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Approaching environmental sustainability of agriculture: environmental burden, eco-efficiency or eco-effectiveness

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Abstract: The main goal of the article is to compare three approaches to measuring environmental sustainability in agriculture: i) the environmental burden index; ii) the sustainable value of eco-efficient production; and iii) the sustainable value of the eco-effective farm, applied to the sample of 130 EUFADN (European Union Farm Accountancy Data Network) regions in 2015. The study indicates a fundamental problem: the notion of environmental sustainability in agriculture differs depending on the criterion we apply. We recognized a principle trade-off in the Common Agricultural Policy (CAP) which consists of compensating for the strain on the natural environment with production or with public goods provision. Studies on these two effects seem to be crucial to draw a consistent development path for the CAP. Our major finding is that public goods-oriented farming is more likely to expand after improving eco-efficiency. This is still a challenge because in European regions, eco-efficient has not meant environmentally sustainable yet.

Keywords: agriculture; environment; EU regions; sustainable development

Discussion on the measures of sustainable development of agriculture is nothing new. In the literature, the issue is most often analysed in its economic, social and environmental aspects (Kates et al. 2005). While the first two are not difficult to evaluate (mostly from the perspective of income, employment, and education), some dilemmas arise in the context of environmental sustainability. One of the major dilemmas is whether: i) to decrease the overall environmental burden of agriculture, no matter the production effects; ii) or to generate the highest production in relation to the polluting means used (e.g. fertilisers, pesticides, energy) and gases emitted – so-called "eco-efficiency"; and iii) or to adopt a consensus consisting in the fact that the inputs used in agricultural production are unfavourable for the natural environment and so simultaneously should be compensated for through agri-environmental activities, which create environmental public goods – so-called "eco-effectiveness". Unfortunately, there is no universally accepted research methodology; however, the eco-efficiency approach (Coelli et al. 2005; Stoate 2009) is dominant in the literature. The aim of the article is to compare the results of three approaches to measuring environmental sustainability: i) the environmental burden index for agriculture; ii) the sustainable value of eco-efficient production; and iii) the sustainable value of the eco-effective farm, applied to the sample of 130 EUFADN regions in 2015 (i.e. region-average farms data from the EU Farm Accountancy Data Network; see more in methodology).

THEORETICAL BACKGROUND: ECO-EFFECTIVE VERSUS ECO-EFFICIENT

The construction of a composite measure of the environmental burden in agriculture is a problematic

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issue. Reytar et al. (2014) point out 25 various indicators related to environmental sustainability. The variables, referring to water consumption, agricultural subsidies, climate change, agricultural production, ecosystem biodiversity, and land use, were deemed to be of key significance. Other approaches point to the issues of pesticide, herbicide, and fungicide in agricultural production, as well as the use of organic and synthetic fertilisers, plant protection products and crop rotation (Saltiel et al. 1994; Hayati et al. 1996; Czyżewski et al. 2018).

The term "eco-efficiency" appeared in the 1990s as a practical tool to measure sustainability. It was introduced by the World Business Council for Sustainable Development (Schaltegger and Sturm 1990; Schaltegger 1996; WBCSD 2000) to identify a management philosophy aimed at encouraging businesses to search for environmental improvements that yield parallel economic benefits. A workable approach to sustainability at the farm level consists in testing whether environmental impacts decrease as the value of economic outputs is maintained or increased (Picazo-Tadeo et al. 2011). However, we have a concern whether such a change in the eco-efficiency reflects a corresponding change in sustainability understood as a responsible use of ecological resources that meet human needs but also preserves these resources for future generations. The eco-efficiency ratio measures a relative level of environmental pressure in relation to the volume of economic activity. In our opinion, the idea of sustainability is more related to the absolute levels of environmental pressure.

So, the eco-efficiency approach may be somewhat contradictory to the idea of environmental sustainability, which should take into consideration the actual environmental effect on farms. In addition, the EU Common Agricultural Policy is evolving: next to its original assumptions related to the food safety and support for agricultural incomes the policy sets new goals related to the respect for the environment or the creation of public goods, in particular environmental ones (Olper 2001). Therefore, it is interesting to what degree the support for agriculture from various Common Agricultural Policy (CAP) programmes affects the increase in the eco-efficiency of farms and to what extent it affects their eco-effectiveness. At this point a certain conflict between the eco-effectiveness and the eco-efficiency might be expected, due to the policy supporting both types of programmes that have a strong impact on the eco-efficiency issues but also such wherein the eco-effectiveness is dominant. This conflict impedes the sustainable development of the agriculture. The results of this research, then, will contribute to the discussion regarding the future of the EU's Common Agricultural Policy after 2020, but also the national and regional agricultural policies. The crucial question is, what should be the output measure in the input-output (I-O) approaches used to assess the environmental sustainability? It is also not certain to what extent the hitherto funding of agriculture facilitates the implementation of goals regarding its sustainable development, and to what extent it consolidates the industrial model of production – where issues of efficiency will be of key importance.

MATERIAL AND METHODS

Composite measure of the environmental burden in agriculture

Taking into account the above-mentioned remarks, the following variables from the EUFADN database (EUFADN Poland 2017; EUFADN 2018) were applied in our study for the construction of a composite measure at the level of an average farm in a given region (EUFADN codes in brackets):

i) Stock density per ha (SE120);
ii) Mineral fertilisers use per ha (SE295/SE025);
iii) Plant protection products use per ha (SE300/SE025);
iv) Total use of energy per ha (SE345/SE025);
v) Woodland area in relation to utilised agricultural area (UAA) (SE075/SE025).

All the European regions were analysed in 2015, as the last available year in the FADN.

The above set of variables fits in with the discussion on the environmental sustainability of agriculture and is relatively well represented in the literature (Latruffe et al. 2016). The indicators were converted into destimulants of the environment quality (if needed). We calculated a composite measure of the environmental sustainability for an average farm in a region using two methods of linear ordering, i.e. Hellwig's approach (Poczta-Wajda and Poczta 2016), and the TOPSIS-CRITIC method (Technique for Order Preference by Similarity to an Ideal Solution – Criteria Importance Through an Intercriteria Correlation: Diakoulaki et al. 1995; Chung-Hsing Yeh et al. 2000). As both gave very similar outcomes, we presented the results according to the basic Hellwig index (H_i) which employs the Euclidean distance from the pattern (z_{max}) for each

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object z_i (the average EUFADN farm in the region), *cf.* Equation (1):

$$H_i = 1 - \frac{D_i}{\mu_D + 2\,\sigma_D}$$

$$D_i = \sqrt{\sum_{j=1}^{m}\left(z_{ij} - z_{maxj}\right)^2} \qquad (1)$$

where: H_i is the composite index for i^{th} farm/region; D_i – the Euclidean distance of the i^{th} farm/region from the best object; z_{ij} – standardised and weighted empirical values of variable j (j = 1, 2, ... , m) from the above mentioned i–iv) in the i^{th} farm/region; μ_D – mean of D; σ_D – standard deviation of D.

The higher the value of the composite index, $H_i \in [0;1]$, the lower the pressure on the environment.

Sustainable value of eco-efficient production

Estimating the environmental sustainable value (ESV) with frontier benchmarking was carried out assuming a trade-off of productivity versus the environment. ESV is a value-oriented method, developed as a mean of measuring the agricultural eco-efficiency at the microeconomic level. This enables a synthetic assessment of a farm's contribution to farming sustainability, taking into account the efficiency resulting from using economic, social and environmental resources in comparison to the opportunity cost (Figge and Hahn 2005; van Passel et al. 2007; Illge et al. 2008; Burja and Burja 2016). ESV has many advantages comparing to the standard data envelopment analysis (DEA) approach, since it also measures the monetary value of the "contribution to the sustainability" that should be borne to achieve it or that was paid in surplus. Thus, it gives much more information useful for policymakers than a simple linear ordering. However, we propose to engage the DEA technique to identify a benchmark unit for the ESV – which is an original contribution. In the literature, the use of DEA techniques to measure eco-efficiency in different sectors, as well as for the assessment of the environmental performance of farms and the agricultural sector, is widely known. However, there are not so many studies which estimate the eco-efficiency at the farm level using the DEA approach. The most recent of them are: Picazo-Tadeo et al. (2011), Gómez-Limón et al. (2012), Picazo-Tadeo et al. (2012), Berre et al. (2015), Gadanakis et al. (2015), Pérez Urdiales et al. (2016), Bonfiglio et al. (2017). In all the cited works, the eco-efficiency improvement is defined in the same way, i.e. as a situation when the environmental impacts decrease, whereas the value of the economic outputs is maintained (or increased). None of the cited studies brings into question the underlying idea of trade-offs between the farm output and the environmental pressure. Indeed, there is a lack of studies on whether the improvement in the farm eco-efficiency ratio is really "sustainable". Many authors took the assumption that "eco-efficient equals more sustainable" for granted. Although some of them admit the opposite, this is not reflected either in the methodology nor in the conclusions (Picazo-Tadeo et al. 2011). In the above context, we have a motivation to confront the eco-efficiency scores for the EUFADN units in the regional cross-section with different approaches to the matter of environmental sustainability. Our analysis also sheds light on the basic characteristics of the most eco-efficient and the most eco-inefficient average farms in the European regions. This information is missing in the cited works, which mainly give only indirect clues as to what farms located on the eco-efficiency frontier are really like (see discussion in the results part of this paper).

We used the ESV measure, which is quite a fresh view and generates output in a more practical way for policy makers (i.e. in monetary units) than the frequently applied DEA. However, we do recall that the ESV calculated in the studies extends the DEA analyses which are primarily used to identify the so-called benchmark units yb_{ij} and rb_{ij}. The input-oriented DEA approach has been applied following the studies of Kuosmanen and Kortelainen (2005), Picazo-Tadeo et al. (2011) and Bonfiglio et al. (2017). The calculation formula for determining the ESV of the farms in the regions is as follows:

$$SV_i = \frac{1}{m}\sum_{j=1}^{m} r_{ij}\left(\frac{y_{ij}}{r_{ij}} - \frac{yb_{ij}}{rb_{ij}}\right) \qquad (2)$$

where: SV_i is the sustainable value afferent to a farm from region i; r_{ij} and rb_{ij} represent respectively the polluting capital (input) used of type j and region/farm i, and of the farm considered as the reference (benchmark) system identified in the DEA analysis as an average of the inputs in farms located on the frontier (with 1 score); y_{ij} and yb_{ij} are the return of the resources (output) of the analysed and benchmark farm identified in the DEA analysis as an average of the outputs in farms located on the frontier (with 1 score);

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$i = 1, \ldots, n$ is the region, and $j = 1, \ldots, m$ is the type of analysed capital (resource).

The *SV*, if it has a minus sign, indicates a value of "clean production" (obtained without the additional input of polluting capital) which ought to be provided by a farm to achieve the benchmark eco-efficiency level, or if it has a plus sign, indicates a clean production exceeding the average eco-efficiency of farms on the frontier. To take into account the size effects and to make comparisons between the farms of various countries, we can calculate the indicator return to cost ratio (*RTCi*). An *RTC* score exceeding 1 can be perceived as a share of the "clean" output with reference to the benchmark unit, while the score below 1 shows an output required to catch up with the benchmark (e.g. 1.11 means that 11% of output is clean in the sense that it would not need polluting inputs comparing to the eco-efficiency or eco-effectiveness of the average farm on the frontier, and 0.95 score means that a unit should replace 5% of output by the "clean" output to catch up with the benchmark). This shows the relative contribution of farms from various countries to the sustainable performance compared to the benchmark that may be used for the ordering:

$$RTC_i = \frac{y_i}{y_i - SV_i} \quad (3)$$

where: y_i stands for the created output.

In the eco-efficiency approach, we use the set of variables described in the previous point: the polluting capitals as the input indicator (crop protection, fertilisers, energy, non-wood area, stocking density) and as the output indicator – total output, including shares of total output crops and total output livestocks.

Sustainable value of the eco-effective farm

In the second ecological approach, we have employed environmental public goods as the effect indicator (y), assuming the so-called "institutional" valuation of public goods by the CAP subsidies (Czyżewski et al. 2017). Hence, we used the same formulas 2–3, and the input indicator is the polluting capitals (as above) but as the effect indicator – is environmental subsidies. This is an alternative approach which has not been examined in the literature.

RESULTS AND DISCUSSION

Based on the analyses carried out, three rankings of EU regions were made, classifying them accord-

Table 1. Descriptive statistics for "Top and Bottom 10" environmentally sustainable EUFADN regions according to their synthetic environmental burden, eco-efficiency, and eco-effectiveness score in 2015

Composite index		Production (EUR/ha)	Wood area /UAA	Fertilisers (EUR/ha)	Pesticides (EUR/ha)	Energy (EUR/ha)	Stocking density (LU/ha)	Environmental subsidies (EUR/ha)	UAA (ha)
Environmental burden	"Top 10" mean	1 945	0.25	45.81	41.42	113.23	1.11	84.61	66.12
	"Bottom 10" mean	9 166	0.00	446.51	363.32	568.53	5.21	32.52	17.63
Eco-efficiency	"Top 10" mean	5 339	0.06	139.67	178.87	279.26	1.47	36.58	41.31
	"Bottom 10" mean	4 493	0.00	304.37	236.90	233.91	8.67	13.50	9.42
Eco-effectiveness	"Top 10" mean	1 632	0.07	83.82	27.68	164.95	1.14	148.17	64.23
	"Bottom 10" mean	5 340	0.00	280.31	221.83	335.10	4.35	0.32	41.97

UAA – utilised agricultural area; LU – livestock unit

Source: own calculation based on EUFADN (EUFADN 2018)

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Table 2. "Top and Bottom 10" environmentally sustainable EUFADN regions according to the composite environmental burden index, eco-efficient, and eco-effective approach (benchmark units calculated using DEA, 130 units, 2015, *RTC*, *SV* in EUR)

	Environmental burden		Eco-efficiency			Eco-effectiveness		
	region	*H*	region	*RTC*	*SV*	region	*RTC*	*SV*
"Top 10"	**Aosta** (ITA)*	0.44	Provence-Alpes-Cote d'Azur (FRA)	1.70	79 304	**Aosta** (ITA)	2.60	4 195
	Slovenia (SNV)	0.23	The Netherlands (NED)	1.65	171 902	Pohjois-Suomi (FIN)	2.04	6 333
	Cantabria (ESP)	0.21	**Alto-Adige** (ITA)	1.64	25 992	Luxembourg (LUX)	1.87	7 309
	Alentejo e do Algarve (POR)	0.20	Trentino (ITA)	1.45	17 003	Etela-Suomi (ELL)	1.62	3 925
	Austria (OST)	0.19	Languedoc-Rouss. (FRA)	1.45	41 789	Sisa-Suomi (FIN)	1.56	2 906
	Asturias (ESP)	0.18	La Rioja (ESP)	1.44	26 582	**Austria** (OST)	1.49	1 605
	Sardegna (ITA)	0.18	Toscana (ITA)	1.41	23 367	Pohjanmaa (FIN)	1.42	3 214
	Lan i Norra (SVE)	0.17	Denmark (DEN)	1.39	91 050	**Alentejo e do Algarve** (POR)	1.09	248
	Alto-Adige (ITA)	0.16	Vlaanderen (BEL)	1.38	75 845	Skogs-och mellanbygdslan (SVE)	1.03	198
	Scotland (UKI)	0.16	Bretagne (FRA)	1.38	75 474	**Cantabria** (ESP)	1.02	117
"Bottom 10"	Trentino (ITA)	0.05	**Bucuresti-Ilfov** (ROU)	0.62	–20 755	Malopolska and Pogorze (POL)	0.0063	–2 682
	Makedonia-Thraki (ELL)	0.05	**Nord-Est** (ROU)	0.62	–5 779	Centru (ROU)	0.0059	–2 363
	Liguria (ITA)	0.05	**Thessalia** (ELL)	0.62	–14 556	**Nord-Est** (ROU)	0.0058	–2 243
	Cyprus (CYP)	0.05	**Makedonia-Thraki** (ELL)	0.60	–15 672	**Nord-Vest** (ROU)	0.0055	–2 707
	Thessalia (ELL)	0.05	Sud-Est (ROU)	0.56	–11 374	**Sud-Vest-Oltenia** (ROU)	0.00	–4 263
	Lombardia (ITA)	0.04	**Nord-Vest** (ROU)	0.53	–8 475	**Sud-Muntenia** (ROU)	0.00	–4 321
	Vlaanderen (BEL)	0.04	**Sud-Muntenia** (ROU)	0.47	–14 379	**Malta** (MLT)	0.00	–10 738
	Veneto (ITA)	0.04	**Vest** (ROU)	0.45	–13 969	Scotland (UKI)	0.00	–14 949
	The Netherlands (NED)	0.04	**Sud-Vest-Oltenia** (ROU)	0.35	–14 280	**Vest** (ROU)	0.00	–3 825
	Malta (MLT)	0.03	Comunidad Valenciana (ESP)	0.19	–237 405	**Bucuresti-Ilfov** (ROU)	0.00	–5 588

H – value of the Hellwig index; *RTC* – value of return to cost ratio; *SV* – value of sustainable value; DEA – data envelopment analysis

ITA – Italy; SNV – Slovenia; ESP – Spain; POR – Portugal; OST – Austria; SVE – Sweden; UKI – United Kingdom; ELL – Greece; CYP – Cyprus; BEL – Belgium; NED – the Netherlands; MLT – Malta; FRA – France; DEN – Denmark; ROU – Romania; FIN – Finland; LUX – Luxembourg; POL – Poland

*bolded regions are duplicated at least in two rankings of the "Top 10" or "Bottom 10" – illustrative example: *RTC* 1.19 means that 19% of output is "clean" in the sense that it would not need polluting inputs comparing to the eco-efficiency or eco-effectiveness of the average farm on the frontier, and the 0.35 score means that a unit should replace 75% of its output with the "clean" output to catch up with the benchmark

Source: own calculation based on EUFADN (EUFADN 2018)

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ing to the composite measure of the environmental burden, eco-efficiency and eco-effectiveness of the agricultural activity conducted on the average farm in the EUFADN region.

Firstly, however, it is worth looking at the averages of the inputs used in the "Top-Bottom" regions in Table 1. They are presented in a consistent form of per ha relations bearing in mind that all the inputs were respectively transformed into destimulants while creating composite indices.

We can see that the intensity of production significantly differs under the three indices in terms of the "Top 10" inputs use as well as production per ha, i.e. those farms/regions which are the most eco-effective and create the lowest environmental burden are very extensive, whereas those which are eco-efficient are distinguished by a few times more intensive production (Table 1). At the same time, the utilised agricultural area of farms in the "Top 10" is much larger than in the "Bottom 10". This is quite a surprising finding that contradicts the common opinion on the environmental sustainability of small farms. On the other hand, it confirms to some extent the results of Gadanakis et al. (2015) which prove that medium farms are more eco-efficient than small ones. Another striking difference consists of the environmental subsidies that might be perceived as payments for the public goods provision. In this sense, the most eco-efficient farms provide 2 and 4 times lower value of public goods than those units that are leading respectively in their environmental burden and eco-effectiveness score. This result is in line with Picazo-Tadeo's et al. (2011) and Bonfiglio's et al. (2017) estimates which show surprisingly strong negative effects of agri-environmental schemes on the eco-efficiency of arable farms. So, we may recall the question, whether the eco-efficient agriculture is truly the one that the EU policy (CAP) is keen on prospering?

In Table 2 we can see that the Italian, Spanish, Portuguese and Austrian regions reoccur in two "Top 10"

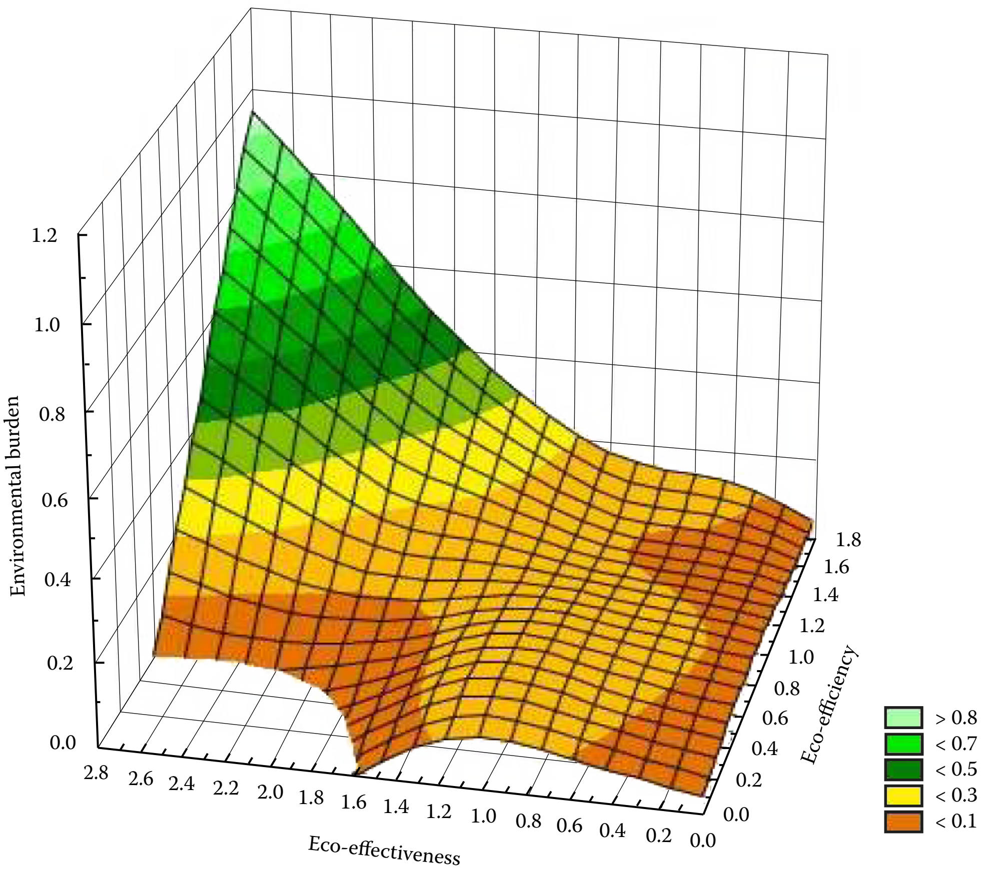

Figure 1. Environmental burden versus eco-efficiency and eco-effectiveness

distance-weighted least squares fitting

Source: own calculation based on EUFADN (EUFADN 2018)

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rankings. However, it is worth noting that the similarities in the rankings concern only the environmental burden and eco-effectiveness approach. This suggests that the "eco-efficiency" criterion tells us a completely different story. A majority of regions from the top eco-efficiency list (except one, Italian) does not appear among those which exert the lowest pressure on the environment or provide a sufficient value of public goods to compensate for the polluting capital used. On the other hand, the high pressure on the environment means sometimes being very eco-efficient. For instance the Netherlands (NED) or Trentino (ITA), which are in the "Top-Bottom" of the highest environmental burden and simultaneously in the "Top 10" for the eco-efficiency. On the other hand, the rankings of the "Bottom 10" for the eco-efficiency and eco-effectiveness are much more similar than the "Top 10" while dominated by the Romanian regions, which seems to be neither efficient in terms of production nor effective in the provision of the environmental goods requested by the CAP.

But should the eco-effectiveness and eco-efficiency be mutually exclusive, or are there ways to satisfy both criteria? Figure 1 sheds more light on this question. It shows a 3D surface plot which reveals the relationships of the environmental burden (*H*) with the eco-effectiveness (*RTC*) referring to the different levels of the eco-efficiency (*RTC*). We can make a striking observation that a strong and positive relationship between the environmental burden and eco-effectiveness appears only on the high level of the eco-efficiency score. Below 1.2 of the eco-efficiency score, the growing eco-effectiveness does not translate into a lower environmental pressure, and below 1.0 of the eco-efficiency score, this relationship (of environmental burden and eco-effectiveness) becomes negative. Hence, it seems to be likely that lowering the agricultural pressure on the environment requires a specific sequence of farms development: firstly achieving a critical eco-efficiency level, then becoming more eco-effective and finally decreasing the environmental pressure. This would mean that any shortcut way is very unlikely, and policymakers should not expect that small farms quickly become environmentally sustainable.

CONCLUSION

The aim of the article was to compare three different approaches to measuring the sustainability of agriculture in terms of the methodology as well as the results of an empirical study carried out on a sample of EU regions. The study indicates a fundamental problem: the environmental sustainability of European regions differs depending on the criterion we apply. If we compare the composite index of the environment pressure with I-O approaches, we have to concede that the latter has significant operational advantages and is easier to stimulate by agricultural policy means. However, we should admit that there are trade-offs in CAP which consist of compensating the strain on the natural environment with… and here you are the principal question: with production or public goods? Our major findings are the following. Public goods oriented farming is more likely to expand after improving eco-efficiency because only in eco-efficient farms the eco-effectiveness goes in line with lowering the environmental pressure. The trade-offs mentioned above appear when the level of the eco-efficiency and the eco-effectiveness is too low. In eco-inefficient farms stimulating eco-effectiveness by environmental subsidies does not result in reducing the environmental burden. Let us remark that the latter is a superior goal of the sustainable development. Hence, agricultural policy should reconsider that small farms are hardly capable of achieving environmental sustainability. We can say there is a sequence of the agricultural development of European farms: productivity => eco-efficiency => eco-effectiveness => lowering absolute pressure on the environment.

As our results show, this challenge (the last step) is still before us, because in the European regions eco-efficient does not mean environmentally sustainable. Policy-makers should think about stimulating eco-efficient farms to be more eco-effective and to enhance small farms to be more eco-efficient. So, there is not a single concept of environmental sustainability. There is, rather, the sequence of sustainable development which we should be striving for within CAP's principles.

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