The impact of digitalizaton on sustainable development

An assessment on the coherency of digitalization and the efficiency in producing sustainable development using data of OECD countries

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Abstract

This study describes the coherence between the degree of digitalization of countries and their sustainable development performance by using a mixed method approach in which both qualitative and quantitative substantiation is provided. In addition to a literature study, the coefficients of a Cobb-Douglas production function are estimated, which are used to measure a country's productivity. In particular, the analysis focuses on 22 OECD countries with data from 2014 to 2020, which cover the produced sustainable development for the sectors: of environment, economy, and society—used to measure countries' productivity and its coherence with digitalization. The results show that digitalization asserts a significant role concerning the added value of a country's productivity and that there is a large margin in the extent to which this digitalization is deployed by countries, which implies that optimal digital transformation needs an accurate strategic approach and use of governance.

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Preface

First of all, I would like to thank the following people; my first supervisor Dr. J.L.T. (Jos) Blank who has closely guided me throughout the process, provided me with a critical view, and came up with new insights that have sharpened my thesis. Then I would like to thank my second supervisor Dr. J.A. (Jan Anne) Annema for the fresh perspectives, positive attitude and the help he offered me. Last but not least, I would like to thank my external supervisor J. M. (Joep) van Dingenen and KPMG for their help during the process, search for data and finding a suitable research topic. This thesis is written for the master degree in Engineering and Policy Analysis. During this master I have been interested in large social problems and finding justification for political decision-making in a quantitative way. The use of data to map the coherence of actual empirical phenomena is what I wanted to incorporate in my thesis to add value in substantiation of decisions. This was ultimately accomplished by adding addition to a major issue related to two major societal topics: digitalization and sustainable development. By combining both qualitative research and quantitative research to answer the question; *'What is the coherency between the degree of digitalization of a country and its performance in the strive for sustainable development?'.* Using the socioeconomic macro view that I have acquired with the master Engineering and Policy Analysis, I seek to provide qualitative and quantitative supported interpretation of this question. I wish you a pleasant reading journey and hope to spark your interest.

Pieter B.M. van Spaendonck
Amsterdam, december 2022

1 Introduction

Digitalization and the strive for sustainable development (SD) are seen as the most significant trends of recent decades, reshaping our global economy (Yeganeh, 2019; Lichtenthaler, 2021). A broad concept of digitalization is the expansion of information and communication technology (ICT) in the economy and contemporary society (Lange et al., 2020). This development and integration of ICT in our society are seen as a powerful force that affects global competitiveness, allowing new sources of economic growth to emerge (Nair et al., 2020). As digitalization creates opportunities, with access to a global network of big data and smart systems connected with the Internet of Things, this development can be seen as an enabler in tackling challenges related to SD (Mondejar et al., 2021).

Digital technologies are increasingly integrated into all different sectors resulting in a wide range of direct and indirect effects. These developments have created an entirely new domain of theoretical and empirical research (Evangelista, Guerrieri & Meliciani, 2014). A big part of this research field has focused on digitalization's economic impact. Most of which elaborate on key performance indicators related to output and productivity growth (Jeske et al., 2018; Porokhovskiy, 2019). On a macro level a large section of the research had been dedicated to the coherency between digitalization and economic measures like GDP and employment (Mammadli & Klivak, 2020; Tomashevski, 2020). Although digitalization has not only had an impact on the economic front but has made its impact in a much broader way in many different domains. In a society where we face enormously complex challenges related to climate change, inequality, overpopulation and keeping nations governable, it is of increasing importance to conduct policy based on a multivariable criteria considering broad impact on different sectors. The impact of digitalization should be measured on a much broader scale and not just by economic variables, or like Nobel prize winner Joseph Stiglitz states: “It’s time to retire metrics like GDP. They don’t measure everything that matters” (2009). This quote sets the stage for a broader view that is applied by European Commission, striving for SD. In a world where policymakers, companies, and individuals increasingly rely on evidence-based decision-making, productivity measurement is a commonly used analytical tool to measure performance concerning the deployment of recourses. A survey of productivity measurement chronicles by Lovell (2022) shows the alternative approaches used over the years and the different underlying theories to measure a country's productivity. So where previously GDP was mainly used as the output value of production, due to challenges posed by climate change, pandemic depression and other developments, productivity measurements have increasingly been used in which, besides GDP, other indicators related to ecological footprint and performance in other areas are measured.

After the COVID-19 pandemic, many governments have set a path for recovery plans. New European stimulus packages of €1.8 trillion should help rebuild the continent and make it a more digitalized, greener, and resilient Europe (European Commission, 2020). As digitalization and SD play a major role in setting the future according to the goals of the European Commission it is important to study the relationship between the degree of digitalization of a country and its performance in the strive for SD. Digitalization has its effect on many different layers of aggregation. In companies, digital transformation triggers change at many different organizational levels, which in turn triggers changes that can be observed from a macro perspective on a national level (Petkovski, Fedajev & Bazen, 2022). Overall, mainly economic growth and productivity growth are identified as essential factors where digitalization has a positive impact (Evangelista et al., 2014). This increase in productivity and also side effects of digitalization have specific impacts on different sectors.

An eminent area of impact by digitalization is the labor market, which constantly has been adapting to its changing environment, for instance, by adapting necessary digital skills and the change and disappearance of certain functions due to technological substitution and the change of business models (Laar et al., 2020). An important aspect of the impact of digitalization is the influence on environmental degradation resulting from the increasing use of digital technologies. An aspect that, in turn, is so multifaceted that it is difficult to pinpoint the actual impact. On the one hand, there is an increasing demand for the consumption of energy and natural resources. On the other hand, this same driver is pushing innovations that accelerate the process of sustainable production (Santarius, Pohl & Lange, 2020). Most current literature shows that the diffusion of digitalization is associated with negative impacts on environmental sustainability because of the sector's high energy consumption. The dual effect of implementing digital technologies in healthcare can also be clearly seen. Innovations offer opportunities for more efficient information sharing, new treatment methods, and better analysis, but they also bring a wide range of new challenges. A common criticism from the healthcare sector is that mandatory online documentation reduces personal contact with the patient and the quality of care. As with companies, the changing environment brings many organizational and managerial challenges (Lapão, 2019). With the increase of digitalization there is an increase in inequality due to differences in access and the understanding of digital technologies. This phenomenon is called ‘the digital divide’ and is an important point concerning the development of digitalization in the coming years (Billon, 2010).

This research aims at fulfilling the shortfall of mixed-method studies on the impact of digitalization on SD to provide a more generalized picture of the extent to which a country is digitalized and its coherence with indicators of environmental protection, economic growth , social equity, safety and healthcare (Elkington, 2018). By qualitatively looking at what previous research has said about the coherence of digitalization and indicators of SD, a better conceptual understanding is formed that is used as the basis of the quantitative data research. Because both input and output factors related to producing SD can influence each other, it is difficult to draw direct causal relationships. In order to be able to draw unambiguous conclusions, we opted for an integral approach in which interdependencies and effects are accounted for. In this paper, panel data regarding SD indicators of 22 OECD countries are used from 2014 until 2020 as input to estimate the coherence between digitalization and efficiency increase in stimulating SD. For this, a multiple regression model is used to determine a Cobb-Douglass production function to estimate the efficiency effects of digitalization. For each country, we assess the efficiency of resource deployment in producing SD output variables and examine the effect of digitalization in this. With the data available from various countries over several years, we can calculate the maximum possible output given the data. The productivity gap, also known as the output distance, indicates the difference between SD and optimal production. Finally, the 'total factor productivities' is calculated, indicating the extent to which the productivity of countries differs from each other and the extent to which the mutual differences are not explained by the data.

The structure of the paper is such that it first outlines a conceptual framework in which the research issue (section 2.1) is discussed, and the concepts of SD (section 2.2) and digitalization (section 2.3) are defined and conceptualized. After this, what has been encountered in previous literature on the impact of digitalization on SD is outlined (section 2.4). Ultimately, this qualitative literature review is used as the basis for selecting representative indicators for SD and conceptualizing its coherence with digitalization (section 2.5). The methodology is explained in Chapter 3, with which the aggregated coherence between digitalization and SD is examined. In this Chapter, the study's theoretical basis (section 3.1) is set, after which the productivity measurement method (section 3.2) is discussed. The Cobb-Douglas production function (section 3.3) is used to measure productivity with respect to a country's input of resources in producing SD, measured by the representative indicators. In Chapter 4, elaboration is given on the data gathered in preparation for the analysis. The selection of the main indicators used to measure SD are substantiated (Section 4.1). Descriptives and interpretations are given of the final data (Section 4.2), after which the way the data is modeled is showcased (Section 4.3). Data analysis is performed using data from 22 OECD countries from the year 2014 up until 2020 using indicators of digitalization controlled by demographic and geographic variables as a predictive value for efficiency concerning indicators of SD. Ultimately, this results in a model that provides insight into the broad coherence between the two megatrends, digitalization, and SD. In Chapter 4, the analysis results are named, after which Chapter 5, 'Discussion', interprets them, highlight the study's limitations, provide suggestions for follow-up research and conclude with recommendations.

2 Conceptual framework

In this section, a theoretical overview of intended research and order within the process is provided. In the conceptual framework, clarification is given on the research issue, corresponding concepts are identified by literature review, defined and brought into perspective with regard to the aim of the research (Leshem & Trafford, 2007). Elaboration is given on the concept of sustainable development (SD), clarifying the use of this broad goal, interpreting what exactly it constitutes and explaining how it can be measured. Then the concept of digitalization be defined and related to SD. What has been written so far about the interrelationship between the two and in what way the extent to which a country has been digitalized can be measured will be substantiated. Finally, this Chapter provides a comprehensive literature review on the coherency of digitalization and the various components of SD. This qualitative literature review will be used as a precedent for the data choice of the final qualitative empirical study.

2.1 Clarifying research issue

The Treaty on European Union states that sustainable development (SD) is a core principle and priority objective concerning their policy-making (Kastrinos & Weber, 2020). Also, the United Nations set specifically Sustainable Development Goals(SDGs), which constitute one of the main trends for all layers of society; decision-makers, companies, and individuals (United Nations, 2015). On the same levels of aggregation, digitalization is transforming current institutes and structures, changing companies' business models, and providing new revenue and value-producing opportunities. As new digital technologies are creating new opportunities, also new sets of opportunities might be created with regard to SD. This would indicate a positive coherence between these two megatrends, although research shows that the impact of digitalization on SD is more versatile than this.

Digitalization can act as a catalyst in the transition to a zero-emission society and connects people worldwide, which could lead to global collaboration between cultures when the urgency of environmental issues is being shared (Gupta et al., 2020). On the other hand, digitalization can also negatively influence SD when it comes to environmental effects, for example, due to increasing greenhouse gas emissions (Alskin-Sivrikaya & Bhattacharya, 2017). Digitalization can also have a reinforcing effect on social inequality, known as the Digital Divide. This versatility that is being described makes it important to investigate the current state of knowledge regarding the aggregated impact of digitalization on SD and whether this is consistent with quantified research on this. By combining these approaches, this study aims to answer the question;

What is the coherency between the degree of digitalization of a country and its performance in the strive for sustainable development?

Literature review shows that, at the moment, research has mainly been focused on digitalization using qualitative methods (Appendix A1; Reis et al., 2020). It is also evident that significantly more research has been focused on empirical research methods in comparison to conceptual methods. In a broad research field like digitalization and its impact on SD, considering a lack of conceptual research, there is room for research into the phenomenon of digitalization and its far-reaching impact. Defining theoretical foundations and collecting relevant research related to this topic is essential to form a clear conceptual framework that underlies this paper. It is also verified that there is a lack of mixed method and generalized research in this area, which predominantly consists of empirical research with qualitative case studies (Yin, 2003). Mixed method studies allow researchers to combine elements of qualitative and quantitative research approaches for the purpose of broader and deeper understanding and confirmation (Schoonboom & Johnson, 2017). In addition, there is an amount of consensus that mixed studies are superior to single methods, as they are considered less prone to biased conclusions or errors (Given, 2008; Choi, Cheng & Zhao, 2016; Seawright, 2016). By using quantitative research methods, it is possible to draw more generalizing conclusions on possible efficiency increases and decreases related to digitalization to gain a clearer broad perspective. The following paragraphs elaborate on the concepts of SD and digitalization, after which clarification is given on the coherence of these two concepts and the state of current knowledge regarding the associated mutual relationships.

2.2 Sustainable development - the concept and definition

As with digitalization, SD is a concept used in different manners in a broad context (Giddings, Hopwood & O'brien, 2002). It often depends on the perspective from which the concept is viewed, and it is, therefore, important to clarify the definition concerning the scope of the research and to relate the concept to digitalization. To begin with, it is crucial to consider the past in order to define the concept of SD. The six decades after World War II up to the crisis of 2008 can be seen as a time when economic development has been at the top of the 'global priority list'. Measurements such as gross domestic product (GDP) and real income per capita were the main goals of macro policy at the time (Rodrik, 2014).

This pursuit of economic growth has caused enormous indirect damage to other domains in these years. In a period where the population has constantly been growing, and economic growth was the main goal, many other problems, such as wealth inequality and environmental degradation, have arisen (Panayotou, 2016; Stiglitz, 2016). Countries all around the world have been exploiting their natural resources at an alarming pace with the aim of constant economic growth (Dang & Pheng, 2015). The Intergovernmental Panel on Climate Change (IPCC) has announced that climate disasters will become more frequent and that global warming, in the status quo, will cause a plus two degrees centigrade rise due to greenhouse emissions (IPCC, 2018). In addition to these environmental effects, much collateral damage has occurred on a social level. More and more research shows that global warming aggravates geographical inequality (Capelli, Constatini & Consoli, 2021). Also, the COVID-19 pandemic has exposed great extents of social, economic, and health inequality that affect almost all societies (Sayed & Peng, 2021). Society and science have recognized these occurrences. Consequently, SD has been increasingly highlighted as a priority for companies, governments, and other international institutions (Levi Jakšić, 2018).

When defining SD, it is possible to emphasize this concept's technological, cultural, social, institutional, and other perspectives. A similarity between these domains is that they all view the concept from a time perspective in which SD is a process that takes place over an extended period of time and indicates a desired, positive change (Ivković, 2014). With SD, not only the ambition of purely economic goals but also non-economic aspects such as social rights, civil society, culture, and environmental protection are strived for. A more generalized and often used way to characterize SD is the three-ring sector view on economy, environment, and society (Gallego, 2006).

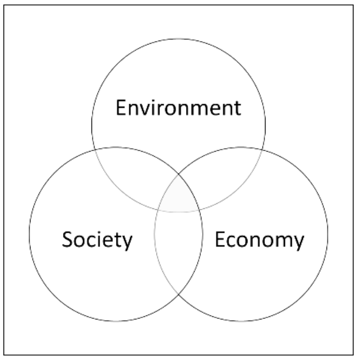

Figure 1. Common three-ring sector view of sustainable development (Giddings, Hopwood & O'brien, 2002)

This represents a simplistic conceptualization of SD (du Plessis, 2000; Barton, 2000). The limitation of this representation is that environment, economy, and society are separated, and that autonomy is suggested concerning the three sectors while being fundamentally linked to each other. Although, the conceptualization allows to classify impacts of digitalization on SD in order to make analysis more straightforward. The conceptualization states that human well-being can only be realized when the synergetic effect of these pillars; economic growth, social equity, and environmental protection occurs. SD as a concept is related to the ambition to develop a, one could say, utopian idea of a harmonious society.

2.2.1 Measuring sustainable development

Much research has been conducted into how SD can be measured. However, to date, there has yet to be a set of universally accepted indicators substantiated with data that is influential in policy. According to research into the measurement of sustainability development, this is caused by the following three main reasons (Parris & Kates, 2003):

1. *the ambiguity of sustainable development;*
2. *the purpose of characterizing and measuring sustainable development; and,*
3. *the confusion of terminology, data, and methods of measurement.*

Apart from the fact that there is no universal benchmark for SD, there is increasing consensus regarding goals and indicators at both a local and global level. The concept of SD mainly aims for a qualitative outcome, taking into account the three different sectors environment, economy, and society (Tomislav, 2018). These fundamental pillars of SD represent the interrelationship and inseparable interaction and imply that they all have to be sustainable to be in mutual balance. This conceptual relationship of sustainability in all sectors is highly complex without the ability to replace natural capital with other forms of capital. The common three-ring sector view is, to a large extent, already integrated into many different fields of human activities. These activities that contribute to SD can be assigned to the three different sectors or can be allocated to overlapping sectors. Figure 2 shows this distribution.

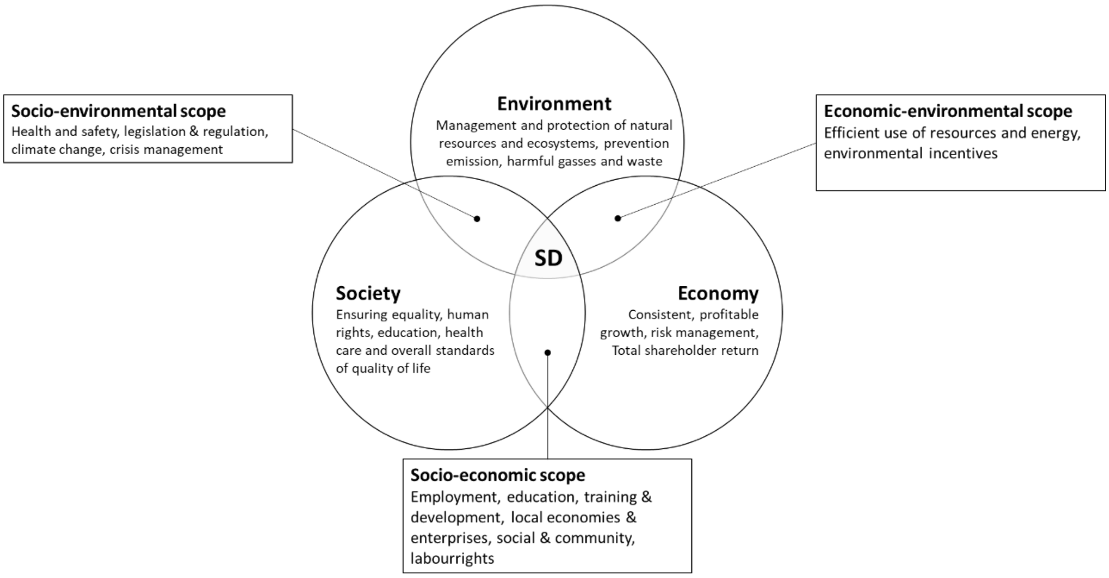

Figure 2. Detailed three-ring sector view of sustainable development (Based on: Tomislav, 2018).

At the UN Conference on SD in New York, the current goals and challenges were reviewed and incorporated into a new resolution that every nation aims to strive for. The 17 new Sustainable Development Goals (SDGs) have emerged from this, aiming to make the qualitative goals concerning SD clearer and supposed to tackle issues that plague the world (United Nations, 2015). The 17 SDGs (Appendix A2) also make it possible to compile corresponding indicators that can quantify the pursuit of SD so that countries can set more precise targets (Halkos, 2021).

2.3 Digitalization – concept and definition

A literature review is provided on the concept of digitalization and related terms to understand more clearly what the term implies. In addition, the term will be linked to the scope of the research. Related to the term digital, several terminologies have been used in the literature (Schallmo & Williams, 2018). Digitization, digitalization, and digital transformation are terms often used interchangeably, indistinctly, or at least in an overlapping way in the literature (Reis et al., 2018; Eling, M., Lehmann, M.). Although varying definitions of these terms are used in the literature, a more unambiguous definition applicable for the context of this paper will be to provide structure, as there is considerable value in understanding the distinction of terms and conceptualizing their interrelation.

Digitization

Digitization is the most straightforward term related to digital. At the dawn of the digital era, digitization was defined as the transformation of analog signals into digital ones (Schumacher, Sihn, & Erol, 2016). Research across different domains define digitization as transforming a physical or analog artifact into a digital one. Simply put, when a non-digital something (location, health record, paper document, photographs etc.) is translated to a digital format which in turn could be used by a computing system (i-SCOOP, 2016).

Digitalization

The term "digitalization" was used for the first time in 1971 in an essay in the North American Review concerning limitations and potential for computer-aided research (Brennan and Kreiss, 2014). Since then, the term has been defined in numerous ways, even similar to the definition of "digitization" (Maxwell & McCain, 1997). Although, regarding this research, it is important to distinguish both terms as most literature does.

Compared to digitization, digitalization is described in a broader context and is characterized as the most significant development transforming society that impacts several domains of daily life, such as the economic, organizational, and social domains (Machekhina, 2017). When related to business organizations, digitalization has more to do with automating and streamlining processes, thereby increasing efficiency. Eling and Lehman debate on this concept of digitalization, clashing between the broad and the narrow, which in the end results in the following middle ground conceptualization; "digitalization is the phenomenon of transforming analog data into digital language (i.e. digitalization), which, in turn, can improve business relationships between customer and companies, bringing added value to the whole economy and society." This definition of digitalization encompasses that the impact of micro applications of "digitization", is having a macro impact in terms of changing businesses as well as society reaching different domains (Reis, 2019).

Digital transformation

A more business-related term is "digital transformation", which mainly refers to the strategic and organizational character that comes with the digitalization of companies. This term in business organizations is seen as an organizational transformation driven by digital and information technologies (Morakanyane, Grace & O'reilly 2017). This organizational change is driven by a strategy formulated and executed by leveraging digital resources to create differential value (Bharadwaj et al., 2013). For example, when organizations adopt strategies implementing and using technologies such as the Internet of Things, big data analytics, communication platforms, social media, and mobile technologies to empower daily operations and create new capabilities (Fitzgerald et al., 2013). Next to this, literature substantiates the customer-orientated nature related to this, formulated as followed by Schuchmann & Seufert (2015); "realignment of technology and new business models to more effectively engage digital customers at every touchpoint in the customer experience life cycle". With these different aspects highlighted, digital transformation encompasses the use of digital capabilities and technologies to influence various aspects of the organization to create value (Morakanyane, 2017).

2.3.1 Framework digitalization

The broad digitalization of organizations and their business models is regarded as one of the most significant developments reshaping the global economy of today (Kotarba, 2017). The global drive to digitalize processes and companies is motivated by the assumption of productivity increase by obtaining a competitive advantage and greater overall performance (Peppard, 2016). As explained in this section, digitalization involves different levels of aggregation. Where it starts with converting analog to digital forms of information and communication, this data is organized and can be automated in processes through digitalization. Multiple streamlined digitalization processes can ultimately lead to digital transformation through strategy at the organizational level.

In this research, the term digitalization is mainly used as an overarching concept which can result in digital transformation when fundamental changes in the organizational structure of a particular sector occur due to the integration of digitalization. The terms digitalization and digital transformation are used for specific explanations when necessary.

← DIGITALIZATION →

Term	**Digitization →**		**Digitalization →**		**Digital transformation**
Activity	Digitize information →	Organize information →	Automate processes →	Streamline processes →	Transform the instituition
Definition	Changing from analog or physical to digital form		Using digital technologies and information to transform individual institutional operations		A series of deep and coordinated culture, workforce and technology shifts that enable new educational and operating models and transform an institution's operations, strategic directions and value proposition

Table 1. Digital framework. Based on Katuu (2022)

Digitalization ultimately impacts the change and creation of business models, creating new opportunities and innovations (Hansen et al., 2011; Tamm et al., 2015). These opportunities and innovations, in turn, have collateral effects on society. Digitalization is mostly seen as one of the main enablers of SD (Van der Velden, 2018). A new variety of tools are being created that have the opportunity when applied in a thoughtful, balanced way, to use resources and services more efficiently in impacting sustainability (Appio et al., 2021; Ardito et al., 2018).

2.3.2 Measuring digitalization

In order to estimate the impact of digitalization on efficiency with regards to SD, in the quantitative part of the study, it is important to have a proper way to measure the degree of digitalization of a country. To measure the degree of digitalization per country, the Digital Economy and Society Index (DESI) is used in this paper. In the analysis, data from 22 OECD countries from 2014 to 2020 will be used as input to draw final conclusions. Since the database mainly uses data from the previous year, the data is consistently used as input for a year prior, so the 2021 data is being used for 2020.

2.3.3 Digital Economy and Society Index (DESI)

To determine the extent to which a country is digitalized, the European Commission has compiled the DESI-index. Since 2014, for all countries of the European Union, this composite index has been compiled out of various indicators (European Commission, 2017).

The current index from 2021 is based on four primary dimensions; Connectivity, Human Capital, Integration of Digital Technology, and Digital Public Services. This has been adjusted from previous years where the dimension 'Use of Internet' was included. For this reason, this dimension has been omitted from the final data, and the indexes of previous years have been recalculated. The DESI-index makes it possible to quantify the performance of different countries and their growth concerning digitalization. In addition, it is possible to zoom in on more specific aspects using the sub-dimensions, allowing us to draw more specific conclusions concerning the final indicators of SD related to the scores of these dimensions. Since the DESI-index is available from 2014 to 2020, it is possible to set up a panel data set for the 22 OECD countries.

2.3.4 Structure of the DESI-index

The DESI-index was compiled according to the recommendations and guidelines from the OECD handbook on constructing composite indicators, a user guide, and methodology (Joint Research Centre-European Commission, 2008). The data used to construct the index is primarily collected from relevant authorities of countries in the European Union. The fact that the indicators in the lowest level of the hierarchy are quantitative ensures that the index is measured in an objective manner(Jovanović, 2018). The DESI has a three-level structure that identifies the dimensions, sub-dimensions, and indicators used to measure the data. The data structure is given in Figure 3, with indicators at the bottom of the tree.

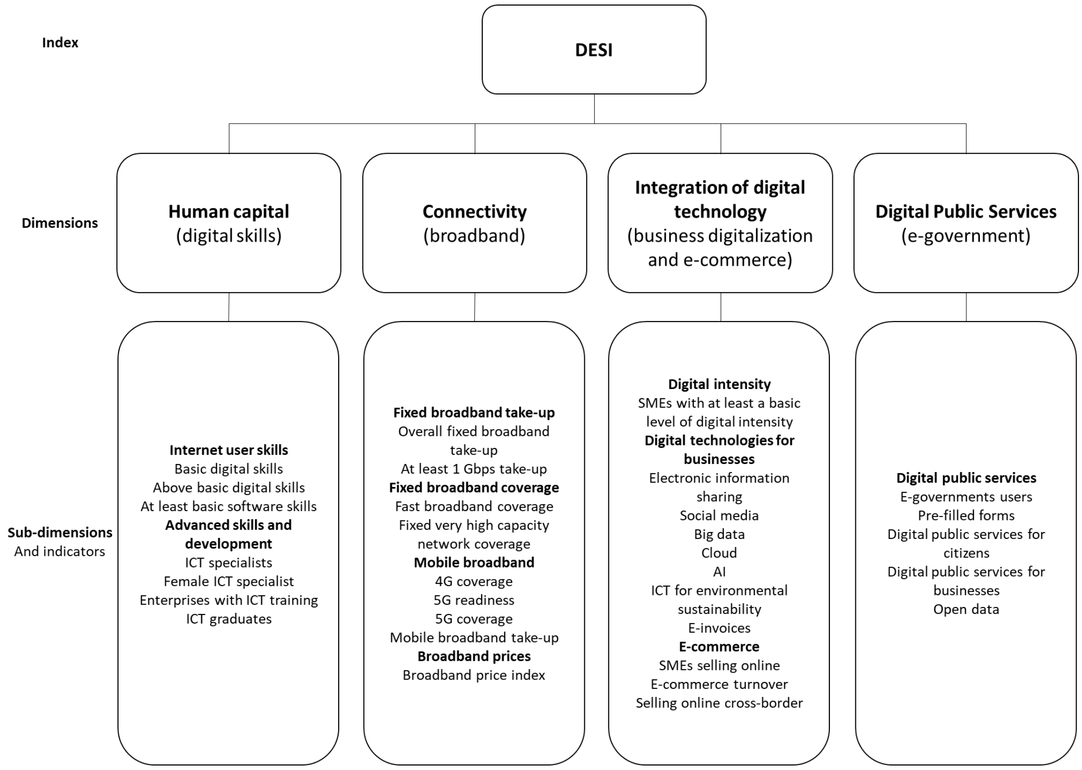

Figure 3. DESI data-tree structure (European Commission, 2021)

According to the European Commission, the four dimensions of the index are considered of equal importance, and therefore, weights have been proportionately assigned to the dimensions. Weights have also been assigned to the sub-dimensions and individual indicators. In turn, the majority of the indicators are estimated to have proportional importance to the total value of the index. This distribution of weights is shown in Table 2.

Sub-dimension	**weight**
1. Human capital 25%	
1a Internet user skill	50 %
1b Advanced skills and development	50 %
2. Connectivity 25%	
2a Fixed broadband take-up	25 %
2b Fixed broadband coverage	25 %
2c Mobile broadband	40 %
2d Broadband prices	10 %
3. Integration of digital technology 25%	
3a Digital intensity	15 %
3b Digital technologies of businesses	70 %
3c e-commerce	15 %
4. Digital public services 25%	
4a e-Government	100 %

Table 2. Composition of the DESI-index

2.4 Impact of digitalization on sustainable development

The digitalization process involves a wide range of technological innovations, applications, and enablers, such as Information Communication Technology (ICT) infrastructure, digital public service, connectivity, digital skills, and other integrations of digital technologies (OECD, 2012). In recent years, digitalization has taken an enormous leap which has left its mark on new revenues that have been found for increasing social interactions and improving the economy, allowing organizations to operate more effectively and efficiently (Ostrom, 2008; Bobylev). This increase in pushing forces of digital innovation has improved the development of the economy, income, jobs, and skills. It has affected other domains, such as the environment and society (World Trade Organization 2018). In addition, digitalization is seen as an organizational transformation concerning businesses in which business model changes, innovative revenue, and new value-producing opportunities arise (Gartner, 2018).

2.4.1 Economic sector

The growth of digitalization and its impact on various domains has increased the urge to understand what precisely this influence entails. One of the three fundamental pillars of SD, the economy, is the domain on which research, for the most significant part, has been focused (Sacco, 2021). Much is written in the literature about how digitalization is creating new business models and how this trend is changing the way of working. This transformation is recalibrating goods and services production, distribution, and consumption (EESC, 2017). Regarding the coherency between digitalization and economic growth, two main scopes are considered: the performance of companies and national economies.

Business-related, digital technologies have an increasing effect on a company's efficiency by more efficiently using capital and labor (Kapsargina et al., 2020). Literature endorses that digitalization is a driver concerning profit maximization and efficiency (OECD, 2017; Osburg, 2017). It offers opportunities concerning data sharing, processing, and basing business decisions upon that. Real-time order data assists companies in planning production and managing inventories better. The Internet of things is being used to receive real-time data that supports companies in deploying staff in the right domain and making timely business decisions. Big data and modern data analysis tools that accompany it offer decision-makers precise and accurate information about their business to distribute and efficiently execute their strategy. Digitalization has stimulated economic development in many different ways; through platforms, customers have become more closely involved in the activities of companies, processes within companies are streamlined, strategic choices being increasingly data-based, robotization and autonomous machines have increased productivity, the ability to control through sensors has contributed to efficiency, and there are many more examples of applications with which digitalization has had its impact on the economy. The trend of digitalization is an inevitable evolution in business development, for which there is constant competition in terms of staying up to date concerning the adaption of digital technologies and the organizational change that is needed for this. Drivers of digital transformation are enhanced competitiveness, cost control, better user experiences, and greater agility for businesses (Digarc, 2018). These developments caused by the adaption of digital technologies have influenced critical economic variables such as productivity, inflation, employment, and lowering market entry barriers (Elding, 2018; OECD, 2016).
Digitalization is a catalyst for economic growth (Li et al., 2020). For developing and developed countries, it brings innovations and offers opportunities to break through to global economies worldwide (Myovella et al., 2020). Therefore, the literature suggests that the digitalization process should be driven by governments(Nair et al., 2020). An important note is that adapting to new technologies is not always straightforward and often comes with new tasks. Moreover, digitalization involves significant investments, and these transformations must also be well managed at an organizational level.

2.4.2 Environmental sector

To this day, there still needs to be a definitive answer about the discussion of whether digitalization, in general, has a positive or negative impact on the environment. Technological developments at first certainly had an increasing impact on the demand for resources from the earth and greenhouse gas emissions. While digitalization has created some environmental degradation issues, it is also seen as one of the critical drivers of the green economy transition (Söderholm, 2020). Due to the digitalization of supply chains, enormous progress has been made in efficiency concerning the use of information and resources in logistic management, the product lifecycle, and the value creation process (Chen, 2020; Parida, 2018). State-of-the-art technologies, such as artificial intelligence, have the potential to create a massively efficiency increase in production, reducing resource usage and optimizing logistics and distribution. This efficiency increase impacts the main KPIs of environmental sustainability since it results in less transportation, reducing energy consumption and CO_2 emissions.

In terms of adverse effects on the environment, it is mainly software's energy consumption and the high-impact hardware lifecycle that are cited. In many cases, mining raw materials such as aluminum, lead, gold, silicon, and copper pollutes the water from surrounding areas, making drinking water toxic and killing fish species(Stewart, 2019). In addition, electronic devices and ICT infrastructure production releases toxic pollutants that have various adverse environmental effects. Adding to these toxic effects, many resources and other commodities are required for these products that are often not recycled and must be transported over long distances (Berkhout, 2004). Manufacturing components such as sensors, microchips, semiconductors, displays, and other hardware require vast amounts of energy input and water for cooling. Thereby, The use of software also consumes considerable amounts of energy. One of the primary energy-consuming aspects of digitalization is cloud technologies and data centers that process large amounts of data. According to some studies, 1TB per year of storage accounts for as much as 35 kg of CO_2 (Williams, 2011).

The literature often cites the Kuznets curve (Kuznets, 1955), an inverted U-curve, which can be applied to the theory that digitalization is initially associated with a negative environmental impact but eventually ensures that these effects will diminish. However, this theory is criticized and mainly refuted on the points that digitalization has a self-reinforcing effect on consumption, energy consumption, and economic growth. It still needs to be determined whether digitalization will eventually lead to a society where economic growth is decoupled from a negative external effect on the environment (Satarius, 2020).

There is still doubt concerning the limitations of digitalization to promote growth-independent development, i.e., "post-growth" or "decoupling" economic development, and whether it greatly reduces resource use and emissions while stimulating social welfare and the functionality of the economy more independent of continued economic growth (Jackson, 2011; Lange, 2018). That digitalization, in many ways, contributes in achieving SD goals is not in doubt. However, the question is whether the positive effects ultimately outweigh the negative and whether this turning point will occur in time.

2.4.3 Societal sector

Digitalization is a trend that underlies recent social and ethical transitions. When looking at social well-being, employment, income, and the ability to make end meets are the primary aspects that reflect this. In addition, equality, safety, and access to good healthcare are standards put forward around the world as essential aspects of it. However, in the field of social well-being, many challenges have also occurred in recent years due to the digitalization of society. Some primary societal aspects that have emerged due to new digital technologies are biased algorithms, the use of data to monitor and influence human choices, its impact on inequality, and replacing humans with robots.

The process of digitalization has had a substantial impact on the labor market in recent years, bringing with it many changes in the shift of functions and jobs. Digitalization has replaced many people's jobs, although this shift has also created new jobs (Goos, 2015). Research shows that a substantial proportion of all human jobs may eventually be replaced by robotization (Frey, 2015).

In addition to this, digitalization contributes to inequality in several ways. One elaboration is that the low-educated have a higher risk of being hired for less stable jobs than the high-educated (Acemoglu, 2002). Research shows that digital technologies and high-skilled professionals go hand in hand and that low-skilled workers have a considerable disadvantage in the labor market (Cirillo et al., 2021). Emerging digital technologies give 'digital natives' an advantage over 'digital immigrants' (Dittes et al., 2019). Access to digitalization comes with great benefits. Information and communication technology (ICT), i.e., products that allow information to be stored, retrieved, manipulated, transmitted, or received in digital form, can enhance access to goods and services; create and maintain a safe, independent living environment; facilitate self-management of age-related challenges; and enable social participation and connectedness (Sixsmith & Gutman, 2013). Older people, for example, generally have less knowledge about and access to ICT. In this regard, 'the digital divide' divides older people from younger ones, leading to significant inequalities (Casado-Muñoz, Lezcano, & Rodríguez-Conde, 2015; Graham, 2010). This digital divide refers to inequality of opportunity due to unequal access to emerging ICTs between and within countries(Cullen, 2001; van Dijk & Hacker, 2006; Yu, 2011).

Today, digitally intensive occupations have better job opportunities, especially in companies with technologically competitive strategies. Nowadays, many digital workers are considered part of the gig economy. The term gig economy refers to individuals (e.g. freelancers) who are occasionally deployed or for a short term to perform specific tasks or projects or on short notice to perform certain tasks that are IT related(Tan et al., 2021). For instance, about 30% of the US adult population is involved in the gig economy, and many gig workers are classified as unemployed (Bracha & Burke, 2021). This is just one example of what extent digitalization permeates every sector.

As mentioned before, the healthcare sector is important when looking at society's SD. Although almost all industries have been highly subject to digitalization in recent years, it is clear that digitalization has not yet had such an impact as in other industries. For example, we still talk about 'digital health' and 'eHealth', whereas other industries are already fully functioning on digitalization. Digitalization offers advantages in diagnostics and the impact of digital technologies on health, such as wearable devices and improved surveillance (McKee et al., 2019). However, negative aspects still prevent the health sector from digitalizing. Examples include; the risk of cyberattacks, 'fake news' or misinformation and disinformation, discrimination by artificial intelligence, and privacy breaches. The Director General of the World Health Organization states that "Ultimately, digital technologies are not ends in themselves; they are vital tools to promote health, keep the world safe and serve the vulnerable" (Adhanom, 2019). Because in the healthcare sector, human lives can be directly at stake, digitalization is handled carefully here, while in other industries, the opposite is often the case.

When digital technologies are properly integrated, they should lead to higher productivity, lower prices, new products, an increase in demand, and, therefore, an increase in employee demand. It is substantiated that digitalization has so far led to restructuring industries and sectors and reallocating human and capital resources but has not led to higher unemployment (OECD, 2016). Much literature shows the complementarity of humans and machines, contradicting the replacement character attributed to digitalization. Internet and social media are also digital aspects that have greatly influenced the social domain in recent years. These platforms allow people to express their opinion in the public domain. Literature shows that the internet's opposing sides impact a free democracy, in which individuals have the space to form their own political and social views (Habermas,1993). The internet promotes social polarization rather than rational discussion (Bimber, 2003; Papacharissi, 2002). Because of the multivariate character of the impact of digitalization on the social domain and its multifaceted influence, it is fascinating to look at its aggregated impact in this domain as well.

2.5 Conceptualization of the coherence between digitalization and sustainable development

The conceptualization of the impact of digitalization on sustainable development(SD) is based upon the previously defined concepts and the interrelationships being described by the literature. The different types of impacts of digitalization have been described for the three sectors of Tomislav. To determine the coherence of digitalization and SD, specific sectors are used to structure indicators by which SD can be measured. The global framework of indicators with which the United Nations measures the 17 SDGs consists of no less than 248 indicators. The purpose of these indicators is to quantify the goals for 2030 across all three sectors: environment, economy, and society. However, the large number of indicators makes it difficult to conclude the impact of digitalization on SD. Therefore, deductively we first examine which qualitative impacts of digitalization on SD are mainly mentioned in the prescribed literature in order to eventually use this as theoretical input for the data analyses in which this impact is attempted to be quantified. Building on this, a source-supported table is presented in the Appendix A3, which shows the impact for each indicator of SD.

When it comes to the conceptualization of interrelationships between digitalization and SD, it is difficult to map them because of the high number of variables. This would lead to a diagram with a myriad of different connections but not add value to the clarifications on the coherence between digitalization and SD. Hence, the choice was made to refer to the table in Appendix A3 with the final relationships examined and qualitative substantiation through a literature review. Based on the conducted literature review, the conceptual framework shown in Figure 4 underlies the qualitative portion of the study. The framework identifies the indicators of the different domains of SD. These indicators include the metric used to measure them. What the conceptualization shows is that there is an interaction between different components of digitalization, as well as those of SD. Forms of digitalization can lead to both desirable and undesirable practices. Prominent examples of this are given in the conceptualization. Digitalization can thus function as an enabler of such practices. Some practices that are enabled are not black or white with regard to SD or have both beneficial and detrimental effects concerning SD. This makes it even more interesting to opt for an integral approach in the quantitative part of the study, looking at SD across all fields of focus and not just specifically per aspect.

In addition, there are indirect effects, making it difficult to identify causal relationships between, for example, applications of digital technologies and sustainable practices. For instance , countries with a well-functioning economy often have safer streets and better healthcare and are also more likely to be digitalized as the transformation to a digital nation needs investment. However, this makes it difficult to state whether, in cases like this, better healthcare is caused by digitalization or rather by a state's economic well-being. In short, causal and bilateral relationships between variables within the scope of this study are diffuse. A more integral approach was therefore chosen, the method of which will be described in Chapter 3. This method will include the various impacts that the forms of digitalization have. These vary from desirable to undesirable practices in terms of impact and may ultimately affect the various sectors of SD. These sectors are divided into the economy, environment, and society. The sector of society, is divided into equality, safety, and health. As an encore, a list of indicators is provided on the right of Figure 4 that is used as a starting point for setting-up the nesceassary data and that will be narrowed in section 4.1.

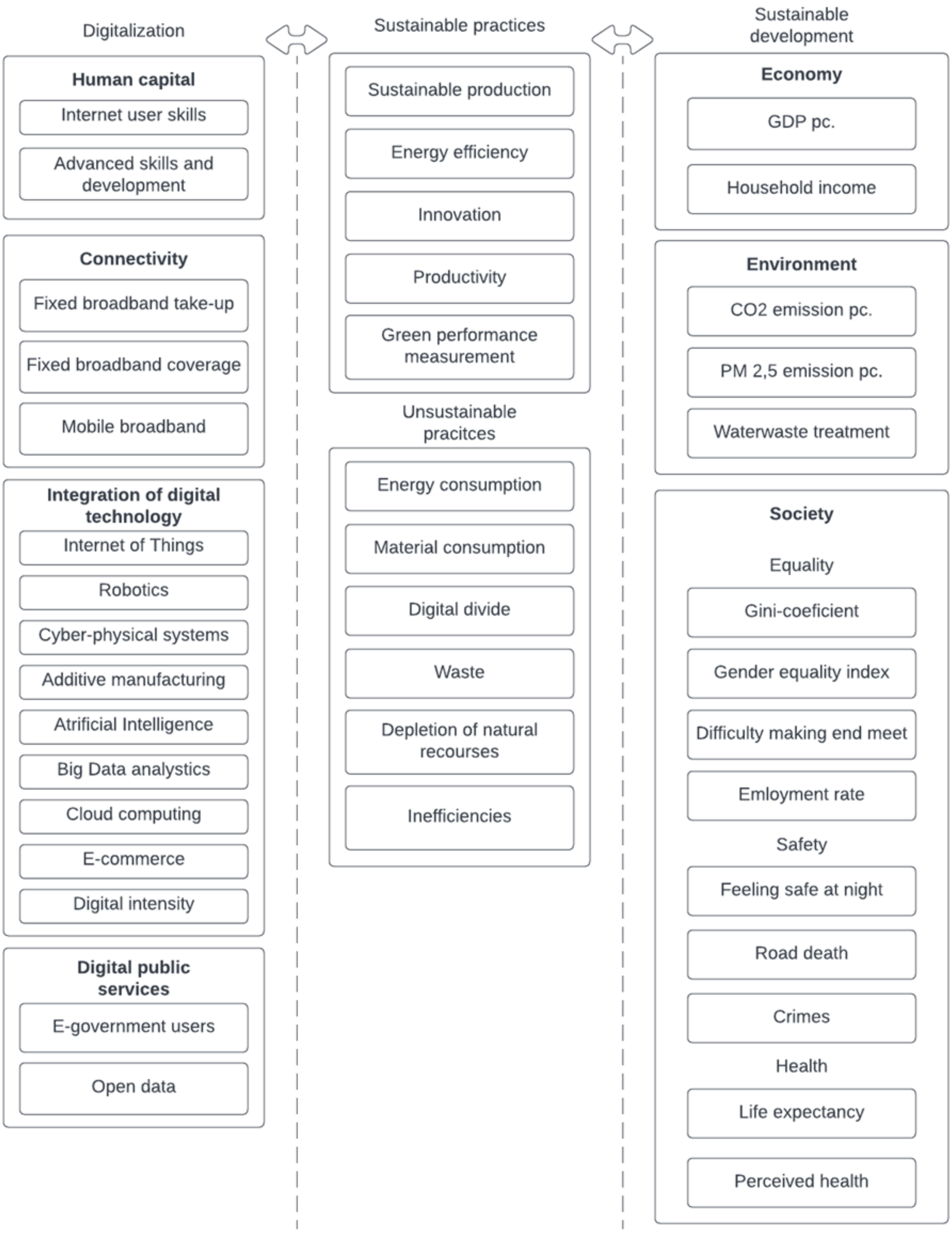

Figure 4. Literature on qualitative impact of digitalization

3 Methodology

The qualitative knowledge from the literature review is used for conceptual understanding and selecting the variables for the quantitative data analyses. First, the theoretical basis of the research question is explained, discussing the interrelationship of the factors concerning SD. In the case study, a multiple regression using panel data is used to determine the coherence between digitalization and these SD indicators. This is done by estimating the Cobb-Douglas production function coefficients that provide insight into tradeoffs between different sectors and the influence of digitalization.

3.1 Theoretical basis

This study assesses the coherence of digitalization and Sustainable Development (SD) indicators at the macro level, questioning how optimal SD can be achieved given a country's input resources. An attempt is made to maximize production concerning outputs in the SD sectors; economy, environment, equality, safety, and health. As for macro production inputs, labor and capital are well-known classical economic input factors of an economy producing output commodities (Robinson, 1953). An overview by Rabar of studies focusing on the macro productivity of OECD countries concerning socio-economic performance shows that labor and capital are used in almost all analyses examining *GDP* and *CO2 emission* as outputs (Rabar, 2017). Due to the broad scope of this study, incorporating the environmental sector with regard to productivity, this set will be extended. For this purpose, the variable primary energy supply is added to the study as a resource input. This variable measures the amount of energy consumed by a country and is more often used regarding macro production research focused on energy efficiency and environmental output (Fong et al., 2022). Energy consumption is seen as a crucial driver of economic growth and as a prime reason for high CO_2 emissions, which in turn are increasingly affected by economic growth (Cai et al., 2018; Andreoni & Galmarini, 2016). Energy consumption is included in the production function as an essential input contributing to producing goods and services (Oryani et al., 2021).

Regarding production and efficiency studies on the societal sector, most research has been conducted on the health sector. The equality and safety sectors have been understudied (Lampe & Hilgers, 2015). These studies focusing on healthcare adopt more of a meso-level scope where a sector's specific structure and characteristics are centralized (Blank & Valdmanis, 2017). According to the review of studies on the efficiency of healthcare production in OECD countries, more specific input variables like health expenditure, number of nurses, and hospital beds are being used (Varabyova & Müller, 2016). Concerning the scope of this study, no specific inputs for sectors are used, but rather country-level aggregated inputs. For example, the labor force can account for a higher number of nurses, and capital can aggregate, for instance, the number of hospitals. Doing so includes important characteristics of countries concerning resource inputs.

As for the outputs, the SD indicators are being used. The selection process of the output variables is outlined in section 2.6 and is finalized in section 4.1. An attempt is made to examine the relationship between all variables simultaneously. Measuring the direct effect of the resource- or digitalization variables of a country on a highly aggregated SD indicator is difficult because of many indirect effects and the large number of other variables involved. For example, environmental factors that cannot be controlled but which do have an impact and also less relevant factors that are difficult to measure or are not included because of practical issues. Figure 5 shows the way the production is modeled and the type of variables included in it.

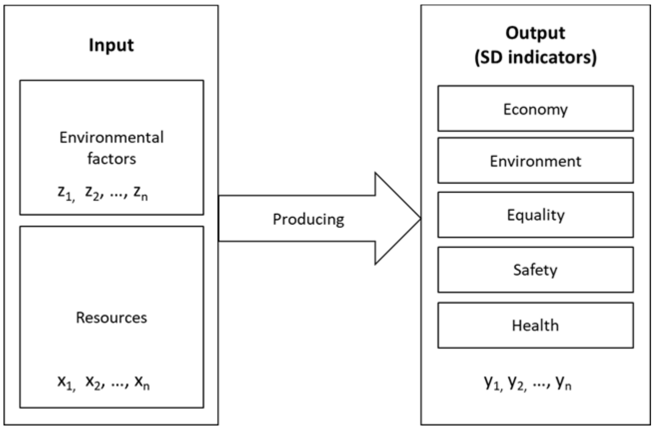

Figure 5. Models production structure

In the structure of this research, different types of factors are considered for inputs and outputs. As for the inputs, a distinction is made between resources and environmental factors. To conclude, environmental factors are considered that people cannot control. Environmental factors are exogenous and cannot be affected by variables in the model's scope. First, starting with one of the better-known environmental factors, namely the average temperature in a country. Research shows that temperature affects productivity levels considerably (Kalkuhl & Wenz, 2020). Literature shows that average temperature increases can affect not only an apparent agricultural sector but all societal sectors (Colacito et al., 2018). For example, higher temperatures have a negative effect on health and thus result in increased hospitalizations. Temperature increases in the future appear to have strong influences on the economy across the globe. They are widely estimated to have a strong negative effect on future estimated GDP per capita (Burke et al., 2015). Thereby, research shows that higher temperatures negatively affect labor productivity, resulting in collateral impact in all sectors (Yildirim et al., 2009). This, therefore, makes it an important variable to include in the analysis.

Population density, which indicates how many people per square meter live in a country, is another characteristic of countries that can impact productivity. Studies show that a higher population density leads to better knowledge transfer and productivity. However, a counterproductive effect is that it can lead to a higher degree of congestion and possibly have adverse effects (Garces-Voisenat, 2012). Research in developed and developing countries shows that population density positively influences productivity. This influence works both in the short term (contemporary effect) and in the longer term (delayed effect). Research on the environmental impact of population density highlights, as with economic growth and energy consumption, that these factors have an increasing impact on the amount of CO_2 emissions in a country (Ohlan, 2015).

In this case, the decision-making units (DMUs) are the OECD countries. For outputs, a representative Key Performance Indicator (KPI) is chosen for each SD sector: economy, environment, equality, safety, and health. This was done to avoid having to include too many variables in the final analysis so that the results could be interpreted more unambiguously. The SD-, resource-, and environmental variables are respectively denoted by y_m, x_n and z_o. To assess the relationship between these inputs (resources) and outputs (SD indicators), it is interesting to see what trade-offs are made concerning resource deployment. To interpret this, a regression is performed using the mathematical Cobb-Douglas function that models the relationship between production output and production inputs.

3.2 Productivity measurement

Productivity is a measurement that implies the relationship between resources and produced output quantities, as shown in Eq. 1. The structure by which national resources are used to produce outputs shown in Figure 5 can be captured in a mathematical equation. To comprehend this translation, it is essential to understand the basics of production, where an amount of resource inputs leads to a certain amount of outputs.

$$Productivty = \frac{p_1 y_1 + p_2 y_2 + \cdots + p_M y_M}{w_1 x_1 + w_2 x_2 + \cdots + w_N x_N}$$

p_m = *weight of product m;*
w_n = *weight of resource n;*
y_m = *quantity of product m;*
x_n = *quantity of resource n*

Within the concept of productivity, we speak of efficiency and technical change, which are the building blocks of productivity variation. Efficiency is a derivative of productivity that focuses on the static part of productivity. This term mainly emphasizes the part of productivity that can be linked to policy and, thus, the way resources are allocated and affected by DMUs. The other elements contributing to the variation are technical changes in time due to technological innovation and environmental changes that can affect productivity, as elaborated in section 3.1. Digitalization is an important component of technical change that indicates its extent and is thus considered to affect a country's overall productivity.

Efficiency can be approached from two perspectives, input-oriented and output-oriented. The former indicates how much input quantities can be proportionally reduced without changing the output quantities produced. However, in the context of this study, the impact of digitalization on a country's efficiency is analyzed to generate the highest possible output concerning SD. This raises interest in assessing efficiency from an output-oriented point of view, implying efficiency reflects how much a country's output quantities can be proportionally expanded without changing the input quantities used (Coelli, 1996). This is done by using the output distance, reflecting the difference between outputs produced by an observed DMU compared to the maximum possible produced outputs using the same amount of resources, with the aim of maximizing outputs at given resources.

To clarify the concept of an output-orientated efficiency, an example of a simple output-distance diagram using two inputs and one output variable is presented in Figure 6. Suppose a production company can provide output by using labor and capital to produce documentaries and movies. Then there are multiple productions of multiple outputs. In that case, the production company must decide how to distribute labor and capital. With this mentioned example, all combinations of production can be represented in a graph, where a fixed input set is assumed. Figure 6 shows the output set and the transformation curve (TRC) showing the optimal production with given input(s). The output distance is marked with the difference between the optimal production and hours of content produced in this example. The output distance in this example is marked with D_0, which shows the difference between a relatively "under-performing" and an optimally performing Decision-Making Unit (DMU).

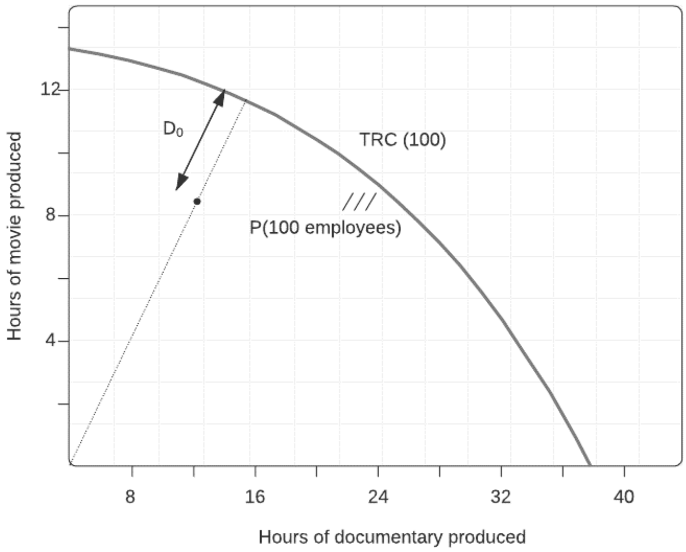

Figure 6.Example - Output distance in transformation curve (TRC)

This output distance can be expressed on a multidimensional scale where multiple inputs can lead to multiple outputs. Here, various mathematical functions can be used to interpret this consistency in production. A commonly used mathematical presentation for this is the Cobb-Douglas function (Vîlcu, 2011).

3.3 The Cobb-Douglass production function

The Cobb-Douglass function was developed in 1928 by Charles Cobb and Paul Douglas (1928) as a mathematical equation to present the functional form of production. The initial hypothesis was to represent total output as a log-linear function. Here, y is the output, and the x's are the different types of recourses used to produce y and β's, which are called the function's parameters. This was initially done with the classical economic variable capital and labor, but the model allows for expansion with multiple inputs or outputs, as shown in Eq. 2.

(2) $y_{it} = \beta_0 x_1^{\beta 1} x_2^{\beta 2} \cdot \ldots \cdot x_m^{\beta n}$

As elaborated in the section on a theoretical basis, several inputs and outputs are to be included in the model. The Cobb-Douglas function can be extended as follows with, for example, two outputs and three inputs;

(3) $1 = \beta_0 y_1^{\beta_1} y_2^{\beta_2} x_1^{\beta_3} x_2^{\beta_4} x_3^{\beta_5}$

If y_1 were to increase and resources remained the same value, this would mean considering a homogeneity principle that y_2 should decrease as output. This characteristic of the Cobb-Douglas function makes it possible to interpret tradeoffs between the SD indicators of different sectors. To calculate the difference with the optimal efficiency, the output distance function can be used to calculate the efficiency of a given country *i* in a given year *t*, given its use of resources and outputs produced. Using the same example, this would look as follows;

(4) $D_0 = \beta_0 \cdot y_{1it}^{\beta_1} \cdot y_{2it}^{\beta_1} \cdot x_{1it}^{\beta_1} \cdot x_{2it}^{\beta_2} \cdot x_{3it}^{\beta_3}$

Finally, an (OLS) regression model will be used to estimate the coefficients of the Cobb-Douglas function. Beforehand, it is important to clearly explain which data will be used as input for this analysis.

4 Data

The final analysis will be performed using data on output variables of SD indicators and input variables from digitalization-, resource- and environmental nature. The dataset used in the analysis has emerged from a collection of variables derived from the literature review. The SD indicators are chosen based on the literature research into the effect of digitalization on SD, divided into three sectors; economy, environment, and society. Wherefore society is divided into the subsectors; equality, safety, and health.

The dataset consists of data of a national aggregation level for 22 OECD countries. The specific countries were chosen based on available data regarding the number of countries and years. Data from the DESI index led to the choice of countries here because the data is only available for EU-27 countries for 2014 - 2020. Other data required for the analysis were only available for OECD countries, so the countries that are part of the OECD and the EU-27 were chosen for the analysis. In addition, several variables lacked data for 2021, so 2021 was not included in the analysis. This has resulted in data from the year 2014 to 2020 for the following 22 countries; Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Portugal, Slovak Republic, Slovenia, Spain, and Sweden. These countries are relatively less divergent from other countries in terms of culture due to geographical proximity, this external factor has less influence on the productivity difference between countries. This is favorable, as cultural differences between countries are ignored due to the scope of the research. However, countries have significant population differences that are not considered in some variables. Regarding efficiency calculations, inputs and outputs must be corrected for this. Hence, when calculating relative efficiency based on data from different countries, this must consider the countries' scale; thus, input and output variables are adjusted for this.

The panel data were mainly obtained from widely recognized sources such as OECDstat, Eurostat, and Worldbank. Table 4 shows the complete set of variables, excluding data on the poverty gap, as there was only data available for this for four years. Changes in corrections and transformations are still being made regarding specific inputs and outputs for the statistical regression. Variables are labeled with the symbol used to denote them, the unit, the expected relationship with digitalization, and the source from which the data was obtained.

Variable	Symbol	Unit	Expected sign	Data source
		Dependant output		
		Economy		
GDP pc.	GDP	CurrentUS$ per capita	NA	The World Bank
Household Income	HOU	CurrentUS$ per capita	+++ (GDP)	Stat OECD
Environment				
CO2 emissions pc.	CO2	Ton per capita	-/+ Kuznets curve	Stat OECD
PM 2.5 emissions pc.	PME	Ton, thousands per capita	-/+ Kuznets curve	Stat OECD
Wastewater treatment	WAS	% Of population	+	Eurostat
		Equality		
Gini-coefficient	GIN	0 - 1	++	The World Bank
Gender Equality index	GEN	0 - 100	++	European Institute of Gender Inequality (EIGE)
Difficulty making end meet	DIF	% Of population	+++	Stat OECD
Employment rate	EMP	% Of population	-/+	Stat OECD
		Safety		
Feeling safe at night	FEE	% Of total population	~	Stat OECD
Road death	ROA	Rate per 100 000 population	-	Stat OECD
Crimes	CRI	% Of population reported Crime, violence or vandalism in the area - EU-SILC survey	+	Eurostat
		Health		
Life expectancy	LIF	Years	+	Stat OECD
Perceived health	PER	% Of adults reporting "good" or "very good" health	-/++ (Health care in general)	Stat OECD
		Independent input		
		Digitalization variables		
DESI overall score	DOV	0 - 100	NA	DESI
DESI human capital	DHU	0 – 25	NA	DESI
DESI connectivity	DCO	0 – 25	NA	DESI
DESI integration of digital technology	DIN	0 – 25	NA	DESI
DESI digital public services	DDI	0 – 25	NA	DESI
		Resource variables		
Labor force pc.	LAB	Employed workers plus the unemployed people looking for work, per capita	NA	World Bank
Total capital stock pc.	CAP	Capital stock at current PPPs (in mil. 2017US$), per capita	NA	Penn World Table (Feenstra, 2015)
Primary energy supply pc.	ENE	Million TOE, per capita	-/++ Kuznets curve (reversed U-curve)	Stat OECD
		Environmental variables		
Average temperature	TEM	C°	NA	The World Bank
Population density	DEN	People per sq. km of area	NA	The World Bank

Table 4. List of variables

The dataset contains missing values, making it impossible to analyze the set with a regression. For each case of missing values, mainly the trend within the country or year was used depending on the missing values. The missing values have been inter- or extrapolated in order to be able to make a realistic estimate for the data shown in Appendix A4. In the final data used for the analysis, 53 data points are missing, mainly due to missing data for the year 2020 for the SD indicators *CO2 emission per capita* and *Gini-coefficient*. However, the total data used for the analysis consists of data from 22 countries over 7 years for 12 different variables and thus contains 1848 data points, meaning less than 3% of the total data is missing. This will have little impact on the final results of the analysis, but it is an aspect to consider with regard to inference for *CO2 emission per capita* and *Gini-coefficient*. For these variables, a value was entered for the year 2020 that considers the trend of the specific country applied to the latter value.

4.1 Choosing sector main indicators

The Pearson correlation coefficient is a way to check the bivariate relationship between variables. Using a correlation matrix in Table 5, combined with prior knowledge gained from the qualitative part of this research, the primary indicator will be chosen for each sector: economy, environment, health, safety, and equality. In this matrix, a minus one would indicate a perfectly negative relationship, whereas a plus one indicates a perfect positive linear relationship. For this correlation matrix, variables are used as input for the analysis that have already been subject to the transformation in question. Thus, undesirable outputs have already been subject to the reciprocal.

	Economy		Environment			Equality				Safety			Health	
	GDP	HOU	CO2	PME	WAS	GIN	GEN	DIF	EMP	FEE	ROA	CRI	LIF	PER
GDP pc.	1													
Household Income	0,861	1												
CO2 emissions pc. (rec.)	-0,421	-0,370	1											
PM 2.5 emissions pc.(rec.)	0,696	0,510	-0,386	1										
Wastewater treatment	0,514	0,569	-0,081	0,106	1									
Gini-coeficient (rec.)	-0,031	0,032	-0,259	-0,139	-0,147	1								
Gender Equality index	0,641	0,695	-0,063	0,132	0,660	0,117	1							
Difficulty making e.m. (rec.)	0,473	0,660	-0,202	0,125	0,500	0,230	0,614	1						
Employment rate	0,165	0,284	-0,002	0,088	0,052	0,319	0,339	0,606	1					
Feeling safe at night	0,446	0,485	-0,376	0,172	0,398	0,365	0,613	0,502	0,344	1				
Road deaths (rec.)	0,442	0,414	0,047	-0,021	0,370	0,121	0,731	0,523	0,437	0,498	1			
Crimes (rec.)	-0,361	-0,323	0,283	-0,046	-0,455	0,077	-0,370	-0,068	0,242	-0,049	-0,274	1		
Life Expectancy	0,573	0,625	-0,375	0,092	0,551	-0,011	0,663	0,320	-0,206	0,506	0,423	-0,600	1	
Perceived Health	0,533	0,507	-0,258	0,029	0,415	0,239	0,544	0,262	-0,215	0,378	0,530	-0,512	0,749	1

Table 5. Correlation matrix –SD indicators

Based on the Pearson correlation matrix, we look at the mutual correlation between indicators of sectors. The first indicators concern the economic sector, where *GDP per capita* and household income have the highest correlations. Since *GDP per capita* is one of the main measures of the economic sector it will be used in further analysis (Halkos and Tzeremes, 2009; Afonso and St. Aubyn, 2013). As far as the environmental sector is concerned, there are three indicators, *CO2 emission per capita*, *PM 2,5 emission per capita,* and *wastewater treatment*. However, *PM 2.5 emission per capita* is excluded because it has too high of a correlation with *GDP per capita.* Although the correlation between the SD indicators of the environmental sector is low, all of them could potentially be included in the analysis, but this is omitted due to the large number of variables. *CO2 emission per capita* is chosen here as it is the most representative indicator with regard to environmental change because it is mostly used in related literature (Rezek et al., 2008; Seif Mohammed, 2022). The sector equality consists of four indicators; *Gini-coefficient, Gender equality index, difficulty making end meet and employment rate.* Remarkable is the fact that gender inequality and income inequality in countries have a relatively low correlation. This means, therefore, that they are two totally different indicators. Income inequality is an indicator that pertains to the total population, and does not have high correlations with *GDP per capita*, like the variables *gender equality* and *difficulty making end meet* which could lead to multicollinearity. Both *Gini-coeficient* and *employment rate* are variables that have a low correlation with the other variables. Since the *Gini-coefficient* has the lowest correlation with variables from other sectors, it is chosen as the main indicator of equality. With regard to the safety sector, the *Feeling Safe* indicator has the highest cumulative correlation within the sector and thus represents it best. The healthcare sector, consists of two indicators, *perceived health and life expectancy. Perceived health,* is chosen as the main indicator since a variable like life expectancy has too long of a delay with respect to the effect of changing input resources. As the correlation is at such a high level within the health sector, *perceived health* is still strongly representative for the variable *life expectancy*. These main indicators(y_n) of the relevant sectors will be included in further analyses, together with the environmental factors (z_n) and the indicator for efficiency through digitalization (u_n) , and the input resource variables (x_n) for the OECD countries.

Regarding input variables, it is evident that there are high correlations between the resource and digitalization variables (Table 6). This is also the case for the DESI overall score, as it aggregates for the other DESI components. It is interesting to note that there are low correlations between the resource and digitalization variables. This makes it relevant to see the added value of digitalization to a country's productivity, as this variable predicts something significantly different compared to the recourse variables. Additionally, the correlations between the resource variables are logically high since larger scaled countries use more energy and have access to more capital and labor.

	Resource			Environmental		Digitalization				
	LAB	CAP	ENE	TEM	DEN	DHU	DCO	DIN	DDI	DOV
Labour force pc.	1									
Total captial stock pc.	0,849	1								
Pri. energy supply pc.	0,873	0,849	1							
Average temperature	-0,060	0,090	-0,264	1						
Population density	0,065	0,243	0,182	0,336	1					
Human Capital	0,006	0,198	0,269	-0,475	0,047	1				
Connectivity	-0,007	0,085	0,011	-0,123	0,075	0,431	1			
Integration of digital tech.	-0,030	0,152	0,118	-0,277	0,172	0,750	0,625	1		
Digital Public services	0,002	0,093	0,116	-0,405	-0,055	0,725	0,738	0,719	1	
DESI overall	-0,007	0,142	0,134	-0,359	0,057	0,805	0,838	0,873	0,935	1

Table 6. Correlation matrix –Input variables

4.2 Data descriptives and interpretation

The descriptives of the values are shown in Table 7. The table shows the values of the variables after the performed transformations. This provides a clearer picture of the values of the data that have been used for the analyses. In Appendix A5, a table is given with the value before the log transformation to get an idea of the original descriptives. For all variables, the symbol and abbreviation are given in terms of designation. In terms of quantitative information, the variables are provided with mean, standard deviation, and minimum and maximum values.

Variable	Symbol	Abreviation	Average	Standard dev.	Min	Max
GDP pc.	y_1	GDP	-0,168	0,571	-1,097	1,199
CO2 emission pc. (reciproke)	y_2	CO2	-0,062	0,362	-0,961	0,632
Gini-coefficient (reciproke)	y_3	GIN	-0,007	0,120	-0,249	0,295
Feeling safe at night	y_4	FEE	-0,010	0,141	-0,460	0,215
Perceived health	y_5	PER	-0,014	0,171	-0,459	0,250
DESI overall score	x_1	DOV	-0,028	0,243	-0,713	0,486
DESI human capital	x_2	DHU	-0,018	0,189	-0,387	0,429
DESI connectivity	x_3	DCO	-0,065	0,367	-1,288	0,747
DESI integration of digital technology	x_4	DIN	-0,057	0,345	-0,905	0,691
DESI digital public services	x_5	DDI	-0,034	0,270	-0,946	0,443
Labor force pc.	x_6	LAB	-0,041	0,248	-2,171	2,034
Primary energy supply pc.	x_7	ENE	-0,094	0,411	-2,543	2,065
Total capital stock pc.	x_8	CAP	-0,100	0,444	-1,999	2,004
Average temperature	z_1	TEM	-0,081	0,450	-1,318	0,506
Population density	z_2	DEN	-0,317	0,832	-2,034	1,327

Table 7. Dataset descriptive, values with * have been factored by 1 000 000

The *labor force per capita* is one of the essential inputs to a nation's economy (Tsai et al., 2016). Another classical macroeconomic input factor is the *total capital stock per capita* which is a rough input measure of the actual physical capital in an economy. Also, the *primary energy supply per capita* of a country is an essential factor in the use of recourses. This indicates the energy produced plus energy imports, minus energy exports, minus international bunker, and plus or minus stock changes. Environmental factors are variables that cannot be influenced by decision-making units (DMUs). Environmental factors include temperature and population density in the analysis.

All data is collected from 22 OECD countries from 2014 up until 2020. The difference in digitalization between these countries highlights the importance of this study. Large variances in input and output values substantiate the significance of statistical interpretation. Composing the Cobb-Douglas function makes it possible to infer which variables contribute to efficiency and which output factors of SD the variance in input factors can be attributed. To justify the study's relevance, the variance in the countries' degrees in the DESI overall score is examined. Table 8 shows the values of the DESI overall scores for 2014 and 2020. On the far right of the table, the delta indicates the difference, visualized by scaled bars from a minimum increase in Latvia to the maximum increase in Denmark. Therefore, since Latvia has the slightest increase, it presents no bar in the visualization in the rightmost column. The countries are sorted from high to low based on the 2014 DESI overall score. What can be noticed from the table is that the degree of digitalization has increased in all countries. This shows that digitalization is a form of innovation and has a cumulative function. Thereby, the visualized bars hint that countries with relatively low levels of digitalization in 2014 are associated with a lower rate of increase in digitalization. The Pearson's correlation between the DESI overall score from 2014 and the increase in digitalization has a value of *0.436*, which implies a 'moderate positive' correlation. This could be underpinned by the reasoning that parts of the population who have better access to digitalization tend to be more efficient with respect to production and innovation and, therefore, have an advantage in increasing their extent of digitalization. This positive loop will be further explored in Chapter 5, where the results will be discussed.

	DESI 2014	**Scale 0 - 70**	**DESI 2020**	**Scale 0 -70**	**Δ DESI**	**Scale min - max**
Finland	45.69		69.60		23.91	
Denmark	44.10		69.33		25.23	
Sweden	43.87		65.22		21.35	
Netherlands	43.38		67.37		23.98	
Luxembourg	42.18		58.85		16.67	
Estonia	39.93		56.51		16.59	
Ireland	39.62		62.74		23.12	
Spain	38.74		60.77		22.03	
Latvia	36.23		49.71		13.48	
Lithuania	35.20		52.71		17.52	
Austria	34.77		54.68		19.91	
Belgium	34.35		50.31		15.95	
Portugal	34.05		50.76		16.71	
Slovenia	33.98		53.37		19.39	
France	32.10		53.33		21.22	
Germany	31.57		52.88		21.31	
Czech Rep.	30.35		49.14		18.80	
Slovak Rep.	28.47		43.45		14.97	
Hungary	26.86		43.76		16.90	
Italy	26.54		49.25		22.71	
Poland	23.62		40.55		16.93	
Greece	20.97		38.93		17.97	

Table 8. DESI overall scores of 2014, 2020 and the delta

To get an impression of the data related to the five main indicators of the SD sectors, Figure 7 shows charts with these variables plus the overall DESI of seven particular countries over the years. This representation is for clarification purposes, but data from all countries will ultimately be included in the analysis. In the representation, no reciprocals are taken for undesirable outputs, thus, the original values of the variables are visualized. The countries were chosen based on the degree of digitalization and the growth they experienced over time. The Slovakia Republic and Italy were chosen because of their low initial level of digitalization with an initial DESI overall < 30. Except for the fact that they have similar initial values, both are shown because the difference in the DESI overall increase is significant, with a fifty percent higher increase for Italy. As for moderately digitalized countries, Latvia, Germany, and Estonia were included, with all three having a DESI overall score between 30 and 40. Among these countries, it is interesting to see that Germany has a relatively high growth rate, Estonia is a relatively low one, and Latvia is the country that experienced the lowest growth concerning digitalization between 2014 and 2020. Finally, two top-tier countries, Denmark and the Netherlands are included in the visualization, with both having high initial values and increases.

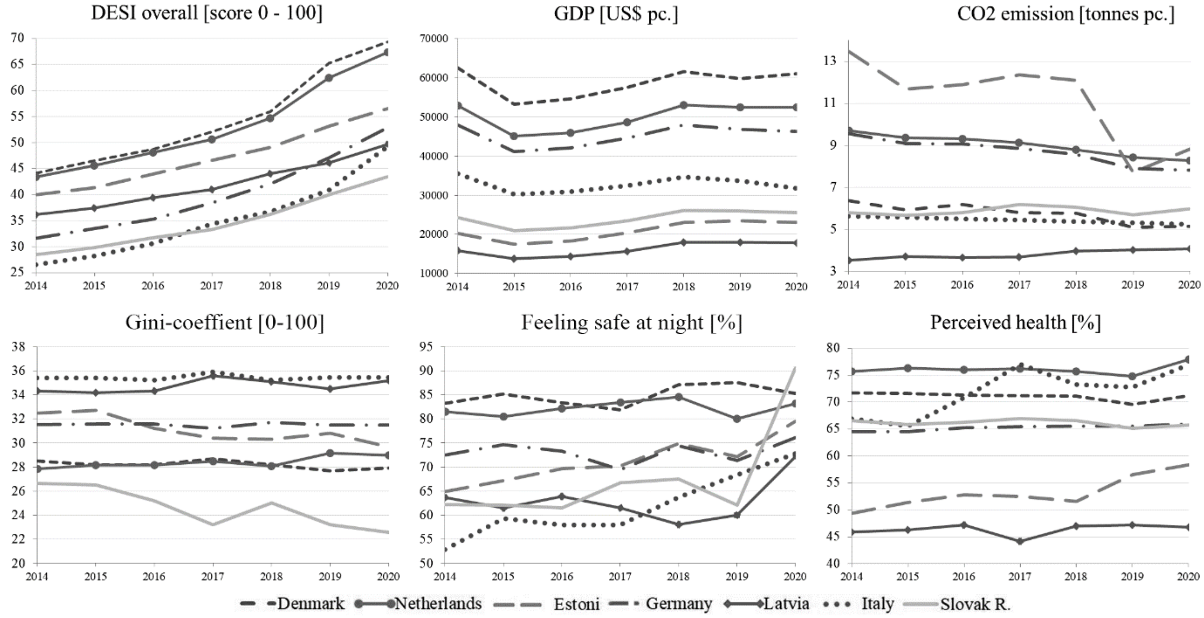

Figure 7. Charts of DESI overall index plus the five main sector indicators (before transformation)

Regarding the economic sector, there are evident differences between countries regarding produced *GDP per capita*. The countries experience roughly the same changes over the years, which can be due to the international economy. *CO2 emissions per capita* (undesirable output) have decreased or remained the same in most countries. Only Latvia's emissions increased slightly, although they emitted significantly less CO2 than the other countries. Estonia experienced the most extreme decrease, which is attributed to greater renewable energy capacity, district heating, and efforts to renovate buildings, of which the first two mentioned are partly enabled by digitalization (Kaaret et al., 2022). Looking at the developments of the *Gini-coefficient* (undesirable output), it can essentially be seen that it has remained relatively unchanged, except for the Slovakia Republic, where the index percentage has decreased, and less income inequality occurs than before. As for the output variable *Feeling safe at night*, all values converge towards that of the safety percentage of the two most digitalized countries of the sample, Denmark and the Netherlands. The graph of perceived health shows that countries that are highly digitalized do not always have higher perceived health value. For example, Estonia is a relatively highly digitalized country but has a low perceived health percentage. Italy has experienced one of the most significant increases in health and digitalization, while in 2014, the country's health expenditure decreased (Falco, 2019). It could be that part of the increase in perceived health is attributable to increases in digitalization.

4.3 Modelling the data

For all undesirable outputs, i.e. SD indicators that have a negative effect with regard to SD at a higher value, the reciprocal is taken of the values (Eq. 6) . The undesirable outputs are in the case of the original data; *CO2 emission*, PM 2,5 emission, *Gini-coefficient*, *difficulty making ends meet, Road deaths and crimes* and *difficulty making ends meet*. All data used is then divided by its average value to ensure all data is about the same size. Then the data is subject to a natural log transformation. In this way, data can be interpreted more easily and meet the assumptions of inferential statistics (Changyong, 2014).

(5) $Desirable\ Y : ln(\frac{y}{MEAN})$

(6) $Undesirable\ Y : ln(\frac{Y}{MEAN}^{-1})$

Given the character of the Cobb-Douglas model, there can only be one input and multiple outputs or vice versa when calculating the coefficients. Therefore, in this study, we choose to transform the outputs to get all variables at one side of the equation so that trade-offs between the SD indicators become visible. Due to this, there is only one output variable, *GDP*, being taken as output of the regression and multiplied by -1 so that it can be taken to the other side of the equation after regression. The other output variables are being subtracted by *GDP* for purposes of the structure shown in Eq. 7. This formula can be converted to a Cobb-Douglas where perfect efficiency is represented (Eq. 8), in which all abbreviations of the variables are switched with their corresponding symbol. This analysis is also carried out with all components of the DESI index; *human capital*, *connectivity, integration of digital technology* and *digital public services*. For this analysis, the equation of the regression and that of the Cobb-Douglas function are represented by Eq. 9 and 10, respectively. The final coefficients are estimated based on an Ordinary Least Squares (OLS) regression. Here, the analysis does not take into account panel data and thus the fact that data points belong to the same DMUs. In drawing conclusions from analyses, it must be taken into account that estimated standard errors are lower and significance in p-values are often too exaggerated.

Model 1 using DESI overall:

(7) $$-\ln(GDP)_{it} = \beta_0 + \beta_1(\ln(\mathrm{CO2}) - \ln(GDP))_{it} + \beta_2(\ln(GIN) - \ln(GDP))_{it} + \beta_3(\ln(FEE) - \ln(GDP))_{it} + \beta_4\ln((PER) - \ln(GDP))_{it} + \beta_5\ln(DOV)_{it} + \beta_6\ln(LAB)_{it} + \beta_7\ln(ENE)_{it} + \beta_8\ln(CAP)_{it} + \beta_9\ln(TEM)_{it} + \beta_{10}\ln(DEN)_{it} + \beta_{11}\ln(T)_{it}$$

(8) $$1 = \beta_0 \cdot y_{1it}^{1} \cdot y_{2it}^{\beta 1} \cdot y_{3it}^{\beta 2} \cdot y_{4it}^{\beta 3} \cdot y_{5it}^{\beta 4} \cdot x_{1it}^{\beta 5} \cdot x_{2it}^{\beta 6} \cdot x_{3it}^{\beta 7} \cdot x_{4it}^{\beta 8} \cdot z_{1it}^{\beta 9} \cdot z_{2it}^{\beta 10} \cdot T_{it}^{\beta 11}$$

Model 2 using DESI components:

(9) $$-\ln(GDP)_{it} = \beta_0 + \beta_1(\ln(\mathrm{CO2}) - \ln(GDP))_{it} + \beta_2(\ln(GIN) - \ln(GDP))_{it} + \beta_3(\ln(FEE) - \ln(GDP))_{it} + \beta_4\ln((PER) - \ln(GDP))_{it} + \beta_5\ln(DHU)_{it} + \beta_6\ln(DCO)_{it} + \beta_7\ln(DIN)_{it} + \beta_8\ln(DDI)_{it} + \beta_9\ln(LAB)_{it} + \beta_{10}\ln(PRI)_{it} + \beta_{11}\ln(CAP)_{it} + \beta_{12}\ln(TEM)_{it} + \beta_{13}\ln(DEN)_{it} + \beta_{14}\ln(T)_{it}$$

(10) $$1 = \beta_0 \cdot y_{1it}^{1} \cdot y_{2it}^{\beta 1} \cdot y_{3it}^{\beta 2} \cdot y_{4it}^{\beta 3} \cdot y_{5it}^{\beta 4} \cdot x_{1it}^{\beta 5} \cdot x_{2it}^{\beta 6} \cdot x_{3it}^{\beta 7} \cdot x_{4it}^{\beta 8} \cdot x_{5it}^{\beta 9} \cdot x_{6it}^{\beta 10} \cdot x_{7it}^{\beta 11} \cdot z_{1it}^{\beta 12} \cdot z_{2it}^{\beta 13} \cdot T_{it}^{\beta 14}$$

5 Results

The purpose of estimating the Cobb Douglas coefficients is to determine factors that explain efficiency and estimate the relationship with the extent of digitalization of a country. Additionally, the coefficients show the trade-offs between the SD output indicators at optimal efficiency. Two models are analyzed based on their outcomes, differing in the digitalization variable(s) included. The DESI overall score (Table 9, model 1) will be taken into account to estimate the overall impact of digitalization, after which it will be subdivided into the four different DESI components; *human capital, connectivity, integration of digital technology* and *digital public services* (Table 10, model 2). This subdivision allows conclusions to be drawn on more specific applications of digitalization. In production theory, when the number of resources increases under homogeneity assumption, efficiency decreases. This means that the coefficients of the input variables should be negative, indicating a negative effect on efficiency when inputs increase. Therefore, the opposite should be true for the SD output indicators.

In both models, it is noticeable that the p-values of the estimated coefficients mostly show to be significant at 5% and even lower and thus imply to be reliable estimates. Results such as these may be biased because of panel effects that are not corrected in the analysis. Two key input variables *labor force per capita* and *total capital stock per capita* do not seem to be significant in the first model and have low significant values in the second model including *primary energy supply per capita*. It can be observed that the assumption that coefficients of inputs are negative and those of output positive are broadly met. The parameters where this does not apply are those of the variables; *labor force per capita, total capital stock per capita* and digital public services in the second model. As for *digital public services*, the extent to which a country's government is digitalized, the coefficient is relatively high with a significant positive direction. Between sectors, efficiency increase has greatest impact *the Gini-coefficient*, then *feeling safe* and relatively little effect on that of *GDP per capita, CO2 emission per capita.* and *perceived health*. It is obvious that the DESI overall parameter has a relatively large significant negative value, this implies that when a country is digitalized to a higher degree, less resources are therefore needed to produce the same output. The positive value of T (time) shows that efficiency increases over time, however, it has a very high standard error which makes it invalid to draw a conclusion from this coefficient.

Variable	Parameter	Coefficient	S.E.	t-Ratio	P-waarde	Corrected t-ratic
Constant	β0	0,020	0,007	2,894	0,004	1,122
y2 CO2 emission pc. (reciproke)	β1	0,136	0,021	6,574	0,000	2,548
y3 Gini-coefficient pc. (reciproke)	β2	0,523	0,059	8,899	0,000	3,449
y4 Feeling safe at night	β3	0,263	0,056	4,700	0,000	1,822
y5 Perceived health	β4	0,049	0,054	0,896	0,372	0,347
x1 DESI overall	β5	-0,159	0,033	-4,857	0,000	-1,883
x2 Labor Force pc.	β6	0,022	0,045	0,482	0,630	0,187
x3 Primary energy supply pc.	β7	-0,052	0,025	-2,123	0,035	-0,823
x4 Total capital stock pc.	β8	-0,040	0,037	-1,081	0,281	-0,419
z1 Average temperature	β9	0,193	0,031	6,204	0,000	2,405
z2 Population density	β10	-0,080	0,013	-5,987	0,000	-2,321
T time	β11	0,005	0,712	0,478	0,642	0,185

Table 9. Cobb Douglass efficiency model – DESI overall (model 1)

The second model distinguishes between the different components of digitalization. It is interesting to note here is that human capital has the largest contributions to efficiency with integration of digital technology and connectivity in second and third place respectively.

Variable	Parameter	Coefficient	S.E.	t-Ratio	P-waarde	Corrected t-ratio
Constant	β0	-0,004	0,018	-0,207	0,863	-0,080
y2 CO2 emission pc. (reciproke)	β1	0,062	0,019	3,302	0,001	1,270
y3 Gini-coefficient (reciproke)	β2	0,465	0,047	9,981	0,000	3,839
y4 Feeling safe at night	β3	0,172	0,046	3,759	0,000	1,446
y5 Perceived health	β4	0,198	0,053	3,763	0,000	1,447
x1 Human capital	β5	-0,469	0,058	-8,069	0,000	-3,103
x2 Connectivity	β6	-0,115	0,029	-3,924	0,000	-1,509
x3 Integration of digital tech.	β7	-0,104	0,026	-3,932	0,000	-1,512
x4 Digital public services	β8	0,333	0,049	6,750	0,000	2,596
x5 Labor Force pc.	β9	0,021	0,035	0,605	0,546	0,233
x6 Primary energy supply pc.	β10	-0,006	0,021	-0,276	0,783	-0,106
x7 Total capital stock pc.	β11	-0,027	0,031	-0,881	0,380	-0,339
z1 Average temperature	β12	0,074	0,028	2,603	0,010	1,001
z2 Population density	β13	-0,051	0,013	-4,020	0,000	-1,546
T time	β14	0,002	0,004	0,564	0,574	0,217

Table 10. Cobb Douglass efficiency model – DESI components (model 2)

The empirical data shows that, as expected on the basis of the qualitative preliminary study, the degree of digitalization of a country has a positive effect on the efficiency with regard to the use of resources to strive for optimal SD, where economy, environment and society are taken into account. Of the different dimensions of digitalization; *human capital* causes the greatest increase in efficiency. With regard to policy making, this would underpin a focus on education in digital skills to allow society to adapt to the rapidly changing digitized environment, to facilitate efficiency gains. It seems that of the different types of dimensions that comprise digitalization, *human capital* causes the greatest increase in efficiency. This would, with reference to policy-making, provide a rationale for focusing on training in digital skills to make society adapt to the fast-changing digitalized environment to foster efficiency gains. Digital public services seems to have a negative impact on efficiency gains related to SD, which could be due to the fact that when investments in public government institutions and the digitalization of those increase, there will be less investment in free market institutions which in turn could have a negative impact on SD production efficiency.

The R^2 values of models 1 and 2, respectively 0.859 and 0.924, initially seem to have a good fit. This implies that, according to the data, models can describe much of the variance with the regression coefficients. Also model 2 is having a higher R^2 value and thus better describes the data in comparison to model 1. One explanation for this could be that with an increasing number of variables, it is more likely that the increase in data, would lead to a better prediction of output variables. It should be mentioned that the standard errors are not clustered. Because of the structure chosen to aggregate data from different countries, it is unlikely that exact standard errors are measured because of the fact that unexplained variance attributed to specific countries is not included. Therefore, a raw correction is applied to the t-values in order to draw better conclusions about the significance values. This correction is based on intra correlation of residuals and is described by the formula of the raw correction factor:

(9) $$t = \sqrt{1 + p_u(N - 1)}$$

t = correction factor least squares standard errors of estimated parameters;
p_u = intra correlation of the residuals;
N = average number of replications in the panel;

It can be noted that no correction for the intercorrelation of independent variables in the model is included in Eq. 9. This means that this correction factor may be underestimated and that corrected standard errors are still a bit off. The reported T-values are therefore underestimated. The correction factors of models 1 and 2 are 2.56 and 2.60, respectively. Dividing the current t-values by these correction factors gives the corrected values by which significance can be indicated. Applying these correction factors to the standard errors and t-values in Table 9 and Table 10 leads to a serious drop of the reliability of the outcomes.
Finally, the unexplained mutual variance of countries was calculated for each country. This is a variance in productivity regarding producing SD that is not supported by the data used and is outside the scope of this study. Think, for instance, of cultural differences that may not be included between countries but that do influence the extent of adaptation of digital technologies and the extent to which a country is agile enough to adapt to the rapidly changing environment or its degree of cautiousness concerning innovation. By taking the residuals from the first model's regression and the negative exponential from this, the 'total factor productivity can be measured per data point. This indicates the extent to which a country is productive relative to the others, which is not explained by the actual variable. The average values per country are shown in Table 11. In addition, the partial value added of a country's DESI score to a country's productivity was also calculated for each. For both scores in Table 11, averages were taken across years per country. So in the case of the partial Total factor productivity (TFP) of DESI the exponent is taken from the negative beta for the DESI overall score, times the average DESI score of a country (after the transformations have taken place).

Country	TFP unexplained variance	Partial TFP of DESI overall score
Austria	1,271	0,998
Belgium	1,238	0,993
Czech Republic	0,562	0,979
Denmark	1,438	1,037
Estonia	0,608	1,015
Finland	1,267	1,041
France	0,970	0,989
Germany	1,264	0,987
Greece	0,516	0,928
Hungary	0,396	0,961
Ireland	1,774	1,019
Italy	0,948	0,966
Latvia	0,464	0,996
Lithuania	0,509	0,998
Luxembourg	3,210	1,022
Netherlands	1,426	1,033
Poland	0,373	0,947
Portugal	0,599	0,992
Slovak Republic	0,452	0,966
Slovenia	0,564	0,995
Spain	0,741	1,016
Sweden	1,410	1,033

Table 11. Total factor productivity per country (average 2014-2020)

There is a significant variance in the unexplained residuals related to a country's productivity when looking at SD production. These differences can be explained by cultural differences, laws and regulations, and other aspects that were not included in the scope of this study. In terms of the partial TFP of the DESI overall score, it is clear that there is consistency between the productivity of countries and the share of the extent to which a country has been digitalized in it.

6 Conclusion

Digitalization is seen as one of the main factors enabling society to strive for sustainable development (SD). This paper sought to contribute to quantifying the relationship between the degree of digitalization of a country and its performance in the strive for sustainable development. In doing so, this broad concept is set out in terms of goals in five different sectors, namely the sectors of; economy, environment, equality, safety, and health. For these sectors, the variables*; GDP per capita*, *CO2 emission per capita*, *Gini-coefficient*, *feeling safe at nigh*t and *perceived health* were chosen for the analysis, respectively. In this analysis, coefficients of a Cobb-Douglas production function were calculated using an OLS regression. This represents the interrelationship of input and output factors. An important disclaimer is that the panel effects of the data for the 22 OECD countries from 2014 to 2020 are not taken into account. Because of this, the estimated coefficients' significance has an exaggerated value. However, because the data are all included in proportion and per capita, the analysis can be used to analyze relative differences and trade-offs.

The qualitative research showed that there had been many studies on the effects of digitalization on sustainable development. An overwhelming part of this research was qualitative, and few studies include the effects of digitalization on different sectors in one analysis. The main two sectors combined in previous research are the economy and environment.

The impact of digitalization on GDP and, thus economy is estimated to be positive due to increasing efficiency and innovation. The idea that digitalization drives profit maximization and efficiency for companies is widely supported. Digitalization is seen as a catalyst for economic growth. Literature also endorses the way digitalization is implemented in companies and sectors in terms of the organization, and governance of it is a critical aspect for maximizing the economic potential of digitalization.

Literature in the area of environment shows much disagreement on the effect of digitalization on the environment. A widely accepted theory in the field of environment is that initially, increasing digitalization will increase efficiency, lower prices, increase consumption, and therefore increase energy consumption and emissions. This theory is based on the Kuznets curve. After digitalization has increased to a certain point, according to this theory, this will have a decreasing effect on emissions by contributing to innovation in the field of reducing emissions and energy consumption. However, it is evident that digitalization is having a negative impact on the environment, mainly due to its increasing effect on resource depletion, energy consumption, and waste production. It is, therefore, vital to focus on the environmental sector when deploying digitalization on a macro level, but also for the digital transformation of companies at the sector level and to stimulate desirable practices in this field.

What is written about the coherency between digitalization and sustainable development concerning the sector of society is particularly broad. It covers many different sectors. The ESG targets of the European Commission mainly consider the effects measured concerning equality, safety, and health sectors. In the equality sector, there is increasing awareness of 'the digital divide' phenomenon underlining opportunity inequality based on differences in access and education concerning digitalization. However, digitalization is an enabler for developing countries' economic growth and innovation. Regarding safety, there is limited coverage in the literature on its connection with digitalization at the macro level. The healthcare sector is a widely discussed industry in the literature regarding productivity measurements and digitalization's impact. This industry is a good example where the disadvantages and challenges of digitalization are heavily weighted. The industry does not digitize at the same pace as the market. In terms of productivity, there are good examples where digitalization helps with efficiency in the health sector.

The OLS regressions of this analysis clearly shows that the degree to which a country is digitalized has a substantial and significant effect on the increase in production efficiency in sustainable development. This study underlines the general trend with regard to the impact of digitalization. The results show that the indicators of SD often show significant values. This is in contrast to the input variable*s labor force per capita*, *primary energy supply per capita* and *total capital stock per capita*. This indicates that these input variables do not appear to have a relatively significant impact on the output factors proportionally. The environmental factors that cannot be influenced or controlled by countries; *average temperature* and *population density* appear to have a significant influence on the production of sustainable development, whereby they appear to have a positive and negative effect on efficiency, respectively. When looking at the effects of the various components of the degree of digitalization of a country; *Human Capital*, *Connectivity*, *Integration of Digital Technologies*, and *Digital Public Services*, as with the extent of digitalization with the *overall DESI score,* can be seen to have a highly significant impact. This has substantiated previous research and shows that it is essential to apply digitalization correctly to optimize efficiency.

In addition, the total factor productivity calculations of the remaining residuals showed a clear correlation between countries' overall productivity and the partial productivity arising from a country's degree of digitalization. This implies a positive coherency between the degree of digitalization of a country and the sustainable development of a country. The difference that the degree of digitalization can make, based on the data, concerning productivity is about 7 percent. This is a significant difference viewed from a macroscope, making digitalization a critical aspect in the strive for sustainable development.

7 Discussion

In this section, key findings are be summarized, interpretations and implications will be shared and discussed, limitations will be acknowledged, and final recommendations will be made.

The analysis has shown that the standard input variables labor force per capita, *primary energy supply per capita*, and *total capital stock per capita* have a relatively low significant added value when looking at productivity concerning SD. In contrast, the digitalization variables, *Human Capital*, *Connectivity*, *Integration of Digital Technologies*, and *Digital Public Services*, and the extent of digitalization with the *overall DESI score* were generally highly significant. The equality, security, and health sectors were found to be most strongly affected by digitalization. In the final total factor productivity calculation of the residuals, it became clear that there are significant differences between countries' overall productivity. The partial share of digitalization in it is of significant importance. With this, the correlation between digitalization and sustainable development is positive and, based on the data to have a maximum effect of 7 percent with regard to SD output. What is interesting to note is that the relative inter-country differences in levels of productivity in Table 11 are very similar to outcomes of productivity measures based on GDP per capita (World bank, 2021). This fact underpins the validity of the analysis.

Regarding main limitation of the study, a two-part aspect is pointed out regarding the validity of the results of significance in the analyses. Panel data is used, data points from different countries over different years. However, there is no direct correction in the model for random and fixed effects with respect to cross-country differences. To counter this, a raw correction is performed based on the intra correlation of residuals to correct the significance scores of the analyses. In addition, the available data from the DESI index is a limiting factor in the amount of data that can be used as input for the study. Since DESI scores can be calculated annually, more and more data will become available in this research domain.

In future research, it is interesting to look at what is qualitatively known about the various components of digitalization and their associated specific effects. Quantifying the impact of these specific components of digitalization, could be an important building block concerning policy-making focused on SD. In order to make the study more valid, mutual panel effects should be taken into account by including random and fixed effects in the regressions. In the future, when more data is available regarding the degree of digitalization of countries, it will be interesting to look at a wider range of intercontinental countries. Specifically for sectors, there is still uncertainty where the kink in the Kuznets curve seems to lie concerning the relationship between digitalization and environmental sustainability.

An increasingly common topic in the field of digitalization is 'the digital Divide', in which an increase in inequality in relation to gender, income, age, and other factors that can influence a group's access to digital is described. However, it can be read in the literature that there is still little quantitative research in this area. With regard to inequality, it is clear that there is a need for quantitative substantiation of the impact of digitalization on gender-, income- and age inequality. Future research could therefore focus on the relative trade-offs and impacts of digitalization on these different elaborations of 'the digital divide'.

Regarding the safety sector, there is little research on the impact of digitalization, which makes this an interesting area to investigate. Previous research in the health sector shows both positive and negative sides of the impact of digitalization.

Digitalization comes with many desirable practices and undesirable practices concerning SD. In general, digitalization plays a significantly positive role regarding the efficient use of resources, achieving optimal productivity, and stimulating innovation. However, this also involves adverse effects that, in turn, require strict focus in order to be mitigated. With digital transformation, it is therefore vital to look at which topics of sustainable development will trigger and how the negative aspects can be reduced or eliminated. Optimal digital transformation will ultimately require a sector-specific look at how best to apply digitalization, as it will ultimately require customization to be applied in an optimal way.

The strategic approach and governance of digitalization is endorsed as one of the critical aspects of a proper roll-out of digitalization and will therefore have to be kept in mind. In many cases, this will require the adaption of laws and regulations. Although, there is also an apparent tilt when looking at what is expected of companies by stakeholders in the market demanding a focus on SD sectors. Further investigating the coherence between the specific components of digitalization and measured performance on sustainable development can be used for countries to focus its recourse deployment more sector-specific concerning SD. Digitalization plays a crucial role in striving for SD development in the coming years. Focusing on maximizing this to our advantage will be sorely needed.

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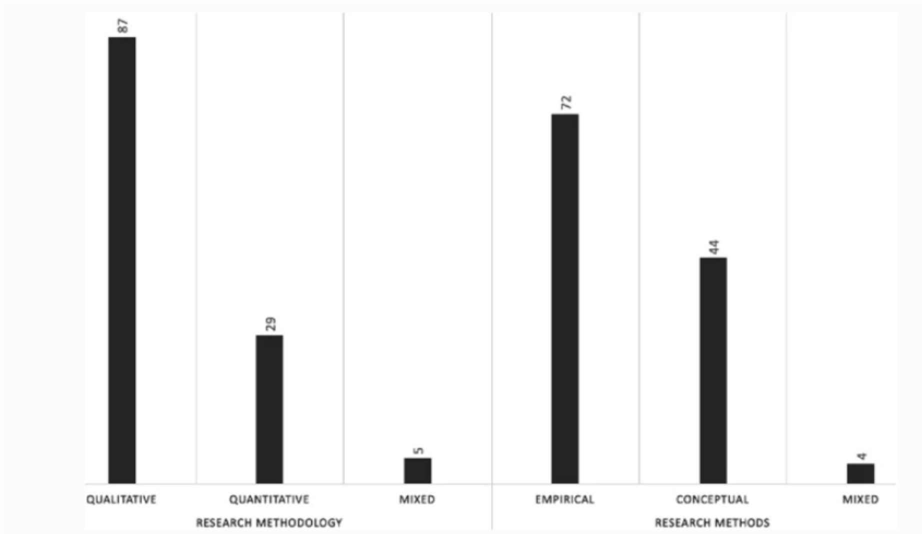
Appendix

A1. Literature review digitalization



A1. Literature review - research methods digitalization (Reis, 2019)

A2. Sustainable Development Goals (SDGs)

SDG	Domain	Goal
1	Society	No poverty
2	Society	Zero hunger
3	Society	Good health and well-being
4	Society	Quality education
5	Society	Gender equality
6	Environment	Clean water and sanitation
7	Society	Affordable and clean energy
8	Economy	Decent work and economic growth
9	Economy	Industry, innovation and infrastructure
10	Economy	Reduced inequalities
11	Society	Sustainable cities and communities
12	Economy	Responsible consumption and production
13	Environment	Climate action
14	Environment	Life below water
15	Environment	Life on land
16	Society	Peace, justice and strong institutions
17	NA	Partnerships for the goals

A2. Sustainable Development Goals (United Nations, 2015)

A3. Literature on qualitative impact of digitalization on SD per indicator

Indicator	Sector	Domain	Corresponding SDG	Effect digitalization	Reference
GDP	Economy	Income	SDG 1, 8	+++	(Katz & Koutroumpis, 2013), (Mammadli & Klivak, 2020), (Naumova, Svetkina, & Korneeva, 2019), (Sabbagh, et al., 2013)
Household Income	Economy	Income	SDG 1, 8	+++ (GDP)	(Katz & Koutroumpis, 2013), (Mammadli & Klivak, 2020), (Naumova, Svetkina, & Korneeva, 2019), (Sabbagh, et al., 2013)
CO2 emissions	Environment	Emissions	SDG 13	-/+ Kuznets curve (reversed U-curve)	(Koilo, 2019), (Lange, Pohl, & Santarius, 2020), (Li, Liu & Ni, 2021), (Kopp, Lange & Nabernegg, 2019), (Usman, et al., 2021)
PM 2,5 emission	Environment	Emissions	SDG 14	-/+ Kuznets curve (reversed U-curve)	(Koilo, 2019), (Lange, Pohl, & Santarius, 2020), (Li, Liu & Ni, 2021), (Kopp, Lange & Nabernegg, 2019), (Usman, et al., 2021)
Wastewater treatment	Environment	Water polution	SDG 6, 11, 13	+	(Adedeji et al., 2022), (Mondejar, 2021)
Gini-coefficient	Society	Equality (digtital divide)	SDG 10	++	(Fiedler, Fidrmuc, & Reck, 2021), (Cruz-Jesus et al. 2017) (Fuchs, 2009), (Martin & Robinson, 2007)
Gender Equality index	Society	Equality (digital divide)	SDG 5, 10	++	(Antonio, 2014), (Bashur et al., 2009), (Christiansen et al. 2014), (Cooper, 2006); (Elena-Bucea, 2021); (Hilbert, 2011), (Liu, 2016); (Mumporeze and Prieler, 2017)
Difficulty making end meet	Society	Equality (digital divid)	SDG 1, 8	+++ (GDP)	(Katz & Koutroumpis, 2013), (Mammadli & Klivak, 2020), (Naumova, Svetkina, & Korneeva, 2019), (Sabbagh, et al., 2013)
Employment rate	Society	Employment	SDG 8	-/+	(Bloom, McKenna & Prettner, 2018), (Krutova, et al., 2021), (Bührer, C., & Hagist, 2017)
Povery Gap	Society	Equality (digtital divide)	SDG 10	++	(Fiedler, Fidrmuc, & Reck, 2021), (Cruz-Jesus et al. 2017) (Fuchs, 2009), (Martin & Robinson, 2007)
Feeling safe at night	Society	Safety	SDG 3, 16	~	~
Road deaths	Society	Safety	SDG 3, 16	-	(Singh, et al, 2021)
Crimes	Society	Safety	SDG 3, 16	+	(O'Malley & Smith, 2022)
Life expectancy	Society	Health	SDG 3	+	(Elmassah & Hassanein, 2022)
Perceived health	Society	Health	SDG 3	-/++ (Health care in general)	(Lapão, 2019), (van Deursen, van Dijk, 2011)

A3. Literature on qualitative impact of digitalization on SD per indicator

A4. Missing values

Variable	Missing values
CO2 emmissions	2020
Wastewater treatment	Estonia:3, Germany: 4, Greece:1, Italy, Portugal: 6, Slovak Rep., Spain: 4
Gini-coefficient	2019:5, 2020
Gender equality index	2014 – 2016, 2020
Feeling safe at night	2019:1, 2020:2
Road deaths	Estonia, Latvia & Slovak
Crime	Belgium, Ireland:1, Potrugal
Life expectancy	2020:1
Perceived health	2020:6

A4.Missing values

A5. Variable descriptives before log transformation

Variable	Symbol	Abreviation	Average	Standard dev.	Min	Max
GDP pc.	y_1	GDP	37279,731	23449,609	12447,440	123678,702
CO2 emission pc. (reciproke)	y_2	CO2	0,163	0,056	0,062	0,307
Gini-coefficient (reciproke)	y_3	GIN	0,033	0,004	0,026	0,044
Feeling safe at night	y_4	FEE	73,030	9,851	46,090	90,560
Perceived health	y_5	Per	80,290	2,590	73,980	83,900
DESI overall score	x_1	DOV	43,820	9,550	23,250	70,060
DESI human capital	x_2	DHU	9,390	2,680	3,792	18,010
DESI connectivity	x_3	DCO	7,900	2,480	2,730	14,870
DESI integration of digital technology	x_4	DIN	14,590	3,590	6,390	22,940
DESI digital public services	x_5	DDI	11,940	2,180	7,850	17,780
Labor force pc.	x_6	LAB	0,515	0,282	0,059	3,942
Primary energy supply pc.	x_7	ENE	3,621*	2,351*	0,028*	28,541*
Total capital stock pc.	x_8	CAP	0,238	0,077	0,068	0,452
Average temperature	z_1	TEM	9,410	3,210	2,520	15,620
Population density	z_2	DEN	137,393	115,216	17,972	518,013

A5. Variable descriptives before log transformation