n} y_{tj}^{bNR}\lambda_j - s_t^{NR-} \leq y_{tk}^{bNR}$, $t = 1,2,\dots,z_2$

$\sum_{c=1}^{C}\sum_{j=1,\neq k}^{n} \lambda_j = 1, s_i^{NR-} \geq 0, s_r^{NR+} \geq 0, s_t^{NR-} \geq 0$

$\sum \lambda_j = 1 , j = 1,2,\dots,n\ (j \neq k), s_i^{NR-} \geq 0, s_r^{NR+} \geq 0, s_t^{NR-} \geq 0, \lambda \geq 0, \theta \leq 1, \phi \geq 1, \omega \geq 1$, where $\sum \lambda_j = 1$, means that we assume variable returns to scale and $s_i^{NR-} \geq 0, s_r^{NR+} \geq 0, s_t^{NR-} \geq 0$ are the slack values for non-radial inputs, good outputs and bad outputs, respectively.

Our model was checked to be robust to zeros and negative values (Cheng, 2014).

It is worth noting that there are different options for including undesirable outputs into an efficiency model (see the review by Halkos & Petrou, 2019). We followed the most common approach, which was to treat undesirable outputs as outputs in the production function in their actual format (Dong et al., 2018; Le et al., 2019; Ullah et al., 2019). As Table 2 shows, we employed **stable manure and slurry** in tons as a proxy for GHG emissions and **soil biodiversity loss** derived from the balance of soil organic matter. We decided to use manure and slurry as proxy for GHG because these two are important sources of ammonia and methane which are crucial greenhouse gases related to agricultural production, in particular livestock production. Small farms in our sample are featured by a relatively little use of mineral fertilizers (which indeed contribute to N_2O emissions).

In this study, the balance of organic matter was calculated as the sum of the area of cultivated crops, the mass of produced natural fertilizers, the mass of straw potentially allotted for plowing and the corresponding coefficients of reproduction and degradation about the area sown on arable land in the farm (Wrzaszcz, 2009):

$$SBL = \frac{(x_i \times w_i) + (y \times w_y) + (z \times w_z)}{\sum_{i=1}^{n} x_i} \times -1 \quad (2)$$

where:

SBL = Soil biodiversity loss (tons/hectare),
x_i = cultivated area of particular groups of crops (in hectares), i = 1, 2, 3, ..., n,
y = amount of natural fertilizers – manure (tons),
z = amount of organic fertilizers – straw (tons),
w_i = reproduction rates or degradation rates of organic matter for groups of crops,
w_y = reproduction rate for natural fertilizers,
w_z = reproduction rate for organic fertilizers.

Measures to improve the health of the agroecosystem are based on two pillars: habitat protection and increasing soil fertility. The balance of soil organic matter is considered a key environmental indicator and a basic determinant of good agricultural management. Organic matter is essential for maintaining the chemical, physical, and biological properties of soils. It is crucial for soil structure stability, water cycling, carbon sequestration, biodiversity, and agricultural productivity (Wrzaszcz, 2018, van Loon et al., 2005). The progressive loss of soil biodiversity is receiving attention in Europe and is becoming one of the most important issues in sustainable agriculture (Gardi et al., 2009; Creamer et al., 2010; JCR, 2012). It originated in unsustainable practices at the very beginning of a farm's development. Whereas GHG emissions are not a major issue in small-scale farming, the loss of soil biodiversity gains importance simultaneously to specialization, intensity growth, and decline in animal production.

Public goods should appear in the socially adjusted production function alongside undesirable outputs. As shown in Table 2, we included several types of socially desirable goods supporting biodiversity with regard to different TF: the **Gini crop diversity index, permanent grassland, orchards, and vineyards**.

Grassland, orchards, and vineyards on small farms are a reservoir of biodiversity. Most often, according to the survey conducted, they are cultivated using traditional, labour-intensive methods with little use of chemicals (see Table 2) and relatively infrequent swaths in the case of grassland, which is used primarily for extensive livestock grazing. These conditions are firstly conducive to the development of the flora and fauna of the grassland ecosystem, and secondly to protect the soil from erosion and allow micro-organisms to grow in the topsoil.

With regard to the field crops farms it is worth recalling how the Gini crop diversity index was computed. The Gini index (G) in this case is a measure of the inequality of land distribution among different types of field crops, i.e., cereals, maize, root crops, pulses, oils and oilseeds, fodder crops, field vegetables, vegetables in greenhouses, gardens, and intercrops for green fodder; it takes a value between 0 and 1. The index would reach a value of 0 (homogeneous distribution) if all types of crops were present on the farm and occupied the same area, while it would reach a value of 1 if the farm cultivated only one type of crop over the entire land area (full monoculture). The index so understood has been inverted here (Div = 1 − G) to show the degree of crop diversity instead of the degree of monoculture. Thus, the higher the value of the index, the greater the degree of crop diversity. This is illustrated by the following formula for a set of crops with attributed area y_i, $i = 1$ to n, which are indexed in non-decreasing order ($y_i \leq y_{i+1}$):

$$Div = 1 - \left[\frac{1}{n}\left(n + 1 - 2\frac{\sum_{i=1}^{n}(n+1-i)y_i}{\sum_{i=1}^{n}y_i}\right)\right] \quad (3)$$

For calculating the index we have also considered intercrops and catch crops, which can be implemented even by a very small farm. Hence, we believe that even 0.1 ha crops farm adopting intercrops/catch crops is better than the similar one which does not do it.

3.4 Research design

We performed a multi-step analysis to address the RQs:

RQ1: First, we computed four base models for each TF, referring to the basic production function (we call them "limited models"), in which agricultural production was treated as a desirable output and typical capital and labor inputs were employed. (i.e., inputs 1–7, see Table 2) Hence, we estimated four limited meta-frontier models, one for each TF. Second, we computed extended models (Huang et al., 2016), including public goods, and undesirable outputs tailored to the given TF (see Table 3) plus uncontrollable policy input, and we compared the results. To answer RQ1 on changes between the efficiency of small farms under a typical production function and an extended model after including additional criteria, we investigated whether the distribution of efficiency scores derived from the two models differs significantly, following the approach proposed by Yang and Pollit (2009) or Huang et al. (2016). More specifically, we employed a nonparametric Wilcoxon rank-sum test. To determine whether there was synergy or a trade-off between technical efficiency and eco-efficiency under the extended model, we used nonparametric Spearman rank correlation between rankings based on the efficiency scores from both models (Guesmi & Serra, 2015; Hai & Speelman, 2020; Soteriades et al., 2015). We further checked how many farms belong to the first quartile (worst performing DMUs) of efficiency distribution simultaneously in both models. We also run this procedure for the fourth quartile (best performing DMUs).

RQ2. To answer R2 and achieve the main goal of the article, in the third step, we performed a detailed analysis of non-radial slack to find potential improvements regarding inputs and reductions of bad outputs and potential expansion of good outputs. In general, slack values appeared together with efficiency calculations, and they showed how much a given input (or bad output) could be reduced or how much a given good output could be expanded without any change in other variables. Although the philosophy behind slack is similar in radial and non-radial models, in radial models slack is usually calculated as the value that remains after making a proportionate movement. The latter indicates the percentage by which DMU should equally decrease/expand all inputs/outputs to achieve the efficiency frontier. In practice, after making proportionate movement, a unit becomes efficient but this may be weak efficiency – the efficiency score for that DMU will be equal to 1 but in VRS model there may still be some potential to decrease some of the inputs or increase the level of some output.

In non-radial models, in turn, there is no proportionate movement, and only slack movement is generated. It means that any distance between actual and optimal level of input (or output) is understood as slack and Any move to the frontier indicates a reduction of slack. To become efficient, DMU needs to eliminate all slacks from which some can be large and others only negligible. However, once the slacks are eliminated, the DMU becomes efficient in strong sense.

In the light of information above, it is clear that one cannot directly compare original slack generated for radial (SM) and non-radial variables (SNR) because after eliminating SM, the percentage of proportionate movement would change (as in radial models it is assumed that proportional movement is made first and then slack movement). To enable accurate comparison we proposed a special formula for modifying SM to make it comparable with its SNR counterparts. The following formula intends to obtain such an modified SM (denoted as SR – modified slack for radial variables), i.e., decrease of input level (or bad output) or increase in good output level, so that after this improvement, the proportionate movement remains the same as its initial value:

$$\frac{PM}{CL} = \frac{PM+SM-SR}{CL+SR} \tag{4}$$

And after transformation:

$$SR = \frac{SM*CL}{PM+CL} \tag{5}$$

where *PM* indicates proportionate movement, *SM* is the original slack movement value, and *CL* is the current level of input, bad output, or good output.

To derive policy recommendations for the whole sector of small farms in the TF under study, we calculated the total SR and SNR for each input/output variable regarding inefficient DMUs. Next, we divided this value by the sum of the initial values of a given input or output for all DMUs and obtained an average value. Assuming we treated our sample as representative of the farm populations of a given TF, we can assess the proportion of input (output) that can be saved (gained) if the slack is eliminated, i.e. the improvement is implemented.

Limitations of the methodology used boil down to the question whether inefficiency slacks are stable over time? Panel data would be of course better but gathering time series from small farms in eastern Europe is hardly feasible. We can however assume that non-radial slacks at DMU level occur because of bounded rationality of farm managers. The reasons of bounded rationality differ, but usually they involve cognitive burdens and thus are systemic in nature. In CEE countries, for example, there is a strong path dependency after the transition from the socialist to market economy, which results in a low trust among farmers and their reluctance to change. Such systemic constraints on rationality are durable. Hence, the structure of slacks (SR) should be theoretically robust to stochastic noise. For instance, even if agricultural production was lower in some years due to external conditions and the efficiency score changed, the structure of non-radial slacks should remain constant (Czyżewski & Kryszak, 2022). The agricultural policy in the long term should address the reasons of appearance of slacks but in short run it also should tackle the existing slacks. For example, if farmer use too much fertilizers because of his/her low education, then it is important to support agricultural education but in shorter perspectives it is useful to implement policy measures that can decrease the fertilizers consumption.

4 Results and discussion

Livestock and permanent crops small farms have, on average, total value of production ca. 10,000 EUR per year while mixed farms and crop farms exhibit smaller average value – 9.4 and 8.6 thousand of euros, respectively. It can be said that farms under different type do not differ a lot with this regard but this is impacted by the criterion applied (Table 2). Interestingly, the average farm size in terms of area do not differ much as well, with the exception of permanent crops farms where average area is half that of the other types (4.97 ha vs 9.02-9.48 ha).

When crop and mixed farms are compared, it can be noticed that mixed farms are more sustainable – they have slightly higher average biodiversity index (0.217 vs. 0.193) and better organic balance (0.07 vs. -0.38) which means that a risk of soil degradation is lower. As expected, the highest use of fertilizers is recorded when it comes to crop farms – an average farm spend 947 EUR per year while the lowest level is for permanent crop farm (633 EUR, on average). The latter have, however, by far the largest expenditures on pesticides – 1246 EUR, on average, while in other types of farms it is between 202 and 578 EUR.

There is no big differences between different types of farm when it comes to labor factor but the average level of AWUs engaged in farming was the lowest among crop farms since this type of agricultural activity is relatively less labor-intensive when compared to others.

The average value of farm assets (machinery and building) is about 19,700 EUR among crop farms up to 25,000 EUR among crop farms. It shows that small farms in central and eastern

European countries do not have significant production assets. The average spending on energy and gas was quite similar for different types of farming – it ranges between 700 EUR (permanent crops) and 733 EUR (livestock farms). The number of livestock units is obviously way the highest among livestock farms – it amounted to 14.6 LSU per farm, on average, but it should be noted that mixed farm possess, on average, 8.91 LSU. Livestock farm operate in the best production environment, as far as subsidies value is concerned. An average farm receives 2,590 EUR while, on the other side, permanent crop farm receives 1,777 EUR.

Let us now address **RQ1: Is there a trade-off or synergy between technical and eco-efficiency? How does the distribution of efficiency of small farms change when environmental criteria and public policies are introduced into the microeconomic production function?**

We can say that the distribution of efficiencies between limited and extended models differs significantly (as manifested by the rank sum test values) and this is true for all farm types in all studied countries. In other words one can say that incorporation of additional public criteria into production function significantly affects the efficiency. It is clear that we cannot directly compare the values of median scores from limited and extended model for a given country and farm type since these scores are calculated under different technological frontier. However, we can conclude that under modified production function, a larger number of DMU is found to be efficient in each of the farm type. These results contradict the findings of Hai and Speelman (2020) and Guth et al. (2022), but they are like those of Huang et al. (2016), cited above.

The results in Table 3 enable to compare the results from a particular model between countries under study. It turns out that in limited models, farms from Moldova were, on average, most efficient in crop, livestock, and mixed production. Serbian farms were most efficient when it comes to permanent crops production. Under extended models, Moldavian farms were best performing in case of livestock and mixed production, while in crop production it was Romania which ranked first in crop production and Serbia in permanent crop production. These results can be surprising since they suggest that farms outside the EU and deprived of support under CAP are, on average, more efficient than their counterparts from the EU countries, such as Poland and Romania. However, we should remember that more efficient doesn't have to mean that they are more economic viable, especially since farms in Moldova are very small. These farms can benefit from backwardness rent, i.e. they use little inputs which increases their efficiency.

Table 3. Median values of efficiency scores (super-efficiency meta-frontier models) and rank sum test z value (in parenthesis)

	CROP		LIVESTOCK		MIXED		PERMANENT	
Country	limited	extended	limited	extended	limited	extended	limited	extended
Serbia	0.236	0.149	-	-	0.314	0.559	0.484	1.002
	(7.841***)		-		(-9.951***)		(-4.66***)	
Romania	0.407	0.220	0.329	1.004	0.386	0.711	0.442	1
	(6.009***)		(-8.525***)		(-9.254***)		(-2.484***)	
Moldova	0.458	0.218	0.538	1.054	0.424	1.185	0.312	0.659
	(4.993***)		(-4.049***)		(-6.887***)		(-7.153***)	
Poland	0.332	0.127	0.191	0.52	0.233	0.365	0.384	0.428
	(13.909***)		(-8.859***)		(-10.13***)		(-2.184***)	
Total	0.354	0.166	0.268	0.851	0.308	0.536	0.375	0.728
	(16.001***)		(-12.248***)		(-16.186***)		(-8.423***)	
Number of efficient DMUs	104	167	44	135	72	239	79	155

*** stands for statistical significance at 99%

To shed more light on the relations between standard technical efficiency calculations and estimations with additional criteria, we also performed Spearman rank correlations on efficiency scores derived from the two models for each farm type (Table 4). The correlation is positive and significant for all studied farm types. However, it is particularly high for mixed farms and permanent crop farms. Thus, we can conclude that there is no trade-off between the economic performance of a farm and its sustainability. We rather found some evidence for synergy effect.

This conclusion is reinforced by the detailed analysis of extreme quartiles of efficiency distribution. For example, the results for crop farms mean that they were 115 DMUs that were classified to the first quartile in both limited and extended model while they were 148 farms classified to highest quartile (best performing) in both models. In other words, the share of DMUs in the common set is 48.5% in 1st quartile and 62.2% in 4th quartile. For other farm types these share clearly exceed 50% with the exception of 1st quartile for livestock production (48.3%). However, we can conclude that the composition of extreme quartile is quite similar between limited and extended models. Our results confirmed the analysis of Guesmi and Serra (2015) for arable Catalan farms or Soteriades et al. (2015) who claim that economic and environmental efficiency can go hand in hand. These results contradict, however, those of Huang et al. (2016), who found that the most efficient farms can have lower eco-efficiency.

Table 4. Share of the same farms belonging to the given quartile of distribution under the limited and extended model and Spearman rank correlation of efficiency scores between both models

QUARTILE	CROP	LIVESTOCK	MIXED	PERMANENT
1st	115/237=**48.5%**	38/70=**48.3%**	115/186=**61.8%**	54/86=**62.8%**
4th	148/238=**62.2%**	43/71=**60.6%**	106/187=**56.7%**	57/86=**66.3%**
CORRELATION	**0.546*****	**0.625*****	**0.690*****	**0.746*****

*** stands for statistical significance at 99%

RQ2.1 What are the potential improvements, in small farms' resources allocation based on the evidence from central and eastern Europe (CEE)?

Answering this question succinctly (Table 5): crop farms could evolve in two directions: landscape guardians and artisanal farmers; livestock farms—the most problematic TF—would either maintain the status quo or choose exit pathways; mixed TF is likely to become landscape guardians; for 20% of permanent crop farms, a pathway of sustainable intensification is open. An additional possibility for all paths is "collective action." This means that in each of the developmental paths, it would be necessary to promote more efficient use of the assets on small farms, which are apparently facing the problem of overcapitalization.

Table 5. The number of farms that could potentially follow main evolution pathways for small farms based on slacks analysis

Farm type	Sustainable intensification	Landscape guardians	Artisanal farmers	Exit path	Status quo	Collective actions*
Crop (n=949)	52 (5%)	376 (**40%**)	367 (**39%**)	25 (3%)	129 (14%)	669 (70%)
Livestock (n=281)	28 (10%)	14 (5%)	0	127 (**45%**)	112 (**40%**)	135 (48%)
Mixed (n=745)	35 (5%)	444 (**60%**)	19 (3%)	67 (9%)	180 (24%)	464 (62%)
Permanent crop (n=345)	79 (**23%**)	12 (3%)	6 (2%)	101 (29%)	147 (**43%**)	145 (42%)

* this includes farms classified for any of the main pathways- therefore percentages in rows do not sum up to 100%; farms with slack on machinery and buildings variable are assigned to this group

RQ2.2 How can agricultural policies create context-specific levers for small-scale farmers that promote eco-efficiency?

In this part we focus on inefficient DMUs only. WE found that policy could develop multi-track stimulation measures toward these outcomes (Tables 6-9): more use of cooperative assets (all TF), reduction of fertilizers (crops, mixed TF), and reduction of pesticides (crops TF). Specifically, in livestock TF, manure and slurry treatments should be supported. In crops and mixed TF, a provision/reduction of PG/bad output could be better triggered, as the slack is more than two times as high as the initial average values. Hitherto, policy measures seemed to be quite ineffective in this field, although in Serbia and Moldova, which are beyond the CAP, the level of inefficiency (slack) mentioned above is significantly higher.

The analysis in Table 6 shows that **crop** farms possess far too many assets in relation to their production potential, and they are highly energy inefficient. Therefore, crop farms could decrease the use of machinery, buildings, and the energy and gas consumption. It seems that the easiest way to decrease the use of these inputs would be horizontal integration and cooperation between farmers, so they do not need to maintain such assets. Another way to become more eco-efficient is to reduce the use of fertilizers and pesticides. The calculated slack has even greater potential for improvement than the EU Green Deal goals (the reduction of pesticides by 50% and fertilizers by 20%). However, a particular large reduction could be implemented in non-EU members, such as Serbia and Moldova. Meanwhile, public policies have not been very effective in stimulating the provision of PG, in contrast to recent studies of small farms from other areas of the world (Liang et al., 2022). There is still room for improvement to at least double the PG outcome.

Table 6. Potential improvements (slacks) in total input/output for inefficient DMUs in crops farm sector (extended model)

Cluster	**Meta-frontier score**	Fertilizers use	Pesticides use	Labour	Utilized agricultural area	Machinery and building	Energy and gas use	LSU	Production value	Gini crop diversity index av.slack/av. value	Soil biodiversity loss t/ha av.slack/av.value
Serbia	0.1490	-69%	-61%	-30%	-0%	-78%	-62%	na	13%	0.634/0.199	-0.644/0.679
Romania	0.2198	-32%	-31%	-15%	-9%	-43%	-37%		17%	0.375/0.183	-0.654/0.196
Moldova	0.2181	-51%	-76%	-16%	-1%	-66%	-42%		13%	0.484/0.200	-0.420/0.518
Poland	0.1270	-54%	-39%	-29%	-3%	-51%	-73%		26%	0.500/0.195	-1.418/0.258
TOTAL	-0.17	**-51%**	**-49%**	-23%	-5%	**-56%**	**-53%**		19.3%	**0.486/0.193**	**-0.791/0.38**

Notes: LSU has a marginal importance for crops farms

Livestock farming encounters the biggest slack in assets and energy. It turns out, however, that the potential to decrease inputs is much smaller than in crops' TF. This mainly concerns Romania and Moldova. There is also a well-known issue regarding the production of manure and slurry, which contributes significantly to GHG emissions. In practice, it is hard to significantly decrease the on-farm output of manure and slurry, but there is a need to support the treatment of slurry to reduce its nuisance and harmful gas emissions. This is better than simply reducing the LSU number, especially since the slack on the LSU in the extended model amounts to only 8% for the total sample. In contrast to crop farms, for livestock farms, we find almost no room to increase the production value. Similarly, it is also very difficult to provide more permanent grassland by these farms.

Table 7. Potential improvements (slacks) in total input/output for inefficient DMUs in livestock farm sector (extended model)

Cluster	**Meta-frontier score**	Fertilizers use	Pesticides use	Labour	Utilized agricultural area	Machinery and building	Energy and gas use	LSU	Production value	Permanent grassland	Manure and slurry
Romania	1.004	na		-16%	-1%	-28%	-22%	-10%	1%	0%	-36%
Moldova	1.054			-14%	-12%	-39%	-20%	-7%	0%	0%	-62%
Poland	0.520			-32%	-9%	-49%	-50%	-6%	1%	1%	-36%
TOTAL	0.851			-23%	-6%	**-39%**	**-37%**	-8%	0.9%	0.5%	**-36.5%**

Notes: pesticides and fertilizers have a marginal importance for livestock farms

Mixed farms are not clearly focused on either crop or livestock production. Therefore, they exhibit relatively large reduction potential with regard to fertilizers, but also for the use of machinery, buildings, and energy and the consumption of gas. With regard to PG/bad provisions, there is great room for improvement in terms of the balance of organic soil and the diversity of crops.

Table 8. Potential improvements (slacks) in total input/output for inefficient DMUs in mixed farm sector (extended model)

Cluster	**Meta-frontier score**	Fertilizers use	Pesticides use	Labour	Utilized agricultural area	Machinery and building	Energy and gas use	LSU	Production value	Permanent grassland, orchards and vineyards	Gini crop diversity index av.slack/av. value	Manure and slurry	Soil biodiversity loss t/ha av.slack/av.value
Serbia	0.559	-26%	-22%	-20%	-4%	-42%	-40%	-38%	0%	5%	0.121/0.194	-32%	-0.064/0.409
Romania	0.711	-43%	-21%	-8%	-3%	-47%	-28%	-19%	1%	2%	0.179/0.258	-20%	-0.054/-0.362
Moldova	1.185	-6%	-25%	-11%	-4%	-26%	-23%	-10%	1%	2%	0.035/0.263	-19%	-0.002/0.033
Poland	0.365	-53%	-7%	-8%	-12%	-55%	-61%	-10%	0%	7%	0.354/0.174	-19%	-0.257/-0.084

TOTAL	0.536	**-45%**	-17%	-11%	-7%	**-47%**	**-46%**	-18%	0.5%	3.6%	**0.212/0.217**	-20.4%	**-0.119/-0.070**

Like the other types of farming, **permanent crop** farms also could significantly reduce the use of fixed assets and energy and the consumption of gas. There is also a relatively high potential to boost their production value.

Table 9. Potential improvements (slacks) in total input/output for inefficient DMUs in permanent crops farm sector (extended model)

Cluster	**Meta-frontier score**	Fertilizers use	Pesticides use	Labour	Utilized agricultural area	Machinery and building	Energy and gas use	LSU	Production value	Orchards and vineyards
Serbia	1.002	-25%	-9%	-10%	-6%	-25%	-16%	na	13%	1%
Romania	1.000	-10%	-3%	-7%	0%	-28%	-21%		54%	0%
Moldova	0.659	-23%	-21%	-20%	-2%	-41%	-32%		48%	1%
Poland	0.428	-20%	-3%	-31%	-1%	-57%	-75%		15%	22%
TOTAL	0.728	-21%	-16%	19%	-1%	**-37%**	**-42%**		**37.3%**	0.9%

Notes: LSU has a marginal importance for permanent crops farms.

To sum up, Tables 6–9 depict the potential for reducing slack in small farms with regard to different TFs. We emphasized above the general directions of agricultural policy support that might be the most effective in this sector. Based on farm-level slack, in this section we could define the beginning of pathways for the development of small farms in CEE (Table 5). These are the options discussed in the state of the art and described in point 3.4. Such a classification allows for the more effective distribution of public funds, pointing out the most likely direction for the development of small farms.

5. Conclusions and recommendation

Our results allow us to outline a vision for the development of the small-farm sector in CEE and the directions of CAP development for small-scale farming. Assuming that distances between DMU's and their relative placement against the frontier are fairly constant over time we can conclude there are no trade-offs between technical efficiency and eco-efficiency in small farms. More economically efficient farms are usually more sustainable when desirable social criteria are joined to the production function. Hence, we disagree with the scenarios for small farms in CEE drawn by Guth et al. (2022), who said that "the high economic strength of a farm is accompanied by a worsening environmental balance or, conversely, an economically weak farm is characterized by a higher environmental balance" (pp. 241-242). We argue for the opposite, based on our results—a small farm can be beautiful and economically viable.

This conclusion by itself suggests that policy support should follow two tracks:

1) In field crop and permanent crop farms, production value support is required as the "artisanal pathways" under the multifunctional model, and "sustainable intensification" is possible. Assuming the representativeness of our sample, we are talking about 19% of the farms in the countries surveyed, i.e., about 395,000 entities. The value of production can be supported in various ways, not the least of which is investment support in the packaging, distribution, and marketing of artisanal products, as well as appropriate educational packages. Equally important, however, are counter-cyclical measures, because small producers can be very sensitive to market fluctuations. The idea would therefore be to maintain coupled payments that have counter-cyclical effects and well-targeted investment subsidies. Meanwhile, the Good Agricultural and Environmental Conditions would be retained and developed, with an emphasis on reducing pesticides and fertilizers, which have created the biggest slack in these TFs. This could be achieved through properly tailored eco-schemes, which will be in effect in the forthcoming CAP period.

2) In contrast, support for the provision of public goods is needed for a similar number of crop farmers and the 60% of mixed farms that represent the "landscape guardian" option. As our research shows, valorization to date through CAP agri-environmental subsidies has not adequately exhausted the potential for the provision of public goods by small-scale farms in these TFs. About 728,000 entities in the countries studied may be involved here. Therefore, besides the typical agri-environmental and climate schemes, it would be beneficial to create quasi-market value for PG. Here, we have in mind tradable site scheme/habitat banking (Santos et al., 2015; Klassert & Möckel, 2013), which could provide funds to subsidize loans for purchasing or leasing land. At the same time, agri-environmental subsidies should be more results-oriented, but focus on the problem areas identified by the slack analysis in this TF, i.e., pesticide use (crop farms only) and fertilizers (crops and mixed farms).

Another thread that should not be neglected is support for "investment cooperation." This issue affects as many as 61% of small farms of all types, or 1.25 million entities, from the countries surveyed. Perhaps it would be appropriate to consider a new type of hybrid support for investments made by cooperatives and producer groups, i.e., horizontal integrated groups of farmers.

A big problem for the rural areas of the countries studied may be "exit pathways," as our research shows. This mainly affects livestock small farms (45%). This may mean that support for livestock production addressed to small entities (de facto, such instruments in the CAP are practically non-existent) should be abandoned altogether, as it promises neither efficiency nor the provision of public goods. In this situation, however, it is necessary to prepare cohesion support for rural areas where livestock farms predominate so those farmers can retrain and take up gainful employment off their farms. However, this applies to a relatively small percentage of small farms, i.e., about 5% in the countries studied, or about 114,000 operators.

On the other hand, it is a quite optimistic conclusion that the "exit pathways" affect so few holders regarding other TFs (except for permanent crops, where it is 29%). This means that small farms have their place in the European model of agriculture, and they could contribute to the goals of sustainable agriculture, both in terms of FNS and the provision of PG.

References

Adenuga, A. H., Davis, J., Hutchinson, G., Donnellan, T., & Patton, M. (2019). Environmental efficiency and pollution costs of nitrogen surplus in dairy farms: a parametric hyperbolic technology distance function approach. Environmental and Resource Economics, 74(3), 1273-1298. doi.org/10.1007/s10640-019-00367-2

Adenuga, A. H., Davis, J., Hutchinson, G., Patton, M., & Donnellan, T. (2020). Modelling environmental technical efficiency and phosphorus pollution abatement cost in dairy farms. Science of The Total Environment, 714, 136690. doi.org/10.1016/j.scitotenv.2020.136690

Allen, B., Hart, K., Radley, G., Tucker, G., Keenleyside, C., Oppermann, R.,Underwood, E., Menadue, H., Poux, X., Beaufoy, G., Herzon, I., Povellato, A.,Vanni, F., Praˇzan, J., Hudson, T., Yellachich, N.(2014). Biodiversity Protection Through Results Based Remuneration of Ecological Achievement. Report Prepared for the European Commission, DG Environment. Institute for European Environmental Policy, London, 167 pp.

Andersen, P., & Petersen, N. C. (1993). A procedure for ranking efficient units in data envelopment analysis. Management science, 39(10), 1261-1264.

Banker, R. D., & Morey, R. C. (1986). Efficiency analysis for exogenously fixed inputs and outputs. Operations research, 34(4), 513-521.

Bartolini, F., Vergamini, D., Longhitano, D., & Povellato, A. (2021). Do differential payments for agri-environment schemes affect the environmental benefits? A case study in the north-eastern italy. Land use Policy, 107, 104862, doi:10.1016/j.landusepol.2020.104862

Beltrán-Esteve, M., Reig-Martínez, E., & Estruch-Guitart, V. (2017). Assessing eco-efficiency: A metafrontier directional distance function approach using life cycle analysis. Environmental Impact Assessment Review, 63, 116-127.

Bonfiglio, A., Arzeni, A. and Bodini, A. (2017). Assessing eco-efficiency of arable farms in rural areas, Agriculture Systems, 151, 114-125.

Cambra-Fierro, J. J., & Pérez, L. (2022). (Re)thinking smart in rural contexts: A multi-country study. Growth and Change, 53(2), 868-889. doi:10.1111/grow.12612

Chen, L., & Jia, G. (2017). Environmental efficiency analysis of China's regional industry: a data envelopment analysis (DEA) based approach. Journal of Cleaner Production, 142, 846-853.

Cheng, G. (2014). Data envelopment analysis: methods and MaxDEA software. Beijing: Publishing House Co. Ltd.

Chiu, Y. H., Luo, Z., Chen, Y. C., Wang, Z., & Tsai, M. P. (2013). A comparison of operating performance management between Taiwan banks and foreign banks based on the Meta-Hybrid DEA model. Economic Modelling, 33, 433-439.

Creamer, R.E., Rimmer, D.L. & Black, H.I.J. 2008. Do elevated soil concentrations of metals affect the diversity and activity of soil invertebrates in the long term? Soil Use and Management, 24, 37-46

Czyżewski, B., Kryszak, Ł., (2022), Sustainable Agriculture Policies for Human Well-Being. Integrated Efficiency Approach, Sustainable Agriculture Policies for Human Well-Being Series, in press, https://link.springer.com/book/9783031097980 (accessed 06.08.2022).

Czyżewski, B., Matuszczak, A., & Miśkiewicz, R. (2019b). Public goods versus the farm price-cost squeeze: shaping the sustainability of the EU's common agricultural policy. Technological and Economic Development of Economy, 25(1), 82-102.

Dakpo, K. H., Jeanneaux, P., & Latruffe, L. (2017). Greenhouse gas emissions and efficiency in French sheep meat farming: A non-parametric framework of pollution-adjusted technologies. *European Review of Agricultural Economics*, *44*(1), 33-65.

Davidova, S., Bailey, A., Dwyer, J., Erjavec, E., Gorton, M., Thomson, K., 2013. Semisubsistence Farming – Value and Directions of Development. European Parliament, Directorate for Internal Affairs. Accessed on 29.06.2020, Available online at: https://www.europarl.europa.eu/RegData/etudes/etudes/join/2013/495861/IPOL-AGRI_ET(2013)495861_EN.pdf.; accessed 06.08.2022.

Davidova, S., Fredriksson, L., Gorton, M., Mishev, P., Petrovici, D., 2012. Subsistence farming, incomes, and agricultural livelihoods in the new member states of the European Union. Environ. Plann. C Govern. Pol. 30, 209–227. https://doi.org/ 10.1068/c1195r.

Dong, G., Wang, Z., & Mao, X. (2018). Production efficiency and GHG emissions reduction potential evaluation in the crop production system based on emergy synthesis and nonseparable undesirable output DEA: A case study in Zhejiang Province, China. PloS one, 13(11), e0206680.

Dwyer, J. (2014). CAP reform proposals for small and semi-subsistence farms. EuroChoices, 13(1): 31–35.

European Parliament (2014). On the future of small agricultural holdings, Report of the committee on Agriculture and Rural Development 2013/2096(INI), Luxembourg, European Parliament.

European Parliament (2021) https://www.europarl.europa.eu/news/en/headlines/society/20211118STO17609/eu-agriculture-statistics-subsidies-jobs-production-infographic) accessed 06.08.2022.

Eurostat 2022, https://ec.europa.eu/eurostat/databrowser/view/ef_olfftecs/default/table?lang=en) accessed 06.08.2022.

FAMFAR 2022 accessible at https://famfar.ans.pila.pl/; accessed 11.05.2023.

FAO, 2014. The State of Food and Agriculture: Innovation in family farming, http://www.fao.

org/publications/sofa/2014/en/, accesed: 14.10.2022.

Gardi, C.; Visioli, G.; Conti, F.D.; Scotti MMenta, C.; Bodini, A. (2016). High Nature Value Farmland: Assessment of Soil Organic Carbon in Europe. Frontiers in Environmental Science 4, 47.

Ghali, M., Latruffe, L., & Daniel, K. (2016). Efficient use of energy resources on French farms: An analysis through technical efficiency. Energies, 9(8), 601.

Goodman, D., DuPuis, E. M., & Goodman, M. K. (2012). Alternative food networks: Knowledge, practice, and politics. Routledge: London and New York.

Gorton, M., Hubbard, C., Hubbard, L., 2009. The folly of European Union policy transfer: why the Common Agricultural Policy (CAP) does not fit Central and Eastern Europe. Reg. Stud. 43 (10), 1305–1317. https://doi.org/10.1080/00343400802508802.

Gruhelski M., Niemczyk J., 2016. Małe gospodarstwa rolne w Polsce a paradygmat rozwoju zrównoważonego (Small farms in Poland and the paradigm of sustainable development). Advances in Food Processing Techniques, no. 2: 134–140.

Guesmi, B., & Serra, T. (2015). Can we improve farm performance? The determinants of farm technical and environmental efficiency. Applied Economic Perspectives and Policy, 37(4), 692-717.

Guth, M., Stępień, S., Smędzik-Ambroży, K., Matuszczak, A. (2022). Is small beautiful? Technical efficiency and environmental sustainability of small-scale family farms under the conditions of agricultural policy support Journal of Rural Studies 89 (2022), 235–247.

Hai, A. T. N., & Speelman, S. (2020). Economic-environmental trade-offs in marine aquaculture: The case of lobster farming in Vietnam. Aquaculture, 516, 734593.

Halkos, G., & Petrou, K. N. (2019). Treating undesirable outputs in DEA: A critical review. Economic Analysis and Policy, 62, 97-104.

Hasund, K.P., 2013. Indicator-based agri-environmental payments: a payment-by-result model for public goods with a Swedish application. Land Use Policy 30 (1), 223-233.

Huang, W., Bruemmer, B., & Huntsinger, L. (2016). Incorporating measures of grassland productivity into efficiency estimates for livestock grazing on the Qinghai-Tibetan Plateau in China. Ecological Economics, 122, 1-11.

IPC-IG, 2019. Rural poverty reduction in the 21st century. Pol. Focus 16 (1). April 2019. International Policy Centre for Inclusive Growth, Brasilia. Accessed on 29.06.2020, Available online at: https://ipcig.org/pub/eng/PIF44_Rural_poverty_reduction_in_the_21st_century.pdf.

JRC Reference Reports (2012), The state of Soil in Europe, Joint research Centre, Luxembourg 2012, accessible at https://esdac.jrc.ec.europa.eu/ESDB_Archive/eusoils_docs/other/EUR25186.pdf (accessed 06.08.2022)

Klassert, C., & Möckel, S. (2013). Improving the policy mix: The scope for market-based instruments in EU biodiversity policy. Environmental Policy and Governance, 23(5), 311-322. doi:10.1002/eet.1623.

Lakner, S., & Breustedt, G. (2017). Efficiency analysis of organic farming systems a review of concepts, topics, results and conclusions. German Journal of Agricultural Economics, 66(670-2020-978), 85-108.

Le, T. L., Lee, P. P., Peng, K. C., & Chung, R. H. (2019). Evaluation of total factor productivity and environmental efficiency of agriculture in nine East Asian countries. Agricultural Economics, 65(6), 249-258.

Lesorogol, C.K., 2008. Contesting the Commons: Privatizing Pastoral Lands in. University of Michigan Press, Kenya.

Liang, H., Meng, Y. & Ishii, K. The effect of agricultural greenhouse gas emissions reduction policies: evidence from the middle and lower basin of Yangtze River, China. Discov Sustain 3, 43 (2022).

Long, X., Luo, Y., Sun, H., & Tian, G. (2018). Fertilizer using intensity and environmental efficiency for China's agriculture sector from 1997 to 2014. Natural Hazards, 92(3), 1573-1591.

Lowder, S.K., Skoet, J., Raney, T., 2016. The number, size, and distribution of farms, smallholder farms, and family farms worldwide. World Dev. 87, 16–29.

Marsden, T., Hebinck, P., Mathijs, E., (2018). Re-building food systems: embedding assemblages, infrastructures and reflexive governance for food systems transformations in Europe. Food Security. 10 (6), 1301–1309.

Peña, C. R., Serrano, A. L. M., de Britto, P. A. P., Franco, V. R., Guarnieri, P., & Thomé, K. M. (2018). Environmental preservation costs and eco-efficiency in Amazonian agriculture: Application of hyperbolic distance functions. Journal of Cleaner Production, 197, 699-707.

Poulton, C., Dorward, A., Kydd, J. (2010). The future of small farms: new directions for services, institutions, and intermediation. World Development. 38, 1413–1428. https://doi.org/10.1016/J.WORLDDEV.2009.06.009.

Santos, R., Schröter-Schlaack, Ch., Antunes, P., Ring, I., Clemente, P. 2015.Reviewing the role of habitat banking and tradable development rights in the conservation policy mix, Environmental Conservation (2015) 42 (4): 294-305, doi:10.1017/S0376892915000089

Sklenicka, P., Janovska, V., Salek, M., Vlasak, J., Molnarova, K., (2014). The Farmland Knowledge, Practice, and Politics. Routledge. Rental Paradox: extreme land ownership fragmentation as a new form of land degradation. Land Use Policy 38, 587–593. https://doi.org/10.1016/J.LANDUSEPOL.2014.01.006.

Song, J., & Chen, X. (2019). Eco-efficiency of grain production in China based on water footprints: A stochastic frontier approach. Journal of Cleaner Production, 236, 117685

Soteriades, A. D., Faverdin, P., March, M., & Stott, A. W. (2015). Improving efficiency assessments using additive data envelopment analysis models: an application to contrasting dairy farming systems. Agricultural and Food Science, 24(3), 235-248.

Staniszewski, J. (2018). Attempting to measure sustainable intensification of agriculture in countries of the European Union. Journal of Environmental Protection and Ecology, 19(2), 949–957.

Stępień, S., Czyżewski, B., Sapa, A., Borychowski, M., Poczta, W., & Poczta-Wajda, A. (2021). Eco-efficiency of small-scale farming in Poland and its institutional drivers. Journal of Cleaner Production, 279, 123721.

Stępień, S., Maican, S. (eds. 2020), Small Farms in The Paradigm of Sustainable Development. Case studies of selected Central and Eastern European countries, "Adam Marszałek" Publishing house, Toruń 2020.

Stringer ,L,.C., Fraserb, E.,D.,G., Harrisc, D., Lyona, F., C., Pereirad, L., Warda, C.,F.,M., Simeltone, E. (2020), Adaptation and development pathways for different types of farmers. Environmental Science and Policy 104 (2020) 174–189.

Thornton, P.K., Kristjanson, P., Förch, W., Barahona, C., Cramer, L., Pradhan, S. (2018). Is agricultural adaptation to global change in lower-income countries on track to meet the future food production challenge? Global Environmental Change 52, 37–48. https://doi.org/10.1016/J.GLOENVCHA.2018.06.003.

Toma, I., Redman, M., Czekaj, M., Tyran, E., Grivins, M., & Sumane, S. (2021). Small-scale farming and food security – policy perspectives from central and eastern europe. Global Food Security, 29 doi:10.1016/j.gfs.2021.100504.

Tone, K. (2001). A slacks-based measure of efficiency in data envelopment analysis. European Journal of Operational Research, 130(3), 498-509.

Tone, K. (2004). A hybrid measure of efficiency in DEA. GRIPS Policy Information Center Research Report.

Ullah, A., Perret, S. R., Gheewala, S. H., & Soni, P. (2016). Eco-efficiency of cotton-cropping systems in Pakistan: an integrated approach of life cycle assessment and data envelopment analysis. Journal of Cleaner Production, 134, 623-632.

Ullah, A., Silalertruksa, T., Pongpat, P., & Gheewala, S. H. (2019). Efficiency analysis of sugarcane production systems in Thailand using data envelopment analysis. Journal of Cleaner Production, 238, 117877.

Urdiales, M. P., Lansink, A. O., & Wall, A. (2016). Eco-efficiency among dairy farmers: the importance of socio-economic characteristics and farmer attitudes. Environmental and Resource Economics, 64(4), 559-574. doi.org/10.1007/s10640-015-9885-1

van Loon, G.W., Patil, S.G., & Hugar, L.B. (2005). Agricultural sustainability. Strategies for assessment. London: SAGE Publications

Vecchio, Y., De Castro, P., Masi, M., & Adinolfi, F. (2021). Do rural development policies really help small farms? A reflection from italy. EuroChoices, 20(3), 75-80. doi:10.1111/1746-692X.12338

Vigani, M. and Dwyer, J. (2020). Profitability and efficiency of high nature value marginal farming in England. Journal of Agricultural Economics, 71(2): 439–464.

Wang, X., Ding, H., & Liu, L. (2019). Eco-efficiency measurement of industrial sectors in China: a hybrid super-efficiency DEA analysis. Journal of Cleaner Production, 229, 53-64.

Wettemann, P. J. C., & Latacz-Lohmann, U. (2017). An efficiency-based concept to assess potential cost and greenhouse gas savings on German dairy farms. Agricultural Systems, 152, 27-37.

Wrzaszcz ,W. (2018), Changes in Farms' Environmental Sustainability in Poland—Progress or Regress? AgBioForum, 21(2): 107-126.

Wrzaszcz, W. (2009). Bilans nawozowy oraz bilans substancji organicznej w indywidualnych gospodarstwach rolnych (Fertiliser balance and organic matter balance on individual farms).). Z badań nad rolnictwem społecznie zrównoważonym (From research into socially sustainable agriculture),7(129), 27-33.

Yang, H., & Pollitt, M. (2009). Incorporating both undesirable outputs and uncontrollable variables into DEA: The performance of Chinese coal-fired power plants. European Journal of Operational Research, 197(3), 1095-1105.

Yang, L., Ouyang, H., Fang, K., Ye, L., & Zhang, J. (2015). Evaluation of regional environmental efficiencies in China based on super-efficiency-DEA. Ecological Indicators, 51, 13-19.

Żmija A., Alexandri C., Czyżewski A., Gorlach K., Kaleta A., Kłodziński M., Kozari J., Sorys S., Urban S., Vanni F., Wilkin J., Zegar J.S. (eds.), 2013. Problemy społeczne i ekonomiczne drobnych gospodarstw rolnych w Europie (Social and economic problems of small farms in Europe). Cracow: Agricultural Advisory Center.

Żmija, Katarzyna & Żmija, Dariusz. (2018). Prospects for the Development of Small Farms in Poland. Conference: Hradec Economic Days 2018At: Hradec Kralove, Czech Republic, 10.36689/uhk/hed/2018-02-055; accessed 06.08.2022.