



Socioeconomic and resource efficiency impacts of digital public services

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Abstract

This paper measures the socioeconomic and resource-efficient influences of digital transformation in the public sector in the European region. To capture the socioeconomic impacts of digital public services, we employ a socioeconomic score index calculated as the unweighted average of the re-scaled scores for changes in employment, exports, and turnover from eco-industries. Regarding resource-efficient impacts, we employ the resource efficiency score index measured as the unweighted average of the re-scaled scores for material, energy productivity, and the intensity of greenhouse gas (GHG) emissions. Measures such as user-centricity, business mobility, and key enablers are used to demonstrate the level of digitalization in the public sector. According to our estimations based on various econometric techniques, digital public services have a favorable effect on the economy and society through a positive impact on employment, exports, and turnover of eco-industries. The effects of digitalization on resource productivity follow a nonlinear U-shaped curve, suggesting that the improvement of resource efficiency is only present when the digital transformation process reaches a certain level.

Keywords Socioeconomic · Resource efficiency · Digital public services; Environmental impacts · European countries

Introduction

Factors contributing to economic development and growth have drawn the attention of different scholars (Poshakwale and Ganguly 2015). According to the neoclassical model, capital, both physical and human, and technological innovation are all key drivers of economic development (Giordano and Giugliano 2015). However, economists have recently begun to place a higher premium on specialized factors such as implementing the digital transformation process in economic and industrial systems, which are becoming more relevant (Ha 2022a, b; Ha and Thanh 2022). As Autio et al. (2018) explain, “digitalization” refers to the process of integrating digital technologies and infrastructures into several facets of business, economy, and society. In recent years, the word digitalization has been bandied around more and more in public discourse, often either incorrectly or

overused (Tilen et al. 2018). It is critical to understand the differences between digitization, digitalization, and digital transformation. A digitalized product or service includes digital components.

Modern economies consider energy efficiency and pollution emission reduction as integral aspects of sustainable growth (Lyu et al. 2021; Zahoor et al. 2021; Zakari and Khan 2021). Based on a database of 30 International Energy Agency (IEA) members, Khan and Hou (2021) demonstrate the critical role that environmental sustainability plays in pollution reduction. Furthermore, environmental sustainability is one of the most important factors in the pursuit of sustainable development goals (Zakari et al. 2022). In the literature, there is a vast number of empirical studies on determinants of environmental sustainability, such as the role of green innovation (Zakari et al. 2022); economic growth, international trade, and clean energy investment (Lyu et al. 2021); industrial value-added, capital formation, urbanization, population growth, and biocapacity (Yang and Khan 2021); the energy consumption and tourism growth (Khan and Hou 2021); or the partnership between countries (Tawiah et al. 2021). A recent study has highlighted the importance of green finance in promoting environmental performance (Zakari and Khan 2021). While both

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determinants and influences of environmental sustainability have attracted much attention from scholars, there are still a number of aspects of environmental sustainability that require further investigation.

As opposed to digitization, which involves automating routine tasks such as converting analog information into digital, digital transformation pertains to the introduction of new business models and digital platforms. When a digital instrument is used to digitize an analog contract record and convert it to a digital contract record that is then saved in PDF format, both digitization and digitalization are employed. On the other hand, digitalization does not include storing the PDF on a computer's hard drive; instead, it involves transmitting the PDF to a cloud service. It may subsequently be read from any computer, anywhere. As a result of using digital technology, businesses may either embrace intelligent and sustainable manufacturing (Liu et al. 2019), or reduce operating expenses and improve worker safety via innovative methods (Zhang 2019). Digitization is also a critical component driving economic and social growth in European (EU) countries, although at a glacial pace (Jurica et al. 2016). During the recent COVID-19 pandemic, digital transformation has become pervasive. Over 70% of directors questioned in Austria, Germany, and Switzerland said that the pandemic may hasten their country's digital transition (Crina et al. 2021).

Digitalization has a beneficial effect on both social behavior and economic advancement. Economists have shown that increasing digitalization adoption may boost growth (Myovella et al. 2020; Solomon and van Klyton 2020), decrease income inequality (Ha 2022a), promote financial development (Ha 2022a), and even diminish the size of the shadow economy (Ha et al., 2021a). Digitalization, according to the few studies that have addressed this perspective, is related to income levels (Ha and Thanh 2022), economic complexity (Ha and Thanh 2022), institutions (Le and Nguyen 2019), and financial development (Ha 2022a). Due to the growing usage of the internet and mobile phones, people worldwide can interact more swiftly and cost effectively (Suvankulov et al. 2012). Consequently, a new economic structure built on information and communication technology (ICT) use is important (Lapatinas 2019) for achieving higher development rates (Donou-Adonsou 2019). The internet and electronic devices have become indispensable for a variety of human socioeconomic activities over time (Visser 2019; Wang and Hao 2018), including education (Bonk 2009) and health care (Korp 2006; McMullan 2006). Notably, digitalization plays a critical role in protecting the energy system (Ha 2022b) and limiting the environmental consequences by enhancing ecological activities like trades in green goods (Ha and Thanh 2022). This paper extends the previous studies by exploring digital transformation's socioeconomic and resource-efficient influences.

Concerns about the environment continue to rank among the top five global threats in terms of both likelihood and impact (World Economic Forum 2021). As a requirement to gain a sustainable competitive advantage, environmental protection has become a vital component of proactive management (Ferrari et al. 2020; Genuino et al. 2017; Sharma et al. 2020; Kyungho 2018; Farida et al. 2021; Sanjay et al. 2019; Prayag et al. 2016). Ecosystem preservation, increasing air quality, safeguarding the integrity of resources, and assuring long-term viability, are just some of the environmental issues that businesses face daily (Anna et al. 2020). The vast majority of business leaders are aware of the importance of environmental policies for cutting costs, enhancing the company's brand, gaining an edge in the marketplace, and improving the bottom line (Liu et al. 2019). On-site recycling, green community outreach, sustainable committee development, and a constant digitalization trend have all been used by several firms to address these problems. Due to industrialization and urbanization, environmental practices have grown even more critical (Rasmi 2016). Many European countries have recently been assessed as being on the verge of an ecological tipping point. Climate change mitigation and greenhouse gas emission reduction have made considerable progress in recent decades. Still, there are still few alternatives to increase environmental protections, reduce natural resource usage, or mitigate the consequences of climate change. Concerns about biodiversity loss, climate change's increasing impact, and resource depletion have weighed heavily on European nations.

Digitalization's influence on the environment has been shown in a variety of ways. Electronic trash collection and subsequent recycling and the repurposing of previously used materials are made more accessible by technology advancements, according to the European Commission (2021). The disposal of solid trash, e-waste, food waste, and agricultural waste is being addressed via digital systems. The research on these systems has also been the focus of many authors, for example, Ferrari et al. (2020), Genuino et al. (2017), Sharma et al. (2020), and Wen et al. (2018). As a result, digital technology may be able to ease environmental pressures and promote biodiversity in a variety of ways. For example, the visualization and transmission of biological data via ICT may boost policy efficiency and public awareness. As a result of digitization, new economic models that protect biodiversity may be built (Liu et al. 2019). Pollution management, sustainable production, and urban sustainability are other key avenues. Heavy and chemical industries have contributed to pollution in the air and water, but digital technology has effectively addressed these issues. It has been demonstrated that digital technology can be used to solve dynamic environmental problems, such as air pollution, carbon emissions, wastewater treatment, and climate change (Chen 2018; Idrees and Zheng 2020; Zhang et al. 2018). In

addition, a firm may expect several positive environmental effects from digitization in the field of sustainable manufacturing. In terms of green energy, energy efficiency, or the use of renewable energy sources, organizations may use digital technology to create smart and sustainable manufacturing practices (Liu et al. 2019). Cleaner and more sustainable processes may lower operational costs and increase worker safety for businesses (Zhang et al. 2017). Furthermore, sustainable production can minimize resource use and degradation (Roy and Singh 2017). In the context of industrialization and urbanization, many scholars have investigated the impact of digitalization on ecosystems and human well-being (Abdul et al. 2021). By utilizing digital technologies such as big data, cloud computing, and artificial intelligence, we can address resource scarcity, transportation congestion, and air pollution (Honarvar and Sami 2019; Wu et al. 2021; Wu et al. 2018).

There has been a shift in how digitization and environmental challenges are linked in the last two years because of the global uncertainty caused by COVID-19. Many parts of the world's economy and society are now unknown due to the COVID-19 issue (OECD 2019). Due to limitations on human-to-human contact and decreased travel, it is clear that this health crisis has had a beneficial influence on the environment by improving outdoor air quality (Dobson and Semple 2020). As a result of social distancing restrictions and statewide lockdowns, there has been an unavoidable increase in the usage of digital technology (De et al. 2020). Consequently, a significant number of individuals have started working and learning from home, which has resulted in a significant increase in electronic and electrical waste (Banga 2019; Sweet and Eterovic Maggio 2015). In terms of waste management, COVID-19 directly influences the environment (Balde and Kuehr 2021).

A number of limitations have been identified in previous studies. First of all, there is currently no paper that provides an in-depth analysis of digitalization's socioeconomic and ecological effects. A second issue is that scholars agree that there is cross-sectional dependence, which biases the results obtained using the conventional method (Canh et al. 2021; Le et al. 2022). Third, there is no clear evidence of nonlinearity. Hence, this article examines digital transformation's effect on socioeconomic conditions and resource efficiency to understand better how digitalization affects nations' environmental performance, especially in the public sector. The main contribution of this paper is to provide a comprehensive analysis of the socioeconomic and ecological impacts of digitalization. In particular, we employ the socioeconomic score index calculated as the unweighted average of the re-scaled scores for changes in employment, exports, and turnover from eco-industries to capture the socioeconomic impacts of digital public services. For the analysis of resource-efficient impacts, we

use the resource efficiency score index, which is based on a re-scaled score of material productivity, water productivity, energy productivity, and the intensity of GHG emissions. These measures, including user centricity, business mobility, and key enablers, are employed to present the digitalization level in the public sector. Another contribution of this paper is to provide empirical and theoretical evidence to reveal how digitalization in the public sector affects the socioeconomy and the ecological system. With the presence of a cross-sectional dependence issue, various econometric techniques, including the panel-corrected standard errors (PCSEs), the feasible generalized least squares estimation method (FGLS), and the two-step general method of moment (the two-step system GMM), are employed to address heteroscedasticity and fixed effects.

We will organize the remainder of this document as follows. We review relevant literature in “Literature review and hypothesis development” section, while we describe the model, data, and estimation procedure in “Empirical methodology” section. Our empirical results are presented in “Empirical results” section. Finally, we conclude the paper in “Conclusions” section.

Literature review and hypothesis development

The nexus between digitalization and economic growth performances

Prior research indicates that digitalization has a number of beneficial economic impacts, including economic growth (Niebel 2018), trade (Adeleye et al. 2021; Ha and Thanh 2022), and productivity (Cardona et al. 2013). Furthermore, the study indicates that digitization benefits financial development. Industrialization is facilitated by the reduction of labor and intermediary expenses brought about by digitalization (Herzog et al. 2017; Pop 2020). Through digitalization, cross-border enterprises may improve their operational efficiency, provide new investment opportunities for international investors, and expand and enter new markets (World Economic Forum 2021). Digitization enhances the efficiency of financial services by lowering the cost of economic activity and increasing the competitiveness of products and services. On the other side, Pradhan et al. (2016) conducted an empirical study and concluded that ICT has a negative effect on financial institution expansion. However, digital technology will never completely replace face-to-face contact between representatives, agents, and brokers, even if it helps lower communication expenses (Ha and Thanh 2022). As a result, it is hard to reach a unified opinion about digitization's positive and negative consequences.

Digitalization directly affects job markets. As a result of this ever-changing environment, the job market's talents have grown more distinctive. As a consequence, future competencies are distinct from existing competencies, and everything is now digital. Thus, the new industrial model has resulted in a multitude of new skills, practically all of which are digital capabilities (Ancarani et al. 2019; Colombo et al. 2019; Messaadia et al. 2018; Moldovan 2019; van Laar et al. 2017, 2018, 2019). Without a doubt, this new discovery will reignite a century-old argument over how new technologies affect the job market. While it may seem to be a recent discussion, it stretches back to the 1800s (Feldmann 2013). As technology advances, the unit cost of commodities decreases, lowering prices and increasing demand and employment. Although certain jobs may become obsolete, others will emerge to fill the void (Say 1821). According to Ricardo (2015), labor markets may thrive if technical advancements do not cause unexpected drops in product prices, boosting profits and investments and resulting in more jobs. Indeed, Schumpeter predicted that new employment would develop as technology advanced (Forges Davanzati 2012). In addition, it has been stated previously that digitalization opens opportunities for investors while expanding to new markets (World Economic Forum 2021), lowering the costs, and sustaining a competitive market for product and service improvement. These factors all contribute greatly to globalization drivers, benefiting export and trade activities. Janssen et al. (2012) state that one of the characteristics of digitalization is the openness of data, which contributes to the economy, paving the way to developing new products and services while creating valuable sectors. These effects do not stop at an economic level; they also exist at the political level, where current policies can be improved while new insights can be investigated. Therefore, regarding eco-industries, digitalizing not only accelerates these industries' coverage but also provides means for people to be more vocal in their demand for such industries, as the practice of open data access can contribute to the access of collective awareness and intelligence.

Digitalization and environmental stewardship

There are very few studies on the effect of digitalization on environmental performance, and those that do exist cover a diverse variety of perspectives, making conclusions difficult to make (Liu et al. 2019). Certain studies have shown a link between digitization and environmental performance; however, other studies imply the opposite. In addition to pollution control, waste management, and sustainable manufacturing, digital technology has the potential to alter environmental sustainability on a range of levels (Feroz et al. 2021). Depending on how digitalization is implemented, it may directly or indirectly affect environmental

performance (Abdul et al. 2021). This impact may be explained in a number of ways. Environmental performance may be harmed as a result of the economy's rapid growth during the internet era, for example (Salahuddin and Gow 2016). Both resource depletion and the eradication of green energy consumption may be attributed to advancements in ICT (Majeed and Tauqir 2020).

The development of a circular economy is enabled by technology improvements, such as recycling electronic waste and reusing obsolete materials, which contribute to a more sustainable environment (Murthy and Ramakrishna 2022). Artificial intelligence (AI), big data, mobile technology, the Internet of Things (IoT), and social media platforms are all examples of digital technologies that benefit society and business (Vial 2019). Enterprises are developing digital products and services to increase environmental sustainability (Feroz et al. 2021). Through the use of AI, the IoT, and other data analytics, companies may promote environmentally friendly practices and reduce waste (Espinoza and Aronczyk 2021). Another technique for addressing uncertain, dynamic, and linked environmental concerns is to apply AI (Ye et al. 2020).

Numerous scholars use a variety of digital transformation methods in their study of the use of digital applications to ensure environmental sustainability. According to Weersink et al. (2018), big data analytics may be used to enhance food system traceability and create new manufacturing strategies. Additionally, the widespread use of next-generation green automobiles enabled by big data may reduce CO₂ emissions. With the assistance of AI and big data, humans will be able to handle concerns such as waste management, global warming, GIS, and land use planning (Sharma et al. 2020). Esmaeilian et al. (2018) and Leng et al. (2020) underline the importance of sustainability in business and industry in terms of using blockchain, expanding product lifecycles, reducing carbon emissions, and maximizing resource usage. Digitalization enables the industrial sector of the economy to employ environmentally friendly production practices and supply chains (Kerdlap et al. 2019; Mao et al. 2019; Wang and Hao 2018). As a consequence of ICT and other technological breakthroughs that have decreased the cost of renewable energy, green manufacturing has been pushed (Rosen and Kishawy 2012).

Digital technologies are also being utilized to create urban sustainability, a mix of smart and sustainable cities, by boosting social well-being in cooperation with ecosystems (Bibri and Krogstie 2017; Huang et al. 2015; Malik et al. 2018). Additionally, digitization has a detrimental impact on the environment on the demand side, as consumers are urged to utilize non-fossil fuels and purchase more environmentally friendly items due to the increase in digitalization (Holmström et al. 2019). Another advantage of international businesses and societies that have been digitized is

the removal of information asymmetry and the decrease of regional transaction costs via R&D spillover effects (Kwon and Kwon 2019). From the given evidence, we put forward our hypothesis:

Hypothesis 1: There is a nonlinear association between digital transformation process and social well-being.

Hypothesis 2: There is a nonlinear association between digital transformation process and environmental performance.

Previous studies were conducted in light of at least three limitations. First, there is no paper that provides a comprehensive analysis of the socioeconomic and ecological impacts of digitalization. Second and more seriously, scholars widely affirm that cross-sectional dependence exists, which makes the estimations obtained from the traditional method biased (Canh et al. 2021; Le et al. 2022). Third, the nonlinear evidence is not clear at all. Our paper, therefore, fills these gaps by providing an analysis of the social and environmental impacts of the digital transformation process. Our article focuses on its nonlinear effects of digitalization. We confirm these conclusions by strictly following the empirical econometric approach and applying the various techniques appropriate to the data with the existence of the cross-sectional dependence to control potential issues, such as multicollinearity, heteroskedasticity, and endogeneity.

Empirical methodology

The present article examines the socioeconomic (SOCE) and the resource-efficient (REEF) influences of digital transformation in the public sector (DPS). This relationship is measured by using the following specifications:

$$\text{SOCE}_{it} = \beta_0 + \beta_1 \text{DPS}_{i,t} + \beta_2 \text{EG}_{i,t} + \beta_3 \text{TS}_{i,t} + \beta_5 \text{FDI}_{i,t} + \beta_5 \text{EPI}_{i,t} + \beta_6 \text{NR}_{i,t} + \beta_7 \text{DM}_{i,t} + \varphi_i + \omega_t + \varepsilon_{ijt}, \quad (1)$$

$$\text{REEF}_{it} = \beta_0 + \beta_1 \text{DPS}_{i,t} + \beta_2 \text{EG}_{i,t} + \beta_3 \text{TS}_{i,t} + \beta_5 \text{FDI}_{i,t} + \beta_5 \text{EPI}_{i,t} + \beta_6 \text{NR}_{i,t} + \beta_7 \text{DM}_{i,t} + \varphi_i + \omega_t + \varepsilon_{ijt}, \quad (2)$$

where i and t , respectively, represent country i and year t . φ_i and ω_t are added into the model to capture the country and year fixed effects, and ε_{ijt} is the error term.

Socioeconomic outcomes (SOCE_OC)

To capture the socioeconomic impacts of digital public services, this article employs the socioeconomic score index (SOCE_OC) measured as the unweighted average of the re-scaled scores for changes in employment, exports, and

turnover. In particular, these indicators include exports of products from eco-industries (SOCE_EX) measured as a share of total exports; employment in environmental protection and resource management activities (SOCE_EM) measured as a share of the workforce and value-added in environmental protection, and resource management activities (SOCE_VA) measured as a share of GDP. The socioeconomic score index reflects the wider effects of eco-innovation activities on society and the economy. A greater index means a better socioeconomic outcome.

Resource efficiency outcomes (REEF_OC)

To capture the resource efficiency impacts of digital public services, we employ the resource efficiency score index (REEF_OC) measured as the unweighted average of the re-scaled scores for material productivity, water productivity, energy productivity, and (greenhouse gas) GHG emission intensity. In particular, these indicators include material productivity measured as a ratio of GDP to domestic material consumption; water productivity measured as a ratio of GDP to total freshwater abstraction; energy productivity measured as a ratio of GDP to gross inland energy consumption; and GHG emissions intensity measured as a share of CO₂ emission to GDP. The resource efficiency score index reflects the wider effects of eco-innovation activities on resource productivity. A greater index means a better resource efficiency outcome.

We collect the data for SOCE_OC and REEF_OC from the organization for economic cooperation and development (OECD) statistics for European countries from 2011 to 2019.

Digital public services (DG_DPS)

Digital public services: Similarly, we based on the study of Ha (2022a) to include four indicators to reflect the level of implementing digitalization in public sectors: the extent to which public service information is made available online; how the online journey is supported; whether public websites are mobile-friendly (DGDPS_UC); and the implementation of eID and eDocument capabilities in services designed to attract foreign businesses. In order to calculate this indicator, a weighted average of business mobility online availability, usability, eID cross-border use, and eDocument cross-border use are taken into consideration (DGDPS_BM), along with eGovernment service provision preconditions (DGDPS_KE). These digitalization variables are available from the eGovernment Benchmarking report and studies for digitalization by Capgemini. The dataset is available from 2011 to 2019 (Table 1).

Table 1 Variable's description

Variable	Definition	Measure	Source	Obs	Mean	SD	Min	Max
SOCE_OC	Socioeconomic outcome	Socioeconomic score index measured as the unweighted average of the re-scaled scores for changes in employment, exports and turnover.	OECD.Stat	0.00	220.00	0.00	220.00	0.00
SOCE_EX	Exports from eco-industries	Exports of products from eco-industries (% of total exports).	OECD.Stat	0.00	244.00	0.00	244.00	0.00
SOCE_EM	Employment in eco-industries	Employment in environmental protection and resource management activities (% of workforce)	OECD.Stat	0.00	234.00	0.00	234.00	0.00
SOCE_VA	Value-added in eco-industries	Value added in environmental protection and resource management activities (% of GDP)	OECD.Stat	0.00	191.00	0.00	191.00	0.00
REEF_OC	Resource efficiency outcomes	Resource efficiency score index is measured as the unweighted average of the re-scaled scores for material productivity; water productivity; energy productivity and GHG emission intensity.	OECD.Stat	216	98.22	52.73	0.00	234.00
REEF_MP	Material productivity	GDP/domestic material consumption	OECD.Stat	216	106.18	59.31	2.00	268.00
REEF_EP	Energy productivity	GDP/gross inland energy consumption	OECD.Stat	216	105.47	68.86	0.00	264.00
REEF_GE	GHG emissions intensity	CO ₂ /GDP	OECD.Stat	172	155.73	102.46	0.00	405.00
DGDPS_UC	User centrality	User centrality index as a weighted average of online availability, usability, and mobile-friendliness.	eGBR	192	78.13	13.24	44.00	97.25
DGDPS_BM	Business mobility	Business mobility index as a weighted average of online availability, usability, eID cross borders and eDocuments cross border.	eGBR	192	63.36	17.39	9.00	100.00
DGDPS_KE	Key enablers	Key enablers index as a weighted average of eID, eDocument, digital post, eSafe and single sign on.	eGBR	192	54.35	25.57	0.00	99.00
EG	Economic growth	The real GDP per capital (constant 2010 US dollars).	WDI	216	33.64	23.50	1.02	111.15
TS	Trade share	The proportion of GDP.	WDI	216	1.30	0.66	0.55	4.08
FDI	Net inflow of foreign direct investment	The proportion of GDP.	WDI	216	0.02	0.26	-1.54	1.63
IND	Industrialization level	The value added to GDP.	WDI	216	0.22	0.06	0.10	0.38
EPI	Environmental performance index	The score is scaled between 0 and 100, where 0 and 100 mean worst and best performance, respectively.	YCELP	216	71.02	7.23	53.89	82.86
NR	Natural rents	The share of the sum of coal rents, mineral rents, natural gas rents, and forest rents to GDP (%).	WDI	216	0.44	0.47	0.00	2.58
DM	Level of democratization	The index of democratization	FSSDA	216	1.65	0.50	1.00	3.00

Digitalization variables are sourced from various surveys, including Eurostat-Community survey on ICT usage in Households and by Individual, Eurostat-ICT Enterprises survey, eGovernment Benchmarking Report

OECD Organization for Economic Cooperation and Development, WDI world development indicator, FSSDA Finnish Social Science Data Archive, WBI World Bank Group Indicator, UMCES University of Maryland Center for Environmental Science

Table 2 Correlation coefficients

	SOCE_OC	SOCE_EX	SOCE_EM	SOCE_VA	REEF_OC	REEF_MP	REEF_EP	REEF_GE							
SOCE_OC	1														
SOCE_EX	0.530	1													
SOCE_EM	0.272	− 0.226	1												
SOCE_VA	0.614	0.00334	0.837	1											
REEF_OC	0.0355	− 0.113	0.870	0.548	1										
REEF_MP	0.662	0.622	0.141	0.366	0.0904	1									
REEF_EP	0.586	0.633	− 0.110	0.0642	− 0.0499	0.812	1								
REEF_GE	0.480	0.364	0.347	0.534	0.202	0.798	0.296	1							
DGDPS_UC	0.368	0.247	0.329	0.400	0.295	0.215	0.222	0.123							
DGDPS_BM	0.350	0.170	0.505	0.493	0.427	0.273	0.133	0.310							
DGDPS_KE	0.259	0.136	0.404	0.422	0.355	0.138	0.0654	0.159							
EG	0.819	0.599	0.206	0.465	0.101	0.817	0.697	0.617							
TS	0.107	0.111	0.220	0.0804	0.290	0.536	0.324	0.543							
FDI	0.219	0.210	− 0.0448	− 0.00928	− 0.0364	0.202	0.306	0.0142							
IND	− 0.586	− 0.393	− 0.148	− 0.179	− 0.186	− 0.379	− 0.464	− 0.143							
EPI	0.714	0.503	0.141	0.432	0.0224	0.407	0.560	0.0875							
NR	− 0.395	− 0.557	0.370	0.176	0.336	− 0.430	− 0.524	− 0.162							
DM	− 0.610	− 0.508	− 0.00132	− 0.317	0.118	− 0.518	− 0.535	− 0.294							
	DGDPS_UC	DGDPS_BM	DGDPS_KE	EG	TS	FDI	IND	EPI	NR	DM					
SOCE_OC															
SOCE_EX															
SOCE_EM															
SOCE_VA															
REEF_OC															
REEF_MP															
REEF_EP															
REEF_GE															
DGDPS_UC	1														
DGDPS_BM	0.631	1													
DGDPS_KE	0.785	0.558	1												
EG	0.256	0.320	0.144	1											
TS	− 0.0939	0.109	− 0.0449	0.522	1										
FDI	0.205	0.113	0.130	0.212	0.0664	1									
IND	− 0.116	− 0.290	− 0.0704	− 0.550	− 0.152	− 0.160	1								
EPI	0.533	0.337	0.348	0.600	− 0.159	0.298	− 0.342	1							
NR	− 0.0113	0.0902	0.160	− 0.387	− 0.135	− 0.0983	0.307	− 0.279	1						
DM	− 0.361	− 0.258	− 0.248	− 0.701	− 0.0990	− 0.284	0.302	− 0.811	0.168	1					

Control variables

We follow the empirical studies in the literature to choose explanatory variables. Trade share (TS), industrialization level (IND), and level of democratization (DM) inflows are included in the explanatory variable list. Following Bu et al. (2019), Shahbaz et al. (2018), and Sun et al. (2019), we also add the proportion of net FDI inflows (FDI) to our theoretical model. Moreover, economic growth (EG),

environmental performance index (EPI), and natural rents (NR) are employed, adding to the number of explanatory variables. After dropping any countries with missing observations, the final sample consists of 50 countries from 2002 to 2018. The correlation matrix between all variables is displayed in Table 2. Table 2 reveals a positive association between digitalization and energy security measures.

In the first stage, we perform the cross-sectional dependence (CD) test introduced by Pesaran (2021) on

Table 3 Cross-sectional dependence tests and stationary tests

Variable (in level)	CD test, Pesaran (2021)	Im-Pesaran-Shin test (Z-bar)	Variable (in difference)	Im-Pesaran-Shin test (Z-bar)
SOCE_OC	7.712***	4.135	DSOCE_OC	- 2.524***
SOCE_EX	4.561***	- 0.453	DSOCE_EX	- 4.251***
SOCE_EM	0.56	5.055	DSOCE_EM	- 4.224***
SOCE_VA	19.481***	- 0.376	DSOCE_VA	- 5.212***
REEF_OC	0.184	- 0.068	DREEF_OC	- 5.050***
REEF_MP	8.126***	0.871	DREEF_MP	- 3.483***
REEF_EP	2.261**	- 1.694**	DREEF_EP	- 5.360***
REEF_GE	0.454	9.812	DREEF_GE	- 2.015**
DGDPS_UC	31.737***	- 2.834***	DDGDPS_UC	- 4.793***
DGDPS_BM	16.161***	- 2.249**	DDGDPS_BM	- 3.437***
DGDPS_KE	16.364***	- 3.042***	DDGDPS_KE	- 4.513***
EG	42.070***	3.007	DEG	- 3.698***
TS	14.973***	0.463	DTS	- 3.241***
FDI	0.103	- 4.056***	DFDI	- 4.653***
IND	7.381***	0.247	DIND	- 3.663***
EPI	12.463***	1.136	DEPI	- 3.219***
NR	32.791***	4.124***	DNR	- 2.238***
DM	0.034	9.771	DDM	- 3.370***

Regarding the CD test, the null hypothesis is that the cross section is independent. *P* value is closed to zero, implying that data are correlated across panel groups. Regarding Im-Pesaran-Shin unit-root test, the null hypothesis is “Panels contain a unit root,” and the alternative hypothesis is “Panels are stationary.”

Table 4 Social-economic effects of digital public services

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(4)	(5)	(6)
	PCSE estimate OUT_SE	OUT_SE	OUT_SE	FGLS estimate OUT_SE	OUT_SE	OUT_SE	Two-step GMM estimate OUT_SE	OUT_SE	OUT_SE
L.eGOV_UC	0.61*** (0.113)			0.61** (0.244)			0.15* (0.084)		
L.eGOV_BM		0.41*** (0.120)			0.41*** (0.154)			0.12* (0.071)	
L.eGOV_KE			0.05 (0.048)			0.05 (0.102)			0.04* (0.055)
L.EG	2.49*** (0.173)	2.42*** (0.143)	2.51*** (0.189)	2.49*** (0.228)	2.42*** (0.229)	2.51*** (0.232)	- 0.34 (0.453)	- 0.68** (0.341)	0.61 (0.627)
L.TS	- 24.14*** (3.837)	- 24.99*** (3.963)	- 24.89*** (3.927)	- 24.14*** (5.523)	- 24.99*** (5.499)	- 24.89*** (5.614)	6.59 (5.712)	13.42 (8.454)	- 20.34 (22.780)
L.FDI	- 7.86 (9.736)	- 6.06 (9.602)	- 8.87 (10.340)	- 7.86 (8.722)	- 6.06 (8.751)	- 8.87 (8.872)	- 0.80 (2.761)	2.57 (2.531)	0.26 (3.291)
L.IND	64.82** (30.638)	87.83*** (33.357)	77.72** (35.381)	64.82 (45.190)	87.83* (45.125)	77.72* (46.078)	- 43.81 (79.180)	- 41.90* (25.278)	35.90 (88.006)
L.EPI	0.95* (0.577)	1.35** (0.583)	1.54** (0.604)	0.95 (0.745)	1.35* (0.702)	1.54** (0.725)	0.34 (0.562)	0.44 (0.362)	0.04 (0.470)
L.NR	- 16.46*** (3.364)	- 18.91*** (3.867)	- 14.53*** (2.967)	- 16.46*** (6.305)	- 18.91*** (6.490)	- 14.53** (6.530)	- 1.86 (6.449)	3.24 (4.568)	- 5.50 (6.514)
L.DM	34.32*** (5.580)	34.27*** (4.778)	34.43*** (5.564)	34.32*** (9.684)	34.27*** (9.660)	34.43*** (9.856)	- 3.72 (8.676)	- 2.63 (4.346)	- 6.39 (13.549)
Observations	168	168	168	168	168	168	168	168	168
Number of countries	24	24	24	24	24	24	24	24	24

Standard errors in parentheses

****p* < 0.01, ***p* < 0.05, **p* < 0.1

Table 5 Mechanism: export, employment, and turnover effects of digital public services

Variables	(1) Exports of products from eco-industries	(2)	(3)	(4) Employment in environmental activities	(5)	(6)	(4) Value added in environmental activities	(5)	(6)
L.eGOV_UC	0.21 (0.225)			1.63*** (0.243)			0.96*** (0.150)		
L.eGOV_BM		0.01 (0.112)			0.99*** (0.125)			0.61*** (0.075)	
L.eGOV_KE			0.33*** (0.098)			0.90*** (0.103)			0.63*** (0.079)
L.EG	1.35*** (0.139)	1.35*** (0.149)	1.38*** (0.129)	0.81*** (0.178)	0.65*** (0.193)	0.92*** (0.144)	1.21*** (0.166)	1.11*** (0.177)	1.29*** (0.155)
L.TS	- 29.82*** (2.590)	- 30.10*** (2.625)	- 29.37*** (3.112)	- 1.70 (5.461)	- 3.97 (6.499)	- 2.03 (4.394)	- 17.26*** (4.421)	- 18.59*** (4.989)	- 17.23*** (3.965)
L.FDI	19.99** (9.643)	19.75** (9.621)	18.85* (9.711)	- 17.16** (8.449)	- 13.09 (9.551)	- 21.79** (9.063)	- 12.02* (6.711)	- 9.39 (7.157)	- 14.99** (6.482)
L.IND	- 56.30** (28.722)	- 52.47* (27.375)	- 35.77 (28.133)	- 73.77** (30.924)	- 15.60 (26.860)	- 0.22 (24.837)	5.35 (25.038)	40.60* (24.422)	53.62* (27.699)
L.EPI	- 1.88*** (0.727)	- 1.66*** (0.515)	- 2.15*** (0.668)	0.96 (1.076)	2.10* (1.102)	1.40 (0.867)	0.65 (0.835)	1.30 (0.812)	0.76 (0.680)
L.NR	- 60.11*** (10.240)	- 59.31*** (9.509)	- 64.59*** (10.920)	55.14*** (6.404)	50.01*** (6.905)	47.92*** (6.682)	39.95*** (4.708)	36.48*** (4.815)	34.09*** (4.429)
L.DM	- 20.96** (8.738)	- 20.91** (8.497)	- 21.21** (9.087)	27.30*** (8.831)	27.23*** (8.552)	26.89*** (8.177)	16.05*** (5.967)	15.99*** (5.645)	15.71*** (5.571)
Observations	168	168	168	168	168	168	168	168	168
Number of countries	24	24	24	24	24	24	24	24	24

Standard errors in parentheses
 *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

the included variables. Then, the Im-Pesaran-Shin unit root test developed by Im et al. (2003) is applied to check the stationarity of the data presence of CD. We report the results in Table 3 and 4. In general, these included variables are cross-sectionally dependent, and some variables are not stationary, but their first-level difference becomes stationary. Based on these properties of our database, we follow Beck and Katz (1995), Ha et al. 2021a; Ha 2022b, Ha and Thanh (2022), and Le and Hoang (2021) to employ the PCSE model for our sample. All explanatory variables are lagged by one period, as represented in Eq. (1) to resolve the endogeneity stemming from the simultaneous relationship between digitalization and the variables capturing the socioeconomic and environmental variables. To guarantee the accuracy of our findings, we replicate our estimations with distinct models, such as FGLS and a two-step system GMM that is used to deal with the potential issue of endogeneity in Eq. (1), as argued by Gala et al. (2018) and Sweet and Eterovic (2019). The sensitivity analysis is also performed by adding other explanatory variables one by one into our estimations. In addition, the mechanisms used to explain the socioeconomic and environmental influences of the digital transformation are added to provide fruitful insights.

Empirical results

Social-economic effects of digital public services

First, we investigate the social-economic effects of digital public services using three estimates, namely the PCSE estimate, the FGLS estimate, and the two-step GMM estimate. The results are reported in Table 3 and 4. The findings from the PCSE estimate indicate that the effects of eGOV_UC and eGOV_BM are positive and statistically significant at a 1% significance level, while the impact of eGOV_KE is statistically insignificant. In addition, the influence of eGOV_UC is the largest, as the coefficients for eGOV_UC, eGOV_BM, and eGOV_KE are 0.61, 0.41, and 0.05, respectively. The results from the FGLS estimate are similar to those of the PCSE estimate. Lastly, a two-step GMM estimate, which helps us to control the possibility of endogeneity, reveals that eGOV_UC, eGOV_BM, and eGOV_KE all have positive and statistically significant effects on OUT_SE. The eGOV_UC is still the indicator with the largest influence, followed by eGOV_BM and eGOV_KE. The results imply that when there is an enhancement in eGOV_UC, digital public services will experience the most considerable development (Andersen et al. 2011; Anthopoulos et al. 2007).

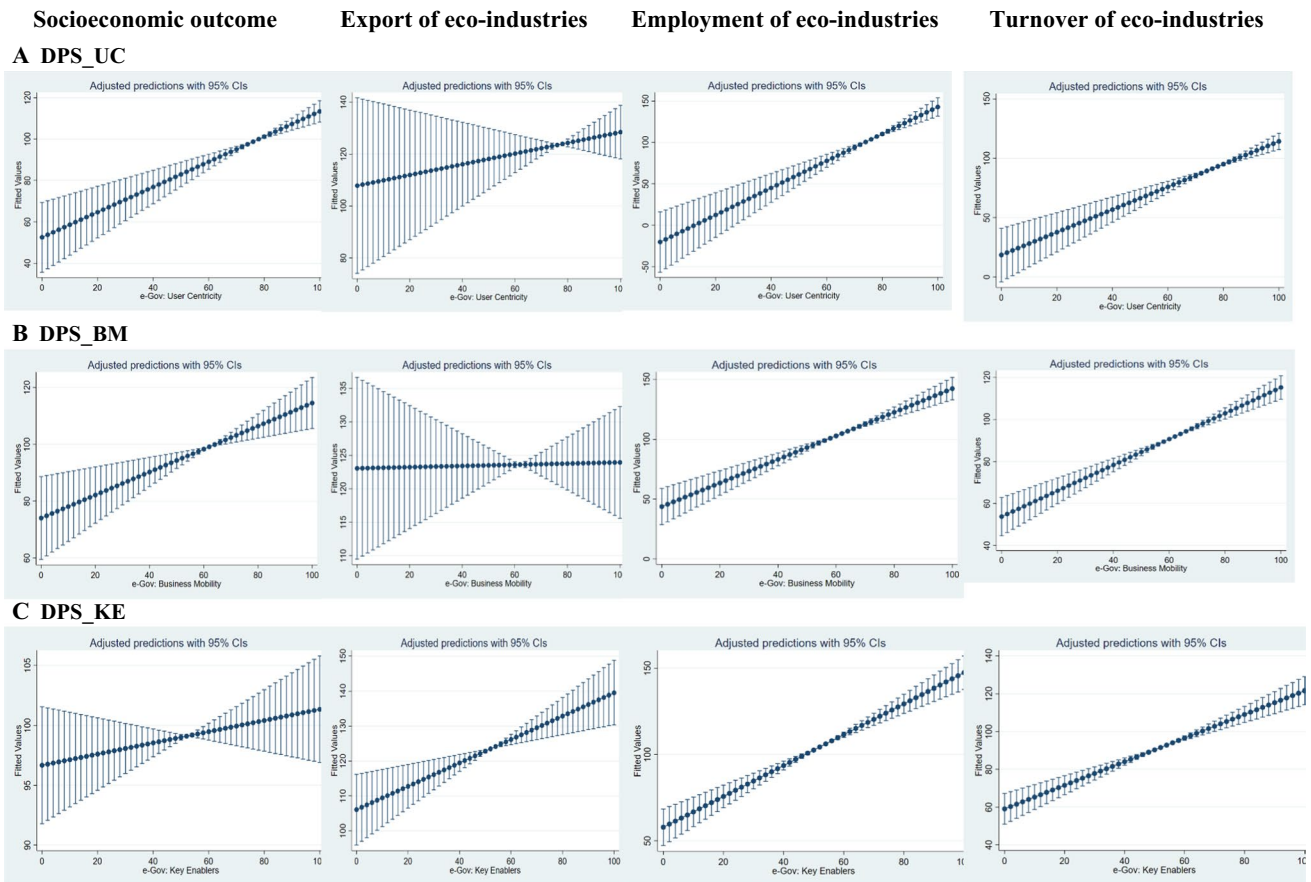


Fig. 1 Predictive margin of digitalization

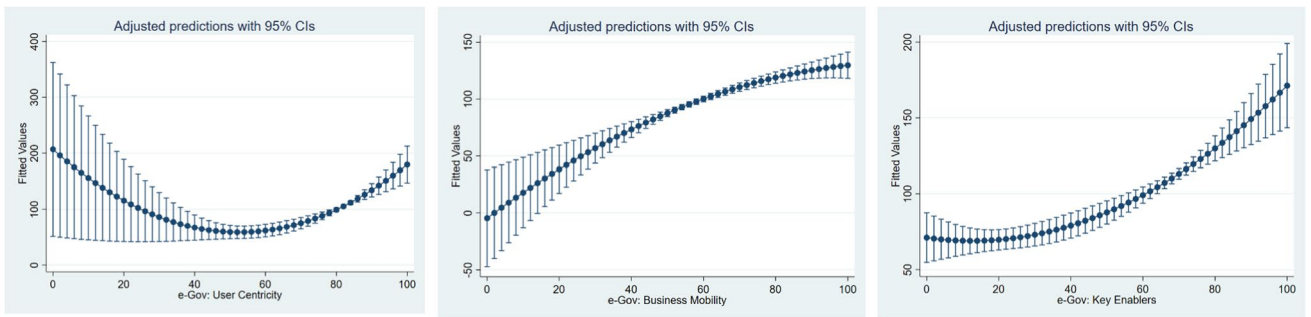


Fig. 2 Predictive margin of digital public services on resource efficiency score index

The following analysis examines the export, employment, and turnover effects of digital public services, which are presented in Table 5. We only focus on exports, employment, and turnover in the eco-industries to give insights into the transmission mechanism through which digitalization affects the socioeconomic. In particular, the effects of eGOV_UC on employment in the eco-industries and the value-added of the eco-industries to the total GDP are positive and statistically significant at a 1% significance

level. Employment and the value-added impacts of eGOV_UC are the largest (Liu et al. 2019), as the coefficients for the influence of eGOV_UC, eGOV_BM, and eGOV_KE on employment in environmental activities and the value-added in environmental activities are 1.63, 0.99, and 0.90 and 0.96, 0.61, and 0.63, respectively. Meanwhile, exports of products from eco-industries appear to be affected the least by digital public services (Grinberga-Zalite and Hernik 2019). eGOV is the only indicator that has a

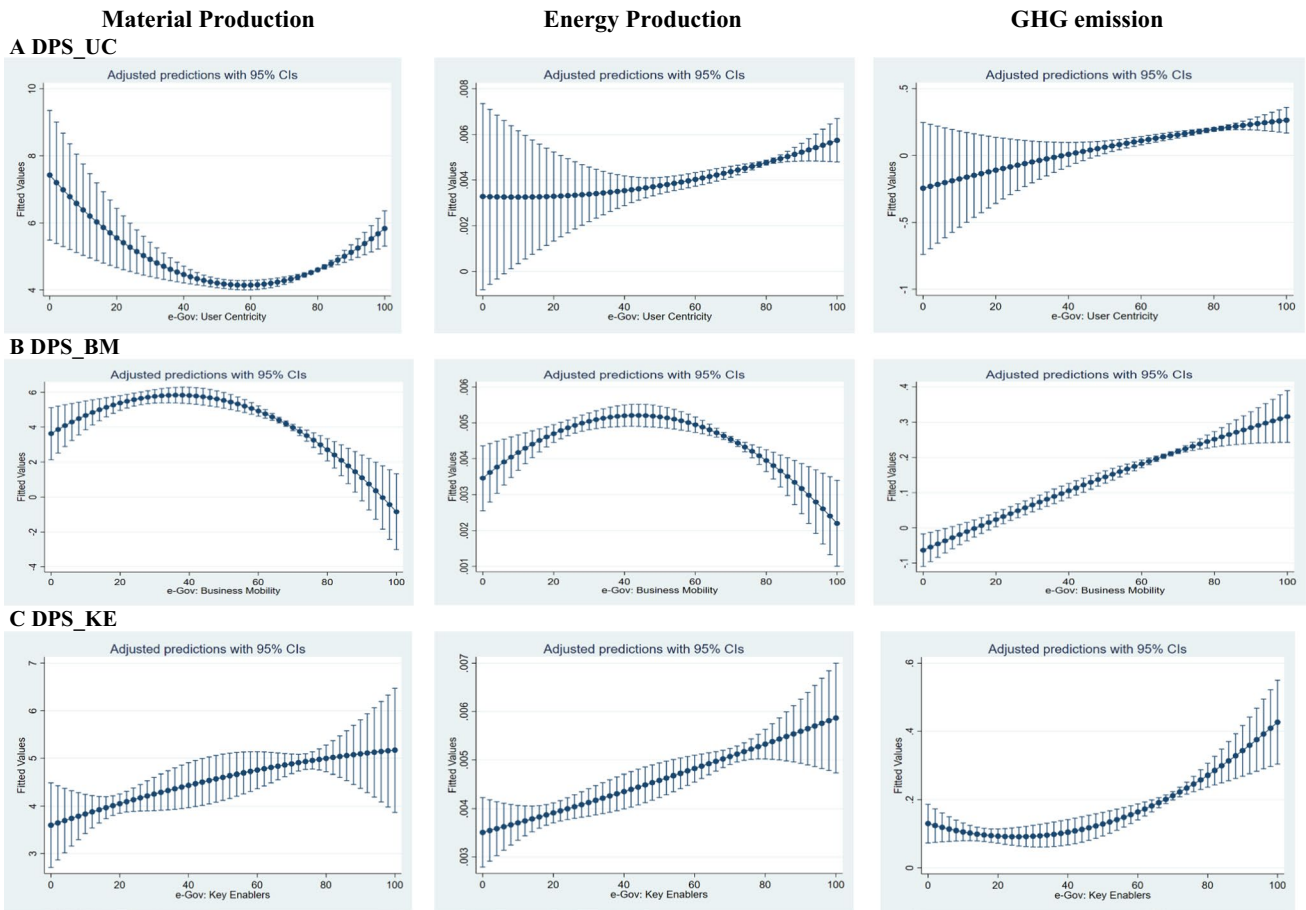


Fig. 3 Predictive margin of digital public services on resource efficiency and environment

statistically significant impact on exports of products from eco-industries, with the coefficient being 0.33. For illustration purposes, we employ the predictive margin of digitalization to display the socioeconomic and environmental effects of digital public services, as in Figs. 1, 2, and 3.

Resource efficiency effects of digital public services

We then study the impacts of digital public services on the resource efficiency score index using three estimates: the PCSE estimate, the FGLS estimate, and the two-step GMM estimate. The results are reported in panels A, B, and C of Table 6. First, panels’ A and B outcomes are identical, indicating that digital public services have linear and nonlinear relationships with the resource efficiency score index. In particular, digital public services indicators, including eGOV_UC, eGOV_BM, and eGOV_KE, have positive and statistically significant impacts on the resource efficiency score index. The influence of eGOV_UC is the largest, followed by eGOV_BM and eGOV_KE, as their coefficients are 1.99, 1.16, and 0.99, respectively. Next, we use the squared terms of digital public service indicators to examine

their nonlinear effects on the resource efficiency score index. It is notable that the impacts of the squared terms of eGOV_UC and eGOV_KE are positive, opposite to that of the squared terms of eGOV_BM. In panel C, it is reported that digital public services have both linear and nonlinear relationships with the resource efficiency score index in the two-step GMM estimate. The impacts are positive and statistically significant. The positive and nonlinear effects of digital public services are consistent with Ha (2022b). In a similar spirit, we also argue that the digital transformation process, especially in the public sector, may have both positive and negative impacts on the ecology. However, in the initial phase of digitalization development, digital public services may adversely affect the ecology and cause environmental degradation. Many other studies, such as Ha and Thanh (2022) and Thanh (2022), also suggest the existence of a nonlinear effect of digitalization in various aspects of the economy.

Table 7 represents the linear effects of digital public services on resource efficiency and the environment. First, in panel A and panel B, the effects of user centrality (DPS_UC) and key enablers (DPS_KE) on material productivity, energy

Table 6 Impacts of digital public services on resource efficiency score index

Panel A: PCSE estimate						
	(1)	(2)	(3)	(4)	(5)	(6)
	PCSE estimate					
Variables	Linear effects	Nonlinear effects				
L.eGOV_UC	1.99*** (0.364)			– 5.64** (2.497)		
L.eGOV_BM		1.16*** (0.147)			2.35*** (0.648)	
L.eGOV_KE			0.99*** (0.118)			– 0.34 (0.492)
L.eGOV_UC2				0.05*** (0.019)		
L.eGOV_BM2					– 0.01** (0.005)	
L.eGOV_KE2						0.01** (0.006)
L.EG	– 0.22 (0.185)	– 0.16 (0.192)	0.09 (0.108)	– 0.24 (0.181)	– 0.16 (0.189)	0.20 (0.139)
L.TS	10.47*** (3.295)	– 0.25 (3.338)	5.36*** (2.076)	13.38*** (3.807)	– 1.12 (3.116)	4.59** (2.048)
L.FDI	– 12.46 (9.778)	– 4.92 (11.298)	– 16.68 (10.700)	– 10.79 (9.992)	– 5.74 (11.157)	– 11.92 (9.760)
L.IND	– 126.01*** (42.272)	– 65.93* (36.562)	– 46.06** (20.422)	– 129.04*** (41.091)	– 75.01* (38.516)	– 46.15** (19.669)
L.DM	2.56 (4.542)	– 6.81 (6.793)	– 1.15 (4.170)	4.38 (4.579)	– 6.47 (6.626)	1.91 (4.870)
Observations	168	168	168	168	168	168
Number of countries	24	24	24	24	24	24
Panel B: FGLS estimate						
	(1)	(2)	(3)	(4)	(5)	(6)
	FGLS estimate					
Variables	Linear effects	Nonlinear effects				
L.eGOV_UC	1.99*** (0.375)			– 5.64* (2.932)		
L.eGOV_BM		1.16*** (0.246)			2.35* (1.204)	
L.eGOV_KE			0.99*** (0.152)			– 0.34 (0.587)
L.eGOV_UC2				0.05*** (0.020)		
L.eGOV_BM2					– 0.01 (0.010)	
L.eGOV_KE2						0.01** (0.006)
L.EG	– 0.22 (0.330)	– 0.16 (0.334)	0.09 (0.317)	– 0.24 (0.323)	– 0.16 (0.333)	0.20 (0.316)
L.TS	10.47 (7.375)	– 0.25 (7.115)	5.36 (6.845)	13.38* (7.313)	– 1.12 (7.146)	4.59 (6.744)
L.FDI	– 12.46 (14.138)	– 4.92 (14.393)	– 16.68 (13.674)	– 10.79 (13.872)	– 5.74 (14.373)	– 11.92 (13.610)
L.IND	– 126.01* (73.915)	– 65.93 (75.450)	– 46.06 (71.842)	– 129.04* (72.457)	– 75.01 (75.764)	– 46.15 (70.702)
L.DM	2.56 (13.188)	– 6.81 (13.060)	– 1.15 (12.483)	4.38 (12.945)	– 6.47 (13.025)	1.91 (12.355)
Observations	168	168	168	168	168	168
Number of countries	24	24	24	24	24	24

Table 6 (continued)

Panel C: two-step GMM estimate						
	(1)	(2)	(3)	(4)	(5)	(6)
	GMM estimate					
Variables	Linear effects	Nonlinear effects				
L.eGOV_UC	0.07** (0.053)			- 1.12** (0.068)		
L.eGOV_BM		0.07*** (0.027)			- 0.69** (0.050)	
L.eGOV_KE			0.07** (0.065)			- 0.28** (0.017)
L.eGOV_UC2				0.01** (0.005)		
L.eGOV_BM2					0.00** (0.004)	
L.eGOV_KE2						0.00* (0.002)
L.EG	- 0.20 (0.421)	- 0.19 (0.372)	0.57 (0.471)	0.15 (0.146)	0.57 (0.558)	- 0.36 (0.335)
L.TS	0.04 (10.436)	7.85 (6.804)	- 18.62 (14.710)	- 4.05 (4.283)	- 21.59 (39.125)	7.59 (7.072)
L.FDI	1.60 (3.755)	2.95 (5.289)	4.81 (3.416)	- 3.12 (3.611)	- 3.07 (5.520)	0.35 (4.919)
L.IND	63.22 (137.295)	- 29.56 (145.790)	- 74.49 (72.994)	180.51*** (65.552)	- 11.92 (84.635)	93.95 (120.083)
L.DM	0.07 (0.772)	0.10 (0.677)	- 0.27 (0.336)	- 0.07 (0.465)	0.93* (0.560)	1.20 (0.908)
Observations	- 0.66	- 1.17	- 5.10	- 6.02	2.79	3.27
Number of countries	(3.277)	(2.734)	(4.546)	(3.908)	(3.777)	(5.332)

Standard errors in parentheses
 *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

productivity, and GHG emission are positive and statistically significant at a 1% significance level. Meanwhile, DPS_BM has negative impacts on material and energy production but positively influences GHG emissions. It is also notable that such effects of DPS_BM are more considerable than those of DPS_UC and DPS_KE. Meanwhile, in the two-step GMM estimate in panel C, the effects of digital public service indicators on energy productivity and GHG emission are statistically significant and positive, except for the impact of DPS_BM on material productivity. The influence of DPS_UC on material productivity is statistically significant and positive, opposite to that of DPS_BM and DPS_KE (Bertram et al. 2021).

Finally, we employ similar estimates to confirm a nonlinear relationship between digital public services, resource efficiency, and the environment. The results of the PCSE model are reported in panel A of Table 8. The impact of the squared terms of DPS_UC on energy productivity (1) is positive and statistically significant at a 1% significance level. Its influence on GHG emissions is negative but statistically insignificant. In addition, the

squared terms of DPS_BM negatively affect the resource efficiency and the environment. The effects on material productivity are the largest, followed by energy productivity and GHG emissions. Regarding the squared term of DPS_KE, it positively affects GHG emission, with the effect being statistically significant at a 10% significance level. The squared terms of DPS_KE have a negative influence on material productivity and a positive influence on energy productivity, but those effects are statistically insignificant. We find identical results in the FGLS estimate in panel B.

On the other hand, panel C, which reports the results of the two-step GMM estimate, shows that the squared terms of DPS_UC have a negative and statistically significant effect on material productivity but barely any influence on energy productivity and GHG emissions. The squared terms of DPS_BM positively affect material productivity, opposite to their impact on GHG emissions. Meanwhile, the squared terms of DPS_KE have negative and statistically significant effects on the indicators representing resource efficiency and environment.

Table 7 Mechanism: resource efficiency and environmental impacts of digital public services: a linear effect

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: PCSE model									
PCSE estimates									
Variables	Material productivity	Energy Productivity	GHG emission	Material productivity	Energy Productivity	GHG emission	Material productivity	Energy Productivity	GHG emission
L.DPS_UC	0.019*** (0.004)	0.000*** (0.000)	0.004*** (0.001)	-0.046*** (0.005)	-0.000*** (0.000)	0.004*** (0.000)	0.016*** (0.003)	0.000*** (0.000)	0.003*** (0.000)
L.DPS_BM									
L.DPS_KE									
L.EG	0.053*** (0.003)	0.000 (0.000)	-0.005*** (0.000)	0.051*** (0.002)	0.000 (0.000)	-0.005*** (0.000)	0.053*** (0.002)	0.000* (0.000)	-0.005*** (0.000)
L.TS	0.492*** (0.177)	0.000*** (0.000)	0.208*** (0.012)	0.432*** (0.169)	0.000 (0.000)	0.185*** (0.008)	0.486*** (0.203)	0.000** (0.000)	0.196*** (0.015)
L.FDI	-0.115 (0.920)	0.000 (0.000)	-0.029* (0.018)	-0.222 (0.801)	0.001 (0.000)	-0.001 (0.024)	-0.255 (0.863)	0.000 (0.000)	-0.050** (0.020)
L.IND	1.427 (1.292)	0.008*** (0.001)	-0.216*** (0.079)	-0.898 (1.786)	0.005*** (0.001)	-0.207** (0.097)	1.424 (1.107)	0.007*** (0.001)	-0.302*** (0.078)
L.DM	-4.168*** (0.098)	-0.003*** (0.000)	0.014 (0.016)	-5.444*** (0.124)	-0.004*** (0.000)	0.050** (0.022)	-4.194*** (0.071)	-0.003*** (0.000)	0.010 (0.015)
Observations	168	168	168	168	168	168	168	168	168
Number of countries	24	24	24	24	24	24	24	24	24
Panel B: FGLS model									
FGLS estimates									
Variables	Material productivity	Energy Productivity	GHG emission	Material productivity	Energy Productivity	GHG emission	Material productivity	Energy Productivity	GHG emission
L.DPS_UC	0.019 (0.024)	0.000** (0.000)	0.004*** (0.001)	-0.046*** (0.016)	-0.000* (0.000)	0.004*** (0.001)	0.016 (0.011)	0.000*** (0.000)	0.003*** (0.000)
L.DPS_BM									
L.DPS_KE									
L.EG	0.053** (0.021)	0.000 (0.000)	-0.005*** (0.001)	0.051** (0.021)	0.000 (0.000)	-0.005*** (0.001)	0.053** (0.021)	0.000 (0.000)	-0.005*** (0.001)
L.TS	0.492 (0.520)	0.000 (0.000)	0.208*** (0.023)	0.432 (0.478)	0.000 (0.000)	0.185*** (0.021)	0.486 (0.497)	0.000 (0.000)	0.196*** (0.021)
L.FDI	-0.115 (0.909)	0.000 (0.001)	-0.029 (0.034)	-0.222 (0.872)	0.001 (0.001)	-0.001 (0.033)	-0.255 (0.907)	0.000 (0.001)	-0.050 (0.033)

Table 7 (continued)

L.IND	1.427 (5.724)	0.008* (0.004)	- 0.216 (0.267)	- 0.898 (5.451)	0.005 (0.004)	- 0.207 (0.254)	1.424 (5.608)	0.007* (0.004)	- 0.302 (0.252)
L.DM	- 4.168*** (1.133)	- 0.003*** (0.001)	0.014 (0.047)	- 5.444*** (1.139)	- 0.004*** (0.001)	0.050 (0.046)	- 4.194*** (1.107)	- 0.003*** (0.001)	0.010 (0.044)
Observations	168	168	168	168	168	168	168	168	168
Number of countries	24	24	24	24	24	24	24	24	24
Panel C: two-step GMM model									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Two-step GMM estimates									
Variables	Material productivity	Energy Productivity	GHG emission	Material productivity	Energy Productivity	GHG emission	Material productivity	Energy Productivity	GHG emission
L.DPS_UC	0.01*** (0.004)	0.00** (0.000)	0.00* (0.000)	0.01 (0.004)	- 0.00* (0.000)	0.00* (0.000)	0.00 (0.002)	0.00** (0.000)	0.00** (0.000)
L.DPS_BM									
L.DPS_KE									
L.EG	0.05 (0.054)	0.00 (0.000)	0.00 (0.000)	- 0.00 (0.005)	0.00 (0.000)	0.00 (0.001)	- 0.00 (0.009)	0.00 (0.000)	- 0.00 (0.000)
L.TS	- 0.53 (0.435)	- 0.00* (0.000)	0.00 (0.005)	- 0.24 (0.147)	- 0.00 (0.000)	- 0.02 (0.021)	- 0.22 (0.133)	- 0.00 (0.000)	0.00 (0.005)
L.FDI	0.15 (0.198)	0.00** (0.000)	0.00 (0.001)	- 0.02 (0.084)	0.00** (0.000)	0.00 (0.002)	- 0.07 (0.140)	0.00* (0.000)	- 0.00 (0.001)
L.IND	13.50 (9.039)	0.00 (0.003)	0.12 (0.108)	1.65 (2.428)	0.00 (0.001)	- 0.05 (0.143)	2.76* (1.632)	0.00 (0.001)	0.07 (0.103)
L.DM	1.14* (0.671)	0.00 (0.000)	- 0.00 (0.002)	0.26* (0.156)	0.00 (0.000)	0.01 (0.013)	0.07 (0.372)	0.00 (0.000)	- 0.00 (0.005)
Observations	168	168	168	168	168	168	168	168	168
Number of countries	24	24	24	24	24	24	24	24	24

Standard errors in parentheses
 *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 8 Mechanism: resource efficiency and environmental impacts of digital public services: a nonlinear effect

Panel A: PCSE model									
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
PCSE estimates									
Material productivity									
L.DPS_UC	-0.113*** (0.032)	-0.000 (0.000)	0.007 (0.007)						
L.DPS_UC2	0.001*** (0.000)	0.000 (0.000)	-0.000 (0.000)						
L.DPS_BM				0.121*** (0.041)	0.000*** (0.000)	0.005*** (0.001)	0.024 (0.029)	0.000 (0.000)	-0.003 (0.002)
L.DPS_BM2				-0.002*** (0.000)	-0.000*** (0.000)	-0.000 (0.000)	-0.000 (0.000)	0.000 (0.000)	0.000** (0.000)
L.DPS_KE									
L.DPS_KE2									
L.leg	0.055*** (0.002)	0.000 (0.000)	-0.005*** (0.000)	0.046*** (0.005)	0.000* (0.000)	-0.005*** (0.000)	0.053*** (0.003)	0.000* (0.000)	-0.005*** (0.000)
L.TS	0.537*** (0.195)	0.000*** (0.000)	0.206*** (0.012)	0.119 (0.217)	-0.000 (0.000)	0.183*** (0.008)	0.482*** (0.202)	0.000*** (0.000)	0.203*** (0.015)
L.FDI	-0.158 (0.884)	0.000 (0.000)	-0.028 (0.018)	-0.676 (0.771)	0.000 (0.000)	-0.002 (0.024)	-0.266 (0.880)	0.000 (0.000)	-0.043*** (0.017)
L.IND	1.754 (1.126)	0.008*** (0.001)	-0.218*** (0.077)	-0.790 (1.949)	0.005*** (0.001)	-0.209*** (0.096)	1.452 (1.061)	0.007*** (0.001)	-0.286*** (0.079)
L.DM	-4.174*** (0.072)	-0.003*** (0.000)	0.013 (0.015)	-6.033*** (0.363)	-0.004*** (0.000)	0.051** (0.021)	-4.178*** (0.068)	-0.003*** (0.000)	0.003 (0.013)
Observations	168	168	168	168	168	168	168	168	168
Number of countries	24	24	24	24	24	24	24	24	24
Panel B: FGLS model									
PCSE estimates									
Material productivity									
L.DPS_UC	-0.113*** (0.032)	-0.000 (0.000)	0.007 (0.007)						
L.DPS_UC2	0.001*** (0.000)	0.000 (0.000)	-0.000 (0.000)						
L.DPS_BM				0.121*** (0.041)	0.000*** (0.000)	0.005*** (0.001)	0.024 (0.029)	0.000 (0.000)	-0.003 (0.002)
L.DPS_BM2				-0.002*** (0.000)	-0.000*** (0.000)	-0.000 (0.000)	-0.000 (0.000)	0.000 (0.000)	0.000** (0.000)
L.DPS_KE									

Table 8 (continued)

L.DPS_KE2		L.DPS_KE2		L.DPS_KE2		L.DPS_KE2		L.DPS_KE2		L.DPS_KE2		L.DPS_KE2		L.DPS_KE2		L.DPS_KE2		L.DPS_KE2		L.DPS_KE2		
Variables	PCSE estimates	Material productivity	Energy Productivity	GHG emission	Material productivity	Energy Productivity	GHG emission	Material productivity	Energy Productivity	GHG emission	Material productivity	Energy Productivity	GHG emission	Material productivity	Energy Productivity	GHG emission	Material productivity	Energy Productivity	GHG emission	Material productivity	Energy Productivity	GHG emission
L. EG	0.055*** (0.002)	0.000 (0.000)	0.000 (0.000)	-0.005*** (0.000)	0.046*** (0.005)	0.000* (0.000)	-0.005*** (0.000)	-0.005*** (0.000)	0.000* (0.000)	-0.005*** (0.000)	0.000 (0.000)	0.000* (0.000)	-0.005*** (0.000)	0.000 (0.000)	0.000* (0.000)	-0.005*** (0.000)	0.000 (0.000)	0.000* (0.000)	-0.005*** (0.000)	0.000 (0.000)	0.000* (0.000)	-0.005*** (0.000)
L. TS	0.537*** (0.195)	0.000*** (0.000)	0.000*** (0.000)	0.206*** (0.012)	0.119 (0.217)	-0.000 (0.000)	0.183*** (0.008)	0.183*** (0.008)	-0.000 (0.000)	0.183*** (0.008)	0.000 (0.000)	0.000*** (0.000)	0.183*** (0.008)	0.482*** (0.202)	0.000*** (0.000)	0.203*** (0.015)	0.482*** (0.202)	0.000*** (0.000)	0.203*** (0.015)	0.482*** (0.202)	0.000*** (0.000)	0.203*** (0.015)
L. FDI	-0.158 (0.884)	0.000 (0.000)	0.000 (0.000)	-0.028 (0.018)	-0.676 (0.771)	0.000 (0.000)	-0.002 (0.024)	-0.002 (0.024)	0.000 (0.000)	-0.002 (0.024)	0.000 (0.000)	0.000 (0.000)	-0.002 (0.024)	-0.266 (0.880)	0.000 (0.000)	-0.043*** (0.017)	-0.266 (0.880)	0.000 (0.000)	-0.043*** (0.017)	-0.266 (0.880)	0.000 (0.000)	-0.043*** (0.017)
L. IND	1.754 (1.126)	0.008*** (0.001)	0.000 (0.000)	-0.218*** (0.077)	-0.790 (1.949)	0.005*** (0.001)	-0.209*** (0.096)	-0.209*** (0.096)	0.005*** (0.001)	-0.209*** (0.096)	0.000 (0.000)	0.007*** (0.001)	-0.209*** (0.096)	1.452 (1.061)	0.007*** (0.001)	-0.286*** (0.079)	1.452 (1.061)	0.007*** (0.001)	-0.286*** (0.079)	1.452 (1.061)	0.007*** (0.001)	-0.286*** (0.079)
L. DM	-4.174*** (0.072)	-0.003*** (0.000)	-0.003*** (0.000)	0.013 (0.015)	-6.033*** (0.363)	-0.004*** (0.000)	0.051** (0.021)	0.051** (0.021)	-0.004*** (0.000)	0.051** (0.021)	0.000 (0.000)	-0.003*** (0.000)	0.051** (0.021)	-4.178*** (0.068)	-0.003*** (0.000)	0.003 (0.013)	-4.178*** (0.068)	-0.003*** (0.000)	0.003 (0.013)	-4.178*** (0.068)	-0.003*** (0.000)	0.003 (0.013)
Observations	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168
Number of countries	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Panel C: two-step GMM model																						
(1) (2) (3) (4) (5) (6) (7) (8) (9)																						
PCSE estimates																						
L.DPS_UC	0.04** (0.031)	0.00 (0.000)	0.00 (0.000)	-0.00 (0.001)	-0.01*** (0.004)	0.00 (0.000)	0.00** (0.000)	0.00** (0.000)	0.00 (0.000)	0.00** (0.000)	0.00 (0.000)	0.00** (0.000)	0.00** (0.000)	0.03* (0.015)	0.00** (0.000)	0.00** (0.001)	0.03* (0.015)	0.00** (0.000)	0.00** (0.001)	0.03* (0.015)	0.00** (0.000)	0.00** (0.001)
L.DPS_UC2	-0.00** (0.000)	-0.00 (0.000)	-0.00 (0.000)	0.00 (0.000)	0.00*** (0.000)	0.00 (0.000)	-0.00*** (0.000)	-0.00*** (0.000)	0.00 (0.000)	-0.00*** (0.000)	0.00 (0.000)	-0.00*** (0.000)	-0.00*** (0.000)	-0.00*** (0.000)	-0.00*** (0.000)	-0.00*** (0.000)	-0.00*** (0.000)	-0.00*** (0.000)	-0.00*** (0.000)	-0.00*** (0.000)	-0.00*** (0.000)	-0.00*** (0.000)
L.DPS_BM																						
L.DPS_BM2																						
L.DPS_KE																						
L.DPS_KE2																						
L. EG	0.00 (0.012)	-0.00 (0.000)	-0.00 (0.000)	-0.00 (0.000)	-0.01 (0.008)	-0.00 (0.000)	0.00 (0.000)	-0.00 (0.000)	-0.00 (0.000)	0.00 (0.000)	-0.00 (0.000)	0.00 (0.000)	0.00 (0.000)	0.00 (0.012)	0.00* (0.000)	0.00 (0.000)	0.00 (0.012)	0.00* (0.000)	0.00 (0.000)	0.00 (0.012)	0.00* (0.000)	0.00 (0.000)
L. TS	-0.50** (0.208)	-0.00 (0.000)	-0.00 (0.000)	-0.00 (0.008)	-0.01 (0.182)	-0.00 (0.000)	-0.00 (0.012)	-0.00 (0.012)	-0.00 (0.000)	-0.00 (0.012)	-0.00 (0.000)	-0.00 (0.012)	0.10 (0.266)	0.10 (0.266)	-0.00 (0.000)	0.00 (0.011)	0.10 (0.266)	-0.00 (0.000)	0.00 (0.011)	0.10 (0.266)	-0.00 (0.000)	0.00 (0.011)
L. FDI	0.00 (0.292)	0.00 (0.000)	0.00 (0.001)	0.00 (0.001)	0.09 (0.055)	0.00** (0.000)	-0.00 (0.001)	-0.00 (0.001)	0.00** (0.000)	-0.00 (0.001)	0.00 (0.000)	-0.00 (0.001)	0.09 (0.190)	-0.22 (0.193)	0.00** (0.000)	-0.00 (0.001)	-0.22 (0.193)	0.00** (0.000)	-0.00 (0.001)	-0.22 (0.193)	0.00** (0.000)	-0.00 (0.001)
L. IND	-4.87 (3.982)	-0.00 (0.003)	-0.00 (0.000)	-0.08 (0.076)	-0.35 (1.255)	-0.00 (0.002)	0.09 (0.190)	0.09 (0.190)	-0.00 (0.002)	0.09 (0.190)	0.00 (0.000)	0.00 (0.004)	5.81 (3.719)	5.81 (3.719)	-0.01 (0.007)	0.03 (0.100)	5.81 (3.719)	-0.01 (0.007)	0.03 (0.100)	5.81 (3.719)	-0.01 (0.007)	0.03 (0.100)
L. DM	0.06 (0.586)	-0.00 (0.000)	-0.00 (0.005)	0.00 (0.005)	-0.19 (0.175)	0.00 (0.000)	0.00 (0.004)	0.00 (0.004)	0.00 (0.000)	0.00 (0.004)	0.00 (0.000)	0.00 (0.000)	0.11 (0.501)	0.11 (0.501)	0.00* (0.000)	0.01 (0.009)	0.11 (0.501)	0.00* (0.000)	0.01 (0.009)	0.11 (0.501)	0.00* (0.000)	0.01 (0.009)
Observations	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168
Number of countries	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24

Standard errors in parentheses
****p* < 0.01, ***p* < 0.05, **p* < 0.1

Conclusions

This paper contributes to the literature by providing a comprehensive analysis of digital public services' socio-economic and environmental impacts. By using an international sample of 24 European countries, the socio-economic and resource efficiency influences of digital transformation in the public sector in European countries are confirmed in this study. Using various econometric techniques, we find that digital public services have a positive impact on the economy and society. In particular, they positively influence employment, exports, and the turnover of eco-industries. The results also illustrate a nonlinear relationship between digitalization and resource productivity. When the digital transformation process increases to a certain level, the resource efficiency also rises, but then it declines afterward.

Governments should identify the best strategy for the digital transformation of the public sector in the context of socioeconomics and resources. The use of digital technology can increase the ability to monitor environmental consequences while promoting economic growth and creating policies that reward companies that improve their environmental performance. Although digitization may be innovative, it can be detrimental to ethical values, and to political, social, and cultural processes if policymakers fail to regulate the process or intervene when necessary. Moreover, incentive policies will probably be necessary to encourage the adoption of technologies that improve environmental outcomes.

Several limitations should be considered when interpreting the findings of our research. To begin with, we utilized archival data gathered exclusively for the European Union. It is essential to consider the role of digitalization in improving the environmental issues in developing countries, where there have been warnings about environmental degradation (Ha et al. 2021b). There are, however, no surveys that follow stringent guidelines for collecting information about the digital transformation process in developing economies (Ha 2022b). Furthermore, digitalization may adversely affect the socioeconomy and the environment due to external factors. In assessing the effectiveness of government policies, it is important to consider economic development and complexity. It is anticipated that the study will provide insights to economists and policymakers regarding the design of policies to promote digital transformation and improve socioeconomic and environmental performance. Research in the future may assess the availability of data sources in order to collect more information on digitalization in developing countries and examine the role of digitalization in these countries.

Appendix

Table 9 Countries in the sample

EU countries		
Austria	Hungary	Portugal
Belgium	Iceland	Slovak Republic
Bulgaria	Ireland	Slovenia
Czech Republic	Italy	Sweden
Denmark	Lithuania	
Spain	Luxembourg	
Estonia	Latvia	
United Kingdom	Malta	
Greece	Netherlands	
Croatia	Poland	

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