ECO-EFFICIENCY IN AGRICULTURE OF EUROPEAN UNION MEMBER STATES

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Abstract. The objective of the paper is to estimate efficiency and eco-efficiency of agriculture in 24 EU Member States from 2006 to 2015. In the study, a panel of yearly aggregated data [Eurostat 2018] of the total value of agricultural goods output (AGO), labour (AWU), utilised agricultural area (UAA), fertilisers N, P, K (NPK) and greenhouse gas (GHG) emissions of agriculture of selected EU Member States were used. The directional distance functions (DDF) approach both with and without undesirable output (GHG emission) were employed. Malmquist-Luenberger indices were applied to measure productivity changes and their decomposition to identify sources of these changes. GHG emission reduction per agricultural output in all EU MS was observed. Significant growth of GHG per UAA occurred especially in the OMS: The Netherlands, Austria, Germany, France, while an increase of GHG per UAA was less pronounced in Bulgaria, Latvia, Hungary (NMS). The highest efficiency and eco-efficiency in agricultural production over 2006-2015 was reached by the Netherlands and Denmark. The most inefficient and eco-inefficient agriculture was noted in the agriculture of Ireland and Finland (OMS). The highest inefficiency among NMS was detected in the agriculture of Lithuania, Poland and Latvia, while the most eco-inefficient were Latvia, Lithuania and Estonia. Improvement of productivity and eco-productivity due to technological improvement occurred in all 24 EU MS. Agricultural technical eco-efficiency fell in Bulgaria, Romania, Greece, Portugal and Hungary.

Introduction

Eco-efficiency is achieved by the delivery of competitively-priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle to a level at least in line with the Earth’s estimated carrying capacity [WBCSD 2000]. Since agriculture is a large contributor to GHG emissions in the EU, there is considerable pressure on this sector to identify the most efficient climate change mitigation policies and measures. The emissions level from EU agriculture in 2015 was one fifth less than its corresponding level in 1990. The overall reduction in GHG emissions from agriculture can be large explained by the reduced use of nitrogenous fertilisers and a reduction in livestock numbers i.e. cattle and sheep. Although the total decrease in agricultural emissions across the EU-28 was 20% between 1990 and 2015, individual Member States showed widely varying trends. The mitigation target is an EU-wide reduction in agricultural GHG emissions of 28% in 2030 compared to 2005.

Eco-efficiency can be assessed at a micro level, meso level and national (macro) level. Eco-efficiency indicators generally value economic and environmental performance jointly. Multiple indicators and methodological approaches have been proposed. They use an eco-efficient frontier and measure relative eco-efficiency as the distance between a production unit and this frontier using parametric or non-parametric approaches. Data Envelopment Analysis (DEA) techniques [Charnes at al. 1978], to estimate frontiers and distance functions, are often used to measure...
efficiency, including the negative output of the production process as an undesirable output, or additional input. Among the most advanced DEA based methods frequently used in the analysis of eco-efficiency are those applying DDF [Färe, Grosskopf 2010]. DDF [Chung et al. 1997] were used as a component in Luenberger productivity indicators to model the joint production of good and bad outputs. Agricultural energy and environmental efficiency of primary sectors in the period 2001-2008 of EU MS using non-radial DEA were examined by George Vlontzos et al. [2014]. It was found that countries with strong environmental protection standards appear to be less energy and environmentally efficient. Low efficiency scores found for Eastern European MS are ascribed to a low level of technology in the primary production process. Tianxiang Li et al. [2016] analysed the main drivers behind energy-related CO₂ emission across agricultural sectors of European countries. Several studies investigated GHG emission and eco-efficiency on a farm level. The DDF approach in eco-efficiency assessment in agriculture were employed by e.g. Andres J. Picazo-Tadeo, José A. Marcedes Beltrán-Esteve and Ernest Gómez-Limón [2011, 2012]. Hervé Dakpo et al. [2017] evaluated efficiency adjusted for GHG emissions for sheep meat breeding farms in France. Silvia Coderoni and Roberto Esposti [2018] investigated the possible role played by the CAP Fischler Reform on agricultural GHG emissions at a farm level in Italy.

The objective of this paper is to estimate and assess development of efficiency and eco-efficiency of agriculture in 24 EU Member States from 2006 to 2015. As a result of technological progress after EU accession, positive development in both efficiency and eco-efficiency of New Member States agriculture is expected.

Research material and methodology

In the paper, the eco-efficiency of agriculture of 24 EU Member States is analysed, assuming that a set of good and bad (undesirable) outputs \((y, b)\) is jointly produced from inputs \(x\). It is assumed that production technology for countries producing S outputs, and U polluting by-products from M inputs is represented by Eq. 1.

\[
P(x) = \{(y, b) | x \text{ can produce } (y, b)\} \tag{1}
\]

where: \(y \in R_+^S, b \in R_+^U, x \in R_+^M\), \(P(x)\) is the output set.

Following Yong Hyun Chung et al. [1997] the following is assumed: null-jointness (desirable outputs cannot be produced if undesirable outputs are not produced), inputs and good outputs are strongly (free) disposable, and bad outputs are weakly disposable (the undesirable outputs are costly to dispose). The production technology is elaborated on by employing DDF as defined in (Eq. 2).

\[
\bar{D}(x, y, b; g_y, g_b) = \max \{\beta | (y + \beta g_y, b - \beta g_b) \in P^s(x)\} \tag{2}
\]

where: \(g = (g_y, g_b)\) is a direction vector, \(g \in R_+^S \times R_+^U\).

The direction vector \(g\) determines the direction of the desirable output increase and the undesirable output decrease. DDF allows to find the maximum increase of the desirable output while simultaneously reducing bad output. Efficiency and eco-efficiency is expressed by the Malmquist-Luenberger productivity index (ML) (Eq. 3). ML is defined between time periods \(t\) and \(t + 1\) on \(P^s(x), s = t, t + 1\)

\[
ML^s = \frac{1 + \bar{D}_0^s(x^t, y^t, b^t; y^t, b^t)}{1 + \bar{D}_0^s(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, b^{t+1})} \tag{3}
\]

where: \(\bar{D}(x, y, b; g_y, g_b) = \max \{\beta | (y + \beta g_y, b - \beta g_b) \in P^s(x)\}, s = t, t + 1\) are the DDF.
Without any restrictions on the two production technologies, the contemporaneous ML productivity index is expressed as a geometric mean of two-period ML productivity indexes (Eq. 4).

\[
ML_{t+1}^{t+1} = \left[ \frac{1 + \overline{D}_o(x^t, y^t, b^t; y^t, b^t)}{1 + \overline{D}_o(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, b^{t+1})} \right]^{1/2}
\]

(4)

The ML productivity index was further decomposed to efficiency and technological changes:

\[
ML_{t+1} = MLEC_{t+1}^{t+1} \ast MLTC_{t+1}^{t+1}
\]

where: MLEC\(_{t+1}^{t+1}\) change in efficiency, MLTC\(_{t+1}^{t+1}\) technological change, ML\(_{t+1}^{t+1}\) > 1 improvement of performance, MLTC\(_{t+1}^{t+1}\) = 1 no shift in the production possibilities frontier. MLEC\(_{t+1}^{t+1}\) > 1 efficiency improvement in period t+1, movement towards the best practice frontier MLTC\(_{t+1}^{t+1}\) > 1.

Shifts of the production possibilities frontier in the direction of ‘more goods and fewer bads’ [Färe et al. 2001, Kumar 2006]. The non-parametric methodology of DEA was applied to estimate DDF values. To deal with infeasibility in DEA for the cross-period distance function calculation, the procedure of Juan Du et al. [2017] was employed assuming that good outputs would not be affected by producing less bad output when optimal.

To distinguish clusters of countries with a similar development of eco-efficiency indicators, the Ward method of cluster analysis was applied. Factor analysis was used to deal with multicollinearity of eco-efficiency indicators. An optimal number of clusters was selected based on \(R^2\) and semi-partial \(R^2\) as well as dendrogram.

In the study, a panel of yearly aggregated data [Eurostat 2018] of good output was used: total agricultural goods output in million EUR (AGO); undesirable output: greenhouse gas (GHG) emissions in thousand tonnes; inputs: labour (annual working units AWU), utilised agricultural area in thousand ha (UAA), fertilisers N, P, K in tonnes (NPK). Data for the period 2006-2015 was considered for the following EU countries: Belgium (B), Bulgaria (BG), the Czech Republic (CZ), Denmark (DK), Germany (DE), Estonia (EE), Ireland (IR), Greece (EL), Spain (E), France (F), Italy (I), Latvia (LV), Lithuania (LT), Hungary (HU), the Netherlands (NL), Austria (AT), Poland (PL), Portugal (PT), Romania (RO), Slovenia (SL), Slovakia (SK), Finland (FI), Sweden (SE) and the United Kingdom (UK).

**Research results**

The increasing trend of the EU 24 agricultural goods output (AGO) was affected by the global crisis of 2009 and 2010. Since 2013, the value of the AGO has been declining, while both greenhouse gas (GHG) emissions and consumption of NPK has been growing (fig. 1). Furthermore, the development within the group of old (OMS) and new EU Member States (NMS) was considered separately. Policy instruments and mitigation strategies had a positive impact on GHG emission reduction per agricultural output in all EU MS over the period 2006-2015 (fig. 2). A pronounced reduction was observed in the agriculture of Ireland, the UK and Sweden (OMS) as well as the agriculture of Lithuania, Latvia and Estonia (NMS). The growth of GHG emission per ha of UAA in many EU countries could be explained by an increasing intensity of land use. A significant growth of GHG per UAA occurred more profoundly in the following old Member States: NL, AT, DE, FR, while an increase of GHG per UAA was less pronounced in BG, LV, HU (NMS). A reduction of GHG emission per UAA occurred in Greece, Ireland, Italy and Sweden (OMS) and in the case of NMS, in Lithuania and Romania. The most efficient and eco-efficient among the old EU MS in the period 2006-2015, on average, were the Netherlands and Denmark (fig. 3). These countries were characterised by intensive
crop and animal production and produced high added value food products. In the agriculture of the 24 EU MS, a higher heterogeneity was detected in inefficiency not accounting for GHG emissions. Performance indicators of old MS’ agriculture were more homogenous with a relatively higher level of efficiency compared to performances of the NMS’ agriculture. The most inefficient and eco-inefficient among old EU MS were observed in the agriculture of Ireland and Finland. Among the NMS, the highest inefficiency was visible in the agriculture of Lithuania, Poland and Latvia, while the most eco-inefficient were Latvia, Lithuania and Estonia. All 24 EU MS improved both their productivity and eco-productivity over the observed period (fig. 4). Highest productivity growth occurred in Italy, Sweden and the UK (OMS) and in NMS in Estonia, Slovakia and the Czech Republic. The countries with the highest cumulative change of eco-TFP were Denmark, Belgium and the Netherlands. These countries reached a reasonably high level of TFP even when ecological behaviour (model without GHG) was disregarded. On the other hand, Romania and Bulgaria’s TFP fell, whereas eco-productivity was maintained. Components of TFP and eco-TFP improvements were also carried out. The catch-up effect (technical efficiency improvement) (fig. 5) was the main contributor to the improvement of TFP in IT, SE, and the UK (OMS) and in EE, CZ, SI (NMS) since their agriculture aims at reaching the most productive of EU MS. A gap between the technical efficiency of Romania, Bulgaria, Latvia and Hungary (NMS) as well as Portugal, Austria, and Spain (OMS) and the
most productive MS (The Netherlands, Denmark) increased over the observed years. Agricultural technical efficiency has improved significantly in the UK, Sweden and Belgium (OMS), in Lithuania, Estonia and Poland (NMS) towards the most technically eco-efficient MS (Italy and The Netherlands) (fig. 5). Technical eco-efficiency fell in Bulgaria, Romania, Greece, Portugal and Hungary. Both, technological and eco-technological improvements occurred in the agriculture of all 24 EU MS (fig. 6). Technological progress contributed to TFP growth in the NMS agriculture mainly in Estonia and Slovakia and among the OMS in Spain, Italy, Greece and Portugal (fig. 6). The introduction of new eco-technology measures contributed to eco-TFP growth in OMS, especially in Denmark, The Netherlands, Belgium and, among the NMS, in Romania, Hungary and Slovenia.

Based on efficiency, productivity measures and their components, taking GHG emission into account, 5 clusters of 24 EU countries were distinguished using cluster analyses. Denmark and The Netherlands (Cluster 5) demonstrated the highest average eco-efficiency and the highest TFP improvement. Countries of the fourth cluster (AT, HU, IT, ES) had reasonably high eco-efficiency. Cluster 1, consisting of 10 countries (CZ, EE, FI, FR, DE, IE, LV, PL, SK, SL), showed the highest eco-inefficiency and the lowest technological improvement. Insignificant improvement of TFP and a fall of eco-efficiency was found in the second cluster: Bulgaria, Greece, Portugal and Romania. The third cluster of BE, LT, SE and the UK reached the highest catch-up effect in the improvement of TFP.

**Summary and conclusions**

It was found that policy and mitigation strategies had a positive impact on GHG emission reduction per agricultural output in all EU MS. A growth of GHG emission per ha of UAA in many EU countries could be explained by increasing intensity of land use. A significant growth of GHG per UAA was most profound in OMS: NL, AT, DE, FR, while an increase in GHG per UAA was less pronounced in BG, LV, HU (NMS). A reduction of GHG emission per UAA occurred in EL, IR, IT, SE (OMS) and in LT, RO (NMS). The highest efficiency and eco-efficiency in agricultural production over 2006-2015 had been reached by the Netherlands and Denmark. Performance indicators of the OMS’ agriculture were more homogenous with a relatively higher level of efficiency compared to the performances of agriculture of NMS. The most inefficient and eco-inefficient agricultures were Ireland and Finland (among the OMS). The highest inefficiency among NMS was observed in the agriculture of LT, PL, LV. The most eco-inefficient were LV, LT and EE. An improvement of both productivity and eco-productivity
occurred in all 24 EU MS. The highest productivity growth was found in IT, SE, UK (OMS) and in EE, SK, CZ (NMS). The highest improvement of eco-TFP was showed by DK, BE and NL, i.e. in the countries also exhibiting the highest TFP improvement, not accounting for GHG emission. The agriculture of Romania and Bulgaria experienced a deterioration in productivity, while being to maintain eco-productivity. The catch-up effect contributed to the improvement of productivity and eco-productivity in some EU MS. A gap between the technical efficiency of RO, BG, LV, HU, PT, AT and S and the most productive, NL and DK, increased. Policy incentives and the introduction of new eco-technologies could be the main sources of eco-TFP growth in OMS especially in DK, NL, BE and, among the NMS, in RO, HU and SL.

The assessment of traditional and environmental efficiency measures in EU MS agriculture at a macroeconomic level reveal their development path and can support policy makers’ decisions on the amendment or introduction of relevant policies.

Bibliography


Streszczenie


Correspondence address
Prof. Ľubica Bartová, PhD
orcid.org/0000-0002-6620-8379
Slovak University of Agriculture in Nitra
Faculty of Economics and Management, Department of Statistics and Operations Research
Tr. A. Hlinku 2, 949 11 Nitra, Slovak Republic
e-mail: lubica.bartova@uniag.sk

Assoc. Prof. Peter Fandel, PhD
Slovak University of Agriculture in Nitra
Faculty of Economics and Management, Department of Statistics and Operations Research
Tr. A. Hlinku 2, 949 11 Nitra, Slovak Republic
e-mail: peter.fandel@uniag.sk

Eva Matejková, PhD
Slovak University of Agriculture in Nitra
Faculty of Economics and Management, Department of Statistics and Operations Research
Tr. A. Hlinku 2, 949 11 Nitra, Slovak Republic
e-mail: eva.matejkova@uniag.sk