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# EFFICIENCY EVALUATION OF HIGHER EDUCATION SECTOR IN EUROPE – WINDOW DEA BASED APPROACH

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## ABSTRACT

*The aim of this study is to evaluate relative efficiency of tertiary education in the period between 2013 and 2020. Since resources used for higher education are scarce and education is mostly publicly funded, it is important to use these resources as efficiently as possible. In this paper, DEA Window Analysis was used, which allows a dynamic evaluation and comparison of efficiency results over time. The empirical analysis is carried out on higher education systems of 30 European countries through eight-year long period. Two inputs (academic staff and general government expenditure on higher education) and four outputs (graduates, mobile students from abroad, citable documents and citations) were chosen as variables in an output-oriented 3-year window DEA model for the assessment of technical efficiency (TE) as well as pure technical (PTE) and scale efficiency (SE) as its components. The results show that efficiency varies across countries and over time. Overall efficiency peaked in 2016 and declines steadily thereafter. When analysing the sources of inefficiency, PTE as a measure of management performance is overall higher than SE as a measure of optimal production size until 2017, except for 2015 when it is slightly lower than SE. We can conclude that the source of inefficiency until 2017 is generally the non-optimal production size. From 2018, the situation changes and management performance becomes the main source of inefficiency. The results of this study may help policy makers in European countries in their efforts to increase the efficiency of higher education.*

***Key words:*** *Efficiency in Higher Education, Window Data Envelopment Anlysis, European Countries, public funding*

## 1. INTRODUCTION

Education is one of the most important factors for economic growth, employment and social inclusion and represents one of the strategic areas of interest for any country, as economic development largely depends on the quality of human capital (Chankseliani, Qoraboyev and Gimranova, 2021). Higher education, as well as research and innovation, which are closely related to it, are essential for the progress of individuals and society. The provision of highly skilled human capital has a direct positive impact on economic growth and increases prosperity (Arbula Blecich, 2020; Kruss, McGrath, 2015; Neamtu, 2015; European Commission, 2017). However, the economic shocks caused by the Covid 19 pandemic, energy crisis and inflation have highlighted the need to achieve education goals in the most efficient way possible, especially considering that education is largely funded with public money.

A renewed EU agenda for higher education as a key priority highlights effective and efficient systems that require targeted and balanced investments and strengthening links between education and research. It also highlights mobility as a priority for higher education systems (ENQUA 2017). Over time, new demands and challenges are being placed on higher education. Since 2019 and the outbreak of the global pandemic, higher education institutions have been forced to work in an online environment. This not only influences academic staff and the adaptation of pedagogical approaches, but also raises organisational issues as well as problems with potentially inadequate technical infrastructure (Edelhard Tømte, 2019; Selwyn, 2016).

In this research, the relative efficiency of the higher education systems of 30 European countries is compared over an eight-year period with the aim of identifying sources of inefficiency.This paper consists of 6 sections. After the Introduction, the rest of the paper is organized as follows. Section 2 presents the theoretical framework and literature review. Section 3 explaines the methodology used, i.e., data envelopment analysis, while Section 4 focuses on the model specification and data selection. Section 5 contains empirical research results and Section 6 concludes the paper.

## 2. THEORETICAL FRAMEWORK AND LITERATURE REVIEW

From the perspective of microeconomic production theory, the activities of an organisation are viewed primarily as a production process that transforms multiple inputs (e.g., capital and labour) into multiple outputs (products) (Salas-Velasco, 2020). Applied to educational production, this input-output approach provides a simplified conceptual framework that views higher education as a process that transforms educational inputs into educational outputs. Higher education institutions are multiproduct enterprises that use multiple inputs to produce multiple outputs (Arbula Blecich, 2020; Maral and Çetin, 2024). In this process of transforming inputs into outputs, it is important to first explain the concept of efficiency in the higher education system. Efficiency as a concept in economic analysis means that resources are not wasted in economic activities (Martínez-Campillo and Fernández-Santos, 2020). Generally, a distinction is made between internal and external efficiency. Internal efficiency or production efficiency refers to the way resources are used in production. Internal efficiency, in turn, can be technical or economic. Technical efficiency reflects an organisation's ability to produce maximum output with available set of inputs and technology. In assessing the efficiency of the higher education system, this means that if higher education institutions produce the best possible output with the available technology in a given period and if all available inputs and resources are used optimally, then the system is using scarce resources efficiently (Cossani et al., 2022). This, in turn, is production efficiency (or internal efficiency) from a technical perspective. External efficiency, on the other hand, often referred to as effectiveness, is when the goods and services produced efficiently in the economy are valued by society. In the case of higher education institutions, external efficiency means that the outcomes of educational processes benefit society. Therefore, higher education institutions must focus not only on the efficient use of resources, but also on the impact of the obtained outcomes (Salas-Velasco, 2020).

Performance evaluation of higher education systems is critical in assessing the extent to which resources provided to the higher education sector are used efficiently to achieve desired outcomes. However, evaluating the efficiency of higher education is not easy, as higher education institutions in higher education systems are multiproduct enterprises with complex production processes, and the perspective chosen depends on the objectives of the evaluation (Arbula Blecich, 2020; Bertoletti, and Johnes, 2021; Gul and Jamal, 2020; Palomares-Montero and García-Aracil, 2011).

There is an extensive literature, both nationally and internationally, on the analysis of efficiency in higher education using a nonparametric approach. Witte and López-Torres (2017); Fuentes et al. (2016) and Rodríguez-Cornejo (2013) made a compilation of previous research on this topic. The beginnings of research on relative efficiency in higher education are dated to the mid-1970s (Brovender, 1974; Verry and Layard, 1975; Tierney, 1980). These studies are specific in that only a single output was used. This proved problematic because higher education institutions produce many different outputs. James (1978) is one of the first authors to address this problem. In his study, he attempted to separate the costs of undergraduate study, graduate study, and research at the university. He concluded that undergraduate costs are overestimated if only one output is used and other outputs are ignored. One of the first efficiency studies to view higher education institutions as organizations that produce multiple outputs was conducted by Cohn, Rhine, and Santos (1989) on a sample of public and private higher education institutions in the United States. The study used three outputs (undergraduate students, graduate students, and scholarships for research) and one input (average college salary). The results showed that economies of scale have a significant impact at both public and private higher education institutions.

Andersson et al. (2017), De Witte and López-Torres (2017) and Maral and Çetin (2024) argue that efficiency in education is a topic of great interest to policy makers, educators, students and other stakeholders in education. In addition to the increased awareness of efficiency in the public sector, the rising cost of education could also be a reason for the increased interest in efficiency in education, as education is becoming more expensive on average than other goods.

Although most research uses HEIs, universities, or university departments as DMUs (Abd Aziz, Mohd Janor and Mahadi, 2013; Andersson and Sund, 2022; Arbula Blecich, 2020; Arbula Blecich and Tomas Žiković, 2016; Chen and Chang, 2021; Moreno-Gómez, Calleja-Blanco and Moreno-Gómez, 2020; Wolszczak-Derlacz, 2017), there are several studies that have evaluated the relative efficiency of higher education systems. An assessment of the relative efficiency of higher education at the level of EU countries has been conducted by Arbula (2012) and Aristovnik and Obadić (2011), Dincă et al. (2021), Stefanova and Velichkov (2020). Torres Samuel et al. (2020) used DEA to assess the efficiency of education and research in Latin American countries. In addition to assessing educational efficiency, they also assess R&D efficiency, since research is an important area for most academic institutions. The relative efficiency of R&D at the level of European countries was studied by Arbula Blecich (2021), Aristovnik (2014, 2012), Halaskova, Gavurova, Kocisova (2020), Lee and Park (2005), Wang and Huang (2007).

There are some logical problems associated with the use of input and output data that traditional models of DEA deal with. It is logical that outputs resulting from the use of inputs have some delay. Therefore, it is better to use one of the dynamic analyses. In this paper a window DEA was used to overcome this logical problem. Window Data Envelopment Analysis is a widely used method for dynamic performance evaluation of peer decision making units (DMUs). It is a nonparametric panel method based on the principle of moving averages. The efficiency measures are obtained by treating each DMU as a separate DMU in different periods. With this approach, the efficiency of different DMUs in different periods can be evaluated through a sequence of overlapping windows.

Sharifian, Ebrahimi, and Alimohammadlou (2017) used the window DEA, to evaluate the efficiency of 12 Shiraz University Colleges during 2009 – 2014. The results show that the proposed WDEA method with double frontier provides more accurate results compared to the traditional analysis. De Jorge Moreno et al. (2019) used data from Spanish public universities to evaluate their efficiency between the academic year 2008/9 and 2014/15. Two-window data envelopment analysis and intertemporal, non-radial, and radial analysis methods were compared to perform the analysis. The main results show a significant deterioration in the efficiency of universities from the academic year 2012/13. Guccio, Martorana, and Mazza (2017) used a DEA - window analysis to analyze the evolution of efficiency of Italian universities and to determine if the performance of Italian universities shows signs of convergence, especially between North and South. The research results suggest that the average performance of the last three years is very similar to that of the whole period and that the performance gap between the North and the South has remained essentially unchanged during this period. Kumar and Thakur (2019) developed a methodology to measure efficiency considering the influence of time using Dynamic DEA. The proposed model considers the time dimension in the link between input and output in dynamic production processes. With their work, they tried to develop a holistic approach for ranking higher education institutions. They tested their model on the sample of business schools in India. Costa, Ramos and Souza (2014) studied intertemporal productivity changes at federal institutions of higher education (IFES) from 2004 to 2008. The research results show that static frontiers underestimate institutional efficiency during the study period, suggesting that intertemporal frontiers are more accurate in calculating efficiency because they account for a variable association between inputs and outputs over time.

## 3. METHODOLOGY

DEA is a non-parametric method based on linear programing used for evaluation of the relative efficiency of homogeneous decision-making units (DMUs). It was originally introduced by Charnes, Cooper and Rhodes (1978) It is used for evaluation of relative efficiency of homogeneous decision making units (DMU) in a way that ratio between weighted inputs and weighted outputs is calculated for every single DMU. Result $\theta$ can vary between 0 and 1 where DMUs with $\theta = 1$ are 100% efficient relative to their peers, while result lower than 1 ($0 \leq \theta < 1$) indicates that DMUs are relatively inefficient. DMUs that are rated as relatively inefficient are compared to DMUs that are efficient compared to them. Relatively efficient DMUs are unable to increase any output, without simultaneously increasing any of their inputs or reducing any of the outputs remaining and vice versa, they are unable to reduce any input, without simultaneously reducing any of the outputs or increasing any of the remaining inputs.

DEA is widely used tool. Primarily it was developed for evaluations of relative efficiency in public sector, but its advantages were quickly recognized and its application has been extended as well on efficiency evaluations in non private sector. Advantages of DEA arise from its ability to accommodate multiple inputs and multiple outputs that can be expressed in different units. In addition, explicit specification between the inputs and the outputs is not required. Further to this, DEA measures relative, not absolute efficiency which means that DMUs function as peers to each other. DMUs that are evaluated as relative efficient are used as benchmark for the relative inefficient DMUs. DEA also has several limitations. Discriminatory power of this method can be limited when a large number of inputs and outputs in regards to number of DMUs are introduced in the model. In addition, results obtained using this method are highly sensitive on selection of inputs and outputs. When using this method carefully and selecting only fundamental input and output variables, most limitations can be overcome.

Before we proceed with explanation of Window DEA model that is used in this paper, basic efficiency concepts will be further elaborated. In terms of efficiency analysis, we distinguish three basic concepts: Technical efficiency (TE), pure technical efficiency (PTE) and scale efficiency (SE). TE gives us information about efficiency of utilization of resources and capability of their allocation for each DMU. It is a measure that provides us with the information about the ability of a certain DMU to transform multiple inputs into multiple outputs compared to its maximum potential. Maximum potential of a DMU presents its efficiency frontier. Usually under TE is assumed CRS (constant returns to scale) efficiency, sometimes also referred as overall technical efficiency because, besides technical efficiency, it measures loss in efficiency that occurs when the DMU does not operate in its most productive scale size. Building on this, TE can be decomposed into two components, PTE and SE that gives us insight into source of inefficiencies. Unlike TE, PTE is affected by management, technology and other exogenous factors why it is treated as a measure of managerial performance. PTE implies VRS (variable returns to scale) efficiency. SE can be calculated by calculating the ratio between TE and PTE, i.e. CRS and VRS efficiency scores. SE gives an information about optimal size of resources, i.e. optimal size of production. DMU is scale efficient if it operates under CRS (Kumar, Gulati, 2008). Variable return to scale measures only technical efficiency, while the constant returns to scale measures technical efficiency as well as efficiency loss when a DMU does not operate in its most productive scale size. In this paper, TE, PTE and SE are computed on two Window DEA models. Beside model type, it is also important to choose model orientation. Which model orientation will be chosen depending on the goal of DMUs. Since we observe relative efficiency of national higher education systems that, with limited resources, want to achieve as much output as possible, output orientation is used.

For a long time, main concern regarding DEA was its inability to measure intertemporal changes in efficiency. Window DEA analysis, among other methods, responded these concerns and represents a representative method for measuring dynamic changes in DMUs efficiency. Unlike standard DEA models (CCR and BCC model) that evaluate relative efficiency in a single period, window DEA analysis is based on a dynamic perspective where the same DMU is treated as completely different DMU in different period. This allows us to use relatively more input and output variables regards to number of DMUs compared to standard models. It enhances the discriminating power when we have a limited number of DMUs (Halkos, Tzeremes, 2009). Additionally, this enables comparison of each DMUs efficiency in a single period with its behaviour in other periods. In order to observe and describe the dynamic change of the efficiency of selected DMUs, window DEA operates based on moving average method which means that when the chosen set window slides for one period, the first (oldest) period of each window will be substituted with the first to the next period.

A set of DMUs N ($n = 1,\dots N$) use r inputs to produce s outputs in in T ($t = 1,\dots T$) period of time. $DMU_n^t$ shows the level of input or output for DMU n in t period of time. Input vector ($X_n^t$) and output vector ($Y_n^t$) are presented as (Jia and Yuan, 2017):

$$X_n^t = \begin{bmatrix} x_n^{1t} \\ \vdots \\ x_n^{rt} \end{bmatrix} \qquad Y_n^t = \begin{bmatrix} y_n^{1t} \\ \vdots \\ y_n^{st} \end{bmatrix}$$

If we consider that the window starts at the time point of k ($1 \le k \le T$), and the window lenght is p ($1 \le w \le T - k$), then input ($X_{kw}$) and output ($Y_{kw}$) matrix of each window (kw) are presented as (Jia and Yuan, 2017):

$$X_{kw} = \begin{bmatrix} x_1^k & x_2^k & \dots & x_N^k \\ x_1^{k+1} & x_2^{k+1} & \dots & x_N^{k+1} \\ \vdots & \vdots & \ddots & \vdots \\ x_1^{k+w} & x_2^{k+w} & \dots & x_N^{k+w} \end{bmatrix} \qquad Y_{kw} = \begin{bmatrix} y_1^k & y_2^k & \dots & y_N^k \\ y_1^{k+1} & y_2^{k+1} & \dots & y_N^{k+1} \\ \vdots & \vdots & \ddots & \vdots \\ y_1^{k+w} & y_2^{k+w} & \dots & y_N^{k+w} \end{bmatrix}$$

In this paper window data envelopment analysis was performed on a 8-years data pool from 30 European countries to detect efficiency trends of their higher education systems over time.

$$w = k - p + 1$$

$$\text{Numberof “different” DMUs (data points)} = n \cdot p \cdot w$$

When it comes to selection of window width, Asmild et al. (2004) argue that it should be small enough to allow the fair comparison over time, but in the same time, large enough to have sufficient size of the sample. In this research, results are presented on 3-year window, so we have six windows: window 1 (2013, 2014, 2015), window 2 (2014, 2015, 2016), window 3 (2015, 2016, 2017), window 4 (2016, 2017, 2018), window 5 (2017, 2018, 2019) and window 6 (2018 2019, 2020). Cooper, Seiford, and Tone (2007) proposed a formula that can be used to determine the number of data points.

where:
n = number of DMUs (in our case no. of countries),
p = length of window,
w = number of windows and
k = number of periods

If we take 8-year period (2013–2020) and 3-year length of window (Sharifian, Ebrahimi and Alimohammadlou, 2017), we can calculate number of data points as it follows:

$$w = 8 - 3 + 1 = 6$$

$$\textit{Numberof “different” DMUs (data points)} = 30 \cdot 3 \cdot 6 = 540$$

This means that in this research there are 540 different data points, so we can accommodate more input and output variables without losing discriminatory power than with standard, non-dynamic models. A problem that arises with DEA is omitted variables. Hassan (2008) conducted a simulation study and found that omitting relevant variables leads to inconsistent efficiency measures.

## 4. EMPIRICAL DATA AND ANALYSIS

In this paper, two inputs (Academic staff (total) and General government expenditure on HE (mil.EUR)) and four outputs (Graduates (total), Mobile students from abroad (total), Citable documents and Citations) are used. Data is collected via Eurostat (Academic staff (total), General government expenditure on HE (mil.EUR), Graduates (total), Mobile students from abroad (total)) and via Sci mago Journal and Country rank (Citable documents, Citations).

Academic staff represents one of the most important inputs to teaching and research and as such is strongly represented in the literature and considers all teaching staff involved in the teaching and research process (Abd Aziz Mohd Janor and Mahadi, 2013; Andersson and Sund (2022), Arbula Blecich, 2020; Liu and Tsai, 2014, Wolszczak-Derlacz and Parteka, 2011). The next input is the university’s financial resources, which are measured by general government expenditure on higher education (Agasisti et al., 2020; Agasisti and Johnes 2009; Agasisti and Perez-Esparrells 2010). This variables are often used in research on the efficiency of higher education. Number of students that graduated is a typical output variable of higher education (Sharifian, Ebrahimi and Alimohammadlou, 2018; Sagarra, Agasisti and Mar Molinero, 2017, Agasisti and Pérez-Esparrells, 2010; Johnes, 2008; Wolszczak-Derlacz and Parteka, 2011).

Mobile students from abroad refers to the number of incoming students, which provides information about the recognisability of institutions (Arbula Blecich, 2020). Academic stuff is, besides teaching, highly involved in research and development, specifically in production of scientific and professional papers. Therefore, citable documents are one of outputs that shows us ability of academic stuff for publication (Agasisti et al., 2020; Andersson and Sund, 2022; Guccio, Martorana and Mazza, 2017). Citations on the other hand are im portant indicator of quality of scientific and professional work (De Jorge Moreno et al., 2018). Software DEA Solver Pro 11.0 is used in the analysis.

When using DEA, positive correlation is mandatory in the selection of appropriate inputs and outputs, as is the fact that all input and output variables must have non-negative values. The input and output correlations for each observed year are shown in Table 1.

Table 1. Input and output correlation coefficients for all variables (2013-2020)

| Correlation (Time period = 2013) | | | | | | |
|---|---|---|---|---|---|---|
| | Academic staff (total) | General government expenditure on HE (mil.EUR) | Graduates (total) | Mobile students | Citable documents | Citations |
| Academic staff (total) | 1 | 0,910533253 | 0,730595997 | 0,652881293 | 0,867401089 | 0,817675007 |
| General government expenditure on HE (mil.EUR) | 0,910533253 | 1 | 0,763844449 | 0,786653684 | 0,92337457 | 0,916261326 |
| Graduates (total) | 0,730595997 | 0,763844449 | 1 | 0,835919227 | 0,875755484 | 0,823903917 |
| Mobile students from abroad (total) | 0,652881293 | 0,786653684 | 0,835919227 | 1 | 0,896457079 | 0,915766396 |
| Citable documents | 0,867401089 | 0,92337457 | 0,875755484 | 0,896457079 | 1 | 0,987230537 |
| Citations | 0,817675007 | 0,916261326 | 0,823903917 | 0,915766396 | 0,987230537 | 1 |
| Correlation (Time period = 2014) | | | | | | |
| | Academic staff (total) | General government expenditure on HE (mil.EUR) | Graduates (total) | Mobile students | Citable documents | Citations |
| Academic staff (total) | 1 | 0,902965179 | 0,743741925 | 0,663367049 | 0,866766337 | 0,821328463 |
| General government expenditure on HE (mil.EUR) | 0,902965179 | 1 | 0,795965165 | 0,82859362 | 0,931485496 | 0,928173106 |
| Graduates (total) | 0,743741925 | 0,795965165 | 1 | 0,842422785 | 0,892089824 | 0,840872086 |
| Mobile students from abroad (total) | 0,663367049 | 0,82859362 | 0,842422785 | 1 | 0,898880464 | 0,915629651 |
| Citable documents | 0,866766337 | 0,931485496 | 0,892089824 | 0,898880464 | 1 | 0,987864854 |
| Citations | 0,821328463 | 0,928173106 | 0,840872086 | 0,915629651 | 0,987864854 | 1 |
| Correlation (Time period = 2015) | | | | | | |
| | Academic staff (total) | General government expenditure on HE (mil.EUR) | Graduates (total) | Mobile students | Citable documents | Citations |
| Academic staff (total) | 1 | 0,909343054 | 0,743736304 | 0,674080827 | 0,853087831 | 0,810484123 |
| General government expenditure on HE (mil.EUR) | 0,909343054 | 1 | 0,800601296 | 0,832574749 | 0,920866765 | 0,920469539 |
| Graduates (total) | 0,743736304 | 0,800601296 | 1 | 0,853051194 | 0,902182116 | 0,848987516 |
| Mobile students from abroad (total) | 0,674080827 | 0,832574749 | 0,853051194 | 1 | 0,90942208 | 0,922144437 |
| Citable documents | 0,853087831 | 0,920866765 | 0,902182116 | 0,90942208 | 1 | 0,987040666 |
| Citations | 0,810484123 | 0,920469539 | 0,848987516 | 0,922144437 | 0,987040666 | 1 |
| Correlation (Time period = 2016) | | | | | | |
| | Academic staff (total) | General government expenditure on HE (mil.EUR) | Graduates (total) | Mobile students | Citable documents | Citations |
| Academic staff (total) | 1 | 0,909492892 | 0,748051522 | 0,689742305 | 0,854649334 | 0,810157331 |
| General government expenditure on HE (mil.EUR) | 0,909492892 | 1 | 0,780391833 | 0,800563726 | 0,897485671 | 0,892723716 |
| Graduates (total) | 0,748051522 | 0,780391833 | 1 | 0,871953406 | 0,913005847 | 0,868107865 |
| Mobile students from abroad (total) | 0,689742305 | 0,800563726 | 0,871953406 | 1 | 0,913956263 | 0,924519383 |
| Citable documents | 0,854649334 | 0,897485671 | 0,913005847 | 0,913956263 | 1 | 0,988485443 |
| Citations | 0,810157331 | 0,892723716 | 0,868107865 | 0,924519383 | 0,988485443 | 1 |
| Correlation (Time period = 2017) | | | | | | |
| | Academic staff (total) | General government expenditure on HE (mil.EUR) | Graduates (total) | Mobile students | Citable documents | Citations |
| Academic staff (total) | 1 | 0,910830222 | 0,75007165 | 0,715276813 | 0,856550976 | 0,81255315 |
| General government expenditure on HE (mil.EUR) | 0,910830222 | 1 | 0,787657635 | 0,827781401 | 0,901020347 | 0,89448953 |
| Graduates (total) | 0,75007165 | 0,787657635 | 1 | 0,884569926 | 0,910643483 | 0,866585636 |
| Mobile students from abroad (total) | 0,715276813 | 0,827781401 | 0,884569926 | 1 | 0,923104199 | 0,930432443 |
| Citable documents | 0,856550976 | 0,901020347 | 0,910643483 | 0,923104199 | 1 | 0,988892854 |
| Citations | 0,81255315 | 0,89448953 | 0,866585636 | 0,930432443 | 0,988892854 | 1 |
| Correlation (Time period = 2018) | | | | | | |
| | Academic staff (total) | General government expenditure on HE (mil.EUR) | Graduates (total) | Mobile students | Citable documents | Citations |
| Academic staff (total) | 1 | 0,909691107 | 0,740641071 | 0,762608197 | 0,854884221 | 0,813913882 |
| General government expenditure on HE (mil.EUR) | 0,909691107 | 1 | 0,798561654 | 0,861417178 | 0,902264039 | 0,89584361 |
| Graduates (total) | 0,740641071 | 0,798561654 | 1 | 0,873624999 | 0,917525158 | 0,879735819 |
| Mobile students from abroad (total) | 0,762608197 | 0,861417178 | 0,873624999 | 1 | 0,934813705 | 0,940990832 |
| Citable documents | 0,854884221 | 0,902264039 | 0,917525158 | 0,934813705 | 1 | 0,990192577 |
| Citations | 0,813913882 | 0,89584361 | 0,879735819 | 0,940990832 | 0,990192577 | 1 |
| Correlation (Time period = 2019) | | | | | | |
| | Academic staff (total) | General government expenditure on HE (mil.EUR) | Graduates (total) | Mobile students | Citable documents | Citations |
| Academic staff (total) | 1 | 0,913788913 | 0,78585507 | 0,798360177 | 0,874832822 | 0,846239072 |
| General government expenditure on HE (mil.EUR) | 0,913788913 | 1 | 0,826942738 | 0,853529605 | 0,895662833 | 0,893452643 |
| Graduates (total) | 0,78585507 | 0,826942738 | 1 | 0,878345813 | 0,9318539 | 0,898614328 |
| Mobile students from abroad (total) | 0,798360177 | 0,853529605 | 0,878345813 | 1 | 0,903748115 | 0,913927983 |
| Citable documents | 0,874832822 | 0,895662833 | 0,9318539 | 0,903748115 | 1 | 0,991607814 |
| Citations | 0,846239072 | 0,893452643 | 0,898614328 | 0,913927983 | 0,991607814 | 1 |
| Correlation (Time period = 2020) | | | | | | |
| | Academic staff (total) | General government expenditure on HE (mil.EUR) | Graduates (total) | Mobile students | Citable documents | Citations |
| Academic staff (total) | 1 | 0,921808885 | 0,760545781 | 0,782665916 | 0,868702339 | 0,639747979 |
| General government expenditure on HE (mil.EUR) | 0,921808885 | 1 | 0,793596777 | 0,814413492 | 0,875309063 | 0,749072176 |
| Graduates (total) | 0,760545781 | 0,793596777 | 1 | 0,845351613 | 0,918376628 | 0,679795469 |
| Mobile students from abroad (total) | 0,782665916 | 0,814413492 | 0,845351613 | 1 | 0,881794875 | 0,702307963 |
| Citable documents | 0,868702339 | 0,875309063 | 0,918376628 | 0,881794875 | 1 | 0,815775914 |
| Citations | 0,639747979 | 0,749072176 | 0,679795469 | 0,702307963 | 0,815775914 | 1 |

Source: Author

The above table shows a high positive correlation between all input and output variables. Highly correlated variables are common in DEA. Dyson et al. (2001) and Ramirez Hassan (2008) argue that the omission of highly correlated relevant variables can lead to inconsistencies in the efficiency estimates of some DMUs.

## 5. RESULTS AND DISCUSSION

To monitor the performance over a period of eight years, a DEA window analysis is performed. The table 1 shows the results of relative efficiency by country. This table shows C-averages, that are, the averages of all four windows for each country. Technical, pure technical and scale efficiency results are presented where $\theta = 1$ indicates that DMU is 100 % efficient relative to their peers, and result lower than 1 ($0 \leq \theta < 1$) have DMUs that are relatively inefficient.

Table 2. Results of technical efficiency, pure technical efficiency and scale efficiency – C – Average

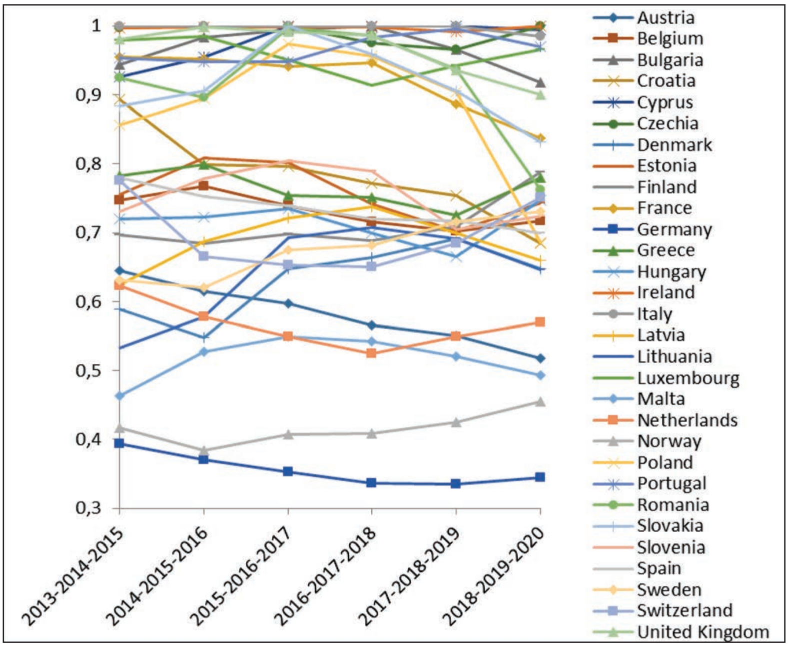
| | TE | PTE | SE |
|---|---|---|---|
| Austria | 0.582 | 0.801 | 0.726 |
| Belgium | 0.731 | 0.838 | 0.873 |
| Bulgaria | 0.967 | 0.974 | 0.992 |
| Croatia | 0.783 | 0.833 | 0.940 |
| Cyprus | 0.979 | 0.996 | 0.983 |
| Czechia | 0.989 | 0.996 | 0.993 |
| Denmark | 0.631 | 0.780 | 0.809 |
| Estonia | 0.759 | 0.829 | 0.915 |
| Finland | 0.711 | 0.895 | 0.795 |
| France | 0.920 | 0.999 | 0.921 |
| Germany | 0.356 | 0.927 | 0.384 |
| Greece | 0.765 | 0.789 | 0.970 |
| Hungary | 0.715 | 0.759 | 0.943 |
| Ireland | 0.997 | 0.999 | 0.998 |
| Italy | 0.997 | 0.998 | 1.000 |
| Latvia | 0.689 | 0.739 | 0.932 |
| Lithuania | 0.642 | 0.675 | 0.950 |
| Luxembourg | 0.956 | 0.970 | 0.985 |
| Malta | 0.516 | 0.979 | 0.527 |
| Netherlands | 0.566 | 0.736 | 0.769 |
| Norway | 0.416 | 0.515 | 0.811 |
| Poland | 0.878 | 0.954 | 0.920 |

| | | | |
|---|---|---|---|
| Portugal | 0.966 | 0.974 | 0.992 |
| Romania | 0.917 | 0.921 | 0.995 |
| Slovakia | 0.914 | 0.933 | 0.980 |
| Slovenia | 0.755 | 0.821 | 0.921 |
| Spain | 0.735 | 0.928 | 0.792 |
| Sweden | 0.676 | 0.875 | 0.772 |
| Switzerland | 0.697 | 0.979 | 0.712 |
| United Kingdom | 0.965 | 1.000 | 0.965 |

Source: Author

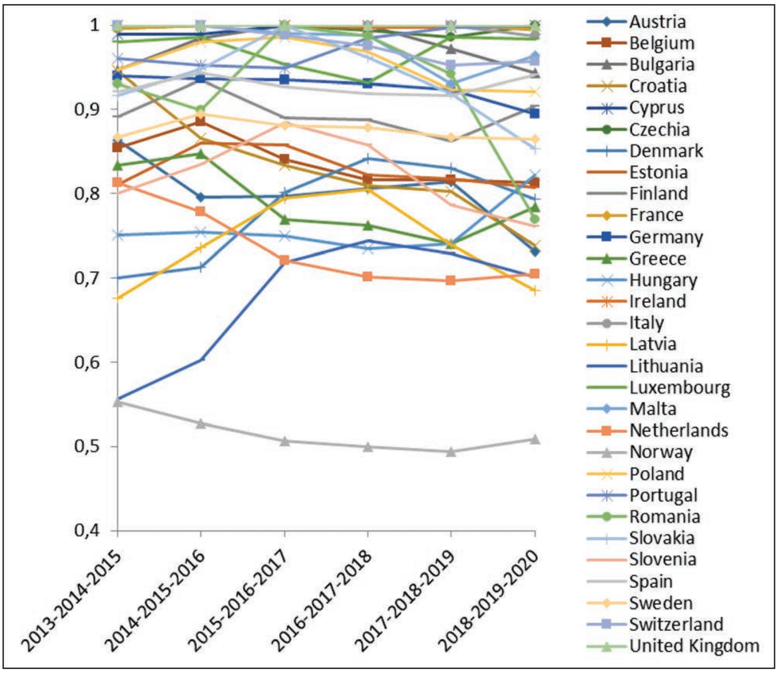
On average, countries are most efficient in pure technical efficiency and least efficient in technical efficiency. There is no single country that is relatively efficient in all categories in all windows. The only country that is relatively efficient in all windows at PTE is the United Kingdom. In the following graphs, the dynamics of relative efficiency for each individual country (by window) will be presented. We analyze all 3 components of efficiency in order to gain insight into the sources of inefficiency in each country, i.e., whether it is management and external factors or whether it is inaction in the optimal size.

Graph 1. Technical efficiency by country (average through window)



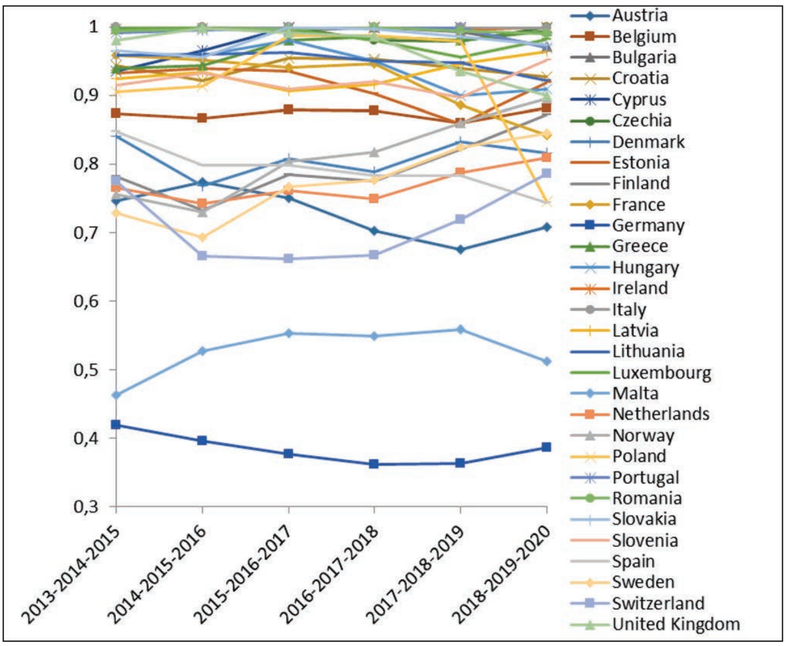

Source: Author

Graph 2. Pure technical efficiency by country (average through window)




Source: Author

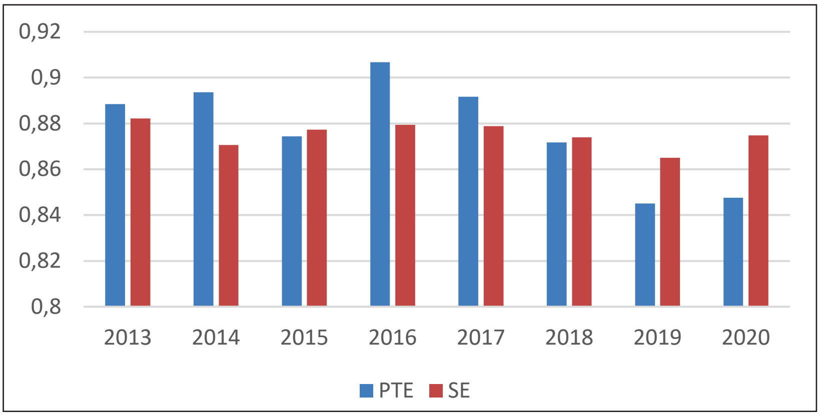
Graph 3. Scale efficiency by country (average through window)




Source: Author

Graph 1 shows technical efficiency (TE) by country, with the average score calculated over a time window. There are six time windows, each three years long. Technical efficiency assumes operation at CRS. In addition to technical efficiency, the efficiency loss that occurs when a DMU is not operating at its most productive scale is also calculated. Bulgaria, the Czech Republic, Cyprus, Ireland, Italy and Slovakia are closest to the efficiency frontier and operate efficiently in at least one time window, while they are close to the efficiency frontier in other windows. The countries with the lowest technical efficiency are Germany and Norway. At first glance, this may seem strange, since these countries are known for the quality of their education. However, quality is not synonymous with efficiency. Efficiency means that maximum outputs is achieved with minimum inputs; we could argue that these countries should produce more output with invested input compared to their peers. The countries with the relatively largest decline in relative efficiency are Austria, Poland and Romania, with relative efficiency in window 6 almost 20 % lower than in window 1. Two main components of TE are PTE and SE. They provide us with information about the sources of inefficiencies. Graph 2 shows pure technical efficiency by country, with the average score calculated over a time window. Pure technical efficiency (PTE) is affected by management, technology, and other exogenous factors, which is why it is considered a measure of management performance. PTE assumes operating at VRS. The United Kingdom, Italy, France, Ireland, Switzerland, Bulgaria, the Czech Republic, Cyprus, Portugal, and Slovakia are closest to the efficiency frontier and operate efficiently in at least one time window, while they are close to the efficiency frontier in other time windows. The country with the lowest PTE is Norway. Lithuania was one of the PTE most inefficient countries in window 1, but experienced strong growth and has higher PTE results than Latvia in window 6 and similar results to the Netherlands, which experienced a decline in PTE efficiency. Germany, which is one of the least TE efficient countries in the middle of the field in terms of PTE results. The country with the biggest drop at PTE is Croatia, with more than 21 % in the comparison between time window 6 and time window 1, followed by Romania with the drop just under 19 %. Graph 3 shows the results of scale efficiency (SE) by country, with the average score calculated over a time window. SE is a ratio between the efficiency values TE and PTE and provides information on the optimal size of resources, i.e., the optimal production size. The VRS measures technical efficiency, while CRS measures technical efficiency as well as the loss of efficiency when a DMU is not operating at its most productive scale. The United Kingdom, Italy, Ireland, Bulgaria, the Czech Republic, Cyprus and Romania are closest to the efficiency frontier and operate scale efficiently in at least one time window, while their results in other time windows are close to the SE frontier. Countries that recorded lowest scale efficiency results are Germany and Malta. Germany, Poland, and Spain recorded relatively the largest decrease at SE that ranges between 16 % and 18 % when comparing results in window 6 with results in window 1.

Graph 4. Results of TE and SE – average by year for all countries




Source: Author

Graph 4 shows the results of PTE and SE as the main components of TE. PTE and SE provide information about the sources of inefficiency. The results show that efficiency varies across countries and over time, with PTE peaking in 2016 and declining sharply thereafter. The results of SE do not show such strong fluctuations, although they were highest in 2013, followed by 2016 and 2017. When analysing the sources of inefficiency, PTE, which is influenced by management, technology, and other exogenous factors, is higher overall than SE, which provides information on the optimal resource size by 2017, except for 2015, where it is slightly lower than SE. We can conclude that the source of inefficiency until 2017 is the non-optimal resource size. From 2018 to 2020, the situation reverses and management, technology and other exogenous factors become the main source of inefficiency.

## 6. CONCLUSIONS

Education is a strategic area of interest for any country, as the quality of human capital strongly influences economic development. The education production function represents the maximum output that can be achieved with the available resources. It serves as a reference for calculating the inefficiency of DMUs that do not achieve this goal. This study compares the relative efficiency of the higher education systems of 30 European countries over an eight-year period with the aim of identifying sources of inefficiency. Window DEA, a nonparametric panel method based on the principle of moving averages, is used and the results are presented in a 3-year window. Since the analysis is conducted from 2013-2020, six windows are identified. Technical efficiency (TE), pure technical efficiency (PTE), and scale efficiency (SE) are calculated and analysed as three components of efficiency to gain insight into the causes of inefficiency in each country, i.e., whether it is management and external factors or whether it is inaction at the optimal scale. Research results indicate that, on average, observed countries are most efficient in pure technical efficiency and least efficient in technical efficiency. In addition, dynamics of TE, PTE and SE for each individual country (by window) is presented. The results show differences in efficiency among the selected countries and point to sources of inefficiency, be it management performance or production size. Considering PTE and SE as the main components of TE, it can be concluded that until 2017 the main source of inefficiency is the non-optimal production size. In the period from 2018 to 2020, the sides have changed and management, technology and other exogenous factors become the main source of inefficiency. This is particularly evident for 2019 and 2020, which can be partly explained by macroeconomic factors, in particular the impact of the Covid 19 pandemic, which has severely affected the European economy. It is interesting to note that the average technical efficiency has fallen sharply compared to 2016, due to a high average decrease in citations with a constant average increase in inputs. There was a slight average increase in other outputs, but this was not enough to compensate for the sharp decline in citations. The situation varies from country to country. Looking at the countries without taking into account the dynamic changes from year to year, Ireland and Italy are closest to the efficiency frontier with a TE value of 0.997, while Germany is the most inefficient with a TE value of 0.356. When interpreting the results, it should be borne in mind that this is a measure of relative efficiency, which provides information on how a particular DMU uses its inputs to achieve outputs. The goal is to minimize inputs and maximize outputs. Since Germany invests more in tertiary education than the EU average (Eurostat, n.d), the cause of inefficiency could be an excessive use of inputs that is not followed by adequate outputs.

However, there are some limitations to this study that should be considered. In the selection of inputs and outputs, some data were not available. Limitations also arise from used method and main limitation of this method is that it cannot deal with missing data. In addition, due to the nature of higher education institutions, there are quality outputs that cannot be measured. Since the model has only been tested in higher education systems, its application can be tested at the HEI or university level or in other industries. Future research should focus on dynamic cross-country or cross-institutional comparisons to identify best practises and factors that contribute to the efficiency of higher education. In addition, the impact of contextual factors such as institution size, location, funding sources, and mission on efficiency scores should be explored. Understanding how these contextual factors affect efficiency will inform policy decisions. Finally, quality measures should be developed and included in the analysis. Assessing the quality of education and research outputs is essential, and combining quality measures with efficiency analysis can provide a more nuanced evaluation.

It is important for policymakers in higher education to know how well the system is working. Since education is predominantly publicly funded, it is important to use those funds as efficiently as possible. In this day and age, when most countries are affected by global chalenges, the efficient use of public funds is increasingly important. The research findings provide insights that can help policymakers in European countries develop strategies to increase the efficiency of higher education.

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# ANALIZA EFIKASNOSTI SEKTORA VISOKOG OBRAZOVANJA U EUROPI - PRISTUP TEMELJEN NA DEA ANALIZI PROZORA

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## SAŽETAK

*Cilj ovog istraživanja je procijeniti relativnu efikasnost visokog obrazovanja u razdoblju od 2013. do 2020. godine. Budući da su sredstva koja se koriste za financiranje visokog obrazovanja oskudna, a obrazovanje se uglavnom financira javnim sredstvima, važno je te resurse koristiti što efikasnije. U ovom radu korištena je analiza prozora u okviru analize omeđivanja podataka (DEA) kojim se omogućuje dinamičko ocjenjivanje i uspoređivanje rezultata efikasnosti tijekom vremena. Empirijska analiza provedena je na sustavima visokog obrazovanja u 30 europskih zemalja kroz osmogodišnje razdoblje. Korištena su dva inputa (akademsko osoblje i opći državni izdaci za visoko obrazovanje) i četiri outputa (diplomirani studenti, dolazna mobilnost, publikacije i citati) kao varijable, a duljina prozora u DEA modelu iznosi tri godine čime je formirano šest prozora. Rezultati su prikazani i analizirani iz perspektive tehničke efikasnosti. (TE), kao i čiste tehničke efikasnosti (PTE) i efikasnosti razmjera (SE) kao njegovih komponenti. Rezultati pokazuju da efikasnost varira od zemlje do zemlje i tijekom vremena. Ukupna efikasnost dosegla je vrhunac 2016. i nakon toga se stalno smanjuje. Kada se analiziraju izvori neefikasnosti, PTE kao mjera uspješnosti upravljanja ukupno je veći od SE kao mjere optimalne veličine proizvodnje do 2017., osim 2015. kada je nešto niži od SE. Možemo zaključiti da je izvor nefikasnostii do 2017. općenito neoptimalna veličina proizvodnje. Od 2018. situacija se mijenja i učinak upravljanja postaje glavni izvor neefikasnosti. Rezultati ovog rada mogu pomoći kreatorima politika u europskim zemljama u njihovim nastojanjima da povećaju efikasnost visokog obrazovanja.*

**Ključne riječi:** *efikasnost u visokom obrazovanju, analiza omeđivanja podataka (analiza prozora), zemlje Europe, javno financiranje*