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The Use of the DEA Method for Measuring the Efficiency of Electronic Public Administration as Part of the Digitization of the Economy and Society

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Abstract: E-Government is one area of digitization that has been under way for several years in European countries. In this paper, we focus on identifying different indices that are aimed at measuring digitalization or e-Government. The results of the analysis showed that there are several indices that focus on this area within the EU, such as EGDI, EPI, LOSI, DGI, e-Government benchmark, Eurostat—Internet use, GII, DSGI, Going Digital toolkit, and DESI. Subsequently, the index areas to be used in the DEA method to measure the efficiency of e-Government-related inputs and outputs within the EU were identified. Inputs and outputs were selected logically and then verified using correlation analysis. Among the input and output indices chosen were Internet usage, DSGI, GII, e-Government benchmark, and interaction with public administration online. From the analysis, three inputs and three outputs were used and the models were output oriented. After implementing the correlation, it can be said that the values between the selected sub-variables are suitable for DEA analysis. Two models were chosen for the calculation, namely the CCR and BCC models. The CCR model found 10 states to be efficient and BCC model found 13 states to be efficient. In addition, in the close analysis, we took a closer look at the CCR model's inference. Countries such as Denmark, Finland, Estonia, Malta, and Portugal were efficient outliers. When comparing the regions within the EU, we can conclude that the countries of Northern Europe are the most efficient in the field of digitalization (e-Government). As many as four countries out of seven are efficient.

Keywords: digital skills; DESI index; EGDI index; e-Government

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1. Introduction

The process of transformation from the traditional paper-based form of communication, data archiving, etc. has been changed by the advent of the Internet and its use within states. Digitization is affecting all aspects of policy and domains, from purchasing of goods and services through the Internet to handling of official business. Digital technology has erased boundaries, including in the way people live, work, and communicate. The public sector is no exception. The impact of the COVID-19 pandemic has also accelerated the uptake of and increased investment in digital technology. A number of countries have rethought the role of the state and forced the development of digital technologies. The pace of progress has varied across countries, as has the overall development of e-Government. There are several metrics for determining different levels of digitization and e-Government. With the development of digital government, public administrations and institutions around the world have changed—both structurally and in terms of the dynamics between governments and people. This can be observed through various indicators that measure the state of digitalization. There are a number of metrics that can be used to measure the state of e-Government within the EU. As early as 2005, the authors Derek Fine and Tamarie Johnson noted that public sector companies face many challenges similar to those of private sector companies, namely in the area of digital assets [1]. Jessica Breaugh, Maike Rackwitz, and Gerhard Hammerschmid argue that government digitization projects require collaborative approaches for successful development and implementation [2]. One of the components of digitalization is e-Government. E-Government refers to the use of information and communication technology (ICT) applications to deliver various government services. It is increasingly recognized that e-Government is moving towards a holistic approach and that sustainable governance requires strategic national planning. The OECD defines the different developments of e-Government [3,4] as follows: Analogue government: closed operations and internal focus, analogue procedures. E-Government: digitization of existing government processes and online delivery of public services through the use of information and communication technologies (ICT), in particular the Internet. Digital government: the use of digital technologies and data to transform the design and implementation of public policies and services to achieve more open and citizen-centric approaches [5]. There are several definitions in the field of e-Government. In addition, these definitions have undergone an evolution as new technologies, such as AI and machine learning, have been added. Table 1 shows the evolution of the concept of e-Government by different authors.

Table 1. Definitions of e-Government.

Sources	Definition—E-Government	Topic
S. Malodia, A. Dhir, M. Mishra et al., 2021 [6]	Socially inclusive, hyper-integrated ICT platforms that are built on an evolutionary system architecture to ensure efficient delivery of government services with transparency, accountability, and responsibility	Future of e-Government: an integrated conceptual framework
Scholta et al., 2019 [7]	Providing services and information to citizens in real time in a personalized way	From one-stop shop to no-stop shop: an e-Government stage model
Spirakis, Spiraki, and Nikolopoulos 2010 [8]	E-Government aims to improve accessibility, efficiency, and accountability. It is based on the dissemination of information and the development of information policies. E-Government leads to increasing citizen participation. The activity of these citizens influences the mechanisms of democracy	The impact of e-government on democracy: e-democracy through e-participation.
Evans and Yen 2006 [9]	e-Government means communication between a government and its citizens through computers and web access. The benefits of speed, responsiveness, and cost containment are excellent	Evolving relationship of citizens and government
UNDPEPA and ASPA 2002 [10]	E-Government is defined as: the use of the Internet and the World Wide Web to provide government information and services to citizens	Benchmarking e-Government: a global perspective
Silcock R. 2001 [11]	E-Government is the use of technology to improve access to and delivery of government services for the benefit of citizens, business partners, and employees.	What is e-Government?

Source: Own processing.

The DEA method is used in various fields. It is now possible to measure the level of efficiency using the DEA (data envelopment analysis) method. The DEA method can also be used in digitization [12,13]. This article focuses on the use of the method in the case of digitalization in the EU and selected countries. The DEA method has different applications;

therefore, it is necessary to look at where this method has been applied. Mohamed Elhag and Silvena Boteva used the DEA method for the conceptual evaluation of energy input–output analysis on the island of Crete. Researchers have also used DEA to evaluate the agricultural sector. The inputs that contributed most to outputs were human factors, soil care, and crop protection [13].

Indicators for measuring digitization: The purpose of this study was to use the DEA method in the field of digitalization within the EU. The OECD identifies efficiency measures in the DESI; however, in this study we identify efficiency using selected indices and their sub-categories that focus on technological efficiency. The OECD research is devoted to the input-oriented model, whereas ours uses the output-oriented model. Therefore, it is necessary to identify possible input and output data. Multi-criteria decision analysis (MCDA) has already been used in another study; therefore, it is appropriate to look at the DEA method and its use. The basic indices include the Digital Economy and Society Index, e-Government Development Index, e-Participation index, Local Online Service Index, Digital Government Index, e-Government benchmark, Eurostat—Internet use, Global Innovation Index, Digital Skills Gap Index, and Going Digital Toolkit. Table 2 lists the individual indices with their abbreviation and the year of their first measurement, followed by more detailed information.

Table 2. Summary of the digitalization and e-Government indices.

Index	Abbreviation	Year of Launch	Data Availability within the		Index Key Areas	Implementer
			EU	World		
E-Government Development Index [14]	EGDI	2003	yes	yes	(EGDI) online service, human capital, telecommunication infrastructure, (EPI) e-information, e-consultation, e-decision making, (LOSI) institutional framework, content provision, services provision, participation and engagement, technology.	OSN
E-Participation Index	EPI	2003				
Local Online Service Index	LOSI	2018				
Digital Government Index [5]	DGI	2019	yes	no	Digital by design, data-driven, acts as platform, open by default, user-driven, proactive	OECD
E-Government benchmark [15]	-	2018	yes	no	User Centricity, Transparency, Key Enablers, Cross-Border Services	European Commission
Eurostat—Internet use [16]	-	2008	yes	no	Internet use: interaction with public authorities	European Commission
Global Innovation Index [17]	GII	2007	yes	yes	Institutions, human capital and research, Infrastructure, market sophistication, business sophistication, knowledge and technology outputs, creative outputs	WIPO
Digital Skills Gap Index [18]	DSGI	2021	yes	yes	Digital skills institutions, digital responsiveness, government support, supply, demand and competitiveness, data ethics and integrity, research intensity	Wiley
Going Digital Toolkit [19]	-	-	yes	yes	Access, use, innovation, jobs, society, trust, market openness	OECD
The Digital Economy and Society Index [20]	DESI	2014	yes	no	Human capital, connectivity, integration of digital technology digital public services	European Commission

Source: Own processing.

For a closer comparison, we chose two main indicators to measure digitalization and e-Government. DESI measures the state of digitalization across the EU. The index provides an overall picture of the state and performance of individual Member States. As Table 1 shows, there are a number of indices focusing on different areas of digitization. A less common area tends to be e-Government [20]. The level of the DESI across the EU is shown in Figure 1.

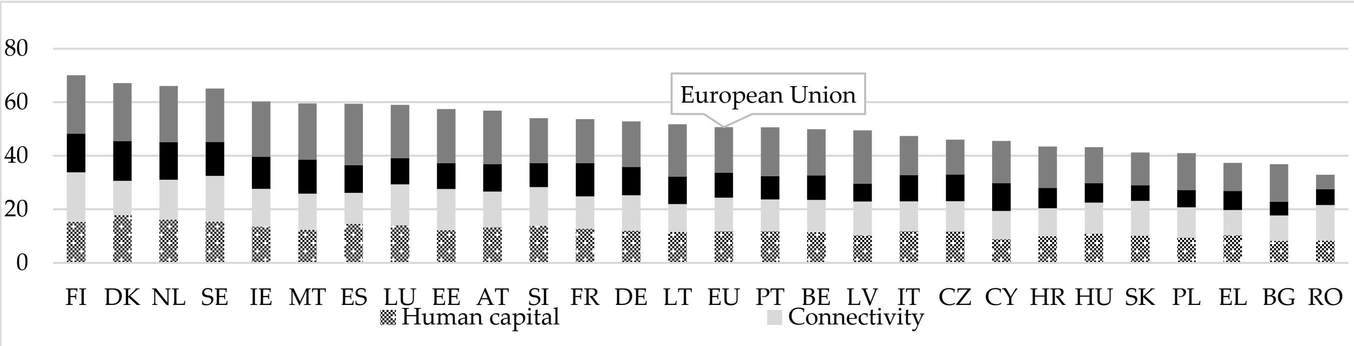

Figure 1. The level of the DESI across the EU.

Table 3 shows the overall digitization scores for Germany, Romania, Lithuania, and Spain from 2018 to 2022 compared to the European average. The overall degree of digitization in the EU is high, but some countries are lagging behind, such as Romania. The pandemic caused a reduction in the adoption of digitization across Europe [20].

Table 3. Overall level of the DESI.

DESI Level over Time	Germany		Lithuania		Spain		Romania		Europe Union
	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Score
DESI 2022	13	52.9	14	52.7	7	60.8	27	30.9	52.3
DESI 2021	11	54.1	14	51.8	9	57.4	27	32.9	50.7
DESI 2020	12	56.1	14	53.9	11	57.5	26	40.9	52.6
DESI 2019	13	51.2	12	51.8	10	53.6	26	36.5	49.4
DESI 2018	14	47.9	12	49.4	10	50.2	26	35.1	46.5

Source: europa.eu, (online). (accessed on 18 January 2022). Available on the Internet: https://lnk.sk/pcr9 (accessed on 16 September 2022). Own processing.

The appropriate DESI score dropped in 2021 because of the COVID-19 pandemic. Of the selected countries, Spain only managed to drop by 0.1. In 2022, all countries except Romania were above the EU average [20].

The Recovery and Resilience Facility is the key instrument at the heart of Next Generation EU, which will support economies in all Member States. Each country focuses on a different area of digitization that is needed in the country. The document focuses on areas such as digital services, data transformation, public procurement, and cyber and information security [20,21].

Germany's recovery and resilience plan supports the digital transition with several investments and reforms. Digital challenges for Germany include lagging investments in digital infrastructure. Germany is investing EUR 3 billion to make public services digitally accessible at federal and regional levels [22].

Lithuania's recovery and resilience plan supports the digital transition with reforms and investments in connectivity of EUR 73 million. The plan also includes substantial reforms and investments to digitalize the public sector (EUR 117 million), to promote digital skills for children, employees, civil servants, senior citizens, etc. [23].

Spain's recovery and resilience plan supports the digital transition with investments in the digitalization of the public administration, in digital skills and digital inclusion, in cyber security, and in connectivity. It will invest EUR 3.6 billion in digital skills training. The plan includes investment of EUR 3.2 billion in the digital transformation of the public administration [24].

Romania's recovery and resilience plan has the objective of addressing most of the country's digital technology. Public administration digitalization investments amount to EUR 1.5 billion. In addition, digitalization of health includes investments of EUR 470 million for developing an integrated e-Health system. In addition, investments for digitalization of education (EUR 881 million) aim at improving digital pedagogical skills, educational content, and educational equipment [25].

In addition to the partial results of Germany, Romania, Spain, and Latvia in the DESI, it is necessary to look at the overall picture of all EU countries. A slight increase in DESI is occurring across the EU, so it is important to see the overall picture of EU digitization. A number of countries, such as Estonia, Denmark, and Finland, are leaders in digitalization. Therefore, it would be useful to establish a method and data to determine the efficiency within the EU in the field of digitalization policy and the e-Government area [14]. The United Nations has created a database to record and store data on the development of e-Government in 193 countries around the world. An important indicator of e-Government development and progress is the e-Government Development Index, abbreviated as EGDI. Out of 43 European countries, 24 countries have achieved a very high EGDI. European Union countries are among the leaders in e-Government because all countries have a high or very high level of EGDI [14]. According to the EGDI, a number of countries have low levels of e-Government, but of the selected countries, all have very high levels of the EGDI, apart from Romania. Table 4 shows the level of the EGDI in selected countries.

Table 4. EGDI levels in selected countries and the five best countries.

Countries		EGDI 2022	Rank 2022	EGDI 2018	Change 2022–2018
TOP 5	Denmark	1	0.9717	0.915	56.7×10^{-3}
	Finland	2	0.9533	0.8815	71.8×10^{-3}
	Republic of Korea	3	0.9529	0.901	51.9×10^{-3}
	New Zealand	4	0.9432	0.8806	62.6×10^{-3}
	Iceland	5	0.941	0.8316	109.4×10^{-3}
Spain		18	0.8842	0.8415	42.7×10^{-3}
Germany		22	0.877	0.8765	0.5×10^{-3}
Lithuania		24	0.8745	0.7534	121.1×10^{-3}
Romania		57	0.7619	0.6671	94.8×10^{-3}

Source: publicadministration.un.org, (online). (accessed on 7 March 2023). Available on the Internet: https://lnk.sk/ughl (accessed on 29 March 2022). Own processing.

Denmark and Finland are in the leading positions (in reverse order compared to the DESI). The top five countries are Denmark, Finland, South Korea, New Zealand, Iceland, and Iceland. Of the selected countries, Spain is the leader followed by Germany, Lithuania, and lastly Romania. Lithuania and Romania recorded the highest number of marriages compared to 2018. Spain's progress has been moderate, but Germany has made almost no progress in 4 years [14]. A total of 87% of services across Europe require identification, either offline or online. Electronic identification solutions (referred to as eIDs) are like online passports. People use their eID to prove who they are online. The European leaders in eID are Iceland, Denmark, Estonia, Finland, Norway, Malta, Lithuania, and Denmark, where more than 90% of services are available through a national eID. Figure 2 shows the digital maturity of all participating countries. The overall maturity score is composed of the four key dimensions of User Centricity, Transparency, Key Enablers, and Cross-Border Services [15].

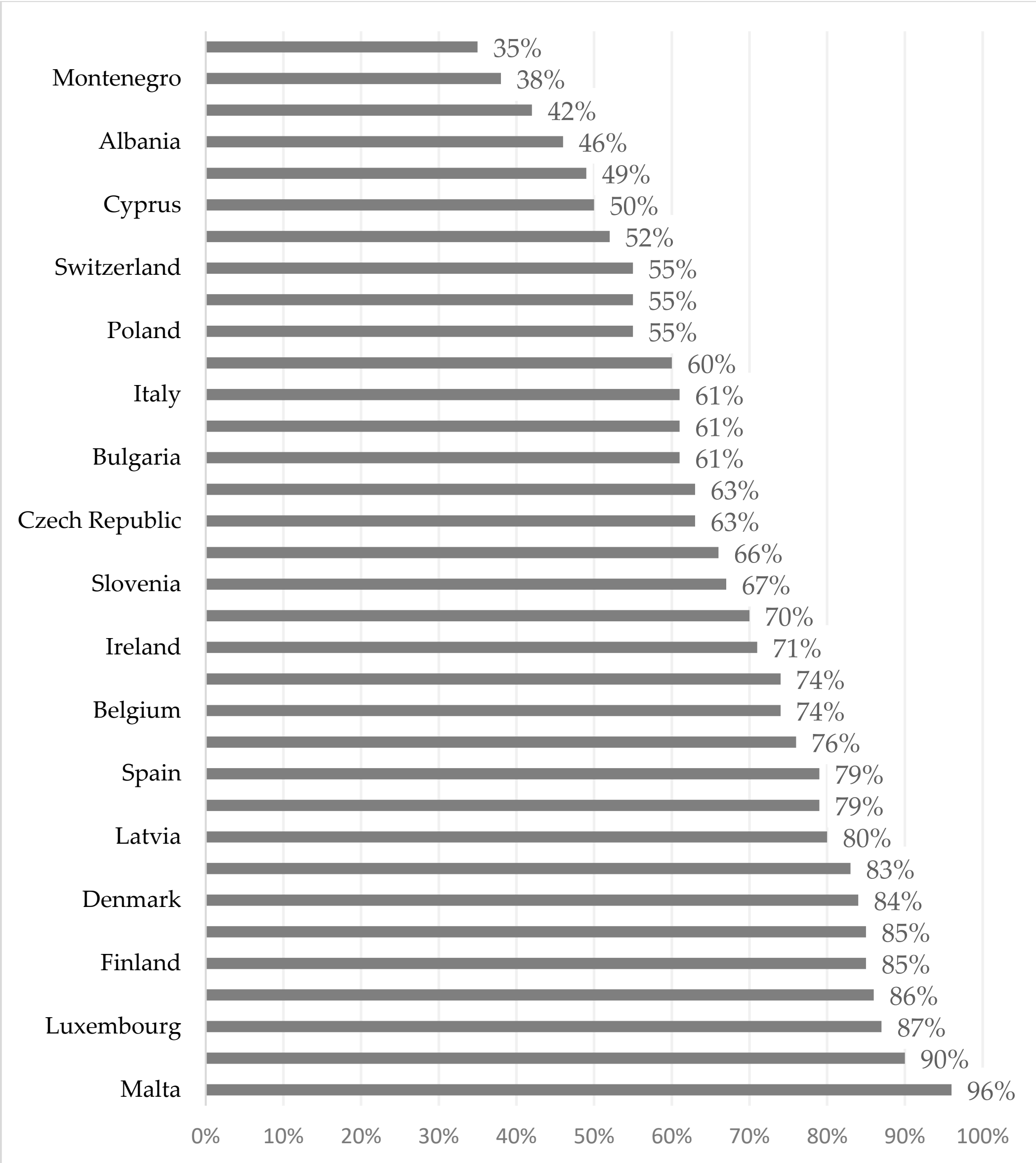

Figure 2. The digital maturity of European countries.

Malta has the most mature digital government, at 96%, followed by Estonia at 90%. The selected countries are ranked Germany (63%), Lithuania (83%), Hungary (66%), and Spain (79%). Lithuania achieved a surprising result as it ranked the best among the selected countries. Overall, most EU countries have a high level of digital maturity [15].

Digital transformation in public administration is very important. There are many studies that deal with this area, and in recent years several academic articles have been written in this field (Table 5).

Table 5. Literature review on digitization and e-Government.

Reference	The Main Purpose of the Study	Topic	Year
I. Dhaoui [26]	The author dealt with the role of e-Government on different aspects of economic and social development in North and Middle East Africa. The outcomes show that most indicators of good governance have a positive contribution to sustainable development. Digitization improves control of corruption and government efficiency.	E-Government for Sustainable Development: Evidence from MENA Countries	2022
G. Onyango, J. Ondiek [27]	The authors explored the role of ICTs, digital platforms, connectivity, and the like in Kenya. The study identified the various problems and concluded by recommending solutions to these problems.	Digitalization and Integration of Sustainable Development Goals (SGDs) in Public Organizations in Kenya	2021
Le Thanh Ha [28]	The authors undertook an analysis that focuses on the impacts of the digital transformation process in the commercial and public sectors on energy security. One of the outcomes shows that digitalization in public services supports the achievement of energy sustainability goals.	Are Digital Business and Digital Public Services a Driver for Better Energy Security? Evidence from a European Sample	2022
Schneider, D. Klumpe, J. Adam et al. [29]	Innovation of new and advanced ICT technologies requires new mechanisms for user identity authentication. The authors deal with the use of an electronic identifier. Based on the digital nudge, eID adoption can be increased by changing the decision environment.	Nudging Users into Digital Service Solutions	2020
P. Tampuu, A. Masso [30]	The authors dealt with the implications of Estonia's e-residency. The results indicate that individual motives for adopting e-residency vary depending on both the nationality of the applicants and the level of e-Government development in the country of origin.	Transnational Digital Identity as an Instrument for Global Digital Citizenship: The Case of Estonia's E-Residency	2019
A. Ullah, C. Pinglu, S. Ullah et al. [31]	The authors explored the role of electronic public administration as a solution to COVID-19 by integrating the implications of the China–Pakistan Economic Corridor (EPEC).	The Role of E-Governance in Combating COVID-19 and Promoting Sustainable Development: A Comparative Study of China and Pakistan	2022
J. Wu, D. Guo [32]	The authors used the data envelopment analysis method to measure the effectiveness of e-Government in Chinese provinces. Moreover, the results show that most of the provincial government websites operate at an inefficient level and in a bad manner.	Measuring E-Government Performance of Provincial Government Website in China with Slacks-Based Efficiency Measurement	2015
K. Härmand [33]	This article provides an overview of what changes have been made to allow virtual general meetings in different countries. In addition, it provides information on the new Estonian legislation regarding remote notarial transactions, annual online meetings, and digital infrastructure.	Digitalization before and after the COVID-19 Crisis	2021
F. Idzi, R. Gomes [34]	The author conducted a literature review with a meta-analysis to better understand how the digital era affects governments, which social aspects should be taken into account.	Digital Governance: Government Strategies that Impact Public Services	2022
S. Paul, S. Das [35]	The author studied the accessibility and usability of e-Governance sites in India. The results show the existence of accessibility problems.	Accessibility and Usability Analysis of Indian e-Government Websites	2020

Source: own processing.

2. Materials and Methods

The aim of this paper is to highlight the use of DEA method in the field of digitalization, focusing on the area of e-Governance, and to identify the various uses of the DEA method in different areas using available indices that identify digitization and e-Governance. The aim of the paper is also to identify the efficiency and inefficiency of countries in the EU in the field of digitalization. The methodology of the article is described in Table 6.

Table 6. Methodology of the article.

Paper	Information	Method	Research Phase
Main data collection	The data were focused on digitization, e-Government, index.	Analysis, method determination	I.
Analysis	Scholarly articles on digitalization, e-Government, DEA method, defining the concept of e-Government and digitalization, identifying index directly related to digitalization. Define different uses of the DEA method in the environmental field.	Analysis, method of collecting and processing information, extraction and compilation methods, method of abstraction	II.
DEA method	Thus, two models, CCR and BCC, were used in the method.	-	III.
	From the analysis, none of the indices that can be used have been filled in. The article was targeted at e-Government, meaning that it was necessary to establish input and output data.	-	
	Determining the number of inputs and outputs, verification of appropriate inputs and outputs,	Multi-correlation method	
	Determination of input and output values, calculation of maximum, minimum, average, directional deviation, modus, and median. Dividing selected countries into regions and EU areas. Identifying efficient and inefficient countries within regions.		
Conclusion, discussion, and results	The conclusion of the thesis contains the evaluation of the results of the DEA analysis carried out, which showed effective and ineffective countries in the field of digitalization.	Synthesis method, deduction method, induction method, generalization method, DEA method, comparisons with other studies	VII.

Source: own processing.

The methodology of digital transformation is shown in the flowchart in Figure 3.

The DEA method provides a ranking of the important management methods. It enables the evaluation of efficiency based on selected inputs and outputs. DEA was first used in 1978 by Charnes, Cooper, and Rhodes as a CCR model. In 1984, Bunker, Charnes, and Cooper introduced a variant of BCC that evaluates the efficiency of decision units under the assumption of variable returns to scale [36,37].

The basic DEA models are the CRR input- and output-oriented model, the BCC input- and output-oriented model, and the SBM model. In addition to these models, there are also modify-variate models which include the Malmquist index and super-efficiency model. The super-efficiency model works on the principle that the effective units are set equal to zero, thus removing them from the ensemble, and thus a new effective frontier is created from which efficiency is measured [37]. The basic objective of the DEA method is to compare organizational units, which are also referred to as DMUs. Each DMU uses a certain number of inputs for its activities and the activities result in certain outputs [38].

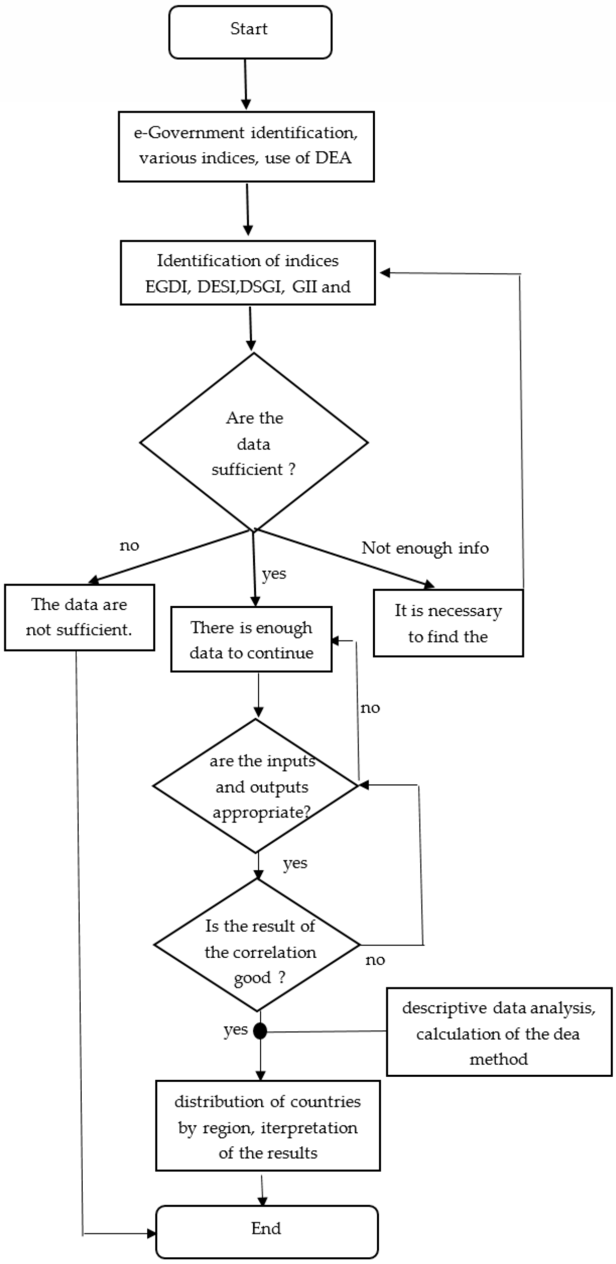

Figure 3. Methodology. (Source: own processing).

DEA models are based on the assumption that there is a set of admissible possibilities. This set is formed by all possible combinations of inputs and outputs, and is bounded by so-called efficient frontiers. Efficient units are those units whose combinations of inputs and outputs lie on the efficient frontier. Efficiency frontiers of the CCR and BCC models are shown in Figure 4.

Figure 4 shows the sets of production options for the CCR and BCC models. The CCR model assumes consistent returns to scale, whereas the BCC model assumes inconsistent returns to scale. The set of options contains a convex hill, which is the set of existing nodes containing input nodes that are larger and output nodes that are smaller than the nodes in the set. The effective level is located on a straight line, or at multiple points on a straight line (see Figure 4). The formulas for calculating the output-oriented CCR and BCC models are shown in Table 7 [39].

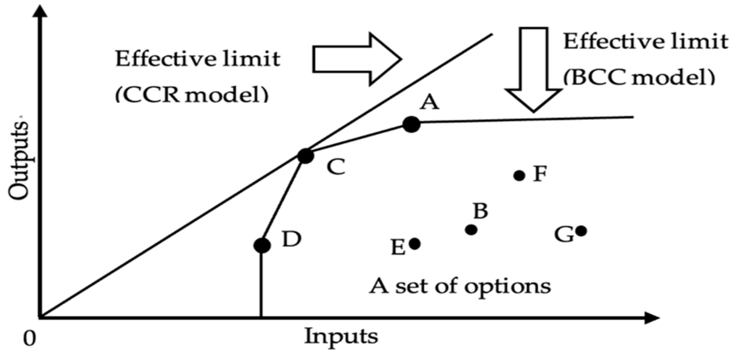

Figure 4. CCR and BCC models shown graphically. (Source: elsevier.com [online]. (accessed on 11 January 2022). Available on the Internet: https://lnk.sk/5789 (accessed on 15 December 2015), own processing).

Table 7. CCR and BCC formulas of the output model.

	CCR Output-Oriented Model	BCC Output-Oriented Model
Minimize	$g = \sum_{j}^{m} v_j \cdot x_{jq}$	$g = \sum_{j}^{m} v_j \cdot x_{jq} + v$
Under the conditions	$\sum_{j}^{r} u_i \cdot y_{ik} \leq \sum_{j}^{m} v_j \cdot x_{jk}$ $k = 1, 2, \ldots, r$ $\sum_{j}^{r} u_i y_{iq} = 1$ $u_i \geq \varepsilon, \quad i = 1, 2, \ldots, r$ $v_j \geq \varepsilon, j = 1, 2, \ldots, r$ u *is arbitrary*	$\sum_{j}^{r} u_i \cdot y_{ik} \leq \sum_{j}^{m} v_j \cdot x_{jk} + v$ $k = 1, 2, \ldots, r$ $\sum_{j}^{r} u_i y_{iq} = 1$ $u_i \geq \varepsilon, \quad i = 1, 2, \ldots, r$ $v_j \geq \varepsilon, j = 1, 2, \ldots, r$ v *is arbitrary*

Source: Own processing.

Regarding model orientation, three variants are distinguished: input-oriented, output-oriented, and non-oriented. The input-oriented DEA model means that an inefficient subject becomes efficient by reducing its inputs while its outputs remain at least at the same level. The aim was to measure the efficiency of outcomes such as satisfaction with eID, interaction with public administration, and number of online services. In this study, we chose an oriented model. The general form of the output-oriented DEA model is determined in Table 7 [37].

The number calculated to express efficiency is called the efficiency value, D. This D-efficiency value can be obtained between 0 and 1.0. If the value is closer to 1.0, the model is more efficient. Since the efficiency value is calculated based on the most efficient node (D-efficiency value of 1.0), it is possible to determine how the nodes that do not reach the value of 1.0 differ from the efficient nodes [37]. The CCR model calculates the weights of the inputs and outputs, called the optimization calculation, so that for a DMU it is as accurate as possible in terms of its efficiency while respecting the maximum unit efficiency conditions of all other units [40].

Selection of Inputs and Outputs

The meaning and purpose of the analysis depends on the chosen inputs and outputs in the model. Inputs and outputs should be logically linked, as this is a production process. To ensure that the inputs and outputs are chosen correctly, we use correlation analysis. Using correlation analysis, we select the relationship between variables and eliminate variables with both very strong and very weak correlations [41,42].

In addition to the appropriate correlation coefficient between the right-hand side variables, the inputs and outputs must be matched to the number of DMUs. The rule of thumb used is the sum of the number of inputs and outputs ≤1/3 or 1/5 of the total number of DMUs.

The statistical relationship between the variables can be determined using the Spearman correlation coefficient. The correlation coefficient r is defined by Relation (1):

$$r = 1 - \frac{6 \cdot \sum_{n=1}^{N} D^2}{N \cdot \left(N^2 - 1\right)} \quad (1)$$

where N = number of elements, D = difference between x_n and y_n, i.e., two rows, r = correlation coefficient.

The correlation coefficient takes values from the interval $\langle -1; 1 \rangle$ and expresses the degree of linear correlation between the variable. A value of −1 indicates absolute indirect dependence, 0 indicates no linear dependence, and 1 indicates absolute direct dependence between two variables. In DEA analysis, it is advisable that the correlation coefficient should not exceed 0.8 or else the efficiency result may be biased. The ideal correlation coefficient is in the range of 0.3–0.8 and, depending on the number of units, is validated at a significance level of 0.05 [42,43].

To use the DEA method, it is necessary to select the input and output units. Deciding on the appropriate input and output units to achieve the desired result is not an easy task. Thus, the method is used within the EU, which has 27 member states. The total number of inputs and outputs (m + s) is sought to be minimized to achieve a good predictive value of the model. As the number of inputs and outputs increases, all DMUs can become efficient. Hence, the model must satisfy the criterion m + s < n/5. In our study, we use 27 subjects and there is one input or output for every 5 subjects. This means that n = 27 and we have to divide this number by 5. This result will give us 5 or 6 inputs or outputs, or a combination of them. The total number of inputs and outputs that can be used is 5 to 6 at most. The input units are chosen from the composite indexes or a separate index. In terms of perspective, the GII: R&D investment index can reflect different levels of economic and social development and serve as an economic input, while the Internet usage index serves as a human input, providing an indication of Internet participation. Regarding the DSGI, it is an economic input to the DEA method. The CCR and BBC models focus on technological efficiency in the framework of e-Government, where 3 outputs have been selected. The models are output-oriented.

The 2 units from the e-Government benchmark are chosen as output units. One of the units is the availability of online e-Government services within the country and the other unit is the satisfaction with eID. The last output index chosen is the interaction with online government. For all input and output indices see Table 8.

Table 8. Input and output DMU units.

Index	Used Attributes from the Index	Index Attribute	Index Direction
Internet usage	Human factor (number of internet users)	Access	-
Digital Skills Gap—DSGI	Economic factor (Area of government support)	Access	-
Global Innovation—GII	Economic factor (R&D (% of GDP)	Access	-
e-Government benchmark	Technological factor (Availability of online e-Government services)	Output	+
e-Government benchmark	Technology factor (eID satisfaction)	Output	+
Interaction with public administration online	Human factor (e-Government—e-Government user communication)	Output	+

Source: Own processing.

We focused on two areas as inputs. The first area is the human factor, which represents the total number of Internet users in the country. The second area is the economic factor. In the economic factor, we chose to promote digital skills. This was because, if the government does not promote the digital skills of the population, it cannot grow the use of digital or e-Government services. The second economic factor is the share of GDP (Gross Domestic Product) supporting innovation. This factor represents the knowledge society, which is important in the world's leading companies and an important factor for competitiveness and innovation creation. The outputs were chosen analogous to the inputs. That is, one of the output factors is the human factor, which represents the overall communication with the public administration online. Subsequently, two technological factors were chosen that represent the basis for the use of e-Government services. One of these is satisfaction with the eID, because if there is low satisfaction with the means of logging in, citizens will not use these services. The second economic factor is the availability of online services, because if there is a low number of online services, citizens are not able to use their desired service. In this analysis using DEA, 6 indices were chosen that may reflect different factors between countries within the EU. Other indices that can be used in this analysis include GDP, HDI, DESI, ICT investment, World Digital Competitiveness Capability Index, number of digital public services for citizens, number of digital public services for businesses, education spending (% of GDP), and others. Based on the selection of values, an input- or output-oriented CCR/BCC model can be created. The EU consists of 27 EU Member States. The aim of our measurement was also determined by the means of measurement or the choice of the model orientation, because we were interested in input–output effects so that we can measure the technological efficiency of e-Government in a given country. The outputs and inputs used in the analysis are unique to the system under consideration. Because we aimed to maximize the outcomes of the technology part of e-Government, we used an output-oriented model [40]. The DEA analysis not only focused on evaluating the efficiency improvement in e-Government for each country, but the countries were also divided into their areas within the EU as much as possible to compare the efficiency scores from the different EU areas. Table 9 shows the inputs and outputs for all DMUs and country breakdown by region.

Table 9. Inputs and outputs data for the DEA method.

DMU	Region within the EU	Country	Inputs			Output		
			Number of Internet Users in [%] Internet Usage	DSGI—Government Support [Score]	Gross R&D Expenditure, % of GDP [Score]	Service Online E-Government in [%]	Satisfaction with eID in [%]	Interaction with Public Administration in [%]
1	western	Luxembourg	99	9	20.6	92	67	49
2	western	Austria	88	5.7	58.8	89	85	67
3	western	Belgium	92	5.2	63.9	87	72	63
4	western	France	92.2	5.6	43.2	90	46	56
5	western	Germany	94	6.2	57.8	87	53	50
6	western	Netherlands	95.3	6.4	42.1	94	86	86
7	eastern	Hungary	89.3	3.1	29.4	90	77	81
8	eastern	Czech Republic	86.8	3	36.5	80	44	64
9	eastern	Slovakia	90	3.5	16.6	63	75	57
10	eastern	Poland	91.5	2.7	25.5	79	77	34
11	eastern	Bulgaria	70	3.9	15.5	67	42	24
12	eastern	Romania	78	2.8	8.5	50	20	12

Table 9. *Cont.*

DMU	Region within the EU	Country	Inputs			Output		
			Number of Internet Users in [%] Internet Usage	DSGI—Government Support [Score]	Gross R&D Expenditure, % of GDP [Score]	Service Online E-Government in [%]	Satisfaction with eID in [%]	Interaction with Public Administration in [%]
13	northern	Sweden	97.3	6.9	64.8	87	75	88
14	northern	Denmark	97.7	5.9	55.7	98	93	92
15	northern	Finland	94.1	6.4	53.9	97	96	88
16	northern	Ireland	92	6.4	22.5	87	45	68
17	northern	Estonia	96.1	7.9	32.9	95	96	75
18	northern	Latvia	89.8	4	12.9	91	86	73
19	northern	Lithuania	97.8	5.3	21.1	85	89	65
20	southern	Slovenia	87	3.5	39.4	79	66	68
21	southern	Spain	93	3.9	25.7	87	83	59
22	southern	Malta	100	6.4	12.3	99	98	58
23	southern	Portugal	88.1	6.6	29.6	95	89	50
24	southern	Croatia	93.2	2.9	22.8	80	60	52
25	southern	Italy	90.8	2.4	28	84	61	31
26	southern	Greece	78.5	1.8	27.4	66	34	66
27	Asia	Cyprus	100	3.6	15	56	8	62

Source: Own processing.

Correlation analysis is an important criterion for determining appropriate inputs and outputs. We performed correlation analysis for each combination of variables. The results of the correlation analysis are shown in Table 10.

Table 10. Values of correlation coefficients between inputs and outputs.

	A	B	C	D	E	F
A	1					
B	0.54	1				
C	0.226	0.354	1			
D	0.537	0.65	0.455	1		
E	0.428	0.461	0.287	0.786	1	
F	0.504	0.374	0.516	0.552	0.486	1

Source: own processing.

Individual letters represent selected inputs and outputs:

- A (number of Internet users in % Penetration),
- B (DSGI—government support),
- C (Gross expenditure on research and development, % GDP), D (service online e-Government),
- E (satisfaction with eID login in [%]),
- F (interaction with public administration).

From the results of the correlation analysis, studying the literature on the use of DEA models, and consultation, it can be said that the values between the variables are suitable for DEA analysis. This confirmed the suitability of the selected inputs and outputs in the proposed DEA models. The descriptive statistics of the inputs and outputs used are shown in Table 11.

Table 11. Descriptive statistics of inputs and outputs used.

	Inputs			Outputs		
	A	**B**	**C**	**D**	**E**	**F**
Max	100	9	64.8	99	98	92
Min	70	1.8	8.5	50	8	12
Average	91.17	4.85	32.68	83.48	67.52	60.67
Standard deviation	6.95	1.86	16.95	12.8	24.08	19.5
Modus	92	5.2	28	87	75	63
Median	100	9	64.8	99	98	92

Source: own processing.

Three inputs and three outputs were used in the analysis. For a more detailed description of the individual inputs and outputs, their maximum, minimum, average value, etc. were evaluated in each input.

3. Results

In this section, we apply the CCR and BCC models to evaluate the efficiency of e-Government in the EU. The computed results of the CCR and BCC models are presented in Table 12. The computation was performed using DEA-application.

Table 12. Results of the DEA analysis.

DMU	Region within the EU	Country	CCR Model	SPF	CCR Ranking	BCC Model	SPF	BCC Ranking
1	western	Luxembourg	0.898	0.898	23	0.899	0.899	26
2	western	Austria	0.969	0.969	12	1	1.006	1
3	western	Belgium	0.907	0.907	22	0.929	0.929	25
4	western	France	0.927	0.927	18	0.935	0.935	23
5	western	Germany	0.871	0.871	26	0.892	0.892	27
6	western	Netherlands	0.979	0.979	11	0.988	0.988	14
7	eastern	Hungary	1	1.161	1	1	1.463	1
8	eastern	Czech Republic	0.916	0.916	21	0.961	0.961	21
9	eastern	Slovakia	0.93	0.93	17	0.986	0.986	15
10	eastern	Poland	1	1.149	1	1	1.149	1
11	eastern	Bulgaria	0.922	0.922	19	1	1.158	1
12	eastern	Romania	0.823	0.823	27	1	1.511	1
13	northern	Sweden	0.961	0.961	13	0.967	0.967	17
14	northern	Denmark	1	1.014	1	1	1014	1
15	northern	Finland	1	1.054	1	1	1054	1
16	northern	Ireland	0.922	0.922	19	0.94	0.94	22
17	northern	Estonia	1	1.002	1	1	1.042	1
18	northern	Latvia	1	1.425	1	1	1.895	1
19	northern	Lithuania	0.933	0.933	16	0.933	0.933	24
20	southern	Slovenia	0.894	0.894	24	0.97	0.97	16

Table 12. *Cont.*

DMU	Region within the EU	Country	CCR Model	SPF	CCR Ranking	BCC Model	SPF	BCC Ranking
21	southern	Spain	0.952	0.952	14	0.962	0.962	20
22	southern	Malta	1	1.195	1	1	1.195	1
23	southern	Portugal	1	1.056	1	1	1.06	1
24	southern	Croatia	0.951	0.951	15	0.962	0.962	19
25	southern	Italy	1	1.086	1	1	1.156	1
26	southern	Greece	1	1.403	1	1	1.606	1
27	Asia	Cyprus	0.874	0.874	25	0.962	0.962	18

Source: own processing.

In addition to the model results, the value of super-efficiency in both models was calculated. The CCR model found 10 states to be efficient and the BCC model found 13 states to be efficient. According to the CCR model, the Slovak Republic has an efficiency rate of 0.930, and according to the BCC model, this value is 0.986. The most efficient countries in terms of e-Government efficiency according to the CCR model are Greece, Italy, Portugal, Malta, Latvia, Estonia, Finland, Denmark, Poland, and Hungary. For the BCC model, these countries are joined by Austria, Romania, and Bulgaria. For some countries, the result may seem surprising, as the level of e-Government is not at a high level compared to other EU countries. However, these countries are becoming efficient because of their inputs.

Big differences between the results of the CRR and the BCC models are seen for Romania and Cyprus, that is, countries can have better results in one area, thus increasing their efficiency level. Table 11 shows the country rankings based on efficiency; for the CCR model, the ranking is given in column 6, and for the BCC model it is given in the last column. The overall efficiency ratio in the CCR model is 0.949 and in the BCC model it is 0.973.

In addition to evaluating the standard efficiency of the models, the so-called super-efficiency model was also used. Next, we discuss the results from the CCR model in the context of super-efficiency. Units that were found to be inefficient in the original model still took on the same values in the super-efficiency model.

3.1. Different among the Area of the European Union

From the results of the analysis carried out, there are obvious differences between the EU regions (Western, Northern, Southern, and Eastern EU regions) in the e-Government efficiency scores within EU-27. In 12 countries, representing almost half of the countries, the efficiency is lower than the average efficiency in the CCR model. This implies that almost half of the countries do not achieve even a primary efficiency score when building e-Government systems. In addition, e-Government services are still not being used to handle government business. The results of the CCR model in the Western EU are shown in Figure 5.

E-Government requires more attention from states with lower average efficiency. Figure 5 shows that within the Western EU the efficiency ranges from 0.871 to 0.979.

None of the Western EU countries have reached the efficient frontier of the CCR model, and thus can be considered inefficient. The highest score within the Western EU was achieved by the Netherlands (0.979) and the lowest by Germany (0.871) for the specified inputs and outputs. The results for the Northern, Eastern, and Southern EU regions are shown in Figure 5.

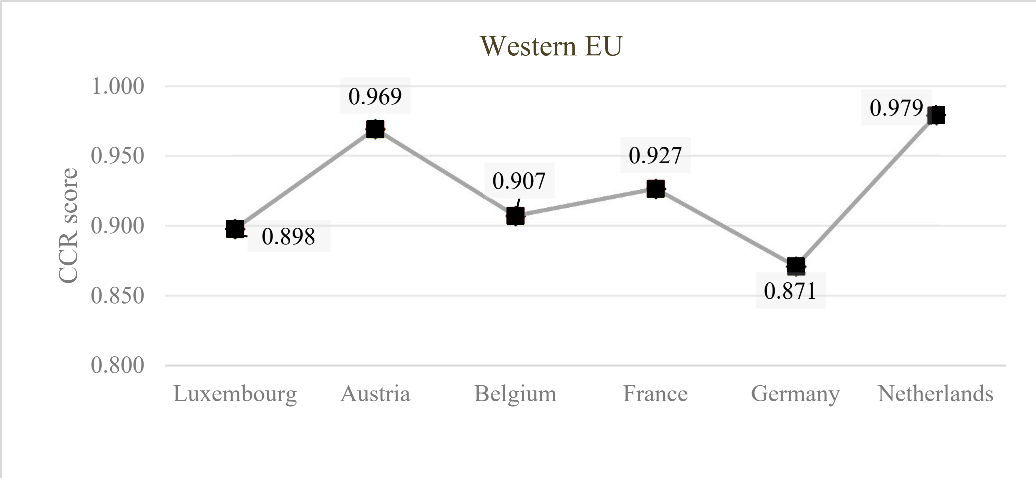

Figure 5. Results of the CCR model in the Western EU. Source: own processing.

Figure 6 shows that for four of the seven countries within Northern EU, the efficiency rate is the highest. Within the Eastern EU there are two efficient countries, and the remainder do not even reach overall primary efficiency. The last area is the Southern EU, and within this region we can observe four of the eight countries are efficient. Through this analysis we found that the Northern EU countries do not invest a large amount of resources in inputs, but produce good quality outputs. On the other hand, the Western EU countries invest a large amount of resources in inputs, but their effect on outputs is not sufficient to be considered efficient. The raises the question of how the outputs should be adjusted or improved to turn an inefficient DMU into an efficient DMU.

Table 13 shows that not every output needs to be changed for the country to become efficient. For some countries, one output needs to be modified, but for others, two out of three outputs need to be modified. Countries that are efficient do not need to modify any output.

Table 13. Changing outputs to achieve efficiencies.

DMU	Country	Output			Change			Changed Output		
1	Luxembourg	92	67	49	0	19.68	15.94	92	86.68	64.94
2	Austria	89	85	67	0	0	0	89	85	67
3	Belgium	87	72	63	0	6.97	0	87	78.97	63
4	France	90	46	56	0	35.85	2.72	90	81.85	58.72
5	Germany	87	53	50	0	27.01	2.66	87	80.01	52.66
6	Netherlands	94	86	86	0.52	0	0	94.52	86	86
7	Hungary	90	77	81	0	0	0	90	77	81
8	Czech Republic	80	44	64	0	24.27	7.28	80	68.27	71.28
9	Slovakia	63	75	57	16.19	0	0	79.19	75	57
10	Poland	79	77	34	0	0	0	79	77	34
11	Bulgaria	67	42	24	0	20.94	22.69	67	62.94	46.69
12	Romania	50	20	12	0	27.48	26.99	50	47.48	38.99
13	Sweden	87	75	88	6.74	13.96	0	93.74	88.96	88
14	Denmark	98	93	92	0	0	0	98	93	92

Table 13. *Cont.*

DMU	Country	Output			Change			Changed Output		
15	Finland	97	96	88	0	0	0	97	96	88
16	Ireland	87	45	68	0	37.8	0	87	82.8	68
17	Estonia	95	96	75	0	0	0	95	96	75
18	Latvia	91	86	73	0	0	0	91	86	73
19	Lithuania	85	89	65	9.25	0	3.19	94.25	89	68.19
20	Slovenia	79	66	68	0	2.75	0	79	68.75	68
21	Spain	87	83	59	0.41	0	6.19	87.41	83	65.19
22	Malta	99	98	58	0	0	0	99	98	58
23	Portugal	95	89	50	0	0	0	95	89	50
24	Croatia	80	60	52	0	2.17	0	80	62.17	52
25	Italy	84	61	31	0	0	0	84	61	31
26	Greece	66	34	66	0	0	0	66	34	66
27	Cyprus	56	8	62	19.05	59.04	0	75.05	67.04	62

Source: own processing.

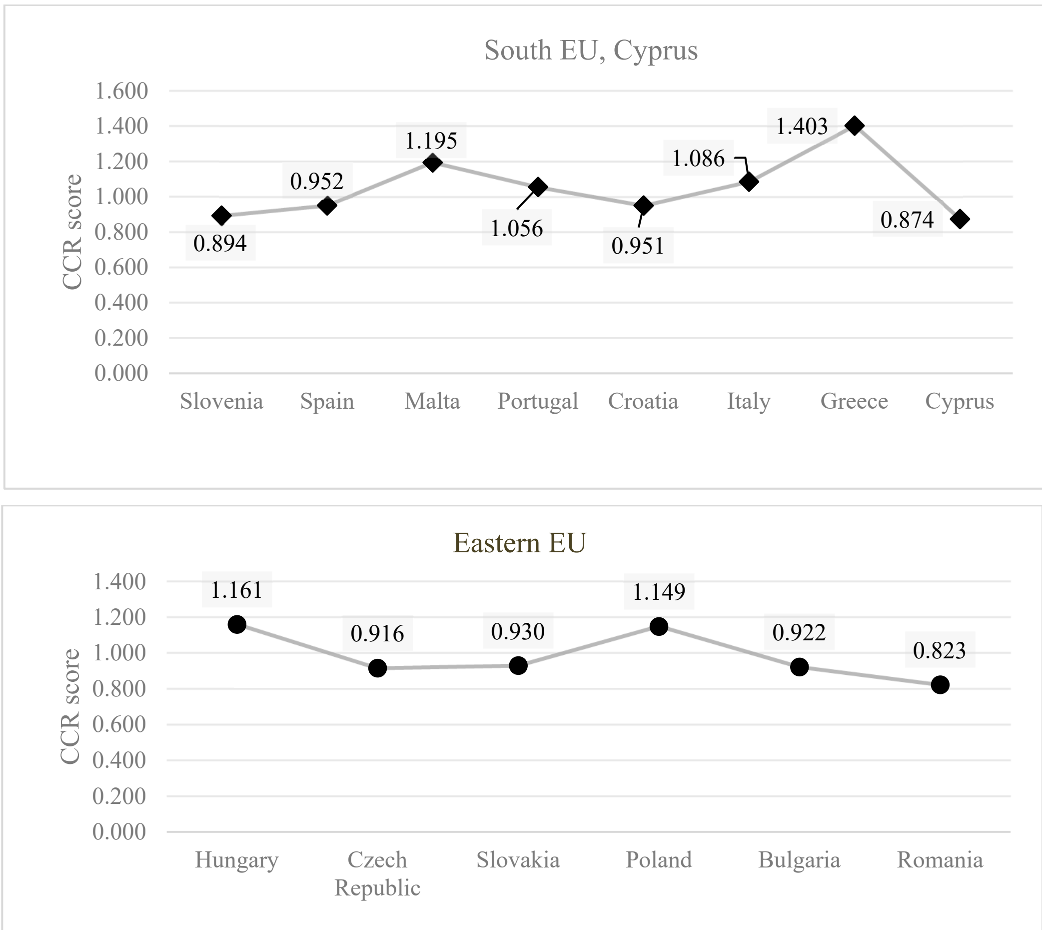

Figure 6. CCR model results across Northern, Eastern, and Southern EU. Source: own processing.

3.2. Change in Outcomes for Selected Countries in the Region

The differences between countries are evident; in order to become effective and achieve a score of 1 in the DEA analysis a country needs to adjust outputs. For this comparison, countries from each EU region were selected. Figure 7 shows the countries and their change in output.

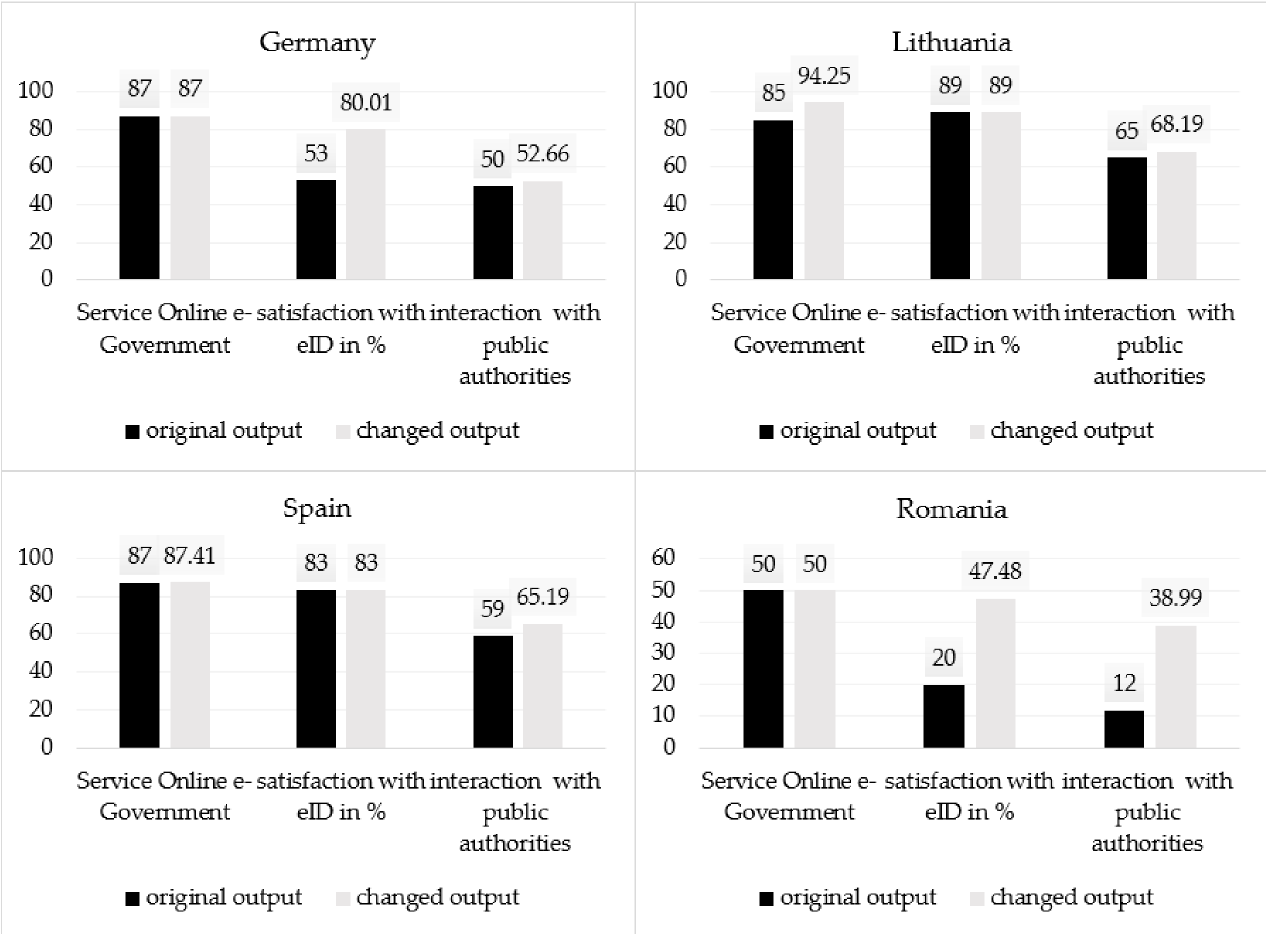

Figure 7. Selected co untries and their change in output.

The results of the analysis show that Germany has to adjust two out of three outcomes. Germany should increase satisfaction with eID by 27% and increase interaction by 2.66 while keeping the same inputs. Consequently, Lithuania should inc rease the number of online e-Government services to 94.25% and increase interaction with the public administration by 3.19. To become efficient, Spain should increase the number of e-Government services by 0.41% and increase interaction with the public administration by 6.19. Romania scored the lowest efficiency of all countries, and to become efficient it should increase satisfaction with eID by 27.48% and increase interaction to at least a score of 38.99 out of 12. The number of online e-Government services is sufficient for the inputs.

The results also show that countries perform well but often fall short in either one or two outputs. It has been shown that public administration can be effectively promoted towards efficient, honest, open, and transparent governance through e-Government. It is essential for the European Union to use e-Government and to optimize and improve processes in communicating with citizens.

DEA analysis shows that some countries do not pay enough attention to building e-Government in some areas. This implies that they are not efficient compared to countries that use less inputs and catch up with high outputs. Governments should encourage greater openness and disclosure of information in government affairs, and the use of e-Government should be increased. In addition, satisfaction with eIDs should also increase, and interaction between citizens and the public administration should be enhanced. Modern public administrations should not only play the role of requesters of e-Government information, but should also be providers of information. Other countries can use similar analysis to identify sources of low efficiency and thus improve efficiency in that area.

4. Discussion

The research problem was to find suitable indicators to measure the efficiency of e-Government within the EU. Based on the results and output of DEA analysis, it is possible to say that some countries are inefficient. The most effective countries in the framework of e-Government are in the Scandinavian region, such as Estonia, Finland, Denmark, and Latvia. The inputs of these countries are in appropriate proportion to the outputs and their level of e-Government. We can see a big difference between Estonia, as a country belonging to the Eastern Bloc and having a relatively low level of GDP, and Denmark, whose GDP is much larger. In addition, this is the problem of Western Europe, which spends a large amount on inputs relative to the level of outputs and thus does not achieve efficiency. Thus, we can conclude that even a country with a low budget can achieve a high level of e-Government, if the spending of resources is effective in relation to their output [44].

One of the opportunities is to improve the transition to digitalization in public services. The European Union has developed several strategies for improving digitalization and e-Government. One is Europe's Digital Decade: digital targets for 2030 and the other is the Recovery Plan for Europe [45,46]. In the coming years, individual Member States will improve their transformation to an e-digital economy and it would therefore be appropriate to focus on measuring the technological efficiency of e-Government. Studies show us that there are several indices that measure different areas of digitalization, e-Government, etc. Therefore, it is useful to use these data to better identify the areas in which some countries, such as Romania and Germany, are lagging behind, in order to improve their performance.

Digitalization plays an important role in all EU policies. Digital solutions bring with them opportunities and are important in rebuilding economies after the COVID-19 crisis, during the ongoing energy crisis, etc., to consolidate their position in the world economy. Digital technologies are increasingly contributing to increased productivity, efficiency, and sustainability and, above all, the overall well-being of the population [47].

Technological development is one of the important aspects that increases the rate of economic growth at the macro level. At the same time, the effective use of technological progress in various spheres of society leads not only to economic but also to social development [48].

The application of digitalization in several areas of the economy and society is taking place at different levels. Digitalization is one of the European Union's priorities. The EU wants to improve the digital skills of its population, provide training for workers, and move towards a digitization in public services that respects fundamental rights and values [49,50].

During the writing of the first section and the determination of the topic of the paper, questions arose that needed to be answered. The questions and answers that arose during the processing of the article are as follows. Is it possible to use the DEA method to determine the efficiency of digitalization within the EU? Yes, it is possible to use the DEA method in different ways if the input parameter is set correctly. Is the data set necessary to meet the requirements of the DEA method available? There are a number of indices that are formed by appropriate input and output data. Is it possible to use the DEA method within the EU and to make comparisons with countries outside the EU? This is not possible because the metrics are not uniform or there are no comparable data. Is it possible to focus only on e-Government in the context of digitalization? Yes, there is a sufficient data set to enable the determination of the efficiency of e-Government digitization in EU Member States. Many authors have been addressing the issue of digitization for several years. The topic of digitization is still relevant, and as we can see in 2022 and 2021, authors are paying attention to this topic all over the world. The level of digitization varies from country to country, as do the solutions. The European Union is one of the leaders in digitization, as confirmed by the EGDI index. However, as the results of this paper show, many countries are efficient and the e-Government parameter in some countries needs to be improved to adequately respond to the input values and avoid unnecessary wastage of resources. These results are also supported by research conducted in China. Within the EU, the problem is similar, in that some countries are inefficient, such as Romania, Lithuania, and Germany. Measuring efficiency using the DEA method can help governments to know which areas need to be improved while maintaining or reducing inputs, in order to achieve the same level of output as other EU countries with which they can establish closer cooperation. Cooperation within the EU will be very important in the future if there is to be unification and closer integration of the eID, foreign residency, use of e-services within the EU, etc. With the increasing digitalization, there is a growing concern about e-waste, which is becoming an issue. The EU is trying to eliminate this problem by gradually modifying the legislation on small and medium-sized e-electronic devices [49–52]. In order to measure the success of the introduction of new rules in the European market, it would be appropriate to measure their efficiency using the DEA method, in all areas, since an efficient approach results in the better use of resources in a given area, which could result in financial savings that could be used in other areas. As mentioned in the first section, many authors have used the DEA method to measure efficiency, e.g., in agriculture, energy, and overall digitalization. The DEA method has a wide range of applications in different fields. As mentioned in the introductory part of this thesis, the recovery and resilience plan is intended to help selected or all countries in their digital transformation. These investments and their results will only be visible in a few years' time. Therefore, we need to trace how effective these financial resources have been in influencing the results of e-Government, whether in terms of eID satisfaction, increased interaction between citizens and public administration, or increased number of online services.

Contributions and Limitations

The article focuses on the use of the DEA method using various indices that include the countries of the European Union. In developing the article, we identified various limits or opportunities for further research.

One of the main limitations is that countries do not record investments or resources used in e-Government for a certain period using a uniform standard, which would enable these data to be examined for use in the DEA method. Another problem is access to data that could be used for non-EU countries. Further limits and restrictions are listed in Table 14.

Table 14. Insights from this study and the limits.

Insight	Execution	Limitation and Opportunities for Further Research
Level of digitalization	Use of DESI and EGDI, e-Government benchmark, LOSI	Impossible to realize efficiency within cities using LOSI (unavailability of data), complicated identification of investments in e-Government.
Survey	Unrealized	Conducting research in selected EU countries.
Country research	European Union countries	Conducting research in non-EU countries such as Colombia, Japan, and South Korea.
The area of digitization	The efficiency of e-Government within the EU	Analyze EU e-Government funding and use it for evaluation. However, there is a problem of accurately identifying investments.
DEA	BCC, CCR models	Use of another DEA model such as the SBM model.

Source: own processing.

5. Conclusions

The article provides an overview of the use of the DEA method, in which we identified that this method is used in different areas of digitization to measure efficiency. In addition, the first part of the paper defines all the available indices to measure digitalization, such as DESI, EGDI, DSGI, E-Government benchmark, GII, and the Going Digital Toolkit. The paper focuses on measuring the efficiency of digitization in e-Government in the context of renewability.

Digitalization can be seen as a tool to achieve sustainable development and provides access to untapped and integrated big data sites with potential benefits for society. Therefore, it is necessary to look at all aspects and areas of digitalization that can contribute to this. One of these areas is e-Government, since it changes the functioning of the state in the digital domain so that it should contribute to reducing the bureaucratic burden on both citizens and state institutions. E-Government brings a number of benefits to citizens, such as 24/7 availability, saving money, and saving time. However, it may also have a secondary impact, particularly in terms of increased demand for electricity and electrical equipment, more waste, greater consumption of scarce resources for battery production, higher electricity consumption in the telecommunications sector, etc. [52–55].

Consequently, authors Abdul-Lateef Balogun, Danny Marks et al. also stated that digitalization is a key factor [53]. As is already evident, several authors have focused on digitalization as one of the key factors. In this paper, we focused on the efficiency of digitalization in the field of e-Government, which may be one of the key elements of the functioning of the state in the future.

The results of this article show that the countries of the Northern European Union are efficient in the field of digitalization. Those countries are Denmark, Finland, Lithuania, and Estonia. The resources they spend on building e-Government infrastructure and services are efficiently matched in outputs.

The results of the CCR model show that 10 of the 27 countries are efficient, representing 37% of the countries. On the other hand, 63% of countries are inefficient within the EU. There are several reasons for this. One cause may be spending excessive resources on inputs, because even countries with less economic power can perform better. These countries are not spending resources efficiently to achieve the desired effect. Countries within the EU should reconsider spending resources on inputs in order to achieve efficient spending of resources on outputs.

Among the limitations that we identified while writing the article is the low number of articles using the DEA method in the e-Government field, although there are a number of studies in other areas of digitalization. Other limitations include the absence of non-EU index data. Having these data could make comparisons outside the EU more feasible. This also suggests an idea for another article, namely, looking for common parameters within the world, or the creation of such an index, which would also include the economic aspects of e-Government in the regions.

In addition, as already mentioned, few studies have examined the use of the DEA method in e-Government. Further research could also measure the outcome of digitalization within the EU using established indices, thereby measuring the impact of digitalization on the economy, society, and public sector. Another possible research area could be the measurement of the efficiency of e-Government based on the time level, because input data could relate to the resources spent on the informatization of society and the output level of digitization.

Not enough attention is paid to digitization and e-Government. Efficiency has not been measured within this area using the DEA method. However, such research has already been conducted in China. The OECD study is devoted to the input-oriented model, whereas ours uses the output-oriented model. See Table 15 for a comparison with another study [55,56].

Table 15. Comparison of the research with other studies.

This Research	Others Researches
Using the DEA method to determine EU efficiency in digitization. Use of the DEA method to determine the efficiency of the EU in the field of digitization or e-Government and focus on the technological part (eID, satisfaction, use of e-Government services).	The OECD study is devoted to the input-oriented model whereas ours uses the output-oriented model. It uses only the DESI index to measure digitization.
Use of CCR, BCC models	Use of the SBM model and CCR model.
Use and identification of different indices in the field of digitization: DESI, EGDI, DSGI, e-Government benchmark, GII, etc.	-
Determining efficiency within the EU area (East, West, North, South).	Determination of efficiency using DEA within China in the respective provinces.
Identifying the use of the DEA method in different areas.	-

Source: own processing.

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