



# Deadweight loss in environmental policy: The case of the European Union member states

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## ABSTRACT

With increased competition for scarce public financial resources and increased pressure on environmental policy, it is necessary to determine the effectiveness of current environmental policy. Therefore, the aim of this article was to determine the deadweight loss in public spending on the preservation of environment quality, including national expenditures, and the Common Agricultural Policy in individual EU countries between the years of 2005–2016. To determine the relative differences in efficiency on environmental policy between EU countries, bootstrapped data envelopment analysis and Malmquist total factor productivity index decomposition was used. It was found that, generally, the environmental prospects for European countries has improved over the last decade and have been reversely correlated to the deadweight loss. However, the inefficiency level of EU countries' policy, is on average, relatively higher than what was reported in different regions of the world. The highest efficiency of environmental spending has been, therefore, achieved in Central-Eastern European and Scandinavian countries and Spain.

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## 1. Introduction

The European Union is facing a number of challenges concerning the environment and pollution. Protecting, conserving, and enhancing the Union's natural capital, turning the Union into a resource-efficient, competitive, low-carbon economy and safeguarding the Union's citizens from environment-related pressures and health risks can be found among the objectives set in The Seventh Environment Action Programme 2014–2020 as well as in the Common Agricultural Policy (CAP) prerogatives (European Parliament, 2013). However, outlooks for fulfilling most of the goals set under these priorities are rather pessimistic (European Environment Agency, 2017). Research predicts further growth of the ecological footprint and stable ecological deficit in Europe despite their impressive policy efforts (Csutora, 2011). One positive

is that foreign investment is conducive to achieving environmental goals (Zhou et al., 2020) and that environmental innovations have become common in industrialized countries (Nagoev et al., 2018). Töbelmann and Wendler (2020) claim that environmental innovation has contributed to reducing carbon dioxide emissions based on EU-27, although an overall innovation activity does not reduce carbon dioxide emissions. Important motivation for this research is also the increasing impact of pollution on people's health. Even short-term exposure to pollution is associated with morbidity and mortality, including conditions such as asthma, bronchitis and chronic lung disease. Numerous studies have quantified the adverse health effects of the pollution (see: Huang et al., 2005; Samoli et al., 2009; Powell et al., 2012). World Health Organization (WHO) estimated that, in 2016, ambient air pollution caused 4.2 million deaths (WHO, 2020). In the world's poorest countries, household air pollution and contaminated drinking water are long-established forms of pollution. In rapidly developing countries, however, also because of that, environmental issues are also getting more and more public attention. According to the latest Eurobarometer, the number of people that indicated climate change as one of the most serious concerns increased from 5% in 2010 to 16% in 2018.

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In contrast to those figures, general government expenditures on environmental protection in the EU remain on a similar level of €69–70 billion since 2008 (Eurostat, 2018), and a reduction of CAP funds is still under question. Increasing fiscal discipline problems could account for this stagnation, particularly with unsustainable budget policies in the southern (Spain, Italy, Portugal, Greece, and Cyprus) and western (Germany, France, and Austria) EU countries (Lee et al., 2018). Such conditions result in increased competition for scarce public resources and a pressure on policy to become more efficient and goal-oriented, as it is reflected by changes proposed for the Common Agricultural Policy after 2020 (European Commission, 2018). In light of the above, assessing and minimizing inefficiency in public spending becomes an issue of great importance; but there are also different premises to revisit the deadweight loss in public policy.

Deadweight loss is traditionally associated with the loss of consumer surplus caused by taxation (Musgrave, 2008). However, deadweight loss can also be understood more generally as inefficiency reflected by waste or suboptimal allocation of resources (Harberger, 1964). There is surprisingly vast body of literature that proves the reverse causality: According to many authors, the environment quality determines the level of public expenditure not vice versa. It means that the policy is usually belated and shaped ex post as a response to the increasing externalities. This type of research is carried out primarily for developing countries. Yahaya et al. (2016) found on a panel of 125 developing countries that air quality significantly determined the health expenditure per capita in these countries, with a particularly strong impact on carbon dioxide. Yang and Zhang (2018) found that exposure to PM<sub>2.5</sub> had a significant impact on household health expenditure, even after socioeconomic characteristics and country locations were included in the model. Moreover, Ma et al. (2016) reported that increase in emissions had even been accompanied by a decrease in public spending. This evidence confirms a raising importance of the deadweight loss issue as the ex post policy can be ineffective or it can't even be subjected to any evaluation of its effectiveness. Prevention is always better than a cure and should be perceived as a priority in public spending.

In this paper, the deadweight loss approach was followed in the context of public expenditures to fill the gap that has recently reoccurred in policy effectiveness studies. By using the bootstrapped data envelopment analysis (DEA) method and Malmquist index decomposition, it was assessed to what extent public expenditures have been wasted. Environmental policy inefficiency (i.e., deadweight loss) can be detected when a benchmark country achieves a similar level of environmental output with lower input of public resources, however, the bootstrapping technique also points out potential improvements for the benchmark unit. This topic has already gathered some scientific attention in recent years (Becker, 2012; Gass, et al., 2013; Holland et al., 2016), but the scope of the analysis was limited to a single policy in a single country. This paper contributes to the above thread by exploring the problem on the European Union member states level including CAP green schemes to the inefficiency analysis as a new contribution. Moreover, the novelty of this study is manifested by the method applied to weighing pollution indicators: pollution components were related to hectares of non-urban areas in each country instead of a commonly used simple emission indicators. Such an approach answered the recently raised argument that non-urban area matter when struggling pollution due to their natural absorbent capacity. For instance, according to calculations by the Centre for Ecology and Hydrology (CEH), plants helped save the lives of around 1900 UK residents in 2015 (Office for National Statistics, 2018).

To sum up, the methodological approach adopted in the paper allows one to (a) assess differences in the deadweight loss of public

expenditures allocated on improvements in environment quality (also in the benchmark units) and (b) identify long-term changes of the inefficiency. Therefore, the aim of this article is to determine the deadweight loss in public spending on the preservation of the environment quality in individual EU countries for 2005–2016. The lower the efficiency score, the greater the loss for the citizens of a given EU country in relation to the inhabitants of countries where there is a greater efficiency of transforming public expenditure into beneficial environmental effects.

Our research strategy consists of four steps. First, a Composite Index of Environmental Prospects (CIEP) using the CRITIC-TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) was computed to describe environmental pressure created by each country in relation to non-urban areas and to assess the CIEP long-term dynamics. In the second step, the bias corrected efficiency of public spending in relation to the environmental effects achieved in individual EU countries was determined and tracked for 2005–2016 by the bootstrapped DEA scores. In the third step, the Malmquist index for the bootstrapped scores was applied to assess technological change in individual EU countries in relation to the whole EU. Finally, to conclude the second and third steps, the total productivity of public spending in individual EU countries on environmental objectives was calculated, reflecting changes in their efficiency and technological progress.

The body of this paper consists of four sections. In the first part, the current state of knowledge about deadweight loss of environmental public expenditures was identified. In the second part, the methods involved in this research were explained. The third part is a description of current environmental pressure and its trends in EU countries. Lastly, the results of efficiency estimations, discussion, and recommendations for policymakers are presented.

## 2. Literature review

Recent literature on deadweight loss in environmental policy tends to focus on ex ante analyses with alternative scenarios, proving differences in deadweight loss value. By contrast, this research represents an ex post approach where efficiencies of past public expenditures are assessed. These types of studies are minimal in comparison with ex ante, impact-assessment-type works (e.g., Mikulic et al., 2016; Rausch and Karplus, 2014). The ex post approach allows for the distinction between two types of research. The first type provides an international comparison of the efficiency of overall public spending (e.g., Adam and Tsarsitalidou, 2019; Adam et al., 2011; Afonso et al., 2005; Sanz-Díaz et al., 2017; Vrontzos et al., 2014), while the second concentrates on specific environmental expenditures (Meleddu and Pulina, 2018; Wang et al., 2009; Wang, 2018).

Among the aforementioned papers, five present a research strategy similar to the one undertaken here. Meleddu and Pulina (2018) evaluated the efficiency of public resource allocation aimed at air, water, and biodiversity intervention in Italian regions. Wang et al. (2009) conducted an empirical analysis on performance of rural eco-environment public expenditure of Chinese local governments in 2003–2006 with the DEA-Malmquist method. Similarly, Wang (2018) studied inefficiencies in fiscal spending on environmental protection. Vrontzos et al. (2014) as well as Adam and Tsarsitalidou (2019) argued that countries with strong environmental policies are less efficient than countries where less public funds are expended on the environment. Sanz-Díaz et al. (2017) compared, using the Malmquist index, growth in eco-efficiency in old member states and those with access to the EU in 2004. An outcome of the studies cited above will be discussed in the results section. However, it is worth noting that these papers do not assess the overall efficiency of expenditures, but rather the

relationship between specific types of public goods and intervention. What's more, their spatial scope is limited to a group of regions in a single country. These directions of research are rarely connected, and this study aims to fill that research gap.

### 3. Methodology

A unique feature of this study is relating the components of the CIEP to the non-urban area or to the utilised agricultural area UAA (if agriculture is the only source of the respective pollutant, cf. Table 1). It was assumed that the non-urban area is a reservoir of natural resources which absorbs the pollution generated by all branches. Forests and other plants absorb particulate matter and agricultural land stores up significant quantities of carbon, leading to a reduction in the presence of CO<sub>2</sub> in the atmosphere. Following a reasoning that a refuge for the natural environment is mainly located in the non-urban area, a question arises whether it would be sufficient to focus only on reducing total emissions while, simultaneously, the natural environment is disappearing through the urbanisation process? To address this dilemma, the environmental prospect was linked to remaining non-urban or agricultural areas in the countries under study. The choice of pollutants stresses an increasing role of agriculture in sustaining the natural environment. It should be recalled that the pollution of rural areas unambiguously impacts human health through the production of food primary products (Grzelak et al., 2019). However, it doesn't mean that the pollution from industry was ignored as all major air pollutants from total sectors of emissions were taken under consideration (Table 1). Such an approach also has other advantages: it mitigates a problem of the size of a country, economy or polluting sector under study while comparing objects, and allows for the easy conversion of destimulants into stimulants in DEA using a reciprocal of the respective pollutant per ha (i.e., ha per pollutant). The environmental prospect was explored in three dimensions: soil pollution, air pollution, and biodiversity (Table 1 and Table A.1). The air quality was assessed using the most common air pollutants emitted by the whole economy (particulates and volatile organic compounds) whereas the soil quality covers such aspects as total erosion, inorganic fertilizer use, ammonia emissions, and GHG from agriculture as a proxy for unsustainable agricultural practices. The chief gases produced by agriculture are methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O); these gases have much greater potential to produce a greenhouse effect than CO<sub>2</sub>. N<sub>2</sub>O is emitted into the atmosphere from agricultural land as a result of microbiological processing of nitrogen fertilisers in the soil (Czyżewski and Kryszak, 2018). A high level of N<sub>2</sub>O per ha is characteristic for a large

monocultural field crops and CH<sub>4</sub> may indicate intensive animal production — both very harmful for the environment (i.e. for the soil).

The scope of the environmental policy assumed in this study covers two types of expenditures. The national expenditure on the input side is the sum of government expenditure in EUR (constant prices) divided per capita in a given country for the use of pollution abatement, protection of biodiversity and landscape, R&D in environmental protection, general environmental protection, as well as waste and wastewater management—the bigger population, the higher expenses for environmental management. Information on this subject is published by Eurostat in individual EU countries (code: gov\_10a\_exp). Expenditure from the EU budget is the sum of the Common Agricultural Policy subsidy in EUR per hectare of utilised agricultural area (UAA) intended for the environmental conservation in rural areas (EUFADN, 2019; codes: Set aside SE073, Set aside premiums SE612, Environmental subsidies SE621, LFA subsidies SE622, Other rural development payments SE623).

To synthesize the pressure on the environment, the CIEP was constructed. The value of the index was determined for individual EU countries separately in each of the target years (2005–2016) by means of the CRITIC-TOPSIS method and then once again normalized for the whole period (Deng et al., 2000; Diakoulaki et al., 1995). A higher value in the CIEP corresponds with lower environmental pressure in a given country, i.e., lower pollution and higher biodiversity.

In the next step of the analysis, a nonparametric method of bootstrapped data envelopment analysis (DEA) was used (Simar and Wilson, 1998). It improves on the classical method of measuring the relative efficiency of units, introduced by Charnes et al. (1978). The bootstrap procedure analyses the sensitivity of measured efficiency scores to sampling variation. Bootstrapping is based on the idea of repeatedly simulating the data generating process (DGP), usually through resampling, and applying the original estimator to each simulated sample so that resulting estimates mimic the sampling distribution of the original estimator. Bootstrapped DEA estimations done in this paper are based on R package FEAR 1.15 (Wilson, 2010). In the bootstrap procedure, Hall percentile intervals based on differences were used, according to Simar and Wilson (1998). This procedure, in comparison to the others, allows for more general DGPs; in particular, for less restrictive efficiency structures. To obtain the results, 2000 bootstrap replications were performed. Efficiency scores calculated in this way were corrected for bias coming from the sample selection process.

Therefore, the countries achieving the highest environmental prospects in relation to the value of public expenditure on

**Table 1**

Variables describing environmental pressure, used to calculate the Composite Index of Environmental Prospects.

	Name and Description	Unit
SOIL QUALITY	Estimated soil erosion by water	tonnes per hectare of non-urban areas
	Consumption of inorganic fertilizers in agriculture Nutrient: Phosphorus	kg per hectare of UAA
	Consumption of inorganic fertilizers in agriculture Nutrient: Nitrogen	kg per hectare of UAA
	Ammonia emissions from agriculture	kg per hectare of UAA
	Greenhouse gas emissions from agriculture	kg per hectare of UAA
AIR QUALITY	Air pollution (non-methane volatile organic compounds) from total sectors of emissions	kg per hectare of non-urban areas
	Air pollutants (Particulates < 2.5 µm) from total sectors of emissions	kg per hectare of non-urban areas
	Air pollutants (Particulates < 10 µm) from total sectors of emissions	kg per hectare of non-urban areas
BIODIVERSITY	Common farmland bird index - tracks the population of a selected group of breeding bird species that are dependent on agricultural land for nesting or breeding	Composite Index 2000 = 100

Source: Eurostat, OECD database

environmental protection have the best practices in supporting environment conservation in the EU. As mentioned above, the approach applied here allows simple conversion of undesirable outputs as the reciprocal of a pollutant per ha (i.e. ha per pollutant), and more complicated methods such as SBM models (Tone, 2003) or the directional distance function (Chung et al., 1997) are not purposeful.

The calculated efficiency ratios of public expenditure on environmental protection, which in this manuscript is called the effectiveness of environmental policy for individual EU countries, are determined by formula (6):

$$E_j = \frac{\sum_{m=1}^M v_m x_{mj}}{\sum_{n=1}^N v_n x_{nj}} \quad (6)$$

where

- $E_j$  - efficiency of environmental policy in the country  $j$ ,
- $M$  - number of indicators describing reciprocal of environmental pressure and the biodiversity (see more in Table 2),
- $N$  - number of public funds supporting environment quality (see more in Table 2),
- $x_{mj}$  -  $m$ -th observed pressure in a  $j$ -th country,
- $v_m$  - "weight" determining the importance of the  $m$ -th pressure (estimated by DEA method),
- $x_{nj}$  -  $n$ -th observed expenditure (public expenditure from national or EU policies on environmental protection) in the  $j$ -th country, and
- $v_n$  - "weight" determining the importance of the  $n$ -th fund.

In the analysis, input-oriented models with variable returns to scale (VRS) were used. Only Malmquist TFP index reflects changes in comparison to frontier technology which reflects constant returns to scale. However, further decomposition and a pure efficiency change indicator takes into account VRS benchmark technology. The input-oriented approach assumes minimisation of inputs for the given level of output (Poldrugovac et al., 2016). Assumption about variable returns to scale was made because it is unlikely, that in a group of countries with widely varied base level of environmental quality and expenditures level, increase in environmental quality will be always proportional to increase in expenditures. It is more probable that the impact of expenditures on environment quality will change, depending on environment quality. This justifies VRS assumption. A lower value of DEA score indicates greater deadweight loss of public funds allocated for environmental objectives. Therefore, countries achieving performance indicators the closest to 1 can be considered as the best practices in supporting environment conservation in the EU. The bootstrapped approach used in this paper results in the most efficient units with a score lower than 1. This difference is a consequence of bias correction included in this method.

In order to determine the frontier (optimal environmental technology) to which all countries will be compared, the following equation was used

$$P(x, y) = \left\{ x_j = > X\lambda_j, y_j = < Y\lambda_j, \lambda_j = > 0, \sum_{j=1}^n \lambda_j = 1 \right\} \quad (7)$$

where

- $P(x, y)$  - a set of possibilities to transform public expenditure into beneficial environmental effects,

- $x_j$  - vector of  $m$  inputs (public expenditure on environmental objectives from the national budget and from the EU budget) in the  $j$ th country,
- $X$  - matrix of inputs for  $n$  countries,
- $y_j$  - vector of outputs (the components of the CIEP) in the  $j$ th country,
- $Y$  - matrix of outputs for  $n$  countries, and
- $\lambda_j$  - weights being coefficients of linear combination.

Establishing a set of possibilities to transform public expenditure into beneficial environmental effects in the sample of surveyed countries allowed us to measure the distance between the best countries in this respect and the rest of the EU, as shown in the formula below

$$E(x_j, y_j) = \min\{\theta : \theta x_j, x_j \in P(x, y)\} \quad (8)$$

where  $E(x_j, y_j)$  is a distance function between the point characterising the relationship of the inputs (public expenditure on environmental objectives from the national budget and from the EU budget) to the outputs (the components of the CIEP) of a given country and the optimal relation in the country located in the frontier;

$\theta$  is the efficiency score of a country's environmental policy; and  $P(x, y)$ ,  $x_j$ ,  $y_j$  as in formula (2).

Specifically, the Malmquist index was computed with the method proposed by Fare et al. (1994) and presented as

$$M_i(x^{t+1}, y^{t+1}, x^t, y^t) = \sqrt{\frac{D_i^t(x^{t+1}, y^{t+1})}{D_i^t(x^t, y^t)} \times \frac{D_i^{t+1}(x^{t+1}, y^{t+1})}{D_i^{t+1}(x^t, y^t)}} \quad (9)$$

where

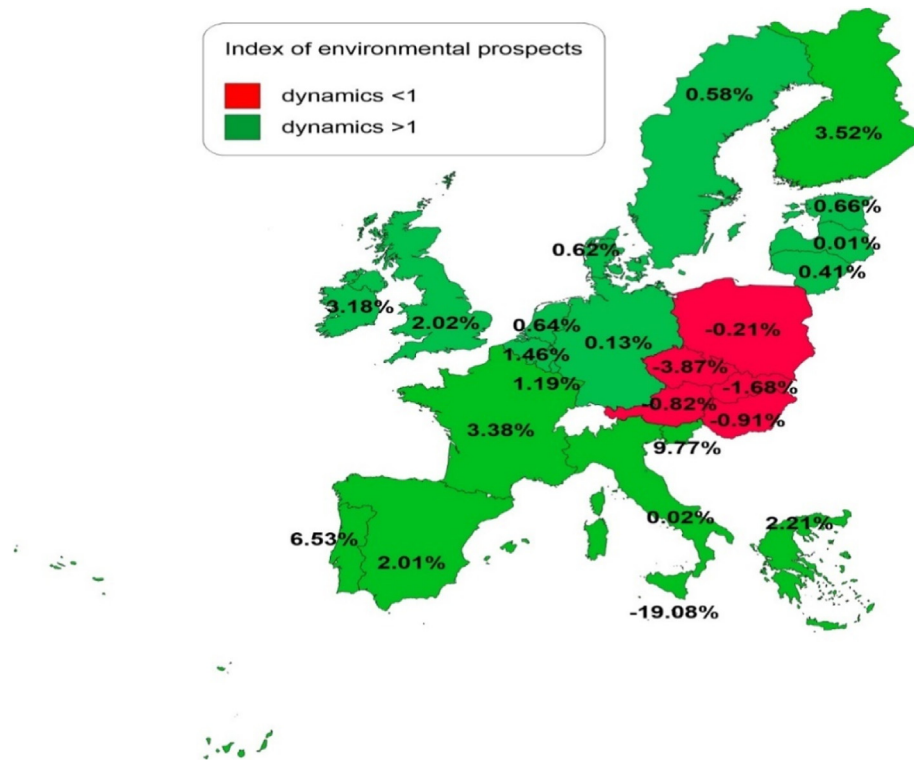
- $M_i$  — the Malmquist TFP index, input oriented,
- $x^t, x^{t+1}$  — vectors of inputs in  $t$  and  $t+1$  periods,
- $y^t, y^{t+1}$  — vectors of outputs in  $t$  and  $t+1$  periods,
- $D_i^t(x^t, y^t)$  — input distance function at  $t$ , the "maximum" proportional decrease of the input vector  $y^t$ , given outputs  $x^t$ ,
- $D_i^t(x^{t+1}, y^{t+1})$  — input distance function at  $t+1$  assuming technology from  $t$ , defined as the maximum proportional change in inputs required to make  $(x^{t+1}, y^{t+1})$  feasible in relation to the technology at  $t$ ,
- $D_i^{t+1}(x^t, y^t)$  — input distance function at  $t$  assuming technology from  $t+1$ , and
- $D_i^{t+1}(x^{t+1}, y^{t+1})$  — input distance function at  $t+1$ .

The Malmquist index represents the productivity of the combination  $(x^{t+1}, y^{t+1})$  relative to the combination  $(x^t, y^t)$ . A value greater than 1 will indicate positive TFP growth from period  $t$  to period  $t+1$ . Otherwise, there is a decrease in the efficiency of environmental policy, which means an increase in the waste of public funds allocated for the purpose of preserving the quality of the natural environment. After decomposition, the Malmquist index can be presented as

$$M_i(x^{t+1}, y^{t+1}, x^t, y^t) = \frac{D_i^{t+1}(x^{t+1}, y^{t+1})}{D_i^t(x^t, y^t)} \times \left[ \left( \frac{D_i^t(x^{t+1}, y^{t+1})}{D_i^{t+1}(x^{t+1}, y^{t+1})} \right) \left( \frac{D_i^t(x^t, y^t)}{D_i^{t+1}(x^t, y^t)} \right) \right]^{\frac{1}{2}} \quad (10)$$

The value outside the brackets represents the technical





**Fig. 1.** Compound annual rate of change of the Composite Index of Environmental Prospects in EU-25 in 2005–2016.  
Source: Own study based on Eurostat

efficiency change (the change in the distance between a given combination of inputs and the optimal combination minimizing the size of inputs for a given size of effects, between periods  $t$  and  $t+1$ , *tech.chg*). The geometric mean in brackets determines the technological changes between period  $t$  and  $t+1$  (change in the optimal combination). Further on, it is possible to decompose technical efficiency change into components describing pure efficiency change (*pure.eff.chg*), which is change calculated relative to the variable-returns technology and scale efficiency change (*scale.eff.chg*) which captures changes in the deviation between the variable returns and constant returns-to-scale technology. Final decomposition of Malmquist TFP is as follows

$$Malmquist_{TFP} = tech.chg \times pure.eff.chg \times scale.eff.chg \quad (11)$$

The last step was assessing the improvements in input and output values that countries have to do to minimize the deadweight loss of public expenditures on the environment. For this, we used so-called target values, which are sums of the original parameter value, radial movement (the distance of the country to the frontier value) and slack movement (movement of the country over the frontier, distance to the peer country value). The greater the difference between the original and the target value (i.e., the lower the ratio), the more improvement the country needs to minimize deadweight loss. Slacks have been calculated in R with the use of the Benchmarking package (Bogetoft and Otto, 2018). Unfortunately, to the best of our knowledge, it is not possible to obtain bootstrapped slacks values, so the ones presented in the paper comes from simple input-oriented DEA with various returns to scales (VRS) analysis.

## 4. Results and discussion

### 4.1. Environmental prospects in EU in 2005–2016

The Composite Index of Environmental Prospects (CIEP) through 2005–2016 improved on average in the EU (see Fig. 1). However, this improvement cannot be noted for all countries. Poland, Czechia, Austria, Slovakia, Hungary, and Malta saw a decrease during the period considered. This may seem controversial in relation to some countries, e.g., Austria where environmental quality is one of the best in the EU; however, we study pressure on the environment, which turns out to be relatively high. The decrease was influenced by the changes that took place in the components of the CIEP. Examples of these changes include an increase in the use of inorganic fertilisers (in particular nitrogen and phosphorus), an increase in greenhouse and ammonia emissions from agriculture, and, in the case of Hungary and Lithuania, increases in air pollutants (suspended particulate matter PM<sub>2.5</sub> and PM<sub>10</sub>) (see Appendix Figure A1). Nevertheless, as a positive European trend in the context of pressure on the environment, decrease of air pollution composed of non-methane volatile organic compounds, as well as decrease in air pollutants PM<sub>2.5</sub> and PM<sub>10</sub> can be mentioned. Negative changes are also observed in the population of endangered bird species and habitats, which is declining. The decrease of the CIEP in 2005–2016 shows that, in EU as like in China, “We must integrate eco-effectiveness and eco-efficiency into concrete sustainable development strategies, questioning whether limited resources are being used correctly” (Wang and Côté, 2011). This effort is necessary in all EU countries but in particular in those countries wherein the indicator of environmental prospects during the

analysed period decreased. The above results are similar to the study by Zafeiriou et al. (2018) and Fellman et al. (2018) who noted that in the European Union, the relationship between economic performance and greenhouse gas emissions from the agricultural sector has become a particularly high priority.

The CIEP dynamics should be analysed in the context of its components (see Appendix Figure A1). There is a striking example in Italy, where soil erosion is the highest in the EU, and use of inorganic, phosphorus fertilizers and ammonia emissions are also relatively high. In the Netherlands, the greenhouse gas emissions from agriculture are noticeably high and, in overpopulated Malta, high soil erosion and levels of air pollution ought to be noticed. Relatively low levels of the CIEP are also recorded in Slovenia, Belgium, Luxembourg, Austria, and Germany. The highest values are observed in Latvia and Estonia with the lowest soil erosion, one of the lowest ammonia and greenhouse gas emissions in the EU, and the lowest air pollution (Fig. 2).

#### 4.2. Deadweight loss in environmental policy in EU

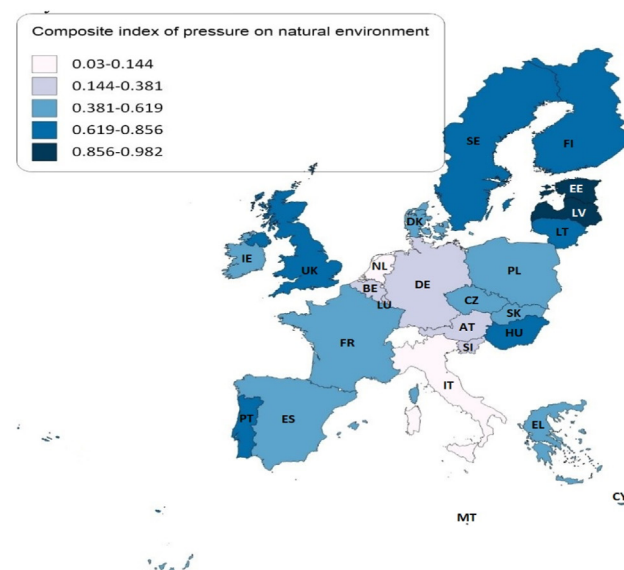
First, the results of deadweight loss calculations are presented. The results with the average value of the CIEP are compared to check whether these two problems are connected (Fig. 3).

The countries identified with the highest level of deadweight loss were Luxembourg and Austria. Among these countries, mismatch between environmental pressures and expenditures can be identified. In Austria, expenditures on pollution abatement are relatively high, while this problem is not as alarming as soil erosion and biodiversity loss. In Luxembourg, wastewater management consumes significant outlays, while the greatest threat seems to be air pollution. Another interesting case is Malta, third in the rankings. This country belongs to the top-ten countries in the world with the highest population density, reaching 1500 persons per km<sup>2</sup>. Of the 315 km<sup>2</sup> of total land area, 122 km<sup>2</sup> are non-urban area. Hence, the relationship between polluting outputs to natural resources in the island territory is relatively high but is not impacting

the life quality of citizens so much. In the analysed period, electricity was mainly produced in oil plants which emitted relatively high amounts of PM. In Malta, potential pollution is spread over the sea—but this does not change the high environmental pressure within the country's territory. Hence, the highest sums allocated for environmental protection (on average 385 euro/ha from CAP funds and 7300 euro/ha from the budget) did not result in good environmental prospects. Particularly high amounts were allocated on waste and water management, while the air pollution should gather greater concern but resources allocated for pollution abatement are relatively limited.

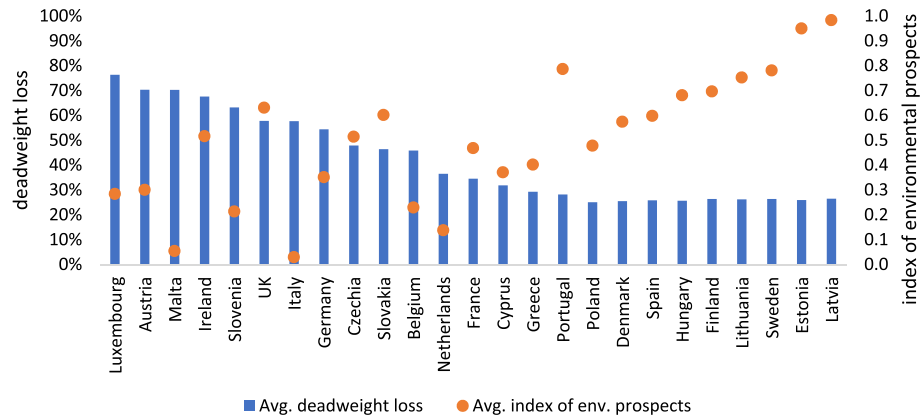
By contrast, Baltic (Lithuania, Latvia, and Estonia) and Scandinavian (Denmark, Sweden, and Finland) countries served as a benchmark for the rest of Europe over the entire assessed period. However, the bootstrapped procedure revealed that deadweight loss still exists in those countries accounting for around 25%. Comparing the CIEP for these countries, one can tell that the country with the most efficient and successful environmental policy was Latvia, with one of the lowest deadweight loss and the highest index of environmental prospects. The result obtained for Baltic countries is confirmed by the study by Moutinho et al. (2017). The cited authors used labour productivity, capital productivity, and the share of renewable energy in GDP as inputs and the ratio GDP per GHG emissions as an output.

The average value of deadweight loss for all the countries was equal to 42%. Interestingly, we can observe a negative correlation between deadweight loss and the CIEP with a Pearson's value of almost  $-0.7$ . This means that countries where environmental prospects are better, are also more efficient in implementing environmental policy. The results of this analysis, therefore, confirm previous observations by Vlontzos et al. (2014). These authors found that countries with strong environmental policies are less efficient than countries where fewer public funds are imparted to environmental policies. Adam and Tsarsitalidou (2019) found a similar relationship. They have proven that a more eco-efficient score of country is associated with both lower spending and taxes

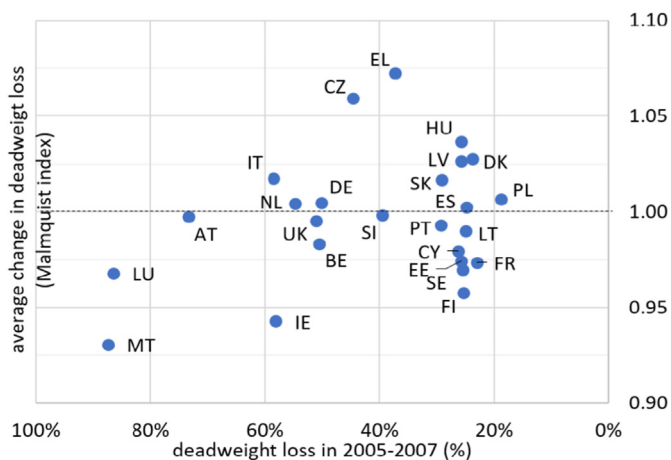


Legend: BE - Belgium, CZ - Czechia, DK - Denmark, DE - Germany, EE - Estonia, IE - Ireland, EL - Greece, ES - Spain, FR - France, IT - Italy, CY - Cyprus, LV - Latvia, LT - Lithuania, LU - Luxembourg, HU - Hungary, MT - Malta, NL - Netherlands, AT - Austria, PL - Poland, PT - Portugal, SI - Slovenia, SK - Slovakia, FI - Finland, SE - Sweden, UK - United Kingdom

Fig. 2. Value of the composite index of environmental prospects in EU-25 in 2005–2016.  
Source: Own study based on Eurostat



**Fig. 3.** Average deadweight loss and Composite Index of Environmental Prospects in EU-25 countries in the 2005–2016.  
Source: Own study based on Eurostat



**Fig. 4.** Changes in deadweight loss and its basic level for environmental public expenditures in EU-25 countries, in the 2005–2016.  
Source: Own study based on Eurostat

to environmental areas. This is contradictory to an assumption of diminishing returns in environmental policy but intuitively explainable. It could be assumed that decreasing environmental pressures from very high to high is easier and less costly than decreasing it from low to very low. However, our results prove an opposite dependency. On the other hand, such a result might prove that it is less costly to keep environmental pressure on low levels than to try decreasing it. To verify these issues, information about the changes in deadweight loss values is important. This is provided by analysis conducted with Malmquist TFP index.

Fig. 4 depicts that countries characterised by high levels of deadweight loss from the very beginning did not manage to improve (Austria, Luxembourg, and Malta). Their deadweight loss even increased. Only four countries with deadweight loss below the average in 2005–2007 (Italy, the Netherlands, Germany, and Czechia) managed to improve. Furthermore, except Czechia, this growth was not much higher compared to countries which had been the most efficient at the beginning of the analysis (Denmark, Latvia, and Poland). This is proven by an insignificant Pearson coefficient of  $-0.3$ . To find sources of growth and a decrease in deadweight loss, the next step of this research included decomposition of the Malmquist index; the results are presented in Fig. 5.

The average Malmquist TFP index value was slightly below one (0.9971) which indicates stagnation in improvements in the

efficiency of environmental public expenditures. This value comes from the combination of the positive technology change index (1.0086) and negative efficiency change (0.9902). It means that the frontier of efficiency in environmental spending is moving forward and it becomes possible to obtain better environmental results with lower financial inputs, but innovations leading to such improvements are not widespread among EU member states, what results in lower capability to catch up for countries where deadweight loss was higher.

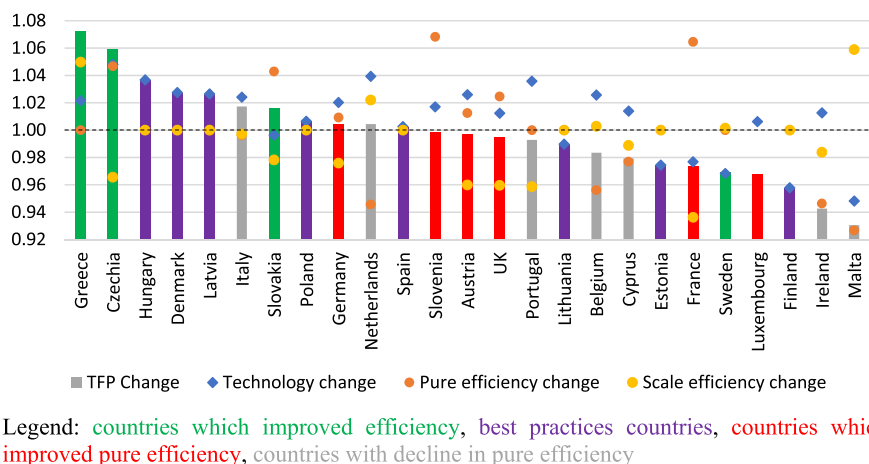
Based on different development patterns, we can distinguish a few groups of countries:

Only four countries improved their efficiency (green bars in Fig. 5). Two of them, Greece and Czechia, managed to relatively improve and decrease their deadweight loss by getting closer to the efficiency frontier, which was also shifting forward. The third country with a positive efficiency change was Slovakia, but, in this case, it was rather the frontier which moved backward (negative technology change) and made it easier to catch up. The fourth country in this group was Sweden, where the efficiency assessment depends on a returns-to-scale assumption. This country was fully efficient, if we assume variable returns-to-scale (VRS), but not under a constant return-to-scale (CRS) assumption. The case was similar for Greece and Portugal.

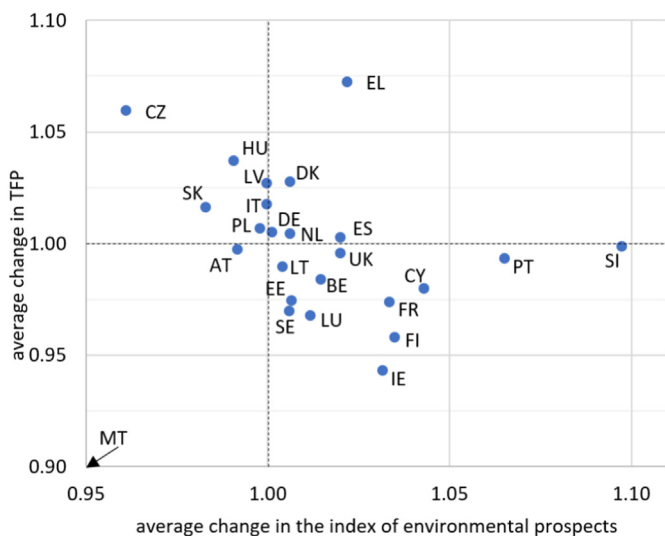
When it comes to the frontier, for the entire assessed period, it was shifted by eight countries (purple bars). Five of them (Hungary, Denmark, Latvia, Poland, and Spain) managed to shift the frontier forward, another three (Lithuania, Estonia, and Finland) moved it backward (technology change was negative). This situation is interpreted as a decrease in technical efficiency, which is effectively a decrease in technology that moved the frontier backward.

For the rest of the countries, changes in their deadweight loss were instead driven by the technology change. It means that the relative distance to the frontier increased. When the frontier moved forward, they moved forward with it and similarly, in the case of negative technological developments, they moved backward. The first situation was the most common (11 of 25 countries). The latter occurred only in France and Malta. It is possible to delimit countries from this group also according to another key—position relative to the CRS and VRS frontier. Some of them improved in relation to VRS frontier (red bars, pure efficiency change above 1). Others were left further from this frontier (grey bars, pure efficiency change below 1). However, the Malmquist TFP index is calculated in relation to the CRS production frontier, that is why final values of these indicators are corrected by the scale efficiency change index.

Fig. 6 provides the answer to the question of which country was the most successful in improving the efficiency of public



**Fig. 5.** Malmquist TFP index decomposition for the efficiency of public expenditures on environment in EU-25 countries, in the 2005–2016.  
Source: Own study based on Eurostat



**Fig. 6.** Changes in deadweight loss of environmental public expenditures and average change of the Composite Index of Environmental Prospects in EU-25 countries, in the 2005–2016.  
Source: Own study based on Eurostat

expenditures on the environment. As mentioned before, higher efficiency might also be the result of a decline in environmental prospects, while the overall goal of the policy should be focused on improving it. That is why better efficiency is only a prerequisite for successful change in the policy. A sufficient condition for efficiency is a simultaneous improvement, or at least a lack of decline, in environmental prospects. From Fig. 6, only seven countries managed to fulfil that criteria in 2005–2016. In this group, there were two leaders: Slovenia, which managed to improve its index of environmental prospects without increasing deadweight loss and Greece which improved the most in deadweight loss reduction. The results of this study are different than the results of the research by Sanz-Díaz et al. (2017). Using the Malmquist index, they found that countries that have been in the EU longer had higher growth in eco-efficiency than the block of countries that joined the EU-25 in 2004.

Based on the results of these studies, it can be said that this does not apply to the efficiency of environmental policy.

Lastly, the sources of deadweight loss were assessed. From a technical point of view, deadweight loss may arise from incorrect resource allocations. In particular, we looked for higher sums dedicated to solving problems that are less severe than others. To trace such situations in EU countries, Table 2 was prepared with the “target” values of certain environmental pressures and public expenditures and then compared them with the real values. The target is a value that a country should achieve to be fully efficient. In the case of some countries, it's noticeable which environmental issues were targeted in an inefficient way. In Austria, Malta, Italy, and Slovenia, we can see high inefficiencies in soil erosion prevention. Italy, Germany, and Luxembourg are problematic with the consumption of inorganic fertilisers (phosphorus and nitrogen respectively). Germany, Slovenia, Austria, and Luxembourg are ineffective in decreasing ammonia emissions. In general, Malta needs to catch up in almost all kinds of emission pressures. Cyprus, Ireland, Germany, and Belgium are particularly weak in GHG emissions from agriculture. Pollution abatement is the most inefficient in the UK, Luxembourg, Belgium, and Czechia. Finally, the efficiency of biodiversity conservation should be a major concern in Austria. On average, the highest ratio was identified for soil erosion, air pollution, and ammonia emission, while the highest share of public expenditures was allocated to waste and wastewater management. Pollution abatement absorbed approximately 10% of funds, and erosion prevention spending has not even been specified in statistics. Hence, we can conclude that incorrect resource allocation might be one of the sources of deadweight loss.

Table 2 includes only countries where VRS DEA inefficiency in any of the assessed years was identified. It is possible to formulate direct recommendations for what type of policy should be given more attention with spending/effects ratio. More problematic is the situation of eight countries which have been a best practices (Denmark, Estonia, Spain, Latvia, Lithuania, Hungary, Finland, and Sweden). Finding recommendations for them is less straightforward, but necessary, as long as the bias-corrected DEA analysis found in those countries, deadweight loss accounted for about 25%. First of all, we may look at the trends in TFP changes. From that, we see a case of Lithuania, Estonia, Finland, and Sweden which, despite remaining at the frontier, worsened their performance. A common



**Table 2**

Sources of deadweight loss in environmental policy in EU countries in 2005–2016.

	outputs									inputs	
	Soil erosion by water	Consumption of inorganic fertilizers: Nutrient: Phosphorus	Consumption of inorganic fertilizers: Nutrient: Nitrogen	Ammonia emissions from agriculture	Greenhouse gas emissions - agriculture	Air pollution (non-methane volatile organic compounds)	Air pollutants (Particulates < 2,5 µm)	Air pollutants (Particulates < 10 µm)	Common farmland bird index 2000 = 100	CAP GREEN BOX	General expenditures
	ratio of target value to real value										
Luxembourg	2.56	1.08	2.00	2.37	2.24	3.26	2.02	1.97	1.10	1.00	1.01
Malta	15.96	1.17	1.65	11.11	4.74	29.44	10.07	11.25	1.09	1.14	1.00
Austria	18.10	1.07	1.08	2.34	1.77	2.08	1.09	1.10	1.37	1.18	1.00
Ireland	1.99	1.30	1.55	1.97	2.34	1.34	1.05	1.11	1.00	1.00	1.01
Slovenia	7.28	1.35	1.18	2.56	1.73	1.86	1.91	1.46	1.17	1.14	1.00
Italy	11.19	3.09	1.07	2.14	1.58	3.64	2.06	1.57	1.03	1.00	1.00
UK	4.34	1.07	1.28	1.02	1.44	4.27	2.01	1.94	1.03	1.00	1.03
Germany	2.20	1.29	2.00	3.07	1.88	2.67	1.20	1.36	1.02	1.00	1.00
Czechia	2.31	1.03	1.67	1.38	1.30	2.28	1.62	1.42	1.11	1.00	1.01
Slovakia	3.71	1.06	1.67	1.48	1.04	1.69	1.81	1.49	1.12	1.05	1.00
Belgium	1.55	1.08	1.51	1.76	2.35	2.01	1.89	1.72	1.04	1.00	1.00
France	2.09	1.23	1.33	1.33	1.25	1.01	1.07	1.00	1.01	1.00	1.17
Netherlands	1.00	1.26	1.36	1.44	1.49	1.59	1.40	1.42	1.06	1.00	1.12
Cyprus	2.74	1.41	1.30	2.23	2.07	1.57	1.01	1.06	1.09	1.03	1.00
Poland	1.31	1.30	1.23	1.25	1.14	1.31	1.26	1.31	1.03	1.00	1.00
Greece	1.08	1.00	1.01	1.00	1.04	1.05	1.01	1.03	1.03	1.01	1.00
Portugal	1.18	1.07	1.01	1.04	1.06	1.11	1.07	1.09	1.00	1.00	1.00
Average	4.74	1.29	1.41	2.32	1.79	3.66	1.97	1.96	1.08	1.03	1.02

Source: own study based on Eurostat

pattern for all of them is a general low pressure on environment and decrease in expenditures (inputs). Their case might suggest that expenditure on maintaining the quality of the environment is now less important than expenditure on improving it. The other four countries (Hungary, Denmark, Latvia, and Spain), where deadweight loss was kept on the lowest possible level, managed to improve environment quality in the most budget-efficient way. At the same time, the index of environmental pressure remained almost unchanged in Latvia, and worsened in Hungary, which may suggest that the environmental policy in those countries was too “budget-oriented”.

The results of this part of the analysis identifies the recommendations to improve the efficiency of environmental policy in those particular countries. Hence, these findings might have potential value for managers and policymakers (Jiang et al., 2020) for the allocation of funds to environmental policy.

Comparing results to the studies cited before, we can conclude that the inefficiency level of EU countries' environmental policy (i.e., deadweight loss) is relatively higher than what is reported in different regions of the world. Meleddu and Pulina (2018) used full and partial frontier data envelopment analysis (DEA), the Malmquist productivity index, and post-DEA. In this study, a specific group of regions outperformed for air and water intervention while the reverse outcome is obtained for biodiversity. The findings also showed a rather low technological change, especially for biodiversity. The latter is also the case in our study. The post-DEA in the cited study indicated that an increase in tourism and agricultural activity exerts a negative impact on the public spending efficiency (air and water policy), while it has a positive influence on biodiversity. This study supports this conclusion in the case of Italy and Malta. These countries have a relatively high share of GDP in the tourism sector and low efficiency of environmental policy. Spain, Cyprus, and Greece contradict this rule. Findings are also in line with the cited article

when it comes to the role of agricultural sector in shaping efficiency in environmental policy. Central-Eastern European countries, which have a relatively big share of UAA in non-urban areas and a large agricultural contribution to the national economy, perform better in environmental spending. On the other hand, Wang (2018) found defects in the fiscal spending on environmental protection using DEA model and Tobit regression in Central China from 2007 to 2015. Among the factors that influenced the efficiency of fiscal spending on environmental protection, he identified GDP per capita as a positive impact and the level of urbanization and industrialization as a negative impact. These findings are not confirmed by this analysis to the extent that GDP evidently is not a determinant factor for deadweight loss in environmental policy. However, based on the results of this analysis, we can also conclude on the negative impact of the urbanization.

Finally, it is important to remember that global trends of environmental degradation show that the latter currently accelerates advocating the need to increase expenditures on protection of natural resources. There is strong evidence to support this thesis reported in IPBES Global Assessment Summary for Policymakers (2019) which summarizes the 1500-page report, acclaimed by the New York Times as “the most exhaustive look yet at the decline in biodiversity across the globe and the dangers that creates for human civilization” (Plumer, 2019). Firstly, the negative effects of human activity on the biosphere are amassing, especially with regard to the bio-diversity: “The biosphere, upon which humanity as a whole depends, is being altered to an unparalleled degree across all spatial scales. Biodiversity – the diversity within species, between species and of ecosystems – is declining faster than at any time in human history ... The global rate of species extinction is already at least tens to hundreds of times higher than the average rate over the past 10 million years and is accelerating” (IPBES, 2019, p. 3,10). Secondly, nature

contributions to people, which together embody biodiversity and ecosystem functions and services, are also deteriorating world-wide. Global trends in the capacity of nature to contribute to good quality of life from 1970 to the present show a decline for 14 of the 18 categories (IPBES, 2019, p.10). These remarks justify to some extent deadweight loss, increasing in some countries in assessed period. It may be the case there, that environmental pressure increases, regardless financial efforts to lower it.

## 5. Conclusions

Results of this study may lead to more general EU-wide recommendations. First, it would be promoting innovative policy tools, which may decrease deadweight loss in the countries lagging in this manner. Calculated Malmquist TFP index close to one suggests stagnation in this field in the analysed period. After decomposition, it turned out to be an effect of relatively slow technological progress (average yearly growth of 0.86%) and lags in its implementation in less efficient countries (average yearly efficiency change of  $-0.98\%$ ).

The second recommendation is to maintain attention to the issue of soil erosion which seems to generate the greatest deadweight loss, and is still very poorly recognized, as evidenced by, for example, the poor availability of data in this area. Policymakers should also struggle with a low technological change for biodiversity. Finally, in view of the limited progress in those areas, perhaps more emphasis should be placed on evaluation of the deadweight loss of environmental projects co-financed from EU funds. This could accelerate the widespread use of good practices aimed at more efficient spending of resources on environmental protection.

Thirdly, a serious concern of environmental policy is a mismatch of the allocation of environmental funds and real environmental burdens. Incorrect resource allocation is a major source of deadweight loss. For instance, in Austria, Malta, Italy, and Slovenia, it caused inefficiencies in soil erosion prevention,

and, in Italy, Germany, and Luxembourg, problems with the overconsumption of inorganic fertilisers. In Cyprus, Ireland, Germany, and Belgium, GHG emissions from agriculture have been neglected; and the inefficiency of biodiversity conservation should be a major concern in almost all European countries.

Finally, it should be emphasized that the efficiency of spending is only a prerequisite for successful change in the policy. A sufficient condition for efficiency that ought to be fulfilled is a simultaneous improvement, or at least a lack of decline, in environmental prospects.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## CRediT authorship contribution statement

**Bazyli Czyżewski:** Conceptualization, Methodology, Supervision, Writing - review & editing. **Anna Matuszczak:** Investigation, Validation, Visualization. **Jan Polcyn:** Data curation, Resources. **Katarzyna Smędzik-Ambroży:** Writing - original draft, Writing - review & editing. **Jakub Stanisławski:** Formal analysis, Software, Writing - review & editing.

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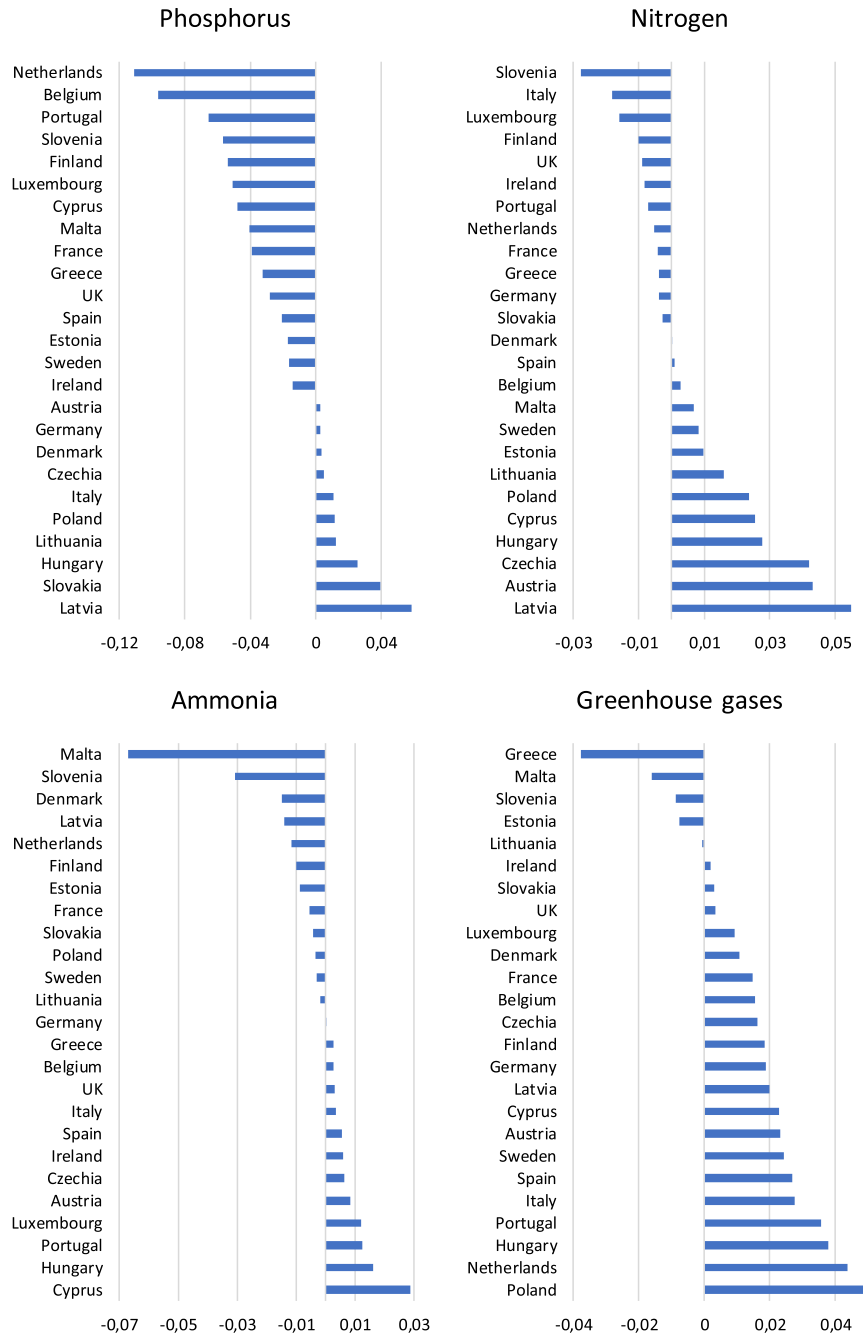
## Appendix

**Table A.1**

Average values for the components of the Composite Index of Environmental Prospects in 2004–2016

Countries	Soil erosion by water tonnes per ha	Phosphorus kg per ha	Nitrogen kg per ha	Ammonia kg per ha	Greenhouse gases kg per ha	Air pollution kg per ha	Air pollutants (2,5) kg per ha	Air pollutants (10) kg per ha	Bird species 2000 = 100
Belgium	1.2	4.7	105.9	45.5	7744.0	60.8	12.8	16.8	78.4
Czech Republic	1.6	4.9	83.0	17.0	2060.9	35.8	6.4	8.5	84.5
Denmark	0.5	4.6	75.1	28.1	4080.7	29.1	5.6	8.3	84.0
Germany	1.2	7.1	101.5	39.9	3935.7	37.4	3.7	7.1	88.7
Estonia	0.2	3.5	32.0	10.8	1330.3	6.5	2.8	4.7	87.7
Ireland	1.1	7.5	75.2	24.1	4315.0	16.3	2.8	5.2	98.0
Greece	4.2	3.9	27.2	8.2	2345.5	19.9	3.7	7.0	0.7
Spain	3.7	6.5	34.1	15.7	1368.2	17.2	3.6	5.8	81.5
France	2.2	7.7	76.4	22.1	2777.2	14.0	3.5	5.1	92.3
Italy	8.3	16.5	45.5	27.3	2364.5	47.3	7.5	9.0	86.5
Cyprus	2.9	9.4	62.3	36.3	4882.8	18.8	2.5	4.5	91.1
Latvia	0.3	4.3	31.2	8.2	1372.7	8.4	3.8	5.3	109.8
Lithuania	0.5	6.0	49.8	9.5	1597.1	10.7	1.3	2.5	78.3
Luxembourg	2.1	4.8	105.8	42.3	5087.9	73.0	10.4	15.0	90.8
Hungary	1.6	5.4	56.2	12.1	1179.0	16.3	5.3	7.8	80.1
Malta	6.0	4.3	62.6	141.0	7115.9	270.4	44.3	75.4	85.9
Netherlands	0.3	5.1	123.0	60.7	10,779.7	98.6	10.3	18.2	76.3
Austria	7.3	4.9	38.8	22.5	2662.8	18.7	2.6	4.3	73.0
Poland	0.9	10.7	69.8	17.9	2160.7	20.7	5.3	9.7	88.7
Portugal	2.2	6.0	29.0	10.9	1886.3	19.5	6.2	9.9	118.0
Slovenia	7.4	8.2	49.0	30.5	3085.0	20.8	6.9	7.8	90.7
Slovakia	2.1	5.2	69.6	15.1	1543.3	18.8	6.3	7.9	93.6
Finland	0.1	5.9	64.4	13.2	2940.0	3.5	0.7	1.2	98.7
Sweden	0.4	4.0	54.7	16.2	2354.1	4.7	0.6	1.1	81.8
United Kingdom	2.1	5.2	59.2	13.5	2630.3	54.5	6.6	10.2	88.1
mean	2.42	6.25	63.25	27.54	3343.98	37.67	6.62	10.33	85.09
std. dev.	2.37	2.71	25.58	26.62	2267.87	52.58	8.24	13.92	19.80

Source: Eurostat



**Fig. A1.** Compound annual rate of change of the Composite Index of Environmental Prospects components in EU-25 in years 2005–2016. Source: own study based on Eurostat

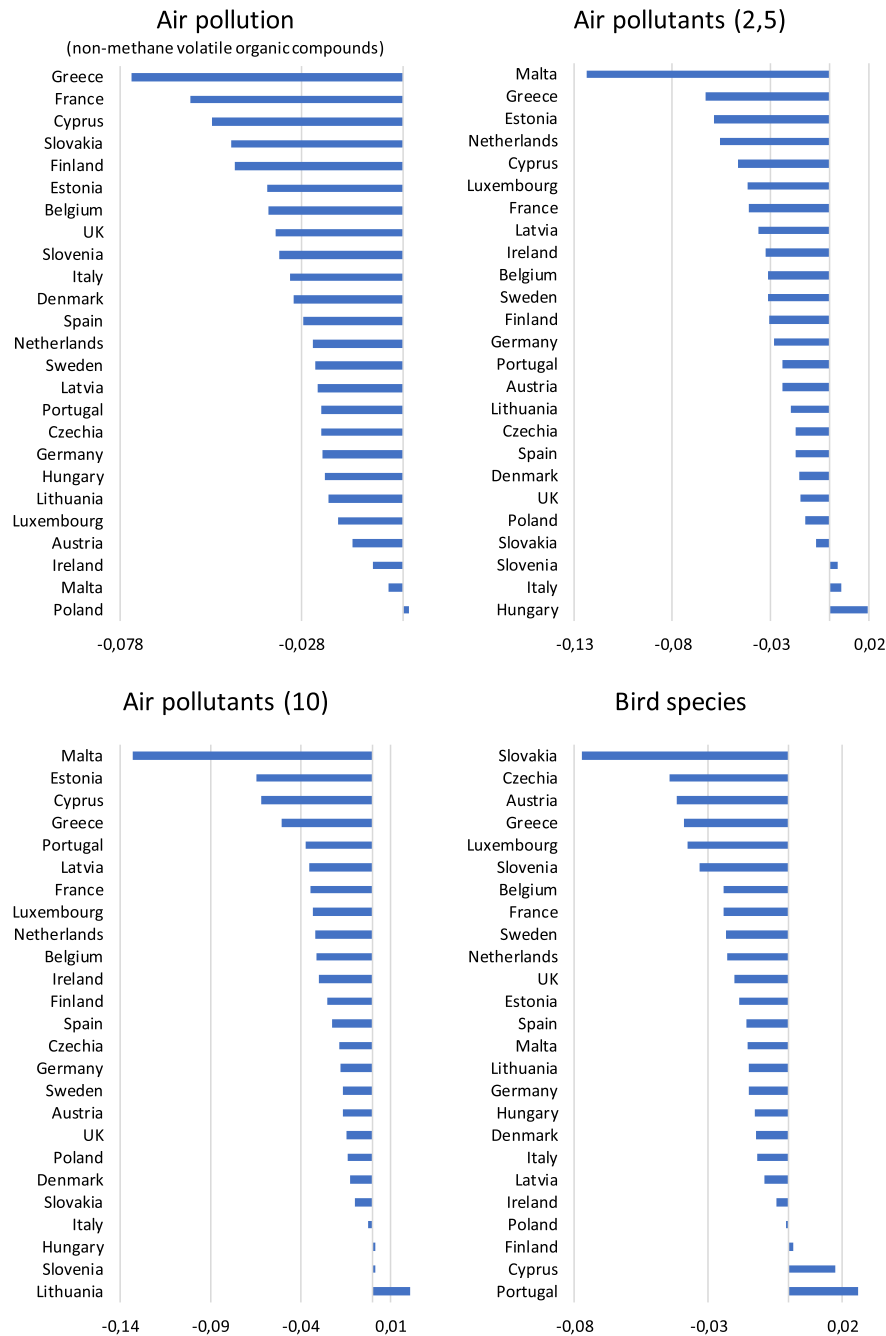


Fig. A1. (continued).

## References

- Adam, A., Delis, M., Kamas, P., 2011. Public sector efficiency: leveling the playing field between OECD countries. *Publ. Choice* 163–183. <https://doi.org/10.1007/s11127-009-9588-7>.
- Adam, A., Tsarsitalidou, S., 2019. Environmental policy efficiency: measurement and determinants. *Econ. Govern.* 20, 1–22. <https://doi.org/10.1007/s10101-018-0219-y>.
- Afonso, A., Schuknecht, L., Tanzi, V., 2005. Public sector efficiency: an international comparison. *Publ. Choice* 123, 321–347. <https://doi.org/10.1007/s11127-005-7165-2>.
- Becker, Ch., 2012. *Sustainability Ethics and Sustainability Research*. Springer Science+Business Media B.V. <https://doi.org/10.1007/978-94-007-2285-9>.
- Bogetoft, P., Otto, L., 2018. *Benchmarking with DEA and SFA*, first ed. Springer-Verlag, New York.
- Chung, Y.H., Färe, R., Grosskopf, S., 1997. Productivity and undesirable outputs: directional distance function approach. *J. Environ. Manag.* 51, 229–240. <https://doi.org/10.1006/jema.1997.0146>.
- Charnes, A., Cooper, W.W., Rhodes, E., 1978. Measuring the efficiency of decision making units. *Eur. J. Oper. Res.* 2, 429–444. <https://www.sciencedirect.com/science/article/abs/pii/0377221778901388>.
- Csutora, M., 2011. From eco-efficiency to eco-effectiveness? The policy-performance paradox. *Soc. Econ.* 33, 161–188. <https://akademai.com/doi/pdf/10.1556/SocEc.33.2011.1.12>.
- Czyżewski, B., Kryszak, Ł., 2018. Impact of different models of agriculture on greenhouse gases (GHG) emissions: A sectoral approach. *Outlook Agric.* 47 (1), 68–76. <https://doi.org/10.1177/0030727018759092>.
- Deng, H., Yeh, C.H., Willis, R.J., 2000. Inter-company comparison using modified TOPSIS with objective weights. *Comput. Oper. Res.* 27, 963–973.
- Diakoulaki, D., Mavrotas, G., Papayannakis, L., 1995. Determining objective weights in multiple criteria problems - the critic method. *Comput. Oper. Res.* 22, 763–770. [https://doi.org/10.1016/0305-0548\(94\)00059-H](https://doi.org/10.1016/0305-0548(94)00059-H).
- EUFADN, 2019. Public data. [https://ec.europa.eu/agriculture/rica/database/database\\_en.cfm](https://ec.europa.eu/agriculture/rica/database/database_en.cfm). (Accessed 24 June 2019).



- European Commission, 2018. Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the financing, management and monitoring of the common agricultural policy and repealing Regulation (EU) No 1306/2013. <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2018%3A393%3AFIN>. (Accessed 31 May 2019).
- European Environment Agency, 2017. Environmental indicator report 2018 in support to the monitoring of the Seventh environment action Programme. EEA Report No 19/2018. <https://www.eea.europa.eu/publications/environmental-indicator-report-2018>. (Accessed 24 June 2019).
- European Parliament, Council of the European Union, 2013. Decision No 1386/2013/EU of the European parliament and of the council of 20 november 2013 on a general union environment action Programme to 2020 "living well, within the limits of our planet". <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32013D1386>. (Accessed 22 June 2019).
- Eurostat, 2018. National expenditure on environmental protection. [https://ec.europa.eu/eurostat/statistics-explained/index.php/Environmental\\_protection\\_expenditure\\_accounts](https://ec.europa.eu/eurostat/statistics-explained/index.php/Environmental_protection_expenditure_accounts). (Accessed 1 January 2020).
- Fare, R., Grosskopf, S., Norris, M., Zhang, Z., 1994. Productivity growth, technical progress and efficiency change in industrialised countries. *Am. Econ. Rev.* 84, 66–83.
- Fellmann, T., Witzke, P., Weiss, F., Van Doorslaer, B., Drabik, D., Huck, I., Salputra, G., Jansson, T., Leip, A., 2018. Major challenges of integrating agriculture into climate change mitigation policy frameworks. *Mitig. Adapt. Strategies Glob. Change* 23, 451–468. <https://doi.org/10.1007/s11027-017-9743-2>.
- Gass, V., Schmidt, J., Strauss, F., Schmid, E., 2013. Assessing the economic wind power potential in Austria. *Energy Pol.* 53, 323–330.
- Grzelak, A., Guth, M., Matuszczak, A., Czyżewski, B., Brelik, A., 2019. Approaching the environmental sustainable value in agriculture: How factor endowments foster the eco-efficiency. *J. Clean. Prod.* 241, 1–9. <https://doi.org/10.1016/j.jclepro.2019.118304>.
- Harberger, A.C., 1964. The measurement of waste. *Am. Econ. Rev.* 54, 58–76. <https://www.jstor.org/stable/1818490>. (Accessed 1 January 2020).
- Holland, R.A., Scott, K., Hinton, E.D., Austen, M., Barrett, J., et al., 2016. Bridging the gap between energy and the environment. *Energy Pol.* 92, 181–189.
- Huang, Y., Dominici, F., Bell, M., 2005. Bayesian hierarchical distributed lag models for summer ozone exposure and cardio-respiratory mortality. *Environmetrics* 16, 547–562. <https://doi.org/10.1002/env.721>.
- IPBES, 2019. Global assessment summary for policymakers. <https://ipbes.net/news/ipbes-global-assessment-summary-policymakers-pdf>. (Accessed 11 January 2020).
- Jiang, H., Hua, M., Zhang, J., Cheng, P., Ye, Z., Huang, M., Jin, Q., 2020. Sustainability efficiency assessment of wastewater treatment plants in China: a data envelopment analysis based on cluster benchmarking. *J. Clean. Prod.* 244, 118729. <https://doi.org/10.1016/j.jclepro.2019.118729>.
- Lee, K.W., Kim, J.H., Sung, T., 2018. A test of fiscal sustainability in the EU countries. *Int. Tax Publ. Finance* 25, 1170–1196. <https://doi.org/10.1007/s10797-018-9488-1>.
- Ma, X., Bi, L., Wang, Z.A., 2016. Effect of air pollution on provincial fiscal investment for environmental protection in China. *Nat. Environ. Pollut. Technol.* 15, 27–34. [http://www.neptjournal.com/upload-images/NL-55-6-\(4\)G-74.pdf](http://www.neptjournal.com/upload-images/NL-55-6-(4)G-74.pdf). (Accessed 1 January 2020).
- Meleddu, M., Pulina, M., 2018. The efficiency of the public intervention on the environment: evidence based on non-parametric and parametric approaches. *J. Clean. Prod.* 183, 744–759. <https://doi.org/10.1016/j.jclepro.2018.02.134>.
- Mikulic, D., Bakaric, I.R., Slijepcevic, S., 2016. The economic impact of energy saving retrofits of residential and public buildings in Croatia. *Energy Pol.* 96, 630–644. <https://doi.org/10.1016/j.enpol.2016.06.040>.
- Moutinho, V., Madaleno, M., Robaina, M., 2017. The economic and environmental efficiency assessment in EU cross-country: evidence from DEA and quantile regression approach. *Ecol. Indic.* 78, 85–97. <https://doi.org/10.1016/j.ecolind.2017.02.042>.
- Musgrave, R.A., 2008. Public finance. In: Durlauf, S., Blume, L.E. (Eds.), *The New Palgrave Dictionary of Economics*, second ed. Palgrave Macmillan, London.
- Nagoev, A.B., Rokotyanskaya, V.V., Batova, B.Z., Bischeikova, F.R., Hokonova, M.Z., 2018. Mobilization of innovation and investment resources for environmental management in Russian federation regions. *Environ. Qual. Manag.* 27, 47–54. <https://doi.org/10.1002/tqem.21564>.
- Office for National Statistics (ONS), 2018. UK air pollution removal: how much pollution does vegetation remove in your area? <https://www.ons.gov.uk/economy/environmentalaccounts/articles/ukairpollutionremovalhowmuchpollutiondoesvegetationremoveinyourarea/2018-07-30>. (Accessed 10 March 2019).
- Plumer, B., 2019. Humans are speeding extinction and altering the natural world at an 'unprecedented' pace. *New York Times*, May 6. <https://www.nytimes.com/2019/05/06/climate/biodiversity-extinction-united-nations.html>. (Accessed 11 January 2020).
- Poldrugovac, K., Tekavcic, M., Jankovic, S., 2016. Efficiency in the hotel industry: an empirical examination of the most influential factors. *Econ. Res.* 29, 583–597. <https://doi.org/10.1080/1331677X.2016.1177464>.
- Powell, H., Lee, D., Bowman, A., 2012. Estimating constrained concentration—response functions between air pollution and health. *Environmetrics* 23 (3), 228–237. <https://doi.org/10.1002/env.1150>.
- Rausch, S., Karplus, V.J., 2014. Markets versus regulation: the efficiency and distributional impacts of U.S. Climate policy proposals. *Energy J.* 35, 199–227. <https://doi.org/10.5547/01956574.35.S11.11>.
- Samoli, E., Zanbetti, A., Schwartz, J., Atkinson, R., LeTertre, A., Schindler, C., Perez, L., Cadum, E., Pekkanen, J., Pald, A., Touloumi, G., Katsouyanni, K., 2009. The temporal pattern of mortality responses to ambient ozone in the APHEA project. *J. Epidemiol. Commun. Health* 63, 960–966. <https://doi.org/10.1136/jech.2008.084012>.
- Sanz-Díaz, M.T., Velasco-Morente, F., Yñiguez, R., Díaz-Calleja, E., 2017. An analysis of Spain's global and environmental efficiency from a European Union perspective. *Energy Pol.* 104, 183–193. <https://doi.org/10.1016/j.enpol.2017.01.030>.
- Simar, L., Wilson, P.W., 1998. Sensitivity analysis of efficiency scores: how to bootstrap in nonparametric frontier models. *Manag. Sci.* 44, 49–61.
- Tone, K., 2003. Dealing with undesirable outputs in DEA: a Slacks-Based Measure (SBM) approach. GRIPS Research Report Series, 2003. [https://www.researchgate.net/publication/284047010\\_Dealing\\_with\\_undesirable\\_outputs\\_in\\_DEA\\_a\\_Slacks-Based\\_Measure\\_SBM\\_approach](https://www.researchgate.net/publication/284047010_Dealing_with_undesirable_outputs_in_DEA_a_Slacks-Based_Measure_SBM_approach).
- Töbelmann, D., Wendler, T., 2020. The impact of environmental innovation on carbon dioxide emissions. *J. Clean. Prod.* 244. <https://doi.org/10.1016/j.jclepro.2019.118787>.
- Vlontzos, G., Naviy, S., Manos, B.A., 2014. DEA approach for estimating the agricultural energy and environmental efficiency of EU countries. *Renew. Sustain. Energy Rev.* 40, 91–96. <https://doi.org/10.1016/j.rser.2014.07.153>.
- Wang, G., Cote, R., 2011. Integrating eco-efficiency and eco-effectiveness into the design of sustainable industrial systems in China. *Int. J. Sustain. Dev. World Ecol.* 18, 65–77. <https://doi.org/10.1080/13504509.2010.527459>.
- Wang, P., 2018. Analysis of the efficiency of public environmental expenditure based on data envelopment analysis (DEA)-Tobit model: evidence from Central China. *Nat. Environ. Pollut. Technol.* 17, 43–48.
- Wang, S., Ran, G., Wang, L., Shi, B., 2009. An evaluation on performance of rural eco-environment public expenditure of Chinese local governments: theoretical and empirical analysis. *Front. Earth Sci. China* 3, 431. <https://doi.org/10.1007/s11707-009-0059-8>.
- WHO, 2020. Mortality and burden of disease from ambient air pollution. [https://www.who.int/gho/phe/outdoor\\_air\\_pollution/burden\\_text/en](https://www.who.int/gho/phe/outdoor_air_pollution/burden_text/en). (Accessed 10 January 2020).
- Wilson, P.W., 2010. FEAR: frontier efficiency analysis with R. R package version 1.15. <http://media.clemson.edu/economics/faculty/wilson/Software/FEAR/FEAR-1.15/fear-user-guide.pdf>. (Accessed 1 January 2020).
- Yahaya, A., Nor, N.M., Habibullah, M.S., Ghani, J.A., Noor, Z.M., 2016. How relevant is environmental quality to per capita health expenditures? Empirical evidence from panel of developing countries. *SpringerPlus* 5, 925. <https://doi.org/10.1186/s40064-016-2505-x>.
- Yang, J., Zhang, B., 2018. Air pollution and healthcare expenditure: implication for the benefit of air pollution control in China. *Environ. Int.* 120, 443–455. <https://doi.org/10.1016/j.envint.2018.08.011>.
- Zafeiriou, E., Mallidis, I., Galanopoulos, K., Arabatzis, G., 2018. Greenhouse gas emissions and economic performance in EU agriculture: an empirical study in a non-linear framework. *Sustainability* 10 (11), 3837. <https://doi.org/10.3390/su10113837>.
- Zhou, Y., Kong, Y., Wang, H., Luo, F., 2020. The impact of population urbanization lag on eco-efficiency: a panel quantile approach. *J. Clean. Prod.* 244, 118664. <https://doi.org/10.1016/j.jclepro.2019.118664>.