Article

The use of the DEA method for measuring the performance of electronic public administration as part of the digitization of the economy and society

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Abstract: Digitalisation is one of the European Union's priorities. The European Parliament is shaping and helping to shape new legislation in this area. Digitisation should also help in the transition to a greener economy and in achieving climate neutrality. E-government is one area of digitisation that has been under way for several years in European countries. In this paper, we have focused 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 effectiveness of e-Government related inputs and outputs within the EU were identified. As can be seen from the analysis, the DEA method has various uses. In order to be able to use the method properly it was necessary to select the most appropriate parameter and to verify their suitability by means of correlation analysis. Among the input and output indices were chosen Internet usage, DSGI, GII, e-Government benchmark, Interaction with public administration online. From the analysis 3 inputs and 3 outputs were used. 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 CCR and BCC model. CCR model evaluated 10 states as efficient and BCC model evaluated 13 states as efficient. In addition, in the close analysis, we have taken a closer look at the CCR model's inference. Countries such as Denmark, Finland, Estonia, Malta, Portugal, etc. 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 4 countries out of 7 are efficient. In a future study it would be useful to use the SBM model and try to measure the impact of digitalization on selected areas such as economy, society, environment, etc.

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

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 the states. Digitization is affecting all aspects of policy and domain from purchasing of goods services through internet to handling of official business. Digital technology has erased Boundaries, and this has been in the way people live, work and communicate. The public sector is no exception. The impact of the pandemic with COVID-19 has also accelerated the uptake and increased investment in digital. A number of countries have re-thought

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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 and that 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 the e-Govermnet within the EU. As early as 2005, 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. [3,4] It is increasingly recognised 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] Analogue government: closed operations and internal focus, analogue procedures. E-Government: digitisation 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 in use such as AI machine learning, etc. have been added. The descriptions of e-Govermnet are given in Table 1.

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 personalised way	From one-stop shop to no-stop shop: An e-government stage model
Spirakis, Spiraki a 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 a 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 a ASPA 2002 [8]	E-Government is defined as: the use of the Internet and the World Wide Web to provide government information and services to citizens	Benchmarking eGovernment: a global perspective
Silcock R. 2001 [8]	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.

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Use of the DEA method in various fields

Nowadays, it is possible to measure the level of efficiency using the DEA (Data envelopment analysis) method. The article focuses on the use of the method in the case of digitalization in the EU and Slovakia. 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 a conceptual evaluation of energy input-output analysis on the island of Crete. This is an environmental area. The researchers used four cultivation practices of tomato, patrice, cucumber and eggplant in the DEA evaluation. The inputs that contributed most to the outputs were labour, fertilization and crop protection. [10] Other authors Y.Barba-Gutiérrez and B.Adenso-Díaz etc. found the ecologic efficiency of electoral and electoral equipment. The paper focuses on different domestic electronic appliances and compares their eco-efficiency calculated using DEA method. [11] In Kenya, researchers have focused on the use of DEA method in tea processing. The results showed that small-scale tea processors in Kenya were consistently eco-inefficient. The average efficiency index is 49%, despite previous initiatives to improve efficiency. [12]

Authors who have used the DEA method include Asmat Ullah and Sylvain R. Perret. They have used the method to analyze the efficiency of irrigated cotton cropping systems in Punjab. The results show that the farmers are environmentally inefficient, mainly due to poor technical inefficiency. [13] The authors Kamran Rashidi and Reza Farzipoor Saen have also focused on measuring environmental efficiency. They used the DEA method where they split the inputs and outputs. They divided inputs into energy and non-energy and outputs were divided into desirable and undesirable. The results showed that Australia, Finland, Ireland, New Zealand and Switzerland are eco-efficient countries. [14]

The World Business Council defined eco-efficiency: 'eco-efficiency is achieved by supplying goods and services at competitive prices that meet human needs and deliver a good quality of life, while gradually reducing environmental impacts and life-cycle resource intensity to a level'. Evaluating eco-efficiency is a complex and multidisciplinary task. The [14,15] DEA method provides a way to measure efficiency in different domains based on selected inputs and outputs. It depends on the author what inputs and outputs he chooses to calculate the desired area of investigation.

Manuel Jesús Hermoso-Orzáez et al. have used the DEA method to measure environment efficiency in European Union countries. The authors used the refined method of analysis (MAN). The results show that 14 out of 28 countries have high relative environmental efficiency. In [16], our paper focuses on the measurement of digital efficiency. Since Maria E. Modejar and Raman Avatar present digitalization as a tool for achieving the Sustainable Development Goals. [17] Sean Pascoe and Toni Cannard etc. found the use of (DEA) method of data envelopment analysis with comparison of multi-criteria decision analysis (MCDA). The authors found that the DEA method had the advantage of not requiring the measures to be comparable and could also directly include the undesirable outcomes in the analysis and also the DEA method was able to produce the same results as MCDA when similar weights were used. The authors concluded that the DEA method is a useful approach to assessing a variety of social, economic, digital or environmental changes. [18] The wide use of the DEA method is indisputable. George Emm Halkos and Nickolaos G.Tzeremes have used the DEA method to evaluate the effectiveness of different countries in biodiversity conservation. [19] In addition, DEA can also be used to measure water quality. Also, in another study, the authors discussed the use of DEA metric to measure capacity utilization in the context of energy and CO2 emission constraints. [20]

The purpose of this study will be the use of the DEA method in the field of digitalization within the EU. As there is no study that identifies the efficiency and transformation rate of digitalization among EU countries. Therefore, it is necessary to identify possible input and output data. The use of 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

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basis index includes 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 skill gap index, going digital toolkit. Table 2. lists the individual indices with the abbreviation and the year of their first measurement, followed by more detailed information on the individual indices.

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

Index	Abbreviation	year of launch	Data availability within the		Index key areas	Implementer
			EU	World		
E-Government Development Index [21]	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 [22]	-	2018	yes	no	user centricity, transparency, Key enablers, Cross-Border Services	European Commission
Eurostat - internet use [23]	-	2008	yes	no	Internet use: interaction with public authorities	European Commission
Global Innovation Index [24]	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 [25]	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 [26]	-	-	yes	yes	access, use, innovation, jobs, society, trust, market openness	OECD
The Digital Economy and Society Index [27]	DESI	2014	yes	no	human capital, connectivity, integration of digital technology digital public services	European Commission

Source: Own processing.

The DESI measures the state of digitalisation across the EU. The index provides an overall picture of the state and performance of individual Member States. As the previous table shows, there are a number of indices focusing on different areas of digitisation. A less common area tends to be e-Government. Table 3 shows the overall digitisation score in Slovakia from 2018 to 2022 compared to the European average.

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Table 3. Overall level of the DESI

Human capital	Slovakia		Europe union	Reaching the EU average
	rank	score	score	
DESI 2018	20	41.9	46.5	4.6
DESI 2019	21	42.9	49.4	6.5
DESI 2020	22	45.2	52.6	7.4
DESI 2021	22	43.2	50.7	7.5
DESI 2022	23	43.4	52.3	9

Source: europa.eu, (online). (cit. 2022-1-18). Available on the Internet: < https://lnk.sk/pcr9 > Own processing.

Slovakia's DESI score has been declining since 2018, and Slovenia is gradually moving towards the EU's level. As we can see in the table, in 2022 Slovakia will be ranked 23rd. Which represents the worst score in the last 5 years.

Although Slovakia has made some progress in all areas in the past year, especially in the indicators of core internet coverage and connectivity deployment, the improvements have not been enough for Slovakia to keep up with the EU average [28].

The DESI index in the area of digital public services shows that the use of digital public administration services is far below the EU average. Of the 27 Member States, Slovakia ranks 24th with a score of 52.0, but the EU benchmark score is 67.3. Slovakia lags far behind, especially in openness of data. The number of e-government users is at 62% in 2022 (EU benchmark 65%). [28]

At the end of 2021, the Slovak government approved a new strategic document "National Concept of Informatisation of Public Administration of the Slovak Republic for 2021-2026."[29] This document is aimed at developing the concept of the EU's strategic priorities of the digital de-decade until 2030. The document focuses on areas such as digital services, data transformation, public procurement and cyber and information security, etc. In addition, the document contains so-called "living situations" for citizens and businesses that should bring about simplified and more efficient digital solutions [29].

Slovak public administration and public services have traditionally achieved a relatively low level of digitisation, which represents a major obstacle to the widespread use of digital public services by citizens and businesses. In the Slovak Recovery and Resilience Plan, Slovakia invests in digital technologies in public administration, with around EUR 650 million allocated to this policy area [29,30].

In addition to the Slovak Republic's partial score in the DESI, it is necessary to look at the overall picture for all EU countries. A slight increase in DESI is occurring across the EU, so it is important to see the overall picture of EU digitisation as a whole. A number of countries, such as Estonia, Denmark, Finland, etc. are leaders in digitalisation. Therefore, it would be useful to establish a method and data to determine the effectiveness within the EU in the field of digitalisation policy and the e-Government area. There are many studies that deal with this area and in recent years several academic articles have been written in this field see Table 4.

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Table 4. Literature review on digitization and e-Government.

Reference	The Main Purpose of the Study	Topic	Year
I. Dhaoui [31]	The author dealt with the role of e-Government on different aspect of economic and social development in the North and Middle East Africa. The outcomes show that most indicators of good governance have a positive contribution to sustainable development. Digitisation improves control of corruption and government efficiency	E-Government for Sustainable Development: Evidence from MENA Countries	2022
G.Onyango,J. Ondiek [32]	The authors explored the role of ICTs, digital platforms, connectivity and the like in Kenya. The study identified the various problems and concludes by recommending solutions to these problems.	Digitalization and Integration of Sustainable Development Goals (SGDs) in Public Organizations in Kenya	2021
Le Thanh Ha [33]	The authors have undertaken an analysis that focuses on the impacts of the digital transformation process in the commercial and public sectors on energy security. The 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. [34]	Innovation of new and advanced ICT technologies requires new mechanisms for user identity authentication. The authors deal with the use of 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 [35]	The authors dealt with the implications of Estonia's e-residency. The results indicate that individual motives for adopting an 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. [36]	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 authors conclude that CPEC can help combat the COVID-19 pandemic.	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 [37]	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 [38]	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.	Digitalisation before and after the Covid-19 crisis	2021
F. Idzi, R. Gomes [39]	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 [40]	The author has studied the accessibility and usability of e-governance sites in India. The results show the existence of accessibility problems. And in development, low priority is given to these problems.	Accessibility and usability analysis of Indian e-Government websites	2020

Source: own processing

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2. Materials and Methods

The aim of this paper is to highlight the use of DEA method in the field of digitalisation focusing on the area of e-Governance. To identify the various uses of DEA method in different areas using available indices that identify digitization and e-Governance. The aim of the paper is to identify the efficiency and inefficiency of countries in the EU in the field of digitalization. Methodology of the article is described in table 5.

Table 5. 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 related to digitalization directly. 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.
	Thus, two models, CCR and BCC, were used in the method.	-	
	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.	-	
DEA method	Determining the number of inputs and outputs, verification of appropriate inputs and outputs,	Multi-correlation method	III.
	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 DEA method ranks among the important management methods. It allows to evaluate 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 [41,42].

The basic DEA models are CRR input and output oriented model, BCC input and output oriented model, SBM model. In addition to these models, there are also Modify-variate models where for example Malmquist index, FDH (Free Disposable Hull) model and super-effectiveness model are included. The super effectiveness 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. [43]

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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. Input quantities are those units that are consumed in a given activity and outputs represent the resulting products. In general, smaller values of inputs and larger values of outputs are preferred. The mathematical expression of efficiency is shown in formula (1.1). [44]

$$effectiveness = \frac{output}{input} \quad (1.1)$$

In practice, it is often necessary to use multiple inputs as well as outputs to measure effectiveness. It should be taken into account that in the total efficiency of production units, there may be a situation where the whole set of inputs and outputs. In this situation, the relationship for the relative efficiency measure is used, which is given by relation (1.2). [44]

$$relative\ efficiency\ rate = \frac{weighted\ sum\ of\ output}{weited\ sum\ of\ input} \quad (1.2)$$

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.44 Efficiency frontiers of the CCR and BCC model (see Figure 17).

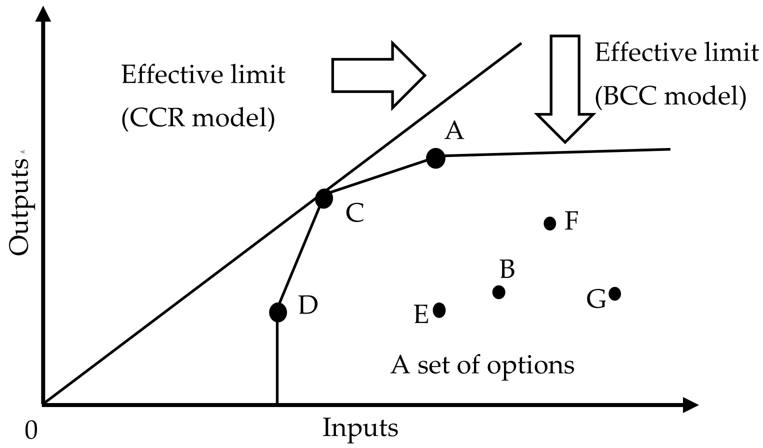

Figure 1. CCR and BCC model shown graphically. (Source: elsevier.com [online]. [cit. 2022-01-11]. Available on the Internet:<https://lnk.sk/5789>, own processing.)

Figure 14 shows the sets of production options for the CCR and BCC models. The CCR model assumes consistent returns to scale, while the BCC model assumes inconsistent returns to scale. The set of options contains a convex hill, which is the set of existing nodes. 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 17). The formulas for calculating the output-oriented CCR and BCC models (see Table 6) [45].

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Table 6. 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	$\sum_{j}^{r} u_i \cdot y_{ik} \leq \sum_{j}^{m} v_j \cdot x_{jk}$ $k = 1,2, \dots, r$ $\sum_{j}^{r} u_i y_{iq} = 1$ $u_i \geq \varepsilon, \quad i = 1,2, \dots, r$ $v_j \geq \varepsilon, j = 1,2, \dots, r$ $u \text{ is arbitrary}$	$\sum_{j}^{r} u_i \cdot y_{ik} \leq \sum_{j}^{m} v_j \cdot x_{jk} + v$ $k = 1,2, \dots, r$ $\sum_{j}^{r} u_i y_{iq} = 1$ $u_i \geq \varepsilon, \quad i = 1,2, \dots, r$ $v_j \geq \varepsilon, j = 1,2, \dots, r$ $v \text{ is arbitrary}$

Source: Own processing.

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 [44]. 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 [46].

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 will use correlation analysis. Using correlation analysis, we select the relationship between variables and eliminate variables with both very strong and very weak correlation [46].

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 the relation:

$$r=1-\frac{6 \cdot \sum_{n=1}^{N} D^2}{N \cdot (N^2-1)} \quad (1.3)$$

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

The correlation coefficient can take values <-1.1>. The correlation coefficient takes values from the interval ⟨-1 ;1⟩ and expresses the degree of linear correlation between the variable. Minus 1 indicates absolute indirect dependence, 0 indicates no, non-existent 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 validated at a significance level of 0.05. [47,48]

To use the DEA method, it is necessary to select the input and output units. Deciding on the appropriate input and output units is not an easy task to achieve the desired result. Thus, the method will be used within the EU, which has 27 member states. The total number of inputs and outputs (m+s) is sought to be minimised 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. 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. As for the DSGI: digital skills support index, it is an economic input to the DEA method.

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 index see Table 17.

Table 7. 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 (eGovernment - eGovernment user communication)	Output	+

Source: Own processing.

In this analysis using DEA, 6 indices have been chosen which 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. Countries can be divided into 4 subregions Eastern, Northern, Southern, Western Europe see Table 14. The DEA analysis will not only focus on evaluating the efficiency improvement in eGovernment for each country, but also the countries will be divided into their areas within the EU as much as possible to compare the efficiency scores from different EU areas. Table 18. also shows the inputs and outputs for all DMUs.

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Table 8. 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 and accept eID login in [%]	interaction with public administration in [%]
1	western	Luxembourg	99.0	9.00	20.6	92	67	49
2	western	Austria	88.0	5.70	58.8	89	85	67
3	western	Belgium	92.0	5.20	63.9	87	72	63
4	western	France	92.2	5.60	43.2	90	46	56
5	western	Germany	94.0	6.20	57.8	87	53	50
6	western	Netherlands	95.3	6.40	42.1	94	86	86
7	eastern	Hungary	89.3	3.10	29.4	90	77	81
8	eastern	Czech Republic	86.8	3.00	36.5	80	44	64
9	eastern	**Slovakia**	90.0	3.50	16.6	63	75	57
10	eastern	Poland	91.5	2.70	25.5	79	77	34
11	eastern	Bulgaria	70.0	3.90	15.5	67	42	24
12	eastern	Romania	78.0	2.80	8.5	50	20	12
13	northern	Sweden	97.3	6.90	64.8	87	75	88
14	northern	Denmark	97.7	5.90	55.7	98	93	92
15	northern	Finland	94.1	6.40	53.9	97	96	88
16	northern	Ireland	92.0	6.40	22.5	87	45	68
17	northern	Estonia	96.1	7.90	32.9	95	96	75
18	northern	Latvia	89.8	4.00	12.9	91	86	73
19	northern	Lithuania	97.8	5.30	21.1	85	89	65
20	southern	Slovenia	87.0	3.50	39.4	79	66	68
21	southern	Spain	93.0	3.90	25.7	87	83	59
22	southern	Malta	100	6.40	12.3	99	98	58
23	southern	Portugal	88.1	6.60	29.6	95	89	50
24	southern	Croatia	93.2	2.90	22.8	80	60	52
25	southern	Italy	90.8	2.40	28	84	61	31
26	southern	Greece	78.5	1.80	27.4	66	34	66
27	Asia	Cyprus	100	3.60	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 9.

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Table 9. Values of correlation coefficients between inputs and outputs

	A	B	C	D	E	F
A	1					
B	0.540	1				
C	0.226	0.354	1			
D	0.537	0.650	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 inter-net users in % Penetration), B (DSGI - government support), C (Gross expenditure on research and development, % GDP), D (service Online e-Governmennt), E (satisfaction with eID appecte eID login in [%]), F (interaction with public administration). From the results of 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 10.

Table 10. Descriptive statistics of inputs and outputs used

	inputs			**outputs**		
	A	B	C	D	E	F
Max	100	9	64.80	99	98	92
Min	70	1.80	8.50	50	8	12
Average	91.17	4.85	32.68	83.48	67.52	60.67
Standard deviation	6.95	1.86	16.95	12.80	24.08	19.50
Modus	92	5.20	28	87	75	63
Median	100	9	64.80	99	98	92

Source: own processing.

3 inputs and 3 outputs were used in the analysis. For a more detailed description of the individual inputs and outputs, their maximum, minimum, average value, etc. are evaluated in each input.

3. Results

In this section, we apply the CCR and BCC model to evaluate the performance of e-government in the EU. The computed results of the CCR and BCC models are presented in Table 11. The computation was performed using dea-application.

Table 11. 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**	**0.930**	**0.930**	**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	1,014	1
15	northern	Finland	1	1.054	1	1	1,054	1
16	northern	Ireland	0.922	0.922	19	0.940	0.940	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	0.970	0.970	16
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	1.060	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 evaluated 10 states as efficient and the BCC model evaluated 13 states as efficient. According to the CCR model, the Slovak Republic has an efficiency rate of 0.930 and according to the BCC model 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, with what inputs these countries are working with they are becoming efficient.

A big difference between the results of the CRR and the BCC model 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

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model the ranking is given in column 6 and for the BCC model in the last column. The overall efficiency ratio in the CCR model is 0.949 and in the BCC model is 0.973.

In addition to evaluating the standard efficiency of the models, the so-called super efficiency model is also used. Next, we discuss the results from the CCR model in the context of super-effectiveness. Units that were evaluated as inefficient in the original model still take on the same values in the super-efficiency model.

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 the 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 eGovernment systems. And e-Government services are still not being used to handle government business. Result of the CCR model in the Western EU (Figure 3).

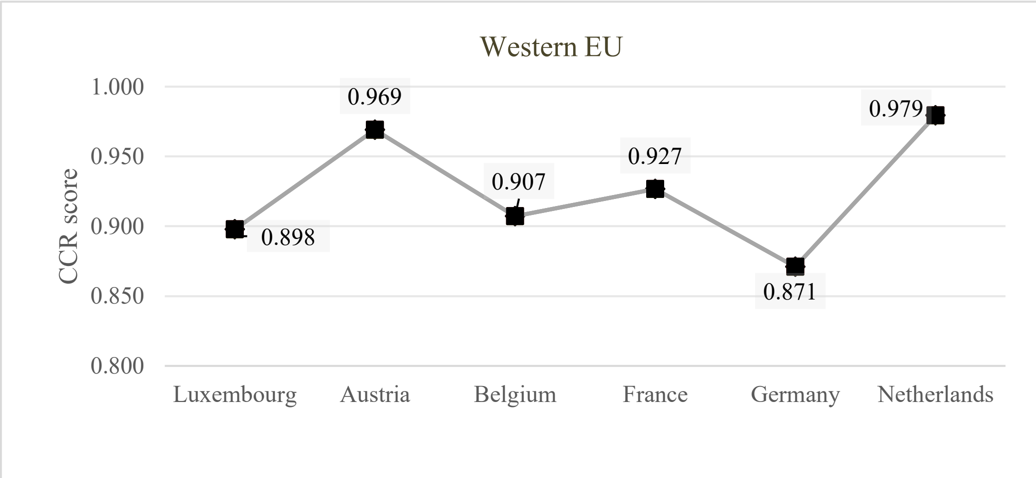

Figure 2. Result of the CCR model in the Western EU. Source: own processing.

E-government requires more attention from states with lower average efficiency. Figure 18 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 4.

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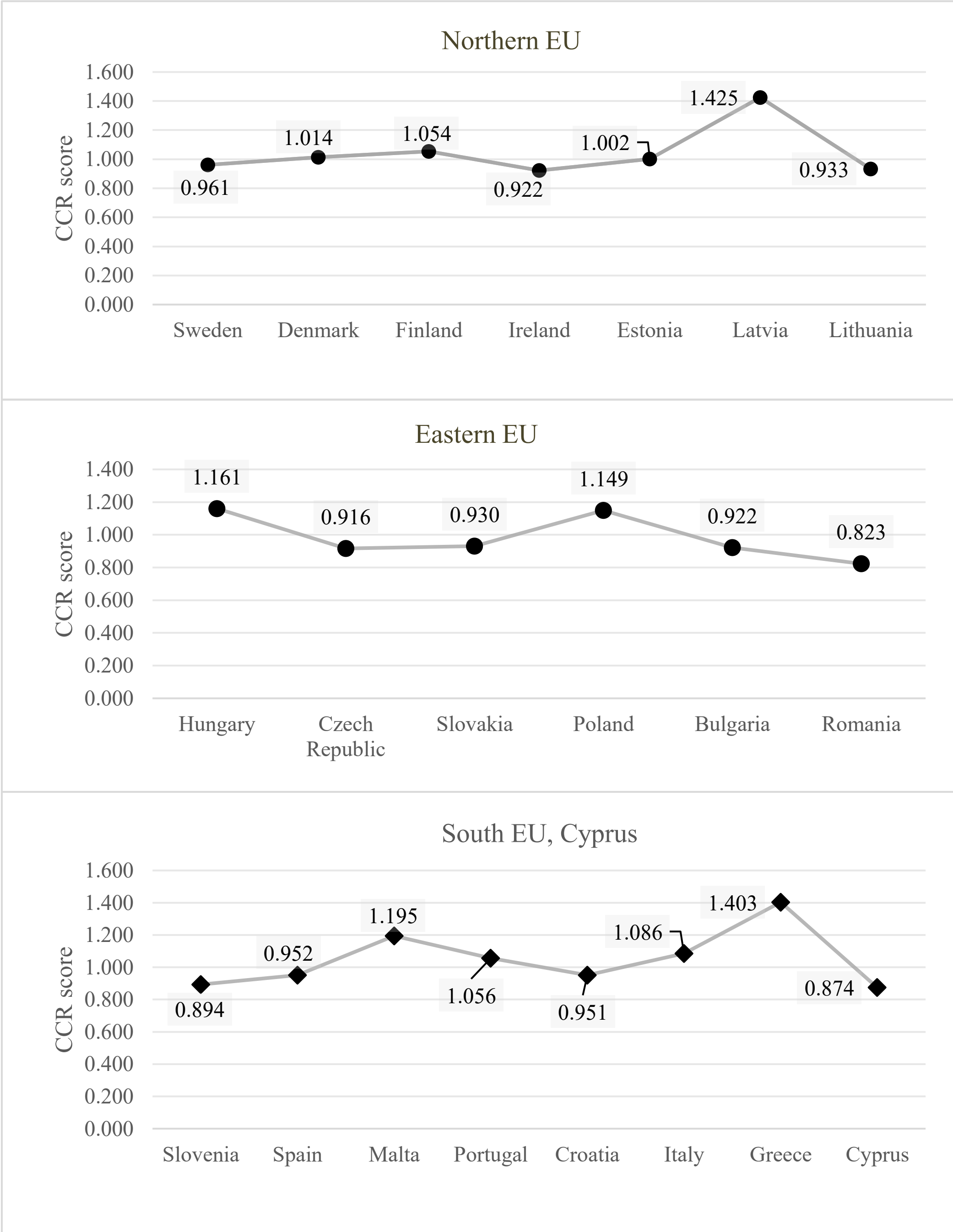

Figure 3. CCR model result across northern, eastern and southern EU. Source: own processing

Figure 14 shows that as many as 4 countries out of 7 within the northern EU. The efficiency rate within the area is the highest. Within the Eastern EU there are 2 efficient countries the rest of the countries do not even reach the overall primary efficiency. The last area is the Southern EU and within this region we can observe that up to 4 countries out of 8 are efficient. Through this analysis we have 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. How should the outputs be adjusted or improved to turn an inefficient DMU into an inefficient DMU (see Table 12).

Table 12. Changing outputs to achieve efficiencies

DMU	country	Output	Output	Output	Change	Change	change	changed output	changed output	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
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.

Table 12 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.

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 have been selected. Figure 5 shows the countries and their change in output.

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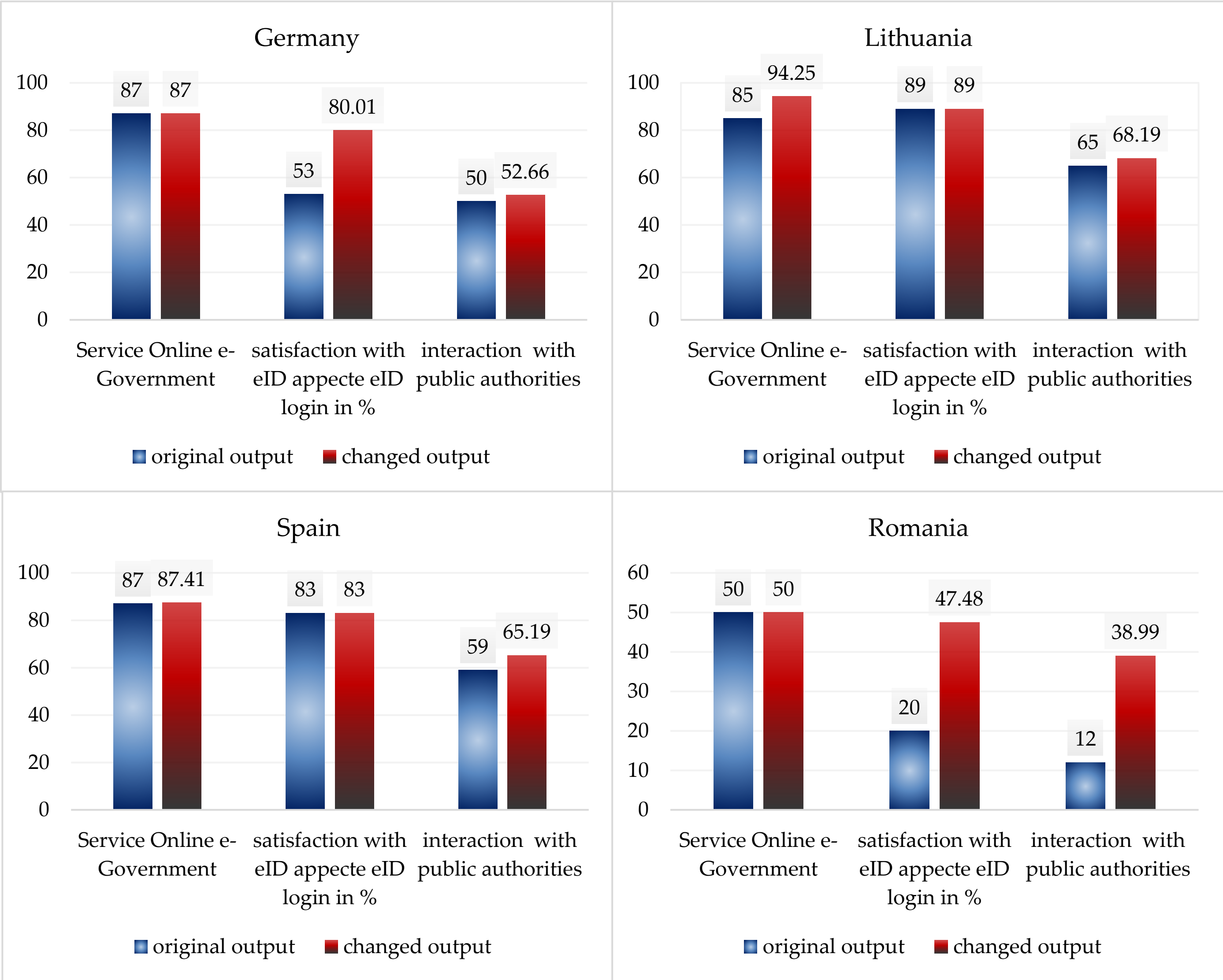

Figure 4. Selected countries and their change in output.

The results of the analysis show that Germany has to adjust 2 out of 3 outcomes. Germany should increase satisfaction with eID by 27% and increase interaction by 2.66 while keeping the same inputs. Consequently, Lithuania should increase the number of online eGovernment services to 94.25% and increase interaction with the public administration by 3.19. To become efficient Spain should increase the number of eGovernment 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 eGovernment services is sufficient to the inputs.

The Slovak Republic scores relatively well in relation to its inputs, both in eID satisfaction and in the level of interaction between citizens and the public administration. However, it lags behind in the number of online services compared to other countries. In order to become efficient, the Slovak Republic should increase the number of online services from 63% to 79.19%, see Figure 6.

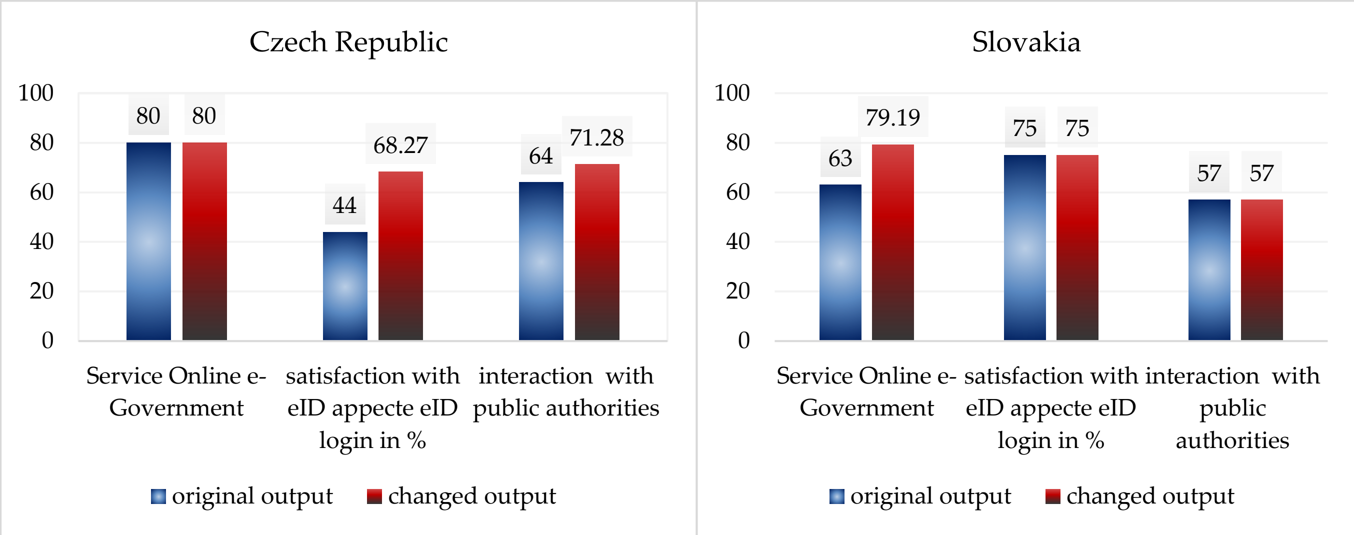

Figure 5. Selected countries and their change in output.

The Czech Republic scores well in the number of online e-Government services up to 80%. To be effective, the Czech Republic needs to improve results or outputs in satisfaction with eID by 24.27% and increase interaction with public administration by 7.28. 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 eGovernment. Given such an opportunity, how to leverage e-government and re-implement the change of government function and optimize business processes is very important for China.

DEA analysis shows that some countries do not pay enough attention in building e-Government in some areas. This implies that they are not efficient compared to countries that give lower 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 eGovernment information, but also of providers of information. Other countries can use similar analysis to identify sources of low performance efficiency and thus improve efficiency in that area.

4. Discussion

The application of digitalisation in several areas of the economy and society is taking place and is taking place at different levels. Digitalisation is one of the European Union's priorities. The European Parliaments are involved in shaping new legislation in this area. Digitisation should also help in the transition to a greener economy and in achieving climate neutrality by 2050. The EU wants to improve the digital skills of its population, provide training for workers and move towards digitisation in public services that respects fundamental rights and values. [49,50]

One of the opportunities is to improve the transition to digitalisation in public services. In this paper, we focus on measuring the effectiveness of e-Government in EU countries, which could lead to a better targeting of policies on this area and thus saving resources to achieve the result or to raise certain fads to the desired level.

Digitalisation plays an important role in all EU policies. Digital solutions bring with them opportunities and are important in rebuilding the economy after the corona crisis, the ongoing energy crisis, etc. to consolidate our position in the world economy. Digital technologies are increasingly contributing to increased productivity, efficiency, sustainability and, above all, the overall well-being of the population. [49,51]

During the writing of the first chapter 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. Is it possible to use the DEA method to determine the effectiveness of digitalization within the EU? Yes, it is possible as different uses of the DEA method if the input parameter is set correctly. Is there a necessary data set to meet the requirements of the DEA method? 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 comparisons with countries outside the EU? Not possible as the metrics would not be uniform or there are no comparable data. Is it possible to focus only on e-Government in the context of digitalisation? Yes, there is a sufficient dataset to determine the effectiveness of e-Government digitisation in EU Member States.

Many authors have been addressing the issue of digitisation for several years. The topic of digitisation 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 digitisation, as confirmed by the EGDI index. However, as the results of the 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 the research conducted in China. Within the EU, the problem is similar in that some countries are inefficient, such as Slovakia, the Czech Republic and so on. 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 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 in eID, foreign residency, use of e-services within the EU, etc.

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. [52]

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. One of them is the uniform connector pinout for small and medium-sized e-electronics. equipment. In addition, it is planned to introduce easier replacement batteries in these devices in the future. [53,54]

In order to measure the success of the introduction of new rules in the European market, it would be appropriate to measure the effectiveness using the DEA method, in all areas. Since an efficient approach results in a better use of resources in a given area, which could bring financial savings that could be used in other areas.

As mentioned from the first chapter, many authors have used the DEA method to measure efficiency, such as in the cultivation of tea in Africa, cucumbers, in measuring the efficiency of plantations, etc. The DEA method has wide uses in various fields.

Digitization, renewability, efficiency are the key elements of this era. Digital transformation is a complex and complicated process, so it is necessary to measure efficiency in comparison with other countries.

4.1. 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 have 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 in a uniform standard, so that this data can 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 8.

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Table 8. Insights from this study and the limits.

Insight	Execution	Limitation and opportunities for further research
Level of digitalization	Use of DESI and EGDI index, e-Government benchmark, LOSI	impossibility to realize efficiency within cities by using LOSI (unavailability of data), complicated identification of investments in the 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, South Korea, etc.
The area of digitization	the effectiveness of e-Government within the EU	Analyse EU e-Government funding and use it for evaluation. However, there is a problem of accurately identifying investments
DEA	BCC, CCR model	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. Where we have 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, Going Digital Toolkit etc. The paper focused on measuring the effectiveness of digitization in the e-Government in the context of renewability.

As stated by the authors of the article "Digitalization to achieve sustainable development goals: Steps towards a Smart Green Planet". Digitalization can be seen as a tool to achieve sustainable development and provides access to untapped to integrated big data sites with potential benefits for society and the environment. In addition, the authors defined digitalization as a pathway to a smart green planet by providing solutions and facilitating sustainable development. [17] 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 whereby, it should contribute from reducing the burden on the environment, such as secondary and hypothetical aspects can be the reduction of paper consumption, the need for personal exertion (reduction of fuel consumption), etc. However, it may also have a secondary impact, in particular on increased demand for electricity. equipment, more electricity, more energy consumption and more energy consumption. waste, consumption of scarce resources for battery production, higher electricity consumption in the telecommunications sector, etc. [55-57]

Subsequently, authors Abdul-Lateef Balogun and Danny Marks etc. also say that digital-ization is a key factor in the sustainable development of the socio-economic dynamics of cities with the potential to foster climate-friendly urban environments and societies [58].

As is already evident several authors as focus on digitalization as one of the key factors. In this paper we have focused on the effectiveness of digitalization in the field of e-Government, which can be one of the key elements of the functioning of the state in the future.

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

If we look at the results of the CCR model, 10 countries out of 27 are efficient, which is 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 too much resources on output. Because even countries with less economic power can perform better. The country is not spending resources efficiently to achieve the desired effect. Countries within the EU do not work sufficiently to achieve efficient spending of resources on output, etc.

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

In addition, as already mentioned few studies of DEA method in e-Government. Further research could also measure the outcome of digitalization within the EU using established indices. Measuring the impact of digitalisation on the economy, society, e-waste.

Not enough attention is paid to digitisation and e-Government. Effectiveness has not been measured within this area and using the DEA method. However, such research has already been conducted in China. See Table 12. for a comparison with another study.

Table 13. comparison of the research with other studies

This research	Others researches
Using the DEA method to determine EU efficiency in digitisation	-
Use of CCR, BCC models	use of the SBM model
Use and identification of different indices in the field of digitisation DESI, EGDI, DSGI, e-Government benchmark, GII etc.	-
Determining efficiency within the EU area (East, West, North, South)	Determination of effectiveness using DEA within Chin in their respective provinces
Identifying the use of the DEA method in different areas	-

Source: own processing

Author Contributions: Conceptualization, K.R.S., M.K., J.S., P.M.; methodology, K.R.S., and M.K.; software, M.K., and P.M.; validation, J.S. and P.M.; formal analysis, M.K. and P.M.; investigation, K.R.S., M.K., J.S. and P.M.; resources, K.R.S., M.K., J.S. and P.M.; data curation, M.K. and P.M.; writing— K.R.S., M.K., J.S. and P.M.; writing—review and editing, K.R.S., M.K.,J.S. and P.M.; visualization, M.K and V.B..; supervision, K.R.S.; project administration, J.S and V.B. All authors have read and agreed to the published version of the manuscript.

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