



ORIGINAL ARTICLE


Citation: Richterová, E., Richter, M., & Sojková, Z. (2021). Regional eco-efficiency of the agricultural sector in V4 regions, its dynamics in time and decomposition on the technological and pure technical eco-efficiency change. *Equilibrium. Quarterly Journal of Economics and Economic Policy*, 16(3), 553–576. doi: 10.24136/eq.2021.020

Contact to corresponding author: Martin Richter, martin.richter@uniag.sk

Article history: Received: 13.03.2021; Accepted: 7.03.2020; Published online: 26.03.2020


Eva Richterová

Slovak University of Agriculture in Nitra, Slovakia

 orcid.org/0000-0001-7265-7413


Martin Richter

Slovak University of Agriculture in Nitra, Slovakia

 orcid.org/0000-0001-6577-9287

Zlata Sojková

Slovak University of Agriculture in Nitra, Slovakia

 orcid.org/0000-0001-5318-8658

Regional eco-efficiency of the agricultural sector in V4 regions, its dynamics in time and decomposition on the technological and pure technical eco-efficiency change

JEL Classification: C14; D24; O13; Q01; R11

Keywords: *agricultural eco-efficiency; Visegrad regions; Malmquist index; technological change; pure technical eco-efficiency*

Abstract

Research background: Agriculture plays a vital role in producing food to ensure food security, but it is one of the biggest contributors to environmental pollution. One of the main goals of the new CAP is to set higher ambitions for environmental actions, which brings into the front the concept of agricultural eco-efficiency. The notion of eco-efficiency includes the economic and also ecological dimensions of sustainable agriculture.

Purpose of the article: The main goal of this paper is to evaluate the eco-efficiency of agricultural production and its dynamics during the years 2013, 2015, and 2017 of NUTS 2 regions within the Visegrad 4 (V4), i. e. The Czech Republic, Slovakia, Hungary, and Poland. The part of the main goal is to verify the research hypothesis that all the biggest agriculture producers are eco-efficient.

Copyright © Instytut Badań Gospodarczych

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Methods: V4 regional eco-efficiency of the agricultural sector is expressed by the Malmquist productivity index and is estimated using the output-oriented Data envelopment analysis (DEA) model, under the assumption of constant return to scale (CRS). The Malmquist index is decomposed to technical eco-efficiency change (EC) and technological change (TC). Based on the eco-efficiency, technological and pure technical eco-efficiency change, V4 regions are classified into three groups: the most progressive regions, the progressive regions, and the regressive regions.

Findings & value added: CZ02: Central Bohemia, CZ04: Northwest, HU33: Dél-Alföld, HU31: Észak-Magyarország, HU32: Észak-Alföld, PL21: Malopolskie, PL41: Wielkopolskie, SK01: Bratislava region, and SK02: Western Slovakia have an eco-effective agricultural sector, the remaining V4 regions have eco-ineffective agricultural sector. The research hypothesis that all the biggest agricultural producers are eco-effective is not confirmed. During the analyzed years, 19 V4 regions improve their agricultural eco-efficiency. The main contributor to eco-efficiency improvement is technological progress, which indicates that producers implement innovations that lead to more eco-efficiency agricultural production.

Introduction

Agriculture plays a vital role in producing food to ensure food security. Worldwide continuous population growth creates pressure on an adequate increase of production and producers are trying to produce as much as possible with given inputs. However, at the same time, the agricultural sector is one of the biggest contributors to environmental pollution. It represents the main source of ammonia pollution and nitrate pollution of ground and surface water. It is also a contributor to the phosphate pollution of rivers and is one of the principal sources of greenhouse gases (GHGs) methane, and nitrous oxide in the atmosphere (FAO, 2001). Sustainable and environmental issues have become frequently discussed topics in scientific and public dispute and become a part of government goals. Policymakers start to pay higher attention to environmental protection. Also, a new Common agricultural policy (CAP) set higher ambitions for environmental and climate action pushing producers to avoid or reduce the environmental consequences of their production (European Commission, 2017).

Environmental and climate actions bring into the front the concept of agricultural eco-efficiency. The agricultural sectors differ not only among nations, but there are huge disparities among regions inside every country. European regions in particular are characterized by a different environment, which inevitably shapes their agricultural structure (Bianchi *et al.*, 2020). Therefore, it is necessary to evaluate agricultural eco-efficiency on the meso (regional) level, while at the same time there is still a lack of studies on this level. According to Lauransa *et al.* (2013), there are not many studies, which are focused on a connection between ecosystem and socio-economic indicators at the regional scale and therefore it is not possible to make a proper sustainability analysis at this level. Mickwitz *et al.* (2006) also

point out that only a few studies analyze eco-efficiency from the regional perspective and most of them are focused only on the regional agricultural eco-efficiency inside one chosen country (Coluccia *et al.*, 2020; Rybaczewska-Błazejowska & Masternak-Janus, 2018; Ren *et al.*, 2020). Therefore our paper is focused on the evaluation of agricultural production eco-efficiency and its dynamics during the years 2013, 2015, and 2017 of NUTS 2 regions within the Visegrad 4 (V4), i. e. The Czech Republic, Slovakia, Hungary, and Poland.

According to Svatoš *et al.* (2013), it is meaningful to compare the agriculture sectors of Visegrad countries, because V4 members have significantly changed their economic structure during the time, while their agriculture sector was one of the most affected parts of their economy. V4 agricultural production was affected twice, at first in 90s because of their transformation from a centrally planned economy to a market one, at second by becoming a part of the European Union.

Agricultural eco-efficiency is evaluated by applying the Malmquist productivity index, computed by output-oriented data envelopment analysis models with a constant return to scale. Measuring V4 regions eco-efficiency level can be based on the following procedure scheme, shown in Table 1 (Staníčková & Melecký, 2012).

The paper is structured as follows. Firstly, the eco-efficiency concept and related studies are introduced; in the second part, the data and the methodologies employed to evaluate agricultural eco-efficiency are described, namely the CCR DEA model and Malmquist index; in the third part, the results of the study are presented; the fourth part includes a discussion with the results of other authors, in the last part, the conclusions together with limitations and suggested objectives for further research are presented.

Literature review

The basics of using the term eco-efficiency date back to the 1990s, when eco-efficiency began to be seen as a useful tool for measuring sustainability. This notion was first introduced by Schaltegger and Sturm (1990) as a “business link to a sustainable development”. In 1992 eco-efficiency was officially defined by the World Business Council for Sustainable Development as „a shipment of competitively priced goods and services, which satisfy human needs by bringing them an appropriate life quality, but at the same time also progressively reducing ecological impact and resource intensity during the whole life cycle to a level at least consistent with the

earth's estimated tolerable capacity" (DeSimone & Popoff, 2000). However, the widely adopted definition in the case of clarifying the concept and estimating the eco-efficiency was proposed by the Organisation for Economic Co-operation and Development, according to which eco-efficiency represents "an efficiency with which ecological resources are used to meet human needs" (OECD, 1998). According to Robaina-Alves *et al.* (2015), eco-efficiency, in general, shows the capability to produce more goods and services and at the same time consume less natural resources and create a less negative impact on the environment. Keating *et al.* (2010) based the eco-efficiency interpretation on the meaning of notion efficiency, which represents the level of output per unit of input, while in the case of eco-efficiency the output side is represented by the food and fiber production and the input side is represented by the ecological resources, e.g. land, water, energy, nutrients, biological diversity, etc. At the same time, they emphasize that with such understanding of eco-efficiency, labor and capital must also be taken into account, as well as the negative agricultural environmental impacts in the form of undesirable outputs. They cite the loss of nutrients, salts, acids, and sediments in the case of terrestrial, aquatic, and marine ecosystems or the contribution to greenhouse gas emissions in the atmosphere as examples of the negative agricultural impact on the ecosystem. Based on the above definitions, eco-efficiency could represent an effective tool for assessing agricultural sustainability and also for developing strategies for policymakers focusing on reducing resource use and negative environmental impacts (UNESCAP, 2009).

The concept of eco-efficiency could be applied to different sectors, or even to specific products (Caiado *et al.*, 2017). Eco-efficiency begins at the micro-level with recommendations to minimize material consumption and energy intensity of goods and services and to maximize the sustainable use of renewables (Pang *et al.*, 2016). The growing government's interest in applying the eco-efficiency principles, which bring long-term benefits in terms of international competitiveness, is behind the fact that this concept is shifting from the firm to the national and regional level (Hur *et al.*, 2004). Many methods have been developed and used to quantify the eco-efficiency performance of agriculture, with the ratio approach and the frontier approach in the foreground. All of them have their advantages and disadvantages (Liu *et al.*, 2020; Bianchi *et al.*, 2020).

The ratio approach relatively expresses the economic value of the produced goods and services to the environmental impacts associated with their production processes. The higher the ratio, the higher the level of eco-efficiency achieved (Huppes & Ishikawa, 2005). The main advantage of indicators calculated using a ratio approach, such as resource productivity,

is their simplicity, which makes them clearer for policymakers and the general public (Camarero *et al.*, 2013). The disadvantage of this approach is that it can only be used if both the numerator and the denominator are integrated into a certain value, and therefore ratio-based indicators make it impossible to combine socio-economic forces that could cause or affect the environmental impact (Zhang, 2008; Shao *et al.*, 2017). The ratio approach is used by Mickwitz *et al.* (2006) and Seppälä *et al.* (2005) to evaluate eco-efficiency in a Finish region Kymenlaakso.

The frontier approach can be divided into two different branches, the first one is the parametric approach, represented by Stochastic frontier analysis (SFA), and the second one is a nonparametric approach, represented by Data envelopment analysis (DEA).

Because of the need to take into account also undesirable output mirrored the environmental consequences of the production and consider both economic and environmental aspects at the same time, the nonparametric approach, which allows computing with more than one output variable, is preferred. DEA represents a practical methodology for aggregating positive and negative environmental impacts to create one comprehensive eco-efficiency indicator because it measures efficiency using linear programming methods, which do not require explicit weights (Dyckhoff & Allen, 2001).

There are several studies, applying different types of DEA methods in a combination with other techniques such as bootstrapping, Tobit regression, fractional regression model, life cycle assessment, and so on, analyzing agricultural eco-efficiency. Rybaczewska-Błazejowska and Gierulski (2018) analyze the eco-efficiency performance of agricultural production of the 28 EU member states, combining two methodological approaches — life cycle assessment (LCA) and data envelopment analysis (DEA) techniques. Based on their results, they conclude that only 10 of the analyzed EU member states, namely Belgium, Bulgaria, Estonia, Finland, Greece, Italy, Malta, the Netherlands, Romania, and Sweden, have relatively eco-efficient agricultural sectors. The rest of the analyzed EU member states — 18 countries are eco-inefficient. Netherlands, Belgium, Italy, and Malta belong to eco-efficient leaders also according Pishgar-Komleh *et al.* (2021). In their study, they applied the newest improved Window Slack-Based Measurement Data Envelopment Analysis (W-SBMDEA) model to analyze the agricultural eco-efficiency of all EU countries during the years 2008–2017. Moutinho *et al.* (2018) analyze the agricultural economic-environmental efficiency of EU countries in the years 2005 and 2010 using DEA and SFA technology. Their findings indicate that only Greece, Malta, and Finland have a stable eco-efficient agricultural sector. According to the

paper's authors' previous research, where analyze the agricultural eco-efficiency of 24 world's biggest agricultural producers for the years 2007 and 2017 using an output-oriented DEA model with two undesirable outputs, not just Italy, but also France, Germany, and Spain belong to the group eco-efficiency leaders (Richterová *et al.*, 2020).

Many Chinese studies analyze agricultural eco-efficiency using different types of improved DEA models too. Pang *et al.* (2016) asses the agricultural eco-efficiency of 31 Chinese provinces using data envelopment analysis, specifically the SBM (slacks-based measure) model, and the Theil index approach. They summarize that highly eco-efficient provinces are concentrated primarily in densely populated areas and that agricultural eco-efficiency is affected mostly by pure technical efficiency. Liu *et al.* (2020) analyze the agricultural eco-efficiency of the same 31 China's provinces as Pang *et al.* (2016) using a modified slack-based model — the Super-SBM Model. Their findings indicate that during the analyzed years 1978–2017, agricultural eco-efficiency increases by 76% and goes through four different development phases, including free development, support for reform, market regulation, and policy incentives. Li *et al.* (2021) use the SBM DEA model too to evaluate the agricultural eco-efficiency of 77 Chinese countries and districts from the year 1999 to 2018. Unlike Liu *et al.* (2020), they argue that during the analyzed years agricultural eco-efficiency shows a declining fluctuating trend and, in contrast with Pang *et al.* (2016), they conclude that the agricultural eco-efficiency improvement depends mainly on the scale efficiency improvement, not on the pure technical efficiency improvement.

However, according to Kortelainen (2008), DEA models cannot analyze dynamic changes of eco-efficiency during the time. Therefore, based on the DEA model, he proposes to use a Malmquist productivity index to catch those dynamic changes and to decompose the total eco-efficiency change on the efficiency change and technological change. Serrão (2008) applies a dynamic eco-efficiency analysis framework established by Kortelainen (2008) and evaluates the agricultural eco-efficiency of 15 chosen EU countries for the years 1990–2004 using the Malmquist index. Serrão (2008) concludes that the overall eco-efficiency is growing mainly thanks to technological progress. To the same results, that agricultural eco-efficiency is affected mainly by technological progress, instead of pure technical eco-efficiency come Wang and Ye (2017) too. They analyze the agricultural ecological efficiency of Guizhou province during the years 2005 to 2015 using the dynamic DEA model — Malmquist productivity index. Their results show that the eco-efficiency of the analyzed Guizhou province agricultural sector is increased yearly by 7% on average. Malmquist index is

used to estimate and compare the eco-efficiency of agriculture in 26 old and the new EU Member States over the period from 2006 to 2015 also by Fandel and Bartová (2018). According to them, eco-efficiency is growing significantly mainly in the old EU Member States.

Research methodology

7 variables, represented economic, but also the environmental, aspect of agricultural production, stand on the input side. Namely, Total intermediate consumption in €/inhabitant, Maintenance of materials in €/inhabitant, Maintenance of buildings in €/inhabitant, Fixed capital consumption in €/inhabitant, Fertilisers and soil improvers in €/inhabitant, Plant protection products, herbicides, insecticides and pesticides in €/inhabitant, Employment per 1000 inhabitants. 2 variables stand on the output side, namely Agricultural output in €/inhabitant and Gross value added in €/inhabitant. Data are obtained from EUROSTAT for the years 2013, 2015, and 2017. Due to the similar geographical conditions all regions of V4 countries are chosen, except Czech region CZ01: Prague, Hungarian regions HU11: Budapest and HU12: Pest, Poland regions PL91: Warszawski stoleczny and PL92: Mazowiecki regionalny, because of missing data.

The following research hypothesis is established: “All the biggest agricultural producers are eco-efficient”.

V4 regional agricultural eco-efficiency is expressed by the Malmquist index, estimated by output-oriented Data envelopment analysis (DEA) model, under the assumption of constant return to scale (CRS) — CCR model (Charnes *et al.*, 1978). DEA cannot be used to estimate an absolute efficiency index, but it can be used to estimate relative efficiency measures, which help us to identify which observed units are efficient and which are not. The advantage of this nonparametric approach is that no explicit weights are required and therefore DEA is a useful methodology for aggregating separate environmental impacts to compile a complex eco-efficiency indicator (Dyckhoff & Allen, 2001).

Let us assume we have n independent homogeneous decision-making units, denoted by DMU_j ($j= 1, 2, \dots, n$). For given p non-discretionary inputs $Z_j = (z_{1j}, z_{2j}, \dots, z_{pj})^T$, each DMU consumes m discretionary inputs $X_j = (x_{1j}, x_{2j}, \dots, x_{mj})^T$ to produce s outputs $Y_j = (y_{1j}, y_{2j}, \dots, y_{sj})^T$ (Hua *et al.*, 2007). Standard linear output-oriented DEA model with a constant return to scale could be written as following linear programming problem:

$$\begin{aligned}
 & \text{Max } \theta_q \\
 & \sum_{j=1}^n y_{rj} \lambda_j \geq \theta Y_{rq} \quad r = 1, \dots, s \\
 & \sum_{j=1}^n x_{ij} \lambda_j \leq X_{iq} \quad i = 1, \dots, m \\
 & \lambda_j \geq 0 \quad j = 1, \dots, n
 \end{aligned} \tag{1}$$

where:

- θ_q the technical efficiency of the DMU_q ,
- λ_j the weight assigned to the DMU_j ($j=1, 2, \dots, n$).

Malmquist productivity index (MPI) measures the multi-factor productivity change between two time periods t and $t+1$. The output-oriented Shephard's distance functions form the basis for MPI calculation and express the maximal proportional radial increase of outputs' vector with a given level of inputs' vector (Shephard, 1970).

For each period t , the production technology, denoted by S^t , express the inputs-outputs transformation as follows:

$$S^t = \{(x^t, y^t): x^t \text{ can produce } y^t\} \quad t = 1, \dots, T \tag{2}$$

It is assumed that the production technology S^t satisfy sufficiently the properties and allow the definition of a meaningful output distance function at time t (Färe *et al.*, 1994):

$$D_0^t(x^t, y^t) = \inf \left\{ \theta: (x^t, \frac{y^t}{\theta}) \in S^t \right\}, \quad t = 1, \dots, T \tag{3}$$

where:

- \inf operator for an indefinite period,
- θ scalar,
- $x^t = (x_1^t, \dots, x_M^t)$ an inputs' vector at the time t
- $y^t = (y_1^t, \dots, y_S^t)$ an outputs' vector at the time t .
- S^t the production technology in a time t .

The output-oriented Shephard's distance functions quantification assumes that the distance function is reciprocal to the Farrell technical efficiency, which can be estimated by the nonparametric method of linear programming — by DEA. Caves *et al.* (1982) built the Malmquist productivity index calculation based on the ratio of two output distance functions, one at

the time t and second at the time $t+1$ for the technology at time t . Its calculation is modified by Färe *et al.* (1994), which estimate the Malmquist productivity index as a geometric mean of two Malmquist indices for the period t and $t+1$, using distance functions relative to the technology at the time t and also at the time $t+1$:

$$M_0^{t+1}(x^t, y^t, x^{t+1}, y^{t+1}) = \sqrt{\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)} \times \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^t, y^t)}} \quad (4)$$

The Malmquist output-based productivity index formula can be equivalently written as:

$$M_0^t(x^t, y^t, x^{t+1}, y^{t+1}) = \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)} \times \sqrt{\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1})} \times \frac{D_0^t(x^t, y^t)}{D_0^{t+1}(x^t, y^t)}} \quad (5)$$

$$M_0^t(x^t, y^t, x^{t+1}, y^{t+1}) = EC \times TC \quad (6)$$

Where the Malmquist index is decomposed to technical efficiency change (EC) and technological change (TC). The expression before the square root represents the technical efficiency change (EC) between two adjacent periods t and $t+1$, and the expression under the square root represents the technological change (TC) between those two adjacent periods. Values of the Malmquist index and its components greater than 1 indicate improvements, values less than 1 indicate declines, and values equal 1 indicate no change in performance.

Results

During the whole analyzed period, the Czech region with the highest agricultural production is CZ03: Southwest, mainly because of the highest Czech production in forestry and fishery. On the second and third positions are regions CZ02: Central Bohemia and CZ06: Southeast, with many rivers and lowlands. On the fourth position is the region CZ05: Northeast, of which most area is covered with lowlands. The areas of the remaining analyzed Czech regions are hilly, with not so optimal agricultural conditions (Figure 1).

From Hungarian regions, the region with the highest agricultural output in euro/inhabitant is a Hungarian biggest region HU33: Southern Great

Plains. Its territory is spread over the Great Hungarian Plain with great conditions for agricultural production. Neighboring region HU32: Northern Great Plains is in the third position during all analyzed years. The Hungarian region with the second biggest agricultural output is HU23: South Transdanubia, situated in the south part of the Transdanubia area with many fertile agricultural areas. The agricultural output of the remaining Hungarian regions is markedly lower (Figure 1).

From the analyzed Poland 's regions, the one with the highest agricultural production is PL84: Podlaskie. Podlasie has the lowest population density of the sixteen Polish voivodeships, and its arable land constitutes around 60% of its total area — most of which is ploughland (around 40%), forests, meadows, and pastures. Podlaskie is followed by PL41: Wielkopolskie, PL81: Lubelskie, PL61: Kujawsko-Pomorskie, and PL62: Warminko-Mazurskie. Most of those regions' territory is covered by lowlands. The rest of Poland's regions are mostly hilly, and therefore their agricultural conditions are not so favorable.

From the Slovak regions, the biggest agricultural producer is SK02: Western Slovakia, the region with the best climate and territory conditions. All other Slovak regions demonstrate significantly lower agricultural output, due to worse conditions. Most of their territory is covered by mountains.

In a cross-country comparison, the V4 region with the highest agricultural output in all analyzed years is the Hungarian region HU33: Southern Great Plains. In 2013 the Polish region PL84: Podlaskie, and in 2015 and 2017 the Hungarian region HU23: Northern Great Plains are in the second position in the value (level) of agricultural output. In the third position is the Hungarian region HU23: South Transdanubia in 2013, and Polish region PL84: Podlaskie in the rest of the analyzed years. In all analyzed years, the Polish region PL22: Slaskie is the V4 region with the lowest agricultural output, Czech region CZ08: Moravian Silesian is the region with second-lowest agricultural output, and Slovak region SK04: Eastern Slovakia is the region with the third-lowest agricultural output.

While the agriculture conditions of some regions could be positive, the reason for their lower agricultural output could be inefficient input-output transformation. V4 regional average eco-inefficiency for three analyzed years (2013, 2015, 2017) is shown in Figure 2, on which eco-efficient regions obtain zero value for inefficiency and eco-inefficient regions obtain value bigger than 0. Inside each V4 country, high disparities among regions are detected. On average, V4 eco-efficient regions are Czech regions — CZ02: Central Bohemia, and region CZ04: Northwest with the largest share of agricultural land managed by organic production methods; Hungarian

regions — HU31: Northern Hungary, HU32: Northern Great Plains, and HU33: Southern Great Plains, situated on the east and south-east part of the country and with great conditions for agricultural production; Polish region PL21: Malopolskie with a low agricultural output in a comparison with other Polish regions, but with the highest share of ecological agriculture, and region PL41: Wielkopolskie with the second-highest agriculture output in Poland; Slovak regions SK01: Bratislava region, and SK02: Western Slovakia with good agricultural conditions thanks to their location. Just 5 of the mentioned eco-efficient regions belong to the biggest agricultural producers. The biggest Czech and Polish agricultural producers are not eco-efficient. Therefore the research hypothesis, that all the biggest agricultural producers are eco-efficient is not confirmed. The eco-efficient regions could not improve their productivity by improving technical efficiency, but only by technological progress, represented by innovation implementation into the production process.

On average, all other V4 regions have an eco-inefficient agricultural sector. The highest eco-inefficiency is observed in the Polish region PL82: Podkarpackie and in the Slovak region SK04: Eastern Slovakia, both with low agricultural output in a comparison with the remaining regions. During the analyzed years, 19 V4 regions improve their agricultural eco-efficiency, and 13 V4 regions do not improve their agricultural eco-efficiency (M_0 in Figure 3). The highest eco-efficiency growth is observed in the eco-inefficient Slovak region SK04: Eastern Slovakia, in which eco-efficiency during analyzed years improves by 39.6% thanks to technological progress (TC) in the first place, but also thanks to the pure technical eco-efficiency improvement (EC). The second-highest eco-efficiency growth is visible in the Czech region CZ04: Northwest, in which eco-efficiency is increasing by 37.8%. The main contributor to its eco-efficiency improvement is its technological progress over the years. The highest eco-efficiency decline occurs in the eco-efficient Poland region PL41: Wielkopolskie, in which eco-efficiency declines by 12.7%, thanks to the technological regress. The second-highest eco-efficiency decline equals 12.1% and is observed in the eco-inefficient Poland region PL84: Podlaskie, mainly because of its technological regress (Figure 3). The highest pure technical eco-efficiency improvement (18.2%) is measured in the eco-inefficiency Slovak region SK03: Central Slovakia, the highest pure technical eco-efficiency deterioration (17.6%) is measured in the eco-inefficient Poland region PL42: Zachodniopomorskie. The highest technological progress (37.8%) is observed in the eco-efficient Czech region CZ04: Northwest, the highest technological regress (12.7%) is observed in the eco-efficient Polish region PL41: Wielkopolskie. According to the value of eco-efficiency, technologi-

cal and pure technical eco-efficiency change, V4 regions are classified into three groups (Figure 4).

The first group (cluster 1) “progressive regions” is given by 15 V4 regions, namely CZ03: Southwest, CZ06: Southeast, HU23: South Transdanubia, HU31: Northern Hungary, HU32: Northern Great Plains, HU33: Southern Great Plains, PL21: Malopolskie, PL22: Slaskie, PL43: Lubuskie, PL51: Dolnoslaskie, PL71: Łódzkie, PL72: Swietokrzyskie, PL81: Lubelskie, SK02: Western Slovakia, and SK03: Central Slovakia. This group is characterized by a growing tendency of eco-efficiency, technical eco-efficiency, and technological progress. The second group (cluster 2) “regressive regions” groups again 15 V4 regions, namely CZ05: Northeast, CZ02: Central Bohemia, CZ07: Central Moravia, CZ08: Moravian Silesian, HU21: Central Transdanubia, HU22: Western Transdanubia, PL41: Wielkopolskie, PL42: Zachodniopomorskie, PL52: Opolskie, PL61: Kujawsko-Pomorskie, PL62: Warminsko-Mazurskie, PL63: Pomorskie, PL82: Podkarpackie, PL84: Podlaskie, and SK01: Bratislava region. On average, these regions are characterized by regress of eco-efficiency, technical eco-efficiency, and also by technological regress. And the last group (cluster 3) “the most progressive regions” is given by only two regions, Slovak region SK04: Eastern Slovakia and Czech region CZ04: Northwest. On average this group is characterized by the highest values of eco-efficiency growth, technical eco-efficiency growth, and technological growth.

On the macro level, the Slovak Republic is a country with the highest total eco-efficiency growth (14.5%) thanks to the highest technical eco-efficiency improvement (8.5%). The Czech Republic is the country with the highest technological progress (9.6%), which reflects the implementation of innovation in agricultural production. During the analyzed years, the agricultural eco-efficiency of V4 countries increases by 3.7%, thanks to technological progress, which is the main contributor to its improvement.

Discussion

From the analyzed 32 Visegrad regions, 9 of them have an eco-efficient agricultural sector. With the specialization on the more concrete goals or areas on the regional level, the number of eco-efficiency units is falling because more environmental indicators have to be taken into consideration. In the case of eco-efficient evaluation in the context of EU growth strategies implementation, just 4 V4 regions are eco-efficient — CZ02: Central Bohemia, CZ04: Northwest, PL42: Zachodniopomorskie, and SK01: Brati-

slava region (Staničková & Melecký, 2012). On the contrary Rybaczewska-Błazejowska and Masternak-Janus (2018) analyze the Poland regions' eco-efficiency with no specific orientation and conclude that 4 of the sixteen Polish regions are being eco-efficient (Wielkopolskie, Podlaskie, Warmińsko-Mazurskie, and Mazowieckie), while with an orientation on the analyzed agriculture sector just 2 Polish regions are eco-efficient — region PL21: Malopolskie and region PL41: Wielkopolskie.

According to Bianchi *et al.* (2020), the eco-efficient regions are those with a high agglomerations concentration, but in the case of agricultural eco-efficiency it is not the same, the eco-efficient regions are those with good climate conditions or also the small ones, oriented mainly on organic farming. Regions with high agglomerations tend to focus on other types of sectors, as they do not have the appropriate conditions for agricultural production.

Based on the results, there is one important difference between influencing factors on a micro and regional level. According to Ehrmann (2008), the larger the farm is and the bigger output it produces, the greater the sustainable value it creates. The same conclusion is also reached by Van Passel *et al.* (2006), Vilke *et al.* (2020), and Stepień *et al.* (2021), who claim that farm size has a positive effect on environmental issues and eco-efficiency. In the case of the regional level, the size of regional agricultural production does not affect its agricultural eco-efficiency. Also, regions which produce really low agricultural output in a comparison with others are eco-efficient (CZ04: Northwest or PI21: Malopolskie).

During the analyzed years, the Slovak Republic is a country with the highest total eco-efficiency growth (14.5%) thanks to the highest technical eco-efficiency improvement (8.5%). Derived national eco-efficiency from the estimated regional eco-efficiency brings the same results as estimated national eco-efficiency. Fandel and Bartová (2018), estimate national eco-efficiency and also consider Slovak and Czech republic to be the V4 countries with the highest eco-efficiency growth. Slovakia has the most eco-efficient agricultural sector among V4 countries also according to Rybaczewska-Błazejowska and Gierulski (2018), followed by Hungary, the Czech Republic, and on the last position Poland, which agricultural eco-efficiency decrease during the analyzed time. So by computing eco-efficiency on a regional level, we can get the matching eco-efficiency for the national level too.

On the macro level, the orientation on the more specific goals doesn't influence the eco-efficiency results so significantly as on the meso level, because countries are not as differentiated as regions in terms of competitive advantages. In the context of the EU growth strategies, Staničková

and Melecký (2012) conclude that the Slovak and the Czech Republic are the most efficient V4 countries too.

On average, the agricultural eco-efficiency of V4 countries increases by 3.7%. The growing tendency of agricultural eco-efficiency during the time, thanks to the strong environmental pressure, is measured also by Liu *et al.* (2020). They declare that the agricultural eco-efficiency of China's 31 provinces is increasing by 76% during the years 1978–2017. The main contributor to the agricultural eco-efficiency growth is technological progress, instead of pure technical efficiency. To the same results come also Carboni and Russo (2017) and Wang and Ye (2017), which investigate the efficiency on the regional level using the Malmquist productivity index. There is no difference in the case of the main eco-efficiency growth contributor on a national level (Mavi & Mavi, 2019).

Conclusions

In every V4 country, some regions have severe conditions for agricultural production and are not so successful in the implementation of ecological issues, but on average the agricultural eco-efficiency is increasing in all V4 countries, except Poland. This fact indicates that the implementation of environmental objectives into the agricultural sector is making progress.

The V4 region with the highest agricultural output in all analyzed years is the Hungarian eco-efficient region HU33: Dél-Alföld. Other V4 eco-efficient regions are CZ02: Central Bohemia, CZ04: Northwest, HU31: Észak-Magyarország, HU32: Észak-Alföld, PL21: Malopolskie, PL41: Wielkopolskie, SK01: Bratislava region, and SK02: Western Slovakia. Those regions could improve their productivity just by technological development, represented by the innovation of the production process. The rest of the biggest agricultural producers are not eco-efficient. Therefore, the research hypothesis that all the biggest agricultural producers are eco-efficient is not confirmed. Based on the results, eco-efficient regions are those with good climatic conditions for agriculture or those that focus primarily on organic farming.

23 V4 regions have an eco-inefficient agricultural sector, which can be improved by more efficient input-output transformation on one side, and by the implementation of innovations on the other side. During the analyzed years, 19 V4 regions improve their agricultural eco-efficiency. Slovak region SK04: Eastern Slovakia improves its eco-efficiency the most, by 39.6%. The highest eco-efficiency decline is observed in Poland's eco-efficient region PL41: Wielkopolskie, in which eco-efficiency decline by

12.7% thanks to the technological regress. According to the eco-efficiency, technological, and pure technical eco-efficiency change, V4 regions are classified into 3 groups: the most progressive regions (2 V4 regions) progressive regions (15 V4 regions), and regressive regions (15 V4 regions). On the national level, the Slovak Republic is the country with the highest eco-efficiency growth, because of the highest technical eco-efficiency improvement, and the Czech Republic recorded the highest technological progress during the years 2013–2017. On average the V4 countries' agricultural eco-efficiency increased by 3.7%, thanks to technological progress, which is the main contributor to its improvement and indicates that producers try to implement improvements that lead to more eco-efficient agricultural production.

Therefore, the most effective way to increase agricultural eco-efficiency is technological progress, i.e. the introduction of new technologies into production meeting new standards that take into account not just more efficient production, but also the ecological goals aimed at green production and environmental protection. Promoting the agricultural sector's eco-efficiency is one of the priority objectives of the Common Agricultural Policy, but based on the results, even if the country has an eco-efficient agricultural sector, it does not mean that all regions inside it have an eco-efficient agricultural sector too. Because of different regional agricultural conditions, the promoting instruments must be built on a lower level than on the macro level. Based on the obtained results, the biggest technological improvement is observed in those regions with low agricultural output and with not such developed agricultural sector and, therefore, introducing the innovations into the agricultural production is not so expensive for them as for bigger producers. Policymakers should pay attention to the increasing subsidies in the case of new technologies introduction for eco-efficient regions with high agricultural production if they want to foster them to be even more eco-efficient. In the case of eco-inefficient regions, it is necessary to find the inefficiency reasons, which could be not just technological regress, but also inefficient input-output transformation.

The weakness of this research is that it did not take into account undesirable outputs which are produced during the agricultural production process, but information about them is not available at the regional level.

Based on the research, we determine the regional eco-efficiency, respectively eco-inefficiency of the V4 agricultural sector, its dynamics over time and reveal that mainly technological progress leads to the eco-efficiency improvement. Further research will be focused on the agricultural eco-inefficiency reasons analysis using sensitivity and scenario analysis, which could help to build more concrete recommendations for practice. Also, we

will determine agricultural sector eco-efficiency external driving forces by analyzing the influence of a chosen factors, as subsidies, production focusing, and so on, using Tobit regression.

References

- Bianchi, M., del Valle, I., & Tapia, C. (2020). Measuring eco-efficiency in European regions: evidence from a territorial perspective. *Journal of Cleaner Production*, 276. 123246. doi: 10.1016/j.jclepro.2020.123246.
- Caiado, R. G. G., Dias, R. F., Mattos, L. V., Quelhas, O. L. G., & Filho, W. L. (2017). Towards sustainable development through the perspective of eco-efficiency – a systematic literature review. *Journal of Cleaner Production*, 165, 890–904. doi: 10.1016/j.jclepro.2017.07.166.
- Camarero, M., Picazo-Tadeo, A. J., Castillo, J., & Tamarit, C. (2013). Eco-efficiency and Convergence in OECD Countries. *Environmental and Resource Economics*, 55(1), 1–20. doi: 10.1007/s10640-012-9616-9.
- Carboni, O. A., & Russu, P. (2017). Measuring and forecasting regional environmental and economic efficiency in Italy. *Applied Economics*, 50(5), 335–353, doi: 10.1080/00036846.2017.1313954.
- Caves, D., Christensen, L., & Diewert, E. (1982). The economic theory of index numbers and the measurement of input, output, and productivity. *Econometrica*, 50(6), 1393–1414, doi: 10.2307/1913388.
- Charnes, A., Cooper, W.W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research*, 2(6), 429–444. doi: 10.1016/0377-2217(78)90138-8.
- Coluccia, B., Valente, D., Fusco, G., De Leo, F., & Porrini, D. (2020). Assessing agricultural eco-efficiency in Italian Regions. *Ecological Indicators*, 116, doi: 10.1016/j.ecolind.2020.106483.
- DeSimone, L. D., & Popoff, F. (2000). *Eco-efficiency: the business link to sustainable development*. Massachusetts: The MIT Press.
- Dyckhoff, H., & Allen, K. (2001). Measuring ecological efficiency with data envelopment analysis. *European Journal of Operational Research*, 132(2), 312–325. doi: 10.1016/S0377-2217(00)00154-5.
- Ehrmann, M. (2008). Comparing sustainable value approach, Data Envelopment Analysis and indicator approaches - an application on German dairy farms. [Conference presentation]. 2008 International Congress, August, 2008, Ghent, Belgium 44140. European Association of Agricultural Economists. doi: 10.22004/ag.econ.44140.
- European Commission (2017). Modernising & simplifying the CAP: climate & environmental challenges facing agriculture and rural areas. Retrieved from https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/key_policies/documents/env_background_final_en.pdf (17. 12. 2020).

- Fandel, P., & Bartova, L. (2018). Eco-efficiency using directional distance functions with undesirable outputs. In *Quantitative methods in economics*. Bratislava: Letra Edu.
- Färe, R., Grosskopf, S., Lindgren, B., & Roos, P. (1994). Productivity growth, technical progress and efficiency changes in industrialized country. *American Economic Review*, 84(1), 66–83.
- Food and Agriculture Organization of the United Nations (FAO) (2001). Agriculture and the environment: changing pressures, solutions and trade-offs. Retrieved from <http://www.fao.org/3/y4252e/y4252e12.pdf> (17. 12. 2020).
- Hua, Z., Bian, Y., & Liang, L. (2007). Eco-efficiency analysis of paper mills along the Huai river: an extended DEA approach. *Omega*, 35(5), 578–587. doi: 10.1016/j.omega.200511.001.
- Huppes G, & Ishikawa M. (2005). A framework for quantified eco-efficiency analysis. *Journal of Industrial Ecology*, 9(4), 25–41. doi: 10.1162/108819805775247882.
- Hur, T., Kim, I., & Yamamoto, R. (2004). Measurement of green productivity and its improvements. *Journal of Cleaner Production*, 12(7), 673–683. doi: 10.1016/j.jclepro.2003.08.004.
- Keating, B. A., Carberry, P. S., Bindraham, P. S., Asseng, S., Meinke, H., & Dixon, J. (2010). Eco-efficient agriculture: concepts, challenges, and opportunities. *Crop Science*, 50, 109–119. doi: 10.2135/cropsci2009.10.0594.
- Kortelainen, M. (2008). Dynamic environmental performance analysis: a Malmquist index approach. *Ecological Economics*, 64(4), 701–715. doi: 10.1016/j.ecolecon.2007.08.001.
- Lauransa, Y., Rankovic, A., Billo, R., Pirard, R. & Mermet, L. (2013). Use of ecosystem services economic valuation for decision making: questioning a literature blindspot. *Journal of Environmental Management*, 119, 208–219. doi: 10.1016/j.jenvman.2013.01.008.
- Li, Z., Hu, M., & Jin, T. (2021). Spatio-temporal evolution and improvement potential of agricultural eco-efficiency in Jiangsu Province. Preprints. doi: 10.20944/preprints202104.0431.v1.
- Liu, Y., Zou L., & Wang, Y. (2020). Spacial-temporal characteristics and influencing factors of agricultural eco-efficiency in recent 40 years. *Land Use Policy*, 97, 104794. doi: 10.1016/j.landusepol.2020.104794.
- Mavi, N. K., & Mavi, R. K. (2019). Energy and environmental efficiency of OECD countries in the context of the circular economy: common weight analysis for Malmquist productivity index. *Journal of Environmental Management*, 247, 651–661. doi: 10.1016/j.jenvman.2019.06.069.
- Mickwitz, P., Melanen, M., Rosenstrom, U., & Seppälä, J. (2006). Regional eco-efficiency indicators – a participatory approach. *Journal of Cleaner Production*, 14(18), 1603–1611. doi: 10.1016/j.jclepro.2005.05.025.
- Moutinho, V., Robaina, M., & Macedo, P. (2018). Economic-environmental efficiency of European agriculture – a generalized maximum entropy approach. *Agricultural Economics – Czech*, 64, 423–435. doi: 10.17221/45/2017-AGRIC ECON.

- OECD (1998). Eco-efficiency. Retrieved from <http://www.oecd-ilibrary.org/docserver/9789264040304-en.pdf?expires=1610456534&id=id&accname=guest&checksum=4EAAB98051BF6FC5C1187040ACD321F7> (14. 12. 2020).
- Pang, J., Xingpeng, Ch., Zhang, Z., & Li, H. (2016). Measuring eco-efficiency of agriculture in China. *Sustainability*, 8(4), 398. doi: 10.3390/su8040398.
- Pishgar-Komleh, S., Čechura, L., & Kuzmenko, E. (2021). Investigating the dynamic eco-efficiency in agriculture sector of the European Union countries. *Environ Sci and Pollut Res*, 28(35), 48942–48954 (2021), doi: 10.1007/s11356-021-13948-w.
- Ren, W., Zhang, Z., Wang, Y., Xue, B., & Chen, X. (2020). Measuring regional eco-efficiency in China (2003-2016): a “full world” perspective and Network Data Envelopment Analysis. *International Journal of Environmental Research and Public Health*, 17, 3456. doi: 10.3390/ijerph17103456.
- Richterová, E., Richter, M., & Palkovič, J. (2020). World’s 24 biggest agricultural producers’ eco-efficiency considering undesirable outputs. *Agris on-line Papers in Economics and Informatics*, 13. doi: 10.7160/aol.2021.13xxxx.
- Robaina-Alves, M., Moutinho, V., & Macedo, P. (2015). A new frontier approach to model the eco-efficiency in European countries. *Journal of Cleaner Production*, 103(15), 562–573. doi: 10.1016/j.jclepro.2015.01.038.
- Rybczewska-Błazejowska, M., & Masternak-Janus, A. (2018). Eco-efficiency assessment of Polish regions: joint application of life cycle assessment and data envelopment analysis. *Journal of Cleaner Production*, 172, 1180–1192. doi: 10.1016/j.jclepro.2017.10.204.
- Rybczewska-Błazejowska, M., & Gierulski, W. (2018). Eco-efficiency Evaluation of Agricultural Production in the EU-28. *Sustainability*, 10, 4544. doi: 10.3390/su10124544.
- Seppälä, J., Melanen, M., Mäenpää, I., Koskela, S., Tenhunen, J., & Hiltunen, M. R. (2005). How can the eco-efficiency of a region be measured and monitored. *Journal of Industrial Ecology*, 9(4), 117–130. doi: 10.1162/108819805775247972.
- Serrão, A. (2008). Measuring eco-efficiency of agricultural activity in European countries: a Malmquist index approach. [Conference presentation]. American Agricultural Economics Association Annual Meeting, Orlando, Florida, 2008. doi: 10.22004/ag.econ.6152.
- Schaltegger, S., & Sturm, A. (1990). Ökologische Rationalität: Ansatzpunkte zur Ausgestaltung von ökologieorientierten Managementinstrumenten. *Die Unternehmung*, 44(4), 273–290.
- Shao, Q., Schaffartzik, A., Mayer, A., & Krausmann, F. (2017). The high ‘price’ of dematerialization: a dynamic panel data analysis of material use and economic recession. *Journal of Cleaner Production*, 167(20), 120–132. doi: 10.1016/j.jclepro.2017.08.158.
- Staníčková, M., & Melecký, L. (2012). Assessment of efficiency in Visegrad countries and regions using DEA models. *Central European Review of Economic*, 15, 145–156. doi: 10.7327/cerei.2012.09.02.

- Stepień, S., Czyzewski, 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. doi: 10.1016/j.jclepro.2020.123721.
- Svatoš, M., Smutka, L., Elshibani, B. A. M., & Mousbah, S. A. (2013). Development of Visegrad countries' agricultural trade in relation to agricultural production development. *Agris on-line Papers in Economics and Informatics*, 5(1), 1–11. doi: 10.22004/ag.econ.148104.
- UNESCAP (2009). Eco-efficiency indicators: measuring resource-use efficiency and the impact of economic activities on the environment. Greening of economic growth series. Retrieved from <https://sustainabledevelopment.un.org/content/documents/785eco.pdf> (17. 12. 2020).
- Van Passel, S., Nevens, F., Mathijs, E., & Van Huylenbroeck, G. (2006). Explaining differences in farm sustainability: evidence from Flemish dairy farms. [Conference presentation]. International Association of Agricultural Economists Conference, Gold Coast, Australia, 2006. doi: 10.22004/ag.econ.25262.
- Vilke, R., Gedminaitė-Raudonė, Ž., Baležentis, T., & Štreimikienė, D. (2020). Farmers' awareness of eco-efficiency and cleaner production as environmental responsibility: Lithuanian case. *Corporate Social Responsibility and Environmental Management*, 28, 288–298. doi: 10.1002/csr.2049.
- Wang, W., & Ye, Y. (2017). Evaluation of agricultural ecological efficiency and its improvement measures in China taking Guizhou province as an example. *Nature Environment and Pollution Technology*, 16(2), 515–521.
- Zhang, B., Bi, J., Fan, Z., & Yuan, Z. (2008). Eco-efficiency of industrial system in China: a data envelopment analysis approach. *Ecological Economics*, 68(1-2), 306–316. doi: 10.1016/j.ecolecon.2008.03.009.

Acknowledgments

This paper is connected to project no. 2/2021/GA FEM named “EU Eco-efficient agriculture – current challenges”

Annex

Table 1. The principal scheme of eco-efficiency modeling

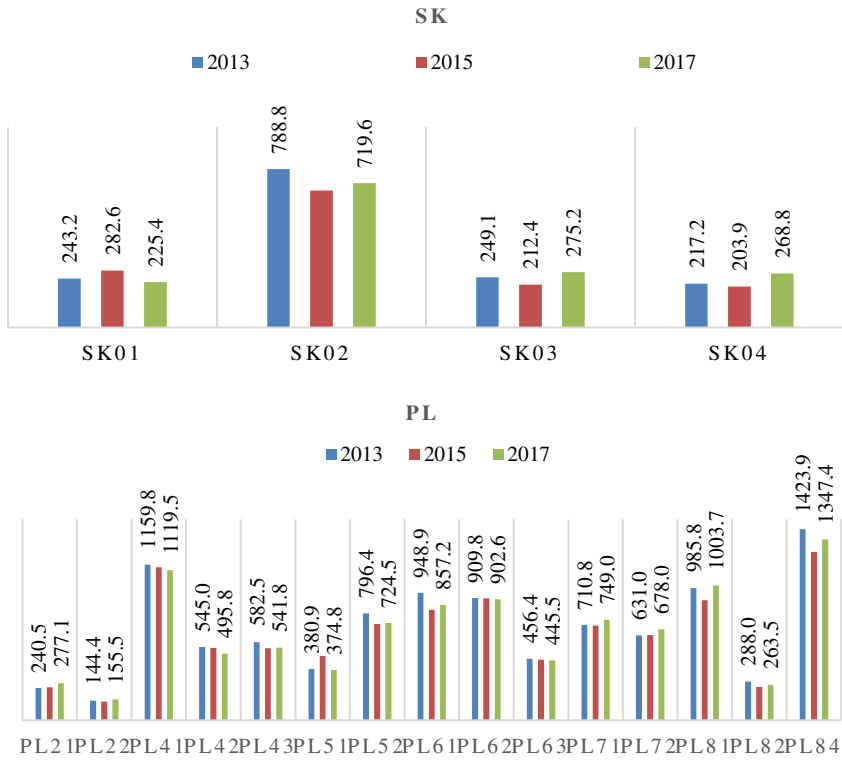
Input /output analysis of data	
1.	Pre-processing stage, including literature study ->>
2.	Chosen indicators collection at a regional level ->>
3.	Data analysis of selected indicators in regions, including basic descriptive statistics ->>
4.	Grouping of selected indicators into input and output.
Data envelopment analysis modeling	
1.	Basic DEA model at regional level ->>
2.	Advanced dynamic index at regional level ->>
3.	Regional eco-efficiency evaluation ->>
4.	Interpretation and comparison of an obtained results.

Source: Staníčková and Melecký (2012, p. 146).

Figure 1. The agricultural output in euro/inhabitant of V4 regions in 2013, 2015 and 2017



Figure 1. Continued



Source: own calculations based on Eurostat (2013, 2015, 2017).

Figure 2. V4 regions` Average Eco-inefficiency for analyzed years

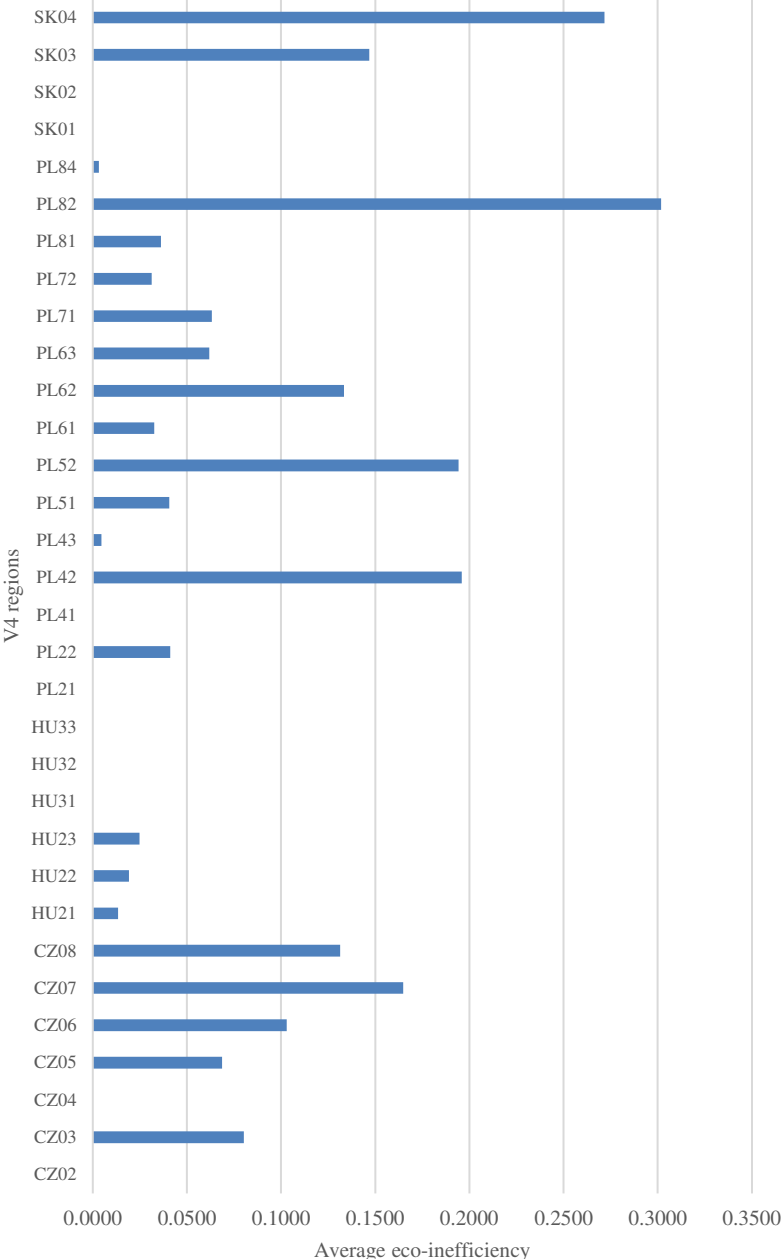
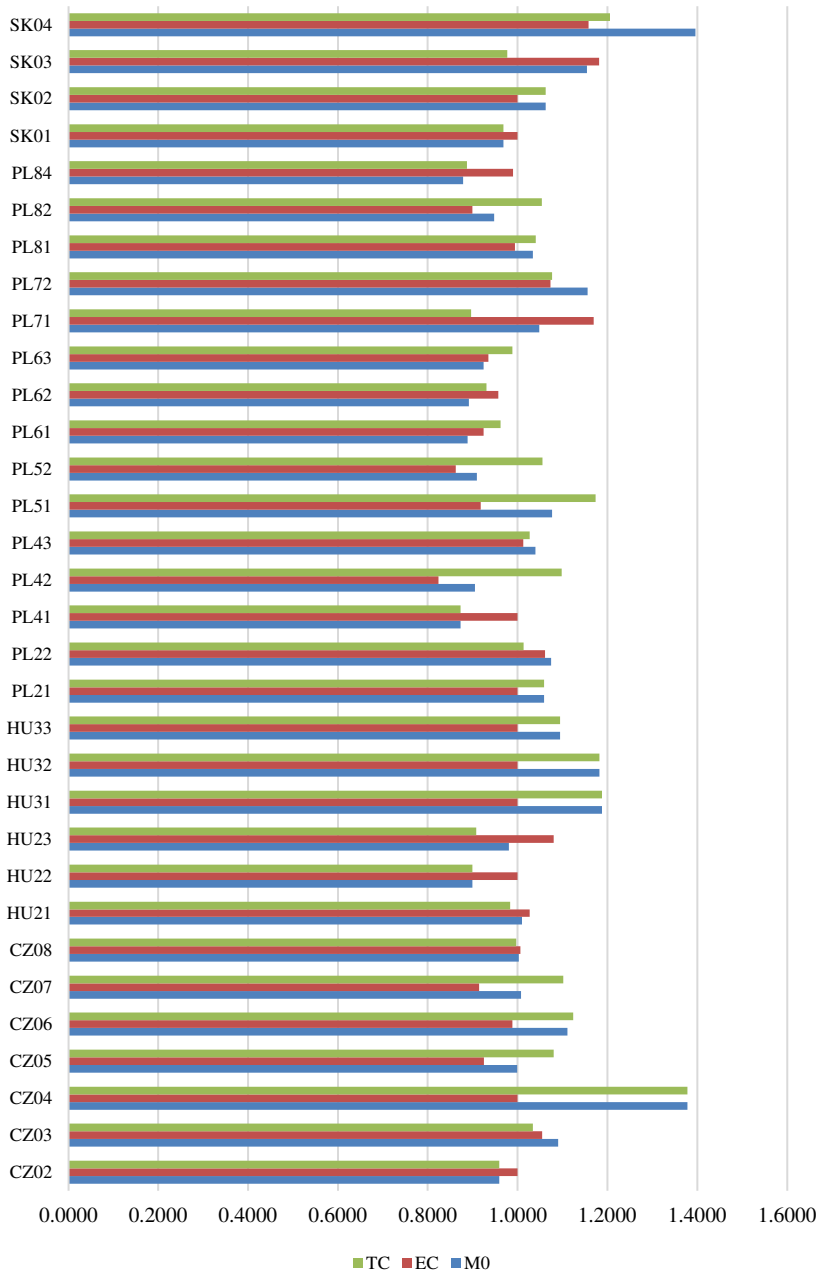
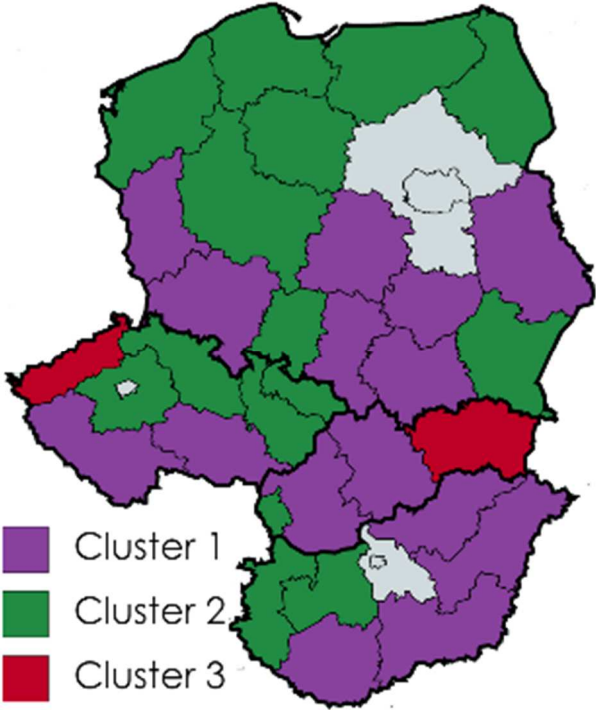


Figure 3. V4 regions` Cumulative change of TFP, represented by M_0



Source: own calculations based on Eurostat (2013, 2015, 2017).

Figure 4. V4 regions agricultural eco-efficiency clusters



Source: own calculations based on Eurostat (2013, 2015, 2017).