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AN INDEX OF DIGITAL FINANCIAL PARTICIPATION FOR EU COUNTRIES: WHERE DOES LUXEMBOURG STAND?

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An index of Digital Financial Participation for EU countries: Where does Luxembourg stand?

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Abstract

We propose an index of digital financial participation to benchmark the level of engagement/participation of EU citizens in an increasingly digitalized financial system. Drawing on data from Eurostat, we adopt a number of variables that reflect households' and individuals' digital skills, digital access, digital device usage as well as other factors to first construct a series of sub-indices that measure different dimensions of digital financial participation. In a second and final step, we combine these composite sub-indices into an overall composite indicator of Digital Financial Participation for EU countries. The information contained in the weights of the sub-indicator variables, as well as the weights of the sub-indicators in the final composite indicator provide potentially useful information for policymakers to assess the potential barriers to digital financial participation and inclusion in the EU. We also construct the indicator using the multi-directional Benefit of the Doubt approach to obtain directional improvement vectors that can help to guide policymakers in fostering participation in digital financial activities and digital financial inclusion.

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JEL classification: C14, C43, C44, I30

Résumé Non Technique

La digitalisation progressive de l'économie concerne les banques centrales par ses effets sur la mesure des prix, le marché du travail, la productivité et l'inflation. En particulier, l'adoption généralisée des appareils mobiles, couplée à une plus grande puissance de traitement, a incité les consommateurs à transférer leurs activités financières en ligne. En effet, l'utilisation des espèces a diminué, les préférences des consommateurs se tournant vers les services financiers numérisés. Cependant, ces développements, ainsi que la fermeture d'une partie des agences bancaires physiques", ont eu un impact sur l'inclusion financière, vu que certains segments de la population rencontrent des difficultés à utiliser les services financiers en ligne. Dans cette étude, nous construisons un indice de participation financière numérique afin de comparer cette activité à travers les pays membres de l'UE. A partir des statistiques Eurostat sur l'économie et la société numérique, nous considérons les compétences numériques des ménages et des individus, l'accès numérique, l'utilisation des appareils numériques ainsi que d'autres facteurs pour d'abord construire une série de sous-indices mesurant différentes dimensions de la participation financière numérique. Les informations contenues dans l'indicateur et ses composantes fournissent des données potentiellement utiles aux autorités pour évaluer les obstacles à la participation et à l'inclusion financière numérique. L'indicateur composite fournit des indications sur les mesures qui pourraient promouvoir la participation aux activités financières numériques et l'inclusion financière numérique. La construction de l'indicateur composite permet également d'éclairer les orientations politiques au niveau national. En donnant la priorité aux domaines identifiés comme ayant un potentiel d'amélioration, les autorités pourraient contribuer à accroître la participation des individus aux activités financières numériques. Des telles politiques ciblées pourraient venir en aide aux personnes con-

frontées à des défis d'accessibilité et élargir la gamme de services financiers. Dans le cas du Luxembourg, nos résultats suggèrent que les mesures publiques devraient donner la priorité aux personnes ayant de faibles compétences numériques. En principe, un soutien pourrait permettre à ces individus d'accéder à des services financiers moins coûteux et plus compétitifs. De plus, les résultats liés à notre mesure d'inclusivité suggèrent que la promotion de la concurrence dans le secteur des télécommunications pourrait élargir l'accès aux services financiers pour les personnes financièrement vulnérables en réduisant les coûts d'abonnement à Internet et aussi les coûts des équipements.

1 Introduction

The digitalization of the European Union's (EU) economy and its implications for the economy and the financial system is of high interest for central banks. These developments are relevant not only for the conduct of monetary policy but also for central banks' role in the smooth operation of payment systems. On 24 September 2020, the European Commission adopted a digital finance package as part of its digital finance strategy to facilitate the digital transformation of the financial system in the EU. The Commission's package includes a number of legislative proposals intended to improve consumers' access to more competitive financial products and services. Among the initiatives is a renewed strategy for modernized and safer retail payments and legislation to promote open banking.

In the context of the EU Digital Decade and the European Digital Skills Agenda, the European Commission has put forward proposals to modernize the EU payment system. The proposed amendments to the Payment Services Directive (PSD)[1] and Payment Services Regulation (PSR)[2], as well as other payment-related legislation such as the Instant Payments Regulation[3] and the Financial Data Access (FiDA) Regulation[4], will help to improve consumer protection and foster competition and innovation in the European retail payments segment. With respect to the FiDA package, after giving their consent, consumers will be able to share their personal data in a manner that provides them with access to better and cheaper financial products and services.

The possible introduction of the Digital Euro, as a retail central bank digital currency

[1] Proposal for the PSD3 directive: `https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52023PC0366`

[2] Proposal for the PSR regulation: `https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52023PC0367`

[3] `https://eur-lex.europa.eu/eli/reg/2024/886/oj`

[4] `https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52023PC0360`

(CBDC), is also likely to result in changes in the way consumers purchase goods and services. The benefits of increasing digitalization in the retail payments market, such as improved efficiency, greater consumer choice and cost savings can be fully realized only if there is widespread adoption of the new technologies and digital methods of payment that leads to a more inclusive and participatory financial system. There are, however, lingering questions over the eventual take-up of retail CBDC as countries that have already introduced them, such as the Bahamas, Jamaica and Nigeria have experienced relatively low levels of adoption. The take-up of innovative digital financial products and subsequently EU citizens' participation in a digitalized economy depend not only on the degree of adoption of these technologies by the population, but also on individuals' level of digital skills, ability to engage in digital finance and willingness to participate in a more inclusive digitalized financial system.

Certain barriers can hinder individuals' participation in digital finance including physical, socio-demographic and financial factors. The possible barriers to digital financial inclusion encompass factors like decreased accessibility, impoverishment, as well as voluntary exclusion. As a result of these barriers, certain segments of society may not equally benefit from developments and technological innovations in digital finance, despite their potential benefits and the expectation that digital finance will offer new channels for delivering a broader range of financial services to excluded groups (Demirguc-Kunt et al. [2018]).

To understand the societal impact of new payment options and digital financial technologies it is first necessary to establish a quantitative benchmark for comparing consumer behaviour and digital financial participation across EU Member States. The objective of this study, therefore, is to identify a set of indicators that can serve as a proxy for digital financial participation for Luxembourg and the EU Member States. After identifying these indicators, we subsequently use them to construct a composite indicator of Digital Financial Participation that can be compared across EU countries.

To leverage on cross-country comparability, the indicators are selected from Eurostat's collection of data on digital skills in the EU. The data from the European Commission's digital skills survey is used to construct the aforementioned composite indicator of digital financial participation that, in our view, captures consumers' degree of participation in digital financial activities. In addition, the composite indicator may also help to provide insights into citizens' willingness to increase their digital financial behaviour, which has relevance for the uptake of retail CBDC. We call this new indicator the Composite Index of Digital Financial Participation (CIDFP).

The rapid pace of digital innovation in the retail payments space poses a spectrum of challenges for individuals as well as small businesses. The COVID-19 pandemic may also have acted to accelerate the adoption and use of digital technology, including for making payments. Although cash remains the most frequently used instrument for payments in the EU, there has been a general decline in firms' acceptance of cash for payment[5]. Further to these developments, the adoption of instant payments as the "new normal", revisions to the Payment Services Directive and the Payment Services Regulation that will strengthen customer authentication and the increasing digitalization of the financial system are expected to impact consumers' financial behaviour across a wide range of age categories and other demographic dimensions. Notwithstanding EU citizens' right to a basic payment account under the directive on payment accounts[6], individuals may

[5] See https://www.ecb.europa.eu/press/use-of-cash/html/ecb.uccea202409.en.html#toc2

[6] Directive 2014/92/EU of the European Parliament and of the Council of 23 July 2014 on the comparability of fees related to payment accounts, payment account switching and access to payment accounts with basic features

nevertheless face exclusionary pressures[7] that could prejudice their ability to benefit from a higher number and quality of financial services. For the purpose of this work, we call this the risk of digital financial exclusion.

Within the EU, digital financial participation is likely to be facilitated through a number of European legislative initiatives including the Regulation on instant payments, the Regulation on a framework for financial data access (FiDA), and the proposal for a Regulation on the establishment of the digital euro[8]. The digital euro, as a CBDC, would help to support digital financial inclusion through its nature as a public good, its accessibility requirements, its intended ease of use, its "privacy by design" and the intention for it to be free of charge for basic use.

Financial inclusion is a concept that can often be misinterpreted. The Global Partnership for Financial Inclusion (GPFI) defines digital financial inclusion as involving "*the deployment of digital means to reach financially excluded and under-served populations with a range of formal financial services suited to their needs, delivered responsibly at a cost affordable to customers and sustainable for providers.*" Digital financial inclusion has also been incorporated into several of the United Nations' Sustainable Development Goals including those to "*strengthen the capacity of domestic financial institutions to encourage and expand access to banking, insurance and financial services for all*"[9] and to "*empower and promote the social, economic and political inclusion of all, irrespective of age, sex, disability, race, ethnicity, origin, religion or economic or other status*"[10]. It therefore

[7]Certain individuals may also voluntarily choose to exclude themselves from the formal financial system due to concerns about privacy, online security or even a broader distrust of centralized authority.

[8]https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52023PC0369

[9]Target 8.10 of the UN's 2030 Agenda for Sustainable Development. https://sdgs.un.org/goals/goal8#targets_and_indicators

[10]Target 10.2 of the UN's 2030 Agenda for Sustainable Development. https://sdgs.un.org/goals/goal10#targets_and_indicators

seems worthwhile to discuss the difference in digital financial inclusion between advanced and emerging and developing countries.

European laws such as the Payment Services Directive (PSD2) and the Payment Account Directive (PAD) ensure that legal residents of Europe have the right to a basic payment account, either for free or for a reasonable fee, for making electronic payments. EU laws also allow consumers to open a bank account in any EU country, regardless of their financial situation[11].

2 Literature Review

In comparison to emerging and developing economies, citizens of the EU face significantly less risk of being excluded from access to basic financial services due to severe deprivation or the lack of formal financial infrastructure and/or services. Nevertheless, certain segments of society may experience difficulties or unequal levels of access to financial services, which can be viewed as a form of exclusion from participation in digital finance. Work undertaken by Broekhoff et al. [2023] has identified some of these "focus groups" in The Netherlands. The results of the Dutch study suggest that there are a number of factors underlying these exclusionary tendencies with the reasons ranging from voluntary exclusion from the increasingly digitalized financial system, exclusion due to poverty or other access-related barriers, social disadvantages, or even a preference for more traditional in-person banking services.

The reasons for digital financial exclusion may also vary across Member States. The study by Broekhoff et al. [2023] on challenges resulting from the digitalization of the payment system finds that, at least in The Netherlands, certain focus groups of bank customers have experienced a decline in payment system accessibility. Those experiencing

[11] https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A32014L0092

lower accessibility to financial services and products consist of physically disabled bank customers, individuals with no internet access, individuals with low digital skill levels and the elderly. The authors consider the decline in accessibility to be a direct consequence of the increasing digitalization of payment services in The Netherlands. Furthermore, the criteria that identifies these individuals is diverse and affects a broad segment of society. Work undertaken by the European Central Bank (2024)[12] has shown that those individuals not having at least one digital payment instrument (e.g. payment cards or accounts) cannot be categorized into a single well-defined group or classification. Indeed, the spectrum of society that does not fully participate in a digitalized financial system is broad and covers younger individuals, urban dwellers, the elderly, those with a low level of financial knowledge, those with low levels of digital skills, etc... The diversity of the affected sociodemographic profiles is considerable and suggests that efforts to address those at risk of a so-called "digital divide" do not conform to a one-size-fits-all solution. It is, however, not possible to adequately address this "digital divide" unless it can be assessed at Member State level. The problem that presents is how to gauge the degree of digital financial inclusion at country level.

Composite indicators (CIs) offer one way to assess cross-country developments in a comparable manner. CIs allow for the evaluation of the performance of a given country in relation to the performance of its peers for a given quantity or performance benchmark. There is a relatively large body of literature on composite indicators. Among some of the more well-known composite indicators are the Human Development Index of Desai [1991], the Sustainable Society Index of de Kerk and Manuel [2008] and the Technology Achievement Index by Desai et al. [2002]. In the context of financial inclusion, many of the composite indicators in the literature have been constructed for developing and emerging

[12]Economic Bulletin, Issue 2 (2024). European Central Bank

economies and focus primarily on financial inclusion in the context of traditional financial services, e.g. Shen et al. [2021].

The determinants of financial inclusion in developing countries can be starkly different than those of advanced economies. For example, the level of financial inclusion in emerging economies is usually measured in terms of fundamental access limitations to basic financial services (i.e. absence of ATMs, inability to open a bank account, etc...). Therefore, composite financial inclusion indicators for developing and emerging economies tend to incorporate indicators of availability of bank/payment accounts, the number of ATMs at a given regional level or the number of mobile money accounts and financial transactions initiated via mobile phone (Sy et al. [2019]; Loukoianova et al. [2019]; Camara and Tuesta [2014]). As we shall argue, the determinants of financial inclusion in advanced economy countries may be significantly different than those of less developed economies.

Although CIs are useful for conveying complex information from a public policy perspective, it is nevertheless clear that in trying to synthesize a multi-faceted phenomenon using a single value, composite indicators may be subject to diverse lines of criticism. These critiques range from the subjectivity of their weighting schemes when fixed weights are used, to the absence of a standard indicator construction methodology. The selection of sub-indicators can also be subject to challenge and criticism. As Cherchye et al. [2007] point out, some of these critiques are fundamental but arise naturally as the result of attempting to depict a multi-faceted and complex set of information in the form of a single indicator. At the same time, part of the attraction of a composite indicator is the aesthetics of presenting a large set of information into a simple and easy-to-communicate format. As Cherchye et al. [2007] argue, however, despite the aforementioned drawbacks, CIs can still be useful for policy evaluation and communication. Composite indicators to benchmark the level of financial inclusion have usually been tailored to developing countries with some examples being given by Al-Smadi [2023], Shen et al. [2021], Banik and Roy [2023], Nguyen [2021], Khera et al. [2022]. In this study, we construct our CIDFP specifically for advanced economy countries in the EU.

3 Methodology for the Construction of the Composite Indicator

With respect to the actual construction of a composite indicator, an array of methodologies can be used. The OECD provides detailed guidance on building composite indicators, including handling data problems, normalization, and weighting, in its handbook (OECD et al. [2008]). Some of the more commonly employed construction methodologies include the assignment of fixed weights to the indicator components, the use of principal component analysis (PCA), data envelopment analysis (DEA) and the Benefit of the Doubt (BoD) approach.

Charnes et al. [1978] were among the first to use DEA as an approach for constructing a composite indicator based on an input-oriented constant returns to scale model. Drawing on Farrell efficiencies (see Farrell [1957], Färe and Zelenyuk [2003]) and the concept of a Decision Making Unit (DMU) with common inputs and outputs, Charnes et al. [1978] proposed a framework for estimating the efficiency of DMUs under which the optimal weighting for each DMU is determined using linear programming. Importantly, the optimization is done using the data for all of the DMUs, with the ranking of one DMU being evaluated relative to all others. The approach therefore avoids having to subjectively assign fixed weights to the various sub-components of a composite indicator. One of the criticisms of the DEA approach is that, in the optimization of DMU efficiency, inputs are not permitted to increase so that only outputs can increase. Therefore, if indicators are present for which a higher value of the indicator corresponds to a worse outcome, these undesirable inputs must be treated as outputs and therefore the DEA model no longer reflects the underlying production process. To address some of the aforementioned issues with DEA, the Benefit of the Doubt (BoD) approach was developed. BoD addresses the input-related issues of DEA by fixing all input values to unity, which effectively amounts to inputs being determined by a central planner. This idea lends well to the concept of Member States determining their own policy objectives as well the EU principle of subsidiarity.

The Benefit of the Doubt (BoD) approach is useful in the EU context particularly in view of the subsidiarity principle. The principle of subsidiarity serves to regulate the exercise of the EU's non-exclusive powers. It rules out EU intervention when an issue can be dealt with effectively at Member State level (i.e. at central, regional or local level). Cherchye et al. [2004] argue that, in the context of a social inclusion index, combining a set of simple indicators into a composite indicator of performance does not have to abandon the principle of subsidiarity. In fact, the use of a composite indicator in the context of subsidiarity can prove to be valuable for policy benchmarking. The use of BoD to construct a composite indicator in the case of the EU allows for taking into account the policy specificities at Member State level. Under the principle of subsidiarity, an endogenous weighting scheme such as BoD that derives indicator weights directly from the data, and therefore accounts for national policy priorities and effects, can be a valuable tool. For example, Ioannou et al. [2008] adopted the Benefit of the Doubt approach to construct an indicator for achievements related to the Lisbon objectives.

The construction of composite indicators using BoD helps to address the problem of combining sub-indicators in the absence of knowledge or any indication of how the sub-indicators should be weighted in order to obtain the final indicator. According to Cherchye et al. [2007], the Benefit of the Doubt approach arises because of the assumption that at least some of the information on how sub-indicators should be aggregated is endogenous in the country-specific data. More specifically, it is thought that with respect to the performance of a country in the context of a given indicator that the better a country performs in that indicator compared to its peers reflects that country's efforts towards, or prioritization of, a certain policy objective. On the other hand, a country that is not as concerned with a given policy objective would be expected to assign less importance to that indicator and therefore perform worse than other countries. This data-driven approach to the weighting of composite indicator sub-components should therefore be viewed in the context of the uncertainty surrounding a weighting scheme.

In practical terms, the BoD approach allows composite indicator weights to vary across countries and objectives through time. As Puyenbroeck [2018] explains, the BoD approach determines weights from the data endogenously through the application of a linear program that maximizes the weights according to an upper bound constraint. Viewed through such a lens, DEA and the BoD approach are linked since the BoD model is effectively an input-oriented constant returns to scale (CRS) formulation of the Charnes et al. [1978] DEA model. However, the key difference is that under BoD, all inputs are set to unit value and the component sub-indicators are considered as the outputs. The BoD model can alternatively be viewed as a formulation under which there is a centralized planner that sets the policy priorities, which in turn correspond to the constituent sub-indicators as the policy objectives. This is, of course, useful in the aforementioned context of the subsidiarity principle of the EU, according to which national authorities may pursue their own tailored policy objectives.

Despite the potential attractiveness of applying the BoD approach in the context of the subsidiarity principle, there are, nevertheless, some shortcomings associated with the basic BoD formulation. As Munda and Nardo [2005] explain, one of the key issues with composite indicators is how the weights on the sub-components are to be interpreted. Specifically, they argue that sub-component weights in a weighted sum of indicator components should be interpreted as substitution rates, implying that the weights should be viewed through the lens of a compensatory relationship or, more simply, as a trade-off rather than as importance coefficients. To avoid the need for this compensatory interpretation, a non-compensatory methodology for the construction of a composite indicator should be used.

Directional distance functions allow for the non-compensatory expansion of desired DMU outputs and the contraction of undesirable DMU inputs allowing the production frontier to be identified. In the context of BoD, the production frontier represents the benchmark for a given DMU's indicator performance. The frontier is such that the distance between each DMU's composite indicator score and the frontier provides a measure of the DMU's efficiency. The relative efficiency of DMUs can then be evaluated in terms of a given DMUs distance from the production frontier. The issue with the directional distance approach is that the directional function is not determined endogenously from the data and has to be set exogenously based on preferences or an intuition regarding the possible directional improvement as explained in Fusco [2015].

In order to avoid having to subjectively identify an improvement direction, we adopt the Multi-directional Benefit-of-the-Doubt (MDBoD) approach developed in Fusco [2023]. Under MDBoD, the direction of improvement is determined directly from the data with improvements in the composite indicator score realized based on input or output excesses rather than improvements in efficiency. Indicator weights and improvement preference directions are determined endogenously from the data, thereby providing improved objectivity in the construction of the indicator. In addition, the MDBoD model imposes non-compensability on the sub-indicators in an objective manner by enhancing the worst performing indicators subject to the condition that a low efficiency in one indicator is not compensated by a high specific efficiency in another indicator. The non-compensability feature of the model allows for the identification of how individual DMUs can improve their composite indicator score without having to make trade-offs across the sub-indicators. More specifically, these improvement directions can provide policymakers with useful information on how a given country can make improvements along specific indicators with a view to improve its standing relative to its peers without having to incur a negative impact on the performance of the other components of their composite indicators.

4 Data and Indicator Selection

Digital financial innovation consists of the provision of digital financial services and products that span a wide range of offerings for investment, payment, insurance and more transparency in the provision or disclosure of financial information, Gomber et al. [2017]. Individuals' adoption of such services will depend on the quality of service, individuals' level of digital skills, broadband penetration, attitudes towards online security and barriers to adoption. We therefore use data collected through the annual EU survey on the use of Information and Communication Technologies (ICT) in households and by individuals, data[13], which is available from Eurostat under the under the "Digital economy and society" statistical theme.

Eurostat's database provides detailed statistics related to digital financial participation at Member State level such as data on the uptake and usage of information and communication technologies (ICT) (including e-commerce, cloud, data analytics, artifi-

[13] `https://ec.europa.eu/eurostat/web/digital-economy-and-society/database/comprehensive-database`

cial intelligence), individuals' digital skills, the level of digitization of businesses (digital intensity index), the size and economic impact of the ICT sector, broadband internet coverage and cybercrime. In terms of their granularity, there is data available for households, individuals, and businesses, the latter collected through the annual EU survey on ICT usage and e-commerce in enterprises, which is part of the European business statistics. The data on households and individuals are collected as part of the social statistics[14]. As the focus of our study is on constructing a composite indicator of individuals' participation in digital finance at Member State level, we restrict the scope of the analysis to those statistics available for households and individuals. These data were collected by Eurostat based on the applicable EU regulations for the different survey years[15]. For households, annual data on internet connections are available, while for individuals a non-exhaustive coverage of the data encompasses a number of relevant areas including internet access and usage, e-commerce activities and e-government activities. Some of the data on individuals is collected at varying frequency, such as every two years and this applies to the privacy and protection of online personal data and data relating to electronic identification.

With respect to granularity, the data coverage includes individuals aged 16 to 74 years and can be broken down by socio-economic variables including different age categories, gender, employment status, country of birth, degree of urbanization, etc.[16] For some countries, but not all, regional breakdowns are available according to the NUTS[17] level 2 statistics. These data are available at national level for all EU Member States, but with

[14] Additional information on the data can be found here: `https://ec.europa.eu/eurostat/web/digital-economy-and-society/information-data`

[15] The relevant implementing and delegating regulations can be found here: `https://ec.europa.eu/eurostat/web/digital-economy-and-society/legislation`

[16] A full description of the data can be found on the Eurostat website. `https://ec.europa.eu/eurostat/web/digital-economy-and-society/database/comprehensive-database`

[17] Nomenclature of territorial units for statistics

some exceptions. The data are released by Eurostat during December of the reference year, having been collected as part of the annual EU survey on the use of ICT in households and by individuals. In the case of the data related to online security concerns, data have not been collected since 2019. Given the relatively infrequent collection of these data, we therefore substitute the missing 2023 values with data for 2019. Any other missing values have been addressed through imputation techniques.

Increased participation in digital finance can be subject to barriers such as privacy related concerns, cybersecurity concerns and other risks related to financial intermediaries' dependency on third-party service providers (see Mhlanga [2020], Pakhnenko et al. [2021]). Based on the availability of indicators in the Eurostat database, we include indicators that capture privacy related concerns in the context of digital financial participation.

The composite indicator of digital financial participation (CIDFP) in this study is an aggregation of seven sub-indicators that, in turn, are themselves constructed from an underlying set of variables so that the composite indicator is assembled in two steps. These seven sub-indicators are not directly observable and are therefore assumed to be latent. The different stages of aggregation allow for drawing potential policy insights at the various levels of indicator aggregation. We propose the following latent sub-indicators to capture the concept of digital financial participation: (i) digital skills, (ii) digital activities, (iii) digital access, (iv) digital device, (v) barriers to digital activity, (vi) security concerns about digital activity and (vii) frequency of digital participation. Similar to Camara and Tuesta [2014] we include both desirable and undesirable indicators as components of the composite indicator. Camara and Tuesta [2014] also construct their financial inclusion index on the basis of sub-indicators that capture the "usage", "barriers" and "access" dimensions, although they do so in the context of traditional financial inclusion[18] rather than digital financial inclusion.

The undesirable indicators are indicative of barriers to digital financial participation and include variables such as high internet equipment costs, lack of sufficient digital skills and other factors as shown in table 1. Those "undesirable" variables for which a higher value results in a lower value of the composite indicator are assumed to have negative polarity. For example, higher values of the barriers indicators result in lower levels of digital financial participation, whereas higher levels of digital skills facilitate participation in digital financial activities and are assumed to have positive polarity.

[18]Traditional financial inclusion in the sense of having access to formal financial services that are not necessarily digital in nature. This form of financial inclusion also encompasses unbanked individuals, the impoverished, those excluded on the basis of geographical distance or those that do not possess adequate documentation that would allow them to open a bank account. Financial inclusion in this context is usually in reference to emerging and developing economy countries.

Sub-indicator	Sub-indicator Component Variables	Eurostat Variable Description	Unit of Measurement	Polarity
Digital Skills	I_DSK2_AB	Individuals with above basic overall digital skills (all five component indicators are at above basic level)	Percent of total individuals	POS
	I_DSK2_B	Individuals with basic overall digital skills (all five component indicators are at basic or above basic level, without being all above basic)	Percent of total individuals	POS
	I_DSK2_LW	Individuals with low overall digital skills (four out of five component indicators are at basic or above basic level)	Percent of total individuals	NEG
	I_DSK2_X	Individuals with no overall digital skills	Percent of total individuals	NEG
Digital Activities	I_ECOM	Internet use: e-commerce activities	Percent of total individual	POS
	I_IUBK	Internet use: Internet banking	Percent of total individuals	POS
	I_IUSELL	Internet use: selling goods or services	Percent of total individuals	POS
	I_IGOVBE	Internet use: request benefits or entitlements (last 12 months)	Percent of total individuals	POS
	I_BFIN_CR	Individuals took a loan or arranged credit from banks or other financial providers over the internet	Percent of total individuals	POS
	I_BFIN_IN	Individuals bought or renewed existing insurance policies, including those offered as a package together with another service (e.g. travel insurance offered together with a plane ticket) over the internet	Percent of total individuals	POS
	I_BFIN_SH	Individuals bought or sold shares, bonds, funds or other investment services over the internet	Percent of total individuals	POS
Digital Access	H_BBFIX	Household internet connection type: fixed broadband	Percent of total households	POS
	H_BBMOB	Household internet connection type: mobile broadband	Percent of total households	POS
Digital Devices	I_IUG_DKPC	Individuals used the internet on a desktop computer	Percent of total individuals	POS
	I_IUG_MP	Individuals used the internet on a mobile phone or smart phone	Percent of total individuals	POS
	I_IUG_TPC	Individuals used the internet on a tablet	Percent of total individuals	POS
	I_IUG_LPC	Individuals used the internet on a laptop	Percent of total individuals	POS
Digital Barriers	H_XACC	Households without access to internet at home, because the access costs are too high (telephone, etc.)	Percent of total households	NEG
	H_XEQU	Households without access to internet at home, because the equipment costs are too high	Percent of total households	NEG
	H_XSEC	Households without access to internet at home, because of privacy or security concerns	Percent of total households	NEG
	H_XSKL	Households without access to internet at home, because of lack of skills	Percent of total households	NEG
	H_XBBNA	Households without access to internet at home, because broadband is not available in the area	Percent of total households	NEG
Digital Security Concerns	I_SBBANK	Security concerns limited or prevented individuals from carrying out internet banking	Percent of total individuals	NEG
	I_SBGOOD	Security concerns limited or prevented individuals from ordering or buying goods or services	Percent of total individuals	NEG
	I_SBGOV	Security concerns limited or prevented individuals from communicating with public services or administrations	Percent of total individuals	NEG
Participation Frequency	I_IDAY	Frequency of internet access: daily	Percent of total individuals	POS
	I_IWK	Frequency of internet access: at least once a week (but not every day)	Percent of total individuals	POS
	I_ILTWK	Frequency of internet access: less than once a week	Percent of total individuals	NEG

Table 1: Variable names and descriptions are from Eurostat. Polarity refers to the manner in which the indicator is interpreted. Variables for which higher values translate into higher values of the composite indicator are assumed to have positive polarity (indicated by "POS" in the table) whereas undesirable indicators are assigned negative polarity ("NEG"). For these indicators a higher value translates into a worse score.

In this study, each of the seven sub-indicators is composed of a set of underlying component variables that have been taken from the Eurostat data. We can use this classification into seven dimensions of digital financial participation as a basis for constructing a set of composite sub-indicators that are computed as follows:

$$
\begin{aligned}
Y_i^{skills} &= \alpha_1 I\_DSK2\_AB + \alpha_2 I\_DSK2\_B + \alpha_3 I\_DSK2\_LW^{(+)} + \alpha_4 I\_DSK2\_X^{(+)} \\
Y_i^{activity} &= \beta_1 I\_ECOM + \beta_2 I\_IUBK + \beta_3 I\_IUSELL + \beta_4 I\_IGOVBE \\
&\quad + \beta_5 I\_BFIN\_CR + \beta_6 I\_BFIN\_IN + \beta_7 I\_BFIN\_SH \\
Y_i^{access} &= \gamma_1 H\_BBFIX + \gamma_2 H\_BBMOB \\
Y_i^{device} &= \theta_1 I\_IUG\_DKPC + \theta_2 I\_IUG\_MP + \theta_3 I\_IUG\_TPC + \theta_4 I\_IUG\_LPC \\
Y_i^{inclusive} &= \mu_1 H\_XACC^{(+)} + \mu_2 H\_XEQU^{(+)} + \mu_3 H\_XSEC^{(+)} \\
&\quad + \mu_4 H\_XSKL^{(+)} + \mu_5 H\_XBBNA^{(+)} \\
Y_i^{permissive} &= \nu_1 I\_SBBANK^{(+)} + \nu_2 I\_SBGOOD^{(+)} + \nu_3 I\_SBGOV^{(+)} \\
Y_i^{freq} &= \psi_1 I\_IDAY + \psi_2 I\_IWK + \psi_3 I\_ILTWK^{(+)}
\end{aligned} \tag{1}
$$

where $\alpha, \beta, \gamma, \theta, \mu, \nu, \psi$ are the weights on the individual component variables that comprise the composite sub-indicator and the superscript $^{(+)}$ indicates variables that have been repolarized, which we explain below. The construction of the sub-indicators requires the determination of the weights in equation 1. For each sub-indicator, the underlying component variables are shown for the 27 Member States of the EU and they are grouped along the seven dimensions of digital financial participation used in the construction of the composite indicator. To construct the composite indicator, the full set of weights $(\alpha, \beta, \gamma, \theta, \mu, \nu, \psi)$ has to be computed from the data.

The **skills sub-indicator** consists of four variables that gauge individuals' level of digital skills according to above basic, basic, low and no digital skills[19]. Having no digital skills or a low level of digital skills is considered to be undesirable in terms of the construction of the composite indicator.

The **activity sub-indicator** consists of different digital financial activities measured as the percentage of total individuals that engaged in these activities during the last year (i.e. 2023). Digital financial activity encompasses a wide range of digital financial participation including internet banking, e-commerce, government benefits/entitlement applications, etc...

The **access sub-indicator** is intended to assess the penetration of digital financial infrastructure in a given country as the percentage of total households having either a fixed broadband or mobile broadband internet connection. Given the limited access modalities, this sub-indicator is constructed only from two underlying variables.

The **device sub-indicator** captures the different devices used by individuals to access the internet and captures usage of desktop PCs, mobile phones, tablet devices and laptop PCs. The preference for devices used to access the internet vary across Member States and can be related to factors such as cost factors and internet access infrastructure.

[19] According to Eurostat: "*Digital skills indicators are composite indicators which are based on selected activities related to internet or software use performed by individuals aged 16-74 in four specific areas (information, communication, problem solving, software skills). It is assumed that individuals having performed certain activities have the corresponding skills. Therefore the indicators can be considered as proxy of the digital competences and skills of individuals. According to the variety or complexity of activities performed, two levels of skills ("basic" and "above basic") are computed for each of the four dimensions. Finally, based on the component indicators, an overall digital skills indicator is calculated as a proxy of the digital competences and skills of individuals ("no skills", "low", "basic" or "above basic")".*
The criteria that determine individuals' level of digital skills is given by Eurostat here: `https://ec.europa.eu/eurostat/cache/metadata/en/isoc_sk_dskl_i_esmsip2.htm`

The **frequency sub-indicator** provides a measure of how often individuals access the internet ranging from daily, to weekly to less than once per week. This indicator acts as a proxy for the frequency of digital financial participation. We consider lower levels of frequency (i.e. less than once per week) to be undesirable from a participation perspective.

The remaining two sub-indicators, namely **digital security concerns** and **digital barriers**, are also considered as undesirable indicators since higher values of these sub-indicators represent a worse outcome from the point of view of digital financial participation. With respect to the composite indicator construction, we consider these undesirable indicators to have negative polarity and therefore these variables will need to be transformed to have positive polarity in order to be incorporated into the final indicator.

There is considerable heterogeneity in the levels across EU Member States. With respect to the digital skills sub-indicator The Netherlands, Finland and Ireland stand out as having high levels of above average digital skills while countries with elevated levels of individuals with no digital skills include Romania, Bulgaria and Italy.

For the digital financial activities sub-indicator, there is substantial variation in the percentage of total individuals that engage in the different activities, suggesting that a diverse array of factors may determine digital financial behaviour at national level. In broad terms, across EU Member States there tends to be higher levels of internet banking and e-commerce and considerably lower levels of online applications for credit and insurance as well as trading of shares. The different levels of activity at Member State level are likely to reflect underlying idiosyncratic factors such as digital skill levels, national banking system structure, availability of these services and other socioeconomic factors like wealth levels. However, a study of the underlying determining factors at Member State level extends beyond the scope of the current study.

For the device sub-indicator, there is a fairly consistent pattern across EU countries with mobile phones being the primary device used by individuals to access the internet, followed by laptop computers. Desktop computers and tablet devices tend to be less utilized.

In terms of the infrastructure used by households to access the internet, fixed broadband is the most common access modality across Member States, but in some cases mobile broadband dominates. These differences may, in part, be explained by factors such as fixed and mobile broadband penetration rates as well as cost-related factors and geographical reasons (i.e. the proportion of households located in urban vs. rural areas). Figures 1 through 7 illustrate the underlying variables across the EU Member States.

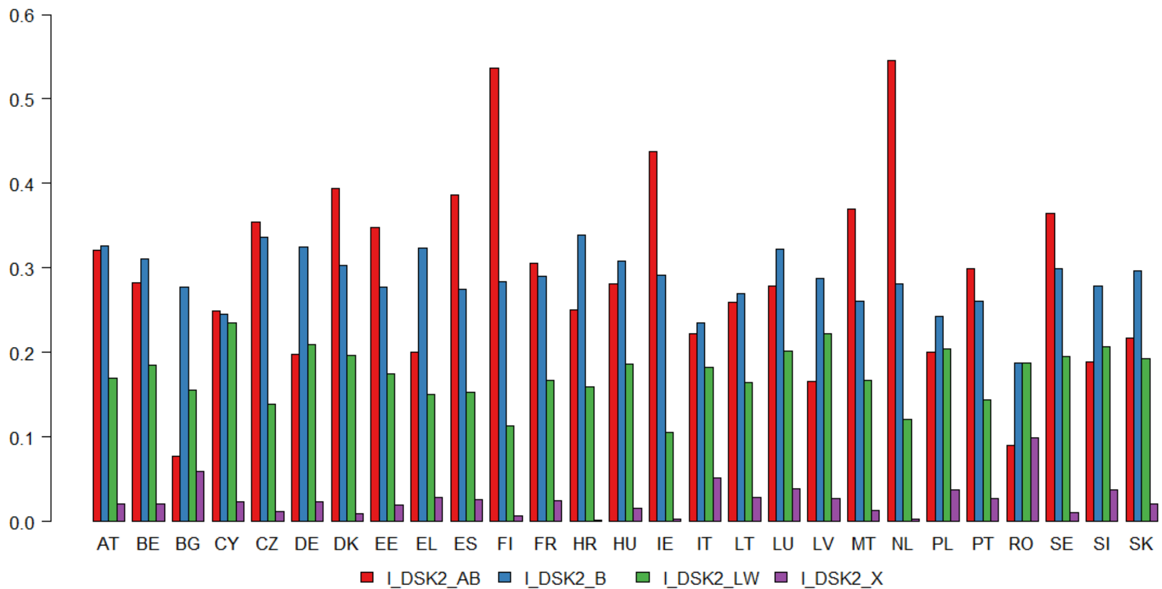


Figure 1: Digital skills sub-indicator - components

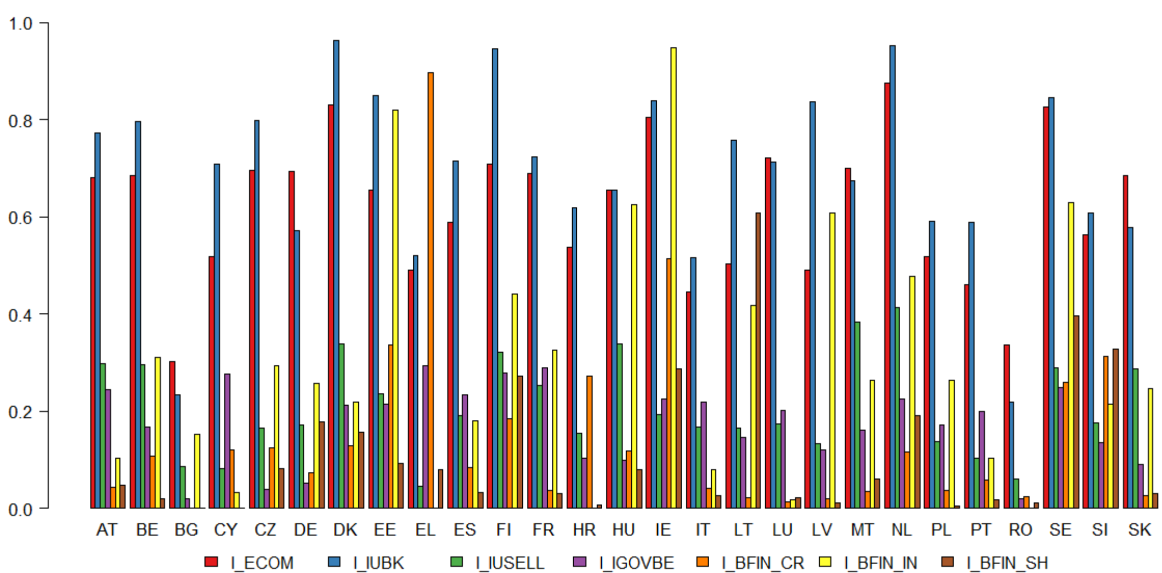


Figure 2: Digital financial activities sub-indicator - components

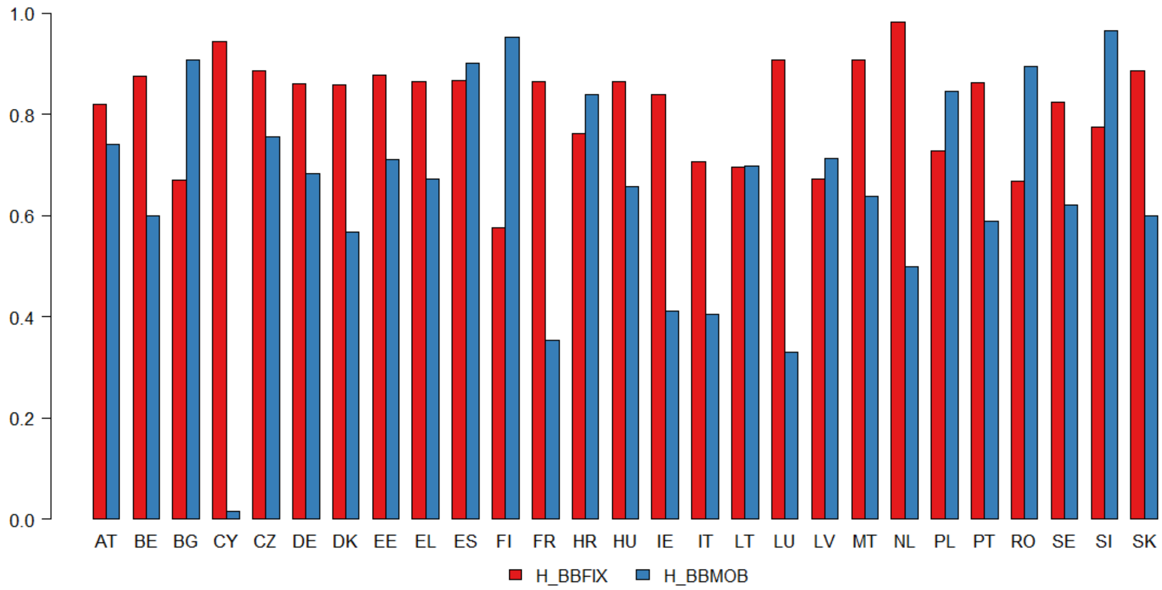


Figure 3: Digital access sub-indicator - components

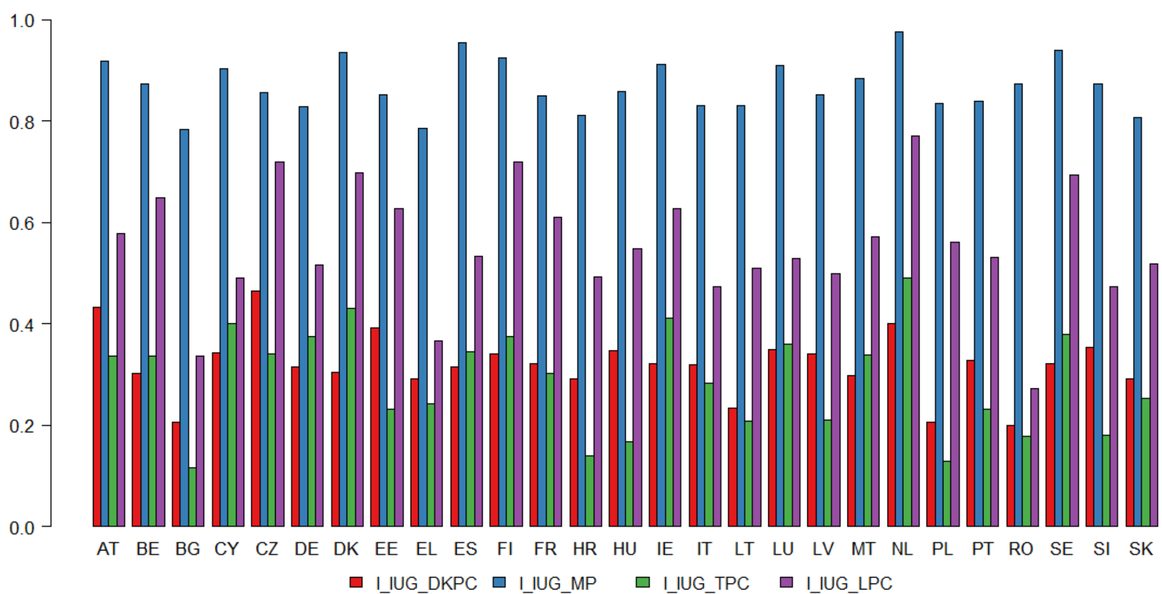


Figure 4: Digital device used for access sub-indicator - components

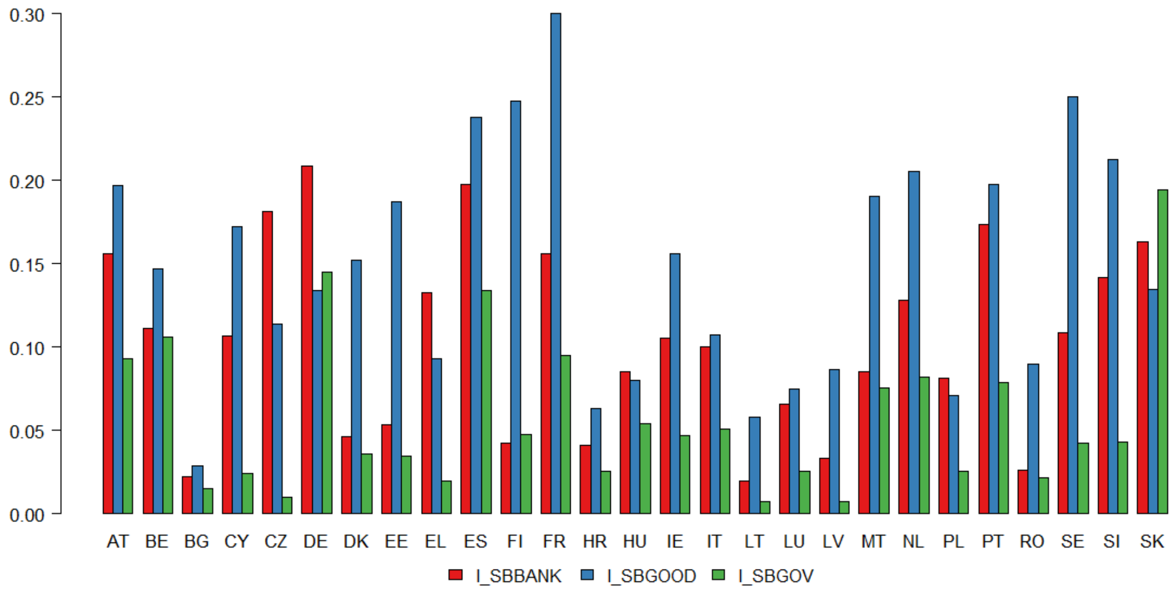


Figure 5: Digital security concerns sub-indicator - components

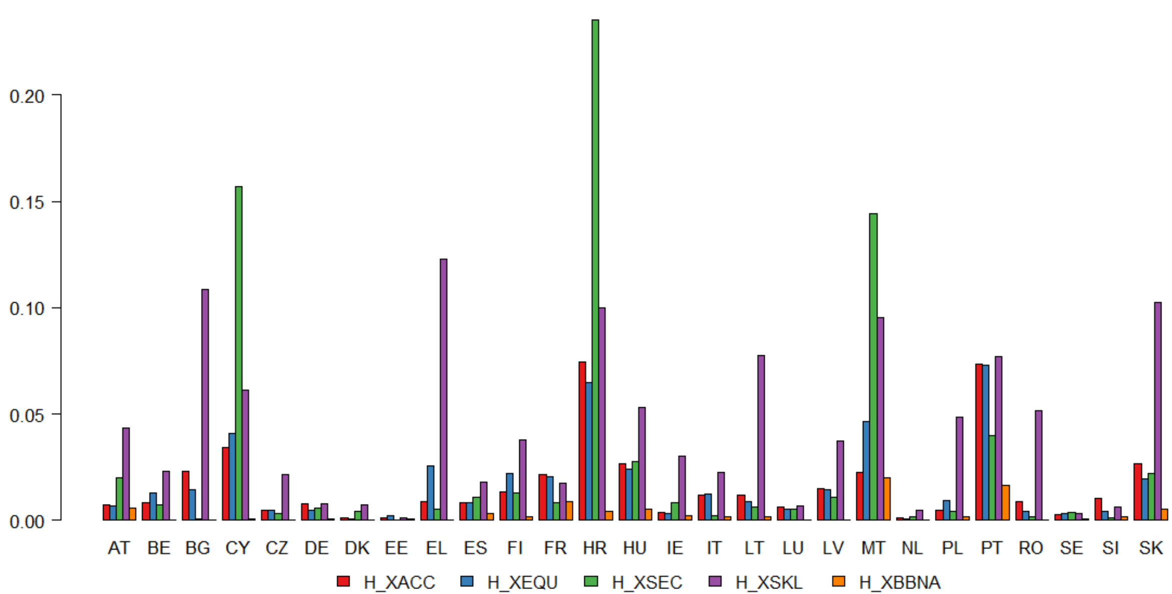


Figure 6: Barriers to digital financial participation sub-indicator - components

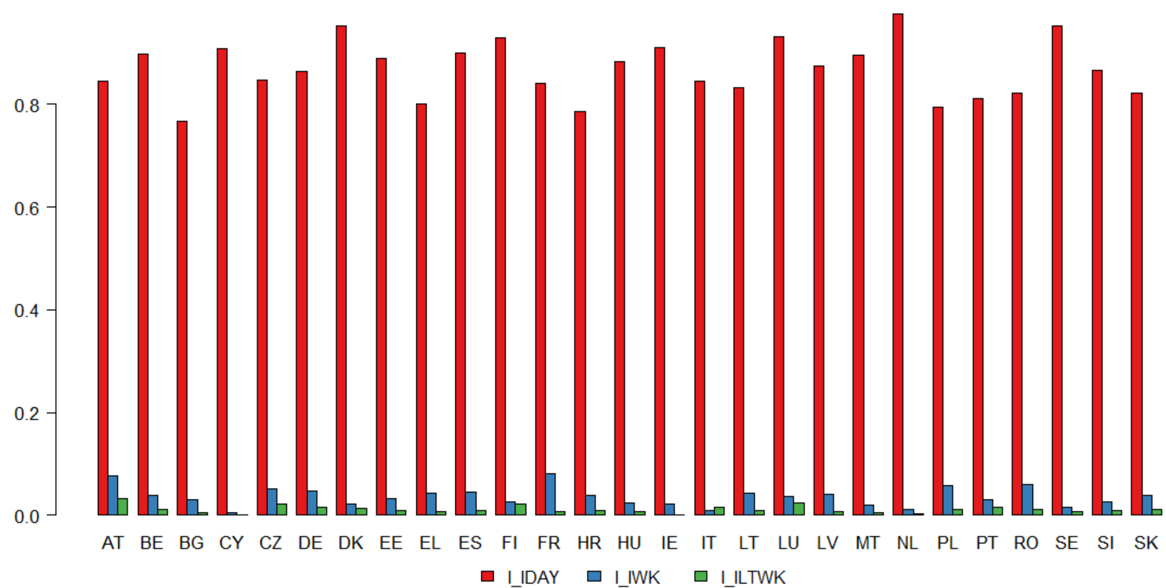


Figure 7: Frequency of digital financial participation sub-indicator - components

The two remaining sub-indicators, *barriers* and *security*, and their components warrant further discussion. Given that higher values of these indicators represent a worse outcome in terms of digital financial participation, they are considered undesirable indicators. In order to incorporate them into the construction of the composite indicator of digital financial participation, they need to be normalized using a min-max procedure for negative polarity variables. Specifically, the normalization that is applied to variables with negative polarity leads to a new variable[20] with positive polarity, $\hat{\theta}$. The transform that results in the new variable with positive polarity is given by:

$$\hat{\theta} = \frac{max(x) - x}{max(x) - min(x)} \tag{2}$$

The transformation of the variables in the *barriers* category has an interpretation that is relevant for assessing digital financial participation. When the *barriers* variables are transformed to have positive polarity, they can be interpreted as a measure of the degree of digital inclusiveness at Member State level.

Figures 8 and 9 show the re-polarized barriers and security concerns variables, respectively. We term these repolarized variables "digital inclusivity" and "security permissiveness". In the case of the inclusivity measure, the elevated levels across the majority of EU Member States suggest that, at least according to this measure, there is already a high degree of digital inclusiveness at EU level.

[20]For countries that have the maximum value in the data set, the numerator of this expression becomes zero. In the construction of the composite indicator, this can lead to undefined values resulting from a division by zero. We therefore follow the common approach in the literature which is to replace the zero values by a small, but finite, number. In this study, zeros are replaced by a value of 0.01 following Fusco [2023].

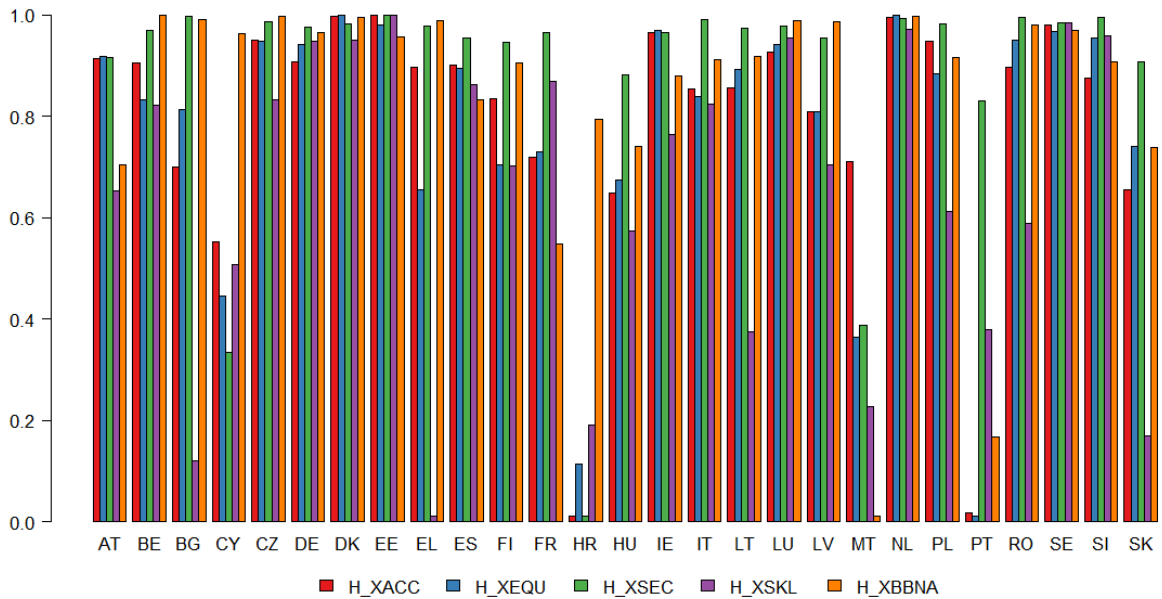


Figure 8: Repolarized "*Barriers*" or "*Digital Inclusivity*" composite sub-indicator variables

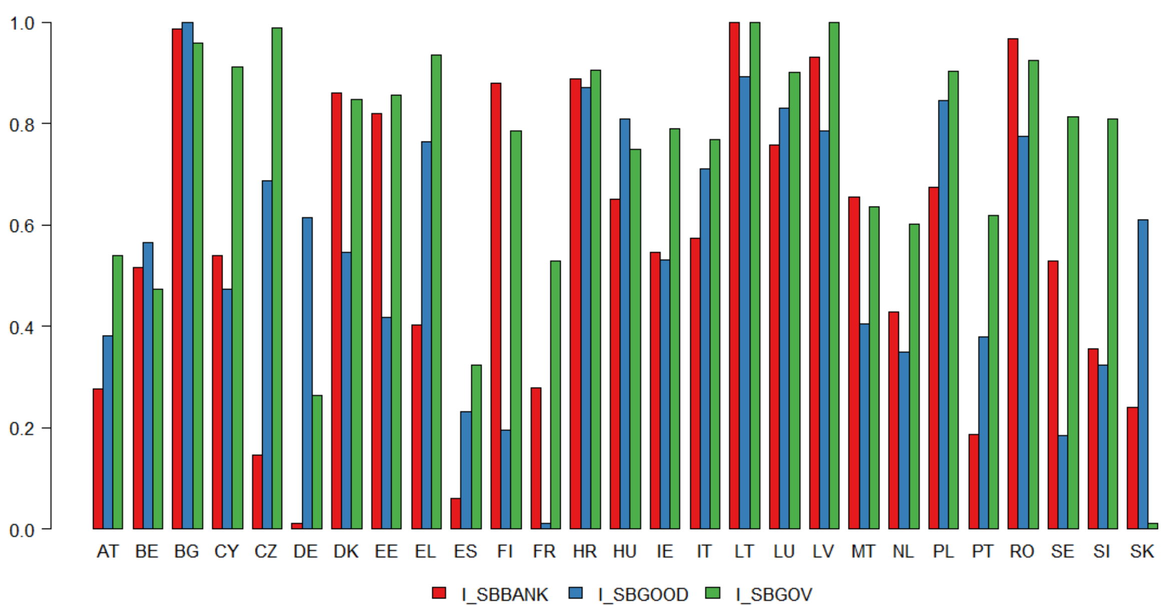


Figure 9: Repolarized "*Security Concerns*" or "*Security Permissiveness*" composite sub-indicator variables

5 Models

5.1 Composite Indicator using Two-stage Principal Component Analysis (PCA)

The Composite Indicator of Digital Financial Participation (CIDFP) can be constructed using Principal Component Analysis (PCA). PCA is a technique that reduces the dimensionality of the original data through the creation of a new variable that is a linear combination of the original variables. The new variables, the principal components, are constructed such that they explain the maximum amount of variance of the original data. PCA is a useful method for constructing a composite indicator given that the output of the analysis, including the rotation vector and the eigendecomposition of the covariance matrix of the original data, provide the weights for combining the individual sub-indicators into the final composite indicator.

PCA provides two outputs that can be used to construct the composite indicator of digital financial participation. The first is the rotation matrix, which is the matrix of eigenvectors that give the directions of maximum variance of the original data. The second output that can be used to construct the composite indicator are the standard deviations of the principal components that can be obtained as the square roots of the eigenvalues of the covariance matrix. It is these eigenvalues that can be used in the calculation of the weights for the composite indicator components.

In the context of this study, the eigenvalues can be thought of as providing an indication of the degree of importance of the data in determining digital financial participation. More formally, the weights of the i^{th} sub-indicator of the composite indicator are determined as:

$$w_i = \frac{\sum_{j=1}^{p} L_{i,j}\lambda_j}{\sum_{j=1}^{p} \lambda_j} \tag{3}$$

Where p is the number of variables (or sub-indicators in the case where the final composite indicator is to be constructed) that are used to construct the sub-indicator, λ_j is the eigenvalue of the j^{th} factor and L_{ij} is the matrix of loadings (i.e. the matrix whose columns contain the eigenvectors).

For the first step of the two-stage PCA approach, the equation for the computation of the sub-indicators follows from equations 1 and 3 and is:

$$Y_i^u = \frac{\sum_{j,k=1}^{p} \lambda_j^u P_{ki}^u}{\sum_{j=1}^{p} \lambda_j^u} \tag{4}$$

$$P_k = X\lambda_j \tag{5}$$

where λ_j is the proportion of the variance (i.e. the eigenvalue) explained by the k^{th} principal component, u is a placeholder for the sub-indicator (i.e. "skills", "activity", etc...) and X is the matrix of variables (as presented in table 1).

The two-step approach to constructing composite indicators has been used by other authors such as Camara and Tuesta [2014], where a two-step PCA approach is used and Freudenberg [2003]. Under the two-step PCA approach, once the sub-indicators are computed through a linear combination of the weighted component variables, the overall composite indicator is subsequently constructed by applying the same approach to the sub-indicators in a second iteration. The result of this final step provides the Composite Indicator of Digital Financial Participation (CIDFP) for country i, which is computed according to:

$$CIDFP_i = \frac{\sum_{j=1}^{7} \lambda_j \left(\phi_{j1} Y_i^{subindic1} + \ldots + \phi_{j7} Y_i^{subindic7} \right)}{\sum_{j=1}^{7} \lambda_j} \tag{6}$$

where ϕ_{jk} are the weights of the composite sub-indicators that result from the application of the first step of the PCA analysis and $subindic_1 \ldots subindic_7$ are the composite sub-indicators for *skills*, *activity*, *access*, *device*, *security* (*permissiveness*), *barriers* (*inclusivity*) and $frequency$.

5.2 Composite Indicator using the Multidirectional Benefit of the Doubt (MDBoD) Approach

In addition to the two-stage PCA approach, we also construct the CIDFP using a completely separate method based on Data Envelopment Analysis (DEA). DEA is a technique that is frequently used in the development of composite indicators (CIs). Charnes et al. [1978] were among the first to use DEA as an approach for constructing a composite indicator based on weights that are endogenously determined from the data. The DEA approach consists of assigning an efficiency measure to a so-called Decision Making Unit (DMU), which in our context is an individual EU Member State. From an economic perspective, the efficiency of each DMU is obtained through the maximization of a ratio of weighted inputs to weighted outputs. The efficiency measure is subject to the condition that it be bounded on the interval $[0, 1]$, zero denoting absolute inefficiency and unity denoting perfect efficiency in transforming inputs into outputs.

Data Envelopment Analysis and the Benefit of the Doubt approach may require imposing constraints on the weights of the simple indicators, either in the form of upper or lower bounds. However, in the absence of clear policy priorities or other criteria that could be used to justify the weight constraints, the selection of weights can be subjective and, in a worst case scenario, entirely arbitrary. Naturally, the choice of weights has a significant impact on the resulting composite indicator, Fusco [2023]. Given that under the principle of subsidiarity, EU Member States are able to fix their own policy objectives and that various idiosyncratic factors may determine countries' priorities with respect to promoting participation in digital financial activities, it would be preferable to dispense with the need for weights altogether and to use a technique that aggregates the simple indicators into a composite indicator without requiring assumptions on the weighting. For these reasons, we adopt the Multidirectional Benefit of the Doubt (MDBoD) approach of Fusco [2023].

MDBoD is a frontier-based method which separates the selection of a benchmark from the determination of the measure of efficiency. It differs from other directional BoD approaches in that the improvement directions of the simple indicators are determined endogenously from the data rather than from the imposition of subjective improvement directions by a policymaker. For each simple indicator, the MDBoD approach seeks to determine the maximum increase required to reach the frontier. The expansion to the frontier is done without increasing the other indicators and therefore is done under non-compensability. Similar to BoD, to reach the frontier, the maximum possible increase in the simple indicators is determined by solving a linear program for each indicator. The benchmark DMU is also determined from an integer program and the solution gives a quantity that is tantamount to the technical inefficiency measure under DEA. This latter quantity can be used to calculate the relative multi-directional specific efficiency for a given simple indicator. The relative multidirectional efficiency is given by:

$$e_h^o = \frac{I_h^o}{I_h^o + \beta_o^* \left(\hat{I}_h^o - I_h^o \right)} \tag{7}$$

Following the explanation in Fusco [2023], the efficiency is interpreted as an expansion potential, such that the amount by which observation o could expand the h^{th} indicator in order to be as efficient as the benchmark, S_o^{PI} and is equal to $1 - e_h^o$. The actual MDBoD composite indicator is calculated (see Fusco [2023]) according to:

$$CI_{MDBoD} = 1 - \frac{\beta_o^* \sum_{h=1}^{K} \left(\hat{I}_h^o - I_h^o \right)}{\sum_{h=1}^{K} I_h^o + \beta_o^* \left(\hat{I}_h^o - I_h^o \right)} \tag{8}$$

Where $\hat{I}^o$ is the ideal reference point over $h = 1, ..., K$ indicators. The denominator of equation 8 gives the benchmark DMU selection, S_o^{PI}, where $S_o^{PI} = I_h^o + \beta_o^* \left(\hat{I}_h^o - I_h^o \right)$. Notably, o is on the efficient frontier, or as Fusco [2023] terms it, the frontier of best practices, when $\beta_o^* = 0$. β_o is defined on $[0, 1]$ and represents the proportion according to which each indicator is added in order to reach the frontier. A full exposition of MDBoD is given in Fusco [2023].

In terms of indicator construction, the MDBoD approach allows for the overall composite indicator scores to differ from the scores of the individual simple indicator efficiencies. This is not the case in other benefit of the doubt approaches where the indicator efficiencies and the composite scores are equal because they are based on an implicit benchmarking. As a result, based on the individual simple indicator scores, it is possible to determine which sub-indicators can be improved in order to increase the overall composite indicator score for a given Member State. The ability to identify localized targets for improvement, which are also objectively determined from the data, is a useful tool from a policy perspective.

To construct the composite indicator of digital financial participation using MDBoD, an approach similar to that used for the PCA indicator is adopted. First the seven composite sub-indicators are constructed from the same set of constituent variables using MDBoD. Constructing the sub-indicators on an individual basis also allows for identifying potential directional improvements in the sub-indicators, thereby providing potentially useful policy insights into how to improve individuals' participation in digital finance along different dimensions. For example, for the digital skills sub-indicator, the MDBoD directional improvement scores can provide insights into how to best target improvements in skill levels in order for a country to move its composite indicator score closer to that of the benchmark country. In the context of MDBoD, the directional improvement scores show how an individual country can improve upon the areas of worst performance without compensating by decreasing the performance of a more efficient and highly performing indicator.

The interest in applying MDBoD, beyond a robustness check on the two-stage PCA approach, is that it can provide targeted indications of the policy actions that can be taken at country level in order to increase a Member State's composite indicator performance relative to its peers.

6 Results

6.1 Two-Stage PCA Results

Two-stage principal component analysis (PCA) was used to construct the seven sub-indicators presented in the first column of table 1. The first step of the PCA analysis was applied to construct the individual composite sub-indicators for *skills*, *activity*, *access*, *device*, *barriers/inclusivity*, *security/permissiveness* and $frequency$ from their underlying component variables as listed in the second column of table 1.

Table 2 shows the principal components for the positive polarity and negative polarity sub-indicator variables that result from the first stage of the PCA approach. For both the positive and negative polarity variables, the first two principal components generally explain over 95% of the total variance of the original data. However, in the case of the $Y^{activity}$ composite sub-indicator, three principal components explain over 95% of the variance.

Princ. Comp.	Cum. Var. Explained
Positive Polarity Indicators	
Y^{Skills}	
PC_1	0.9423
PC_2	0.9785
PC_3	0.9958
PC_4	1
$Y^{Activity}$	
PC_1	0.8673
PC_2	0.9160
PC_3	0.9537
PC_4	0.9721
PC_5	0.9866
PC_6	0.9962
PC_7	1
Y^{Access}	
PC_1	0.9074
PC_2	1
Y^{Device}	
PC_1	0.9344
PC_2	0.9686
PC_3	0.9854
PC_4	1
$Y^{Frequency}$	
PC_1	0.8633
PC_2	0.9518
PC_3	1
Negative Polarity Indicators	
$Y^{Permissiveness}$	
PC_1	0.9495
PC_2	0.9792
PC_3	1
$Y^{Inclusivity}$	
PC_1	0.9672
PC_2	0.9827
PC_3	0.9929
PC_4	0.9989
PC_5	1

Table 2: Cumulative variance explained by the principal components for the positive and negative polarity composite sub-indicators.

Tables 3 and 4 show the corresponding principal components for the composite sub-indicators. For the Y^{skills} sub-indicator, the values for the principal components are relatively evenly distributed across all the skill level variables, but "no skills" (I_DSK2_X) has a higher contribution suggesting that "no skills" is particularly relevant for the sub-indicator. The second principal component is indicative of a relatively high contribution from the "low-skills" variable (I_DSK2_LW). Overall, the distribution of the principal components suggests there is additional relevance related to the low- and no-skilled individuals, which illustrates their importance from a digital inclusivity perspective. Alternatively stated, having a higher proportion of individuals with low to no digital skills is detrimental for digital financial participation.

For the $Y^{activity}$ sub-indicator, the first principal components for I_ECOM, I_IUBK, I_IUSELL and I_IGOVBE are relatively uniformly distributed. Online banking (I_IUBK) has the largest principal component value in absolute magnitude. On the other hand, the contributions from I_BFIN_CR, I_BFIN_IN and I_BFIN_SH are rather small suggesting that the first principal component is related to more traditional financial activities rather than more specialized online activities like online credit and insurance applications and online trading. The second principal component is strongly associated with individuals online government benefit applications (I_IGOVBE) and is therefore likely related to online public services. The third principal component seems to captures the niche online activities (i.e. I_BFIN_CR, I_BFIN_IN and I_BFIN_SH) that were not strongly associated with the first principal component.

The principal component values for the Y^{access} composite sub-indicator reflect the choice between access via fixed broadband infrastructure and mobile broadband infrastructure with the first principal component being associated more strongly with broadband mobile access and the second with fixed broadband access.

For the Y^{device} composite sub-indicator, the values of the first principal component are relatively equally distributed across the different device-related variables, with the highest value associated with laptop computer access (I_IUG_LPC). The highest value in absolute magnitude for the second principal component is associated with desktop PC access (I_IUG_DKPC) and mobile phone access (I_IUG_MP). The higher values for these latter values in the second principal component suggest that desktop PCs and mobile phones have stronger explanatory power in measuring access modalities as they contribute disproportionately more information through the second principal component compared to other components.

The principal components of the Y^{freq} composite sub-indicator are uniformly distributed across the daily and weekly access frequencies but with a noticeably larger contribution from I_ILTWK. Recall, however, that this latter variable has been repolarized and therefore a higher value is associated with more frequent access, suggesting that individuals access the internet on a very frequent basis. The values for the second principal component support this interpretation with the component values for daily and weekly frequency being relatively large.

Table 4 provides the principal component values for the negative polarity indicators. The $Y^{permissiveness}$ and $Y^{inclusivity}$ composite sub-indicators demonstrate a relatively uniform distribution of values for the first principal component, which suggests that the first principal component captures the fundamental nature of these sub-indicators. In the case of the *permissiveness* sub-indicator, the second principal component has a high value for security permissiveness related to online goods purchases (i.e. I_SBGOOD) and therefore online security permissiveness seems to play an important role in relation to digital financial participation.

In the case of the $Y^{inclusivity}$ composite sub-indicator, again, there is a relatively uniform distribution of the first principal component across the variables. However, the second component is strongly associated with households' barriers to online access due to low digital skill levels, while the third component primarily captures households' barriers resulting from the unavailability of broadband access as well as security concerns. Therefore lack of necessary skill, as well as security concerns and access availability play important roles in determining inclusivity. As these indicators are repolarized, the interpretation is that the lower the number of individuals with poor digital skills, the greater the level of the digital inclusivity composite sub-indicator.

Having computed the principal components for each of the seven composite sub-indicators, equations 1, 3 and 4 can be used to construct the sub-indicators. The weights on the sub-indicator component variables, computed according to equation 3, are shown in the far right-hand columns of tables 3 and 4.

Variable	PC_1	PC_2	PC_3	PC_4	PC_5	PC_6	PC_7	weight
Y^{Skills}								
I_DSK2_AB	-0.3949	-0.4426	-0.5966	0.5406	-	-	-	*0.2131*
I_DSK2_B	-0.5395	0.5877	0.3596	0.4840	-	-	-	*0.2576*
I_DSK2_LW	-0.4038	-0.6495	0.6400	-0.1303	-	-	-	*0.2118*
I_DSK2_X	-0.6245	0.1921	-0.3414	-0.6757	-	-	-	***0.3175***
$Y^{Activity}$								
I_ECOM	-0.4702	-0.1915	0.1617	0.0416	0.4204	-0.2771	0.6788	*0.1884*
I_IUBK	-0.5312	-0.0252	0.0482	-0.0007	-0.2156	-0.6366	-0.5129	***0.2196***
I_IUSELL	-0.3880	-0.3853	0.3977	-0.0819	0.2302	0.5889	-0.3693	*0.1558*
I_IGOVBE	-0.4709	0.7114	0.0912	-0.1214	-0.3248	0.3254	0.1942	*0.1741*
I_BFIN_CR	-0.1359	0.3744	-0.4517	0.3322	0.6642	0.0685	-0.2848	*0.0472*
I_BFIN_IN	-0.2782	-0.3664	-0.4885	0.5461	-0.4189	0.2360	0.1426	*0.1262*
I_BFIN_SH	-0.1689	-0.1838	-0.6020	-0.7538	0.0400	0.0701	0.0246	*0.0888*
Y^{Access}								
H_BBFIX	-0.6634	-0.7483	-	-	-	-	-	***0.5208***
H_BBMOB	-0.7483	0.6634	-	-	-	-	-	*0.4792*
Y^{Device}								
I_IUG_DKPC	-0.4605	-0.6824	0.5550	0.1191	-	-	-	*0.2381*
I_IUG_MP	-0.4737	0.5629	0.1577	0.6586	-	-	-	*0.2212*
I_IUG_TPC	-0.4928	0.3901	0.2302	-0.7430	-	-	-	*0.2443*
I_IUG_LPC	-0.5662	-0.2554	-0.7837	-0.0013	-	-	-	***0.2964***
Y^{Freq}								
I_IDAY	-0.5331	0.5373	0.6535	-	-	-	-	*0.2607*
I_IWK	-0.4269	-0.8377	0.3405	-	-	-	-	*0.2915*
I_ILTWK	-0.7305	0.0975	-0.6760	-	-	-	-	***0.4478***

Table 3: Principal components of the positive polarity composite sub-indicators and their respective weights in the final composite indicator.

Variable	PC_1	PC_2	PC_3	PC_4	PC_5	PC_6	PC_7	weight
$Y^{Permissiveness}$								
I_SBBANK	-0.5370	0.4994	0.6799	-	-	-	-	*0.2946*
I_SBGOOD	-0.5168	-0.8317	0.2028	-	-	-	-	*0.3131*
I_SBGOV	-0.6667	0.2425	-0.7047	-	-	-	-	***0.3923***
$Y^{Inclusivity}$								
H_XACC	-0.4498	0.0528	-0.2513	-0.6196	0.5898	-	-	*0.2040*
H_XEQU	-0.4434	0.0343	-0.1030	-0.3927	-0.7981	-	-	*0.2009*
H_XSEC	-0.4920	0.1660	-0.5664	0.6388	0.0396	-	-	***0.2203***
H_XSKL	-0.3728	-0.8792	0.2453	0.1551	0.0617	-	-	*0.1719*
H_XBBNA	-0.4685	0.4422	0.7384	0.1729	0.0993	-	-	*0.2029*

Table 4: Principal components of the negative polarity composite sub-indicators and their respective weights in the final composite indicator.

Figures 10 through 16 show the composite sub-indicators resulting from the application of the first stage of the PCA analysis. The composite sub-indicator for **digital skills** shows important variation across EU Member States with around four countries (CZ, FI, IE and NL) having elevated scores and around seven countries with relatively lower scores (BG, CY, IT, LV, PL, RO and SI). The remaining countries' scores lie in the middle of the distribution. Luxembourg's digital skills composite sub-indicator shows that the component representing individuals with basic digital skills accounts for the majority of the indicator value, but a relatively low portion of the overall value associated with individuals having no digital skills (*I_DSK2_X*) as well as individuals with low digital skills (*I_DSK2_LW*). Recall that these variables are considered undesirable and have been repolarized. Therefore increasing their contribution is tantamount to decreasing the number of low and no-digitally skilled individuals, suggesting that policies directly targetting improving digital skills in these individuals could help increase Luxembourg's Y^{skills} sub-indicator[21].

The composite sub-indicator for **digital activities** shows a higher degree of variation across countries with DK, EE, FI, IE, NL and SE displaying elevated scores and BG and RO with lower overall scores than their peer countries. Luxembourg ranks near the middle of the distribution of the indicator with internet banking (*I_IUBK*) and e-commerce (*I_ECOM*) accounting for more than 50% of Luxembourg's composite indicator value. In-

[21] The Luxembourg government has launched a National Action Plan for digital inclusion targeted towards all citizens: `https://gouvernement.lu/en/dossiers.gouv_mindigital%2Ben%2Bdossiers%2B2022%2Binitiatives-inclusion-numerique.html#bloub-3` and `https://mindigital.gouvernement.lu/fr/publications/document-de-reference/panin-2021.html` (in French). This conclusion is also in line with Luxembourg's 2023 Digital Decade report `https://digital-strategy.ec.europa.eu/en/library/2023-report-state-digital-decade`, which states that "*Luxembourg should continue implementing its policies in the area of digital skills. In particular, Luxembourg should encourage employers to strengthen the digital skills of employees (public and private) and workforce participation in digital training.*"

dividuals' online applications for government benefits (*I_IGOVBE*) also contributes quite importantly towards the indicator score. Luxembourg shows very low contributions from online share purchases (*I_BFIN_SH*), online applications for credit (*I_BFIN_CR*) and online selling activities (*I_IUSELL*) suggesting that a higher level of activity in these areas would serve to increase Luxembourg's *activity* score closer to the benchmark value of the CIDFP.

The composite indicator of **digital access** shown in figure 12 provides a measure of the degree of penetration and availability of internet broadband infrastructure either through a fixed or mobile internet connection. Overall, Italy (IT) scores low compared to its EU Member State peers, while Spain (ES) scores the highest out of all EU Member State countries and has a relatively equal contribution towards its composite sub-indicator score from both fixed and mobile broadband. As for Luxembourg, the value of the composite sub-indicator is dominated by broadband fixed access (*H_BBFIX*) with mobile internet access (*H_BBMOB*) only accounting for a relatively small proportion of the total sub-indicator. Improving mobile broadband infrastructure in Luxembourg could therefore address the lower contribution of this indicator[22].

The **digital device** composite sub-indicator is based on the modality that individuals rely on for internet access including the use of a desktop computer, mobile/smartphone, tablet devices and laptop computers. We used different categories of devices to capture both the fixed and mobile elements of internet access with desktop computers being a strictly fixed modality of access and mobile/smartphones capturing the mobile access

[22]This conclusion is in line with the Luxembourg country report in the context of the Digital Decade. In particular, the 2023 report concludes that "*Luxembourg should continue implementing its policies on digital infrastructure. In particular, it could take additional measures to incentivise the take-up of gigabit and 5G connectivity and continue efforts on the roll-out of gigabit connectivity, in particular streamlining the permit procedures and facilitating access to public property to extend fixed and densify mobile networks.*".

element to the maximum extent possible. As figure 13 shows, the device-related composite sub-indicator scores vary significantly across EU Member States. The Netherlands (NL) stands out above its EU peers with a *device* composite sub-indicator score of unity and a relatively uniform contribution to the overall indicator from the sub-components. The remaining EU countries all score below 0.8, with Bulgaria (BG) and Romania (RO) having scores much lower than other EU countries. Other low-scoring countries include Greece (EL), Croatia (HR), Lithuania (LT) and Poland (PL). For Luxembourg, the indicator value is composed of a relatively equal partition of the different device types.

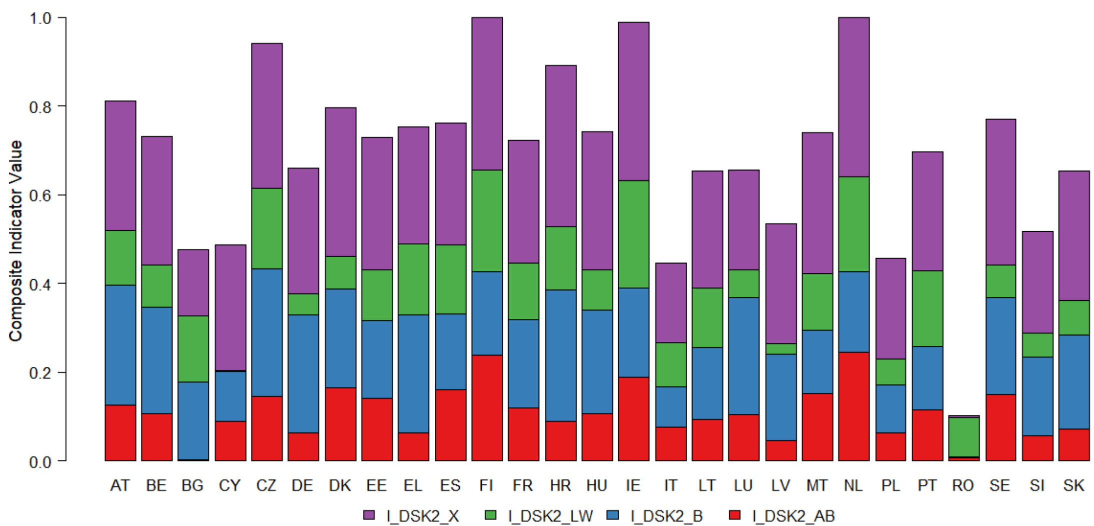


Figure 10: Digital Skills composite sub-indicator using PCA

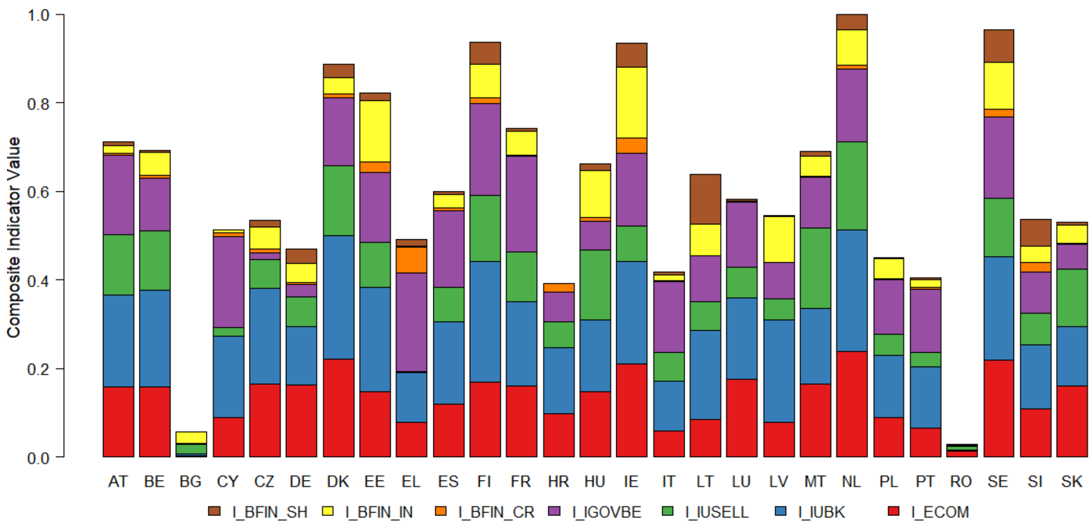


Figure 11: Digital Activity composite sub-indicator using PCA

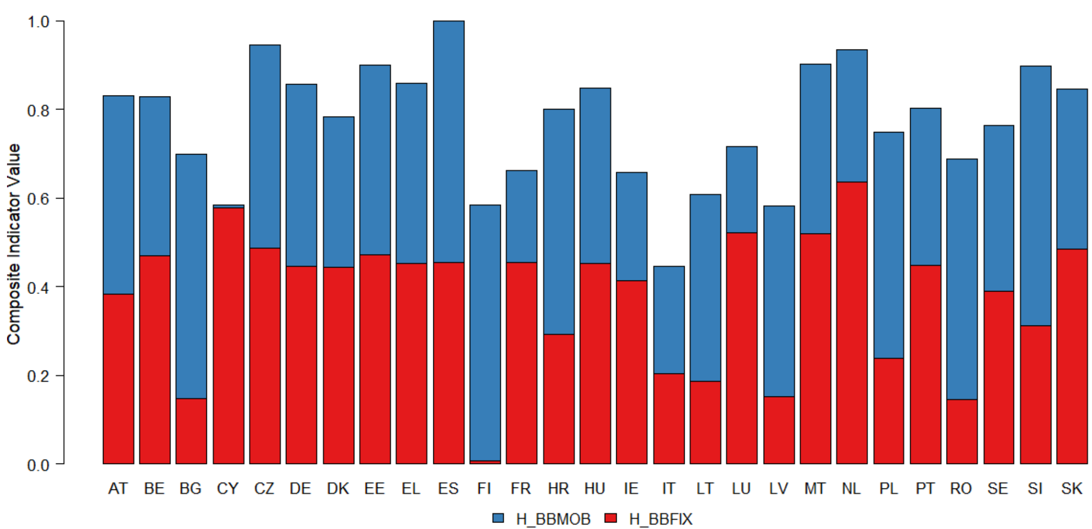


Figure 12: Digital Access composite sub-indicator using PCA

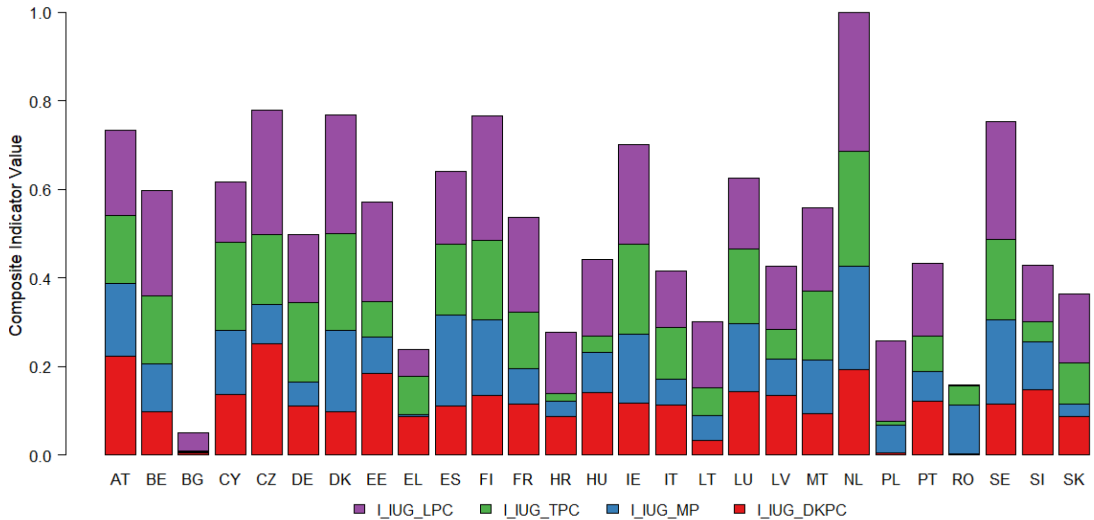


Figure 13: Digital Device composite sub-indicator using PCA

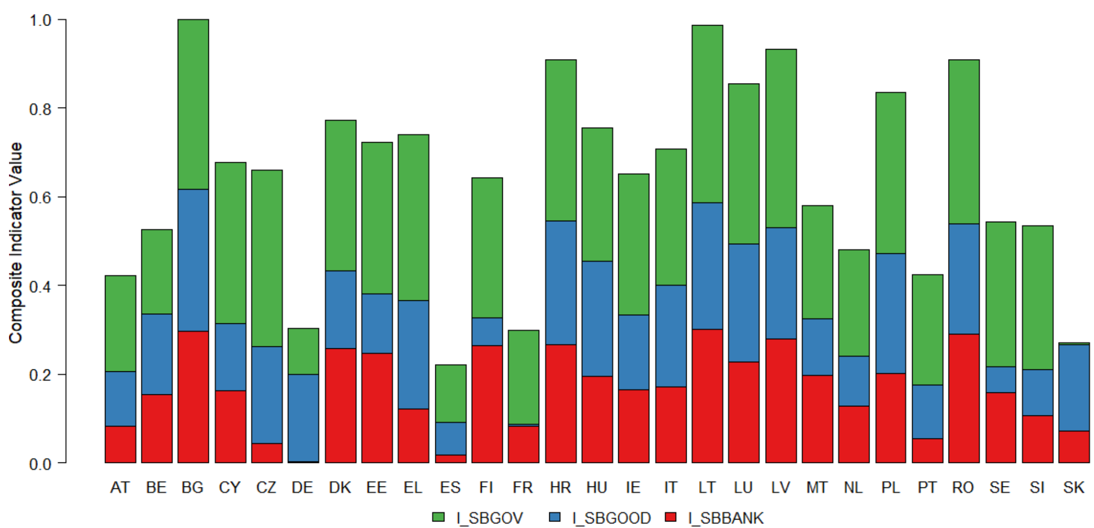


Figure 14: Digital Security Permissiveness (re-polarized security concerns) composite sub-indicator using PCA

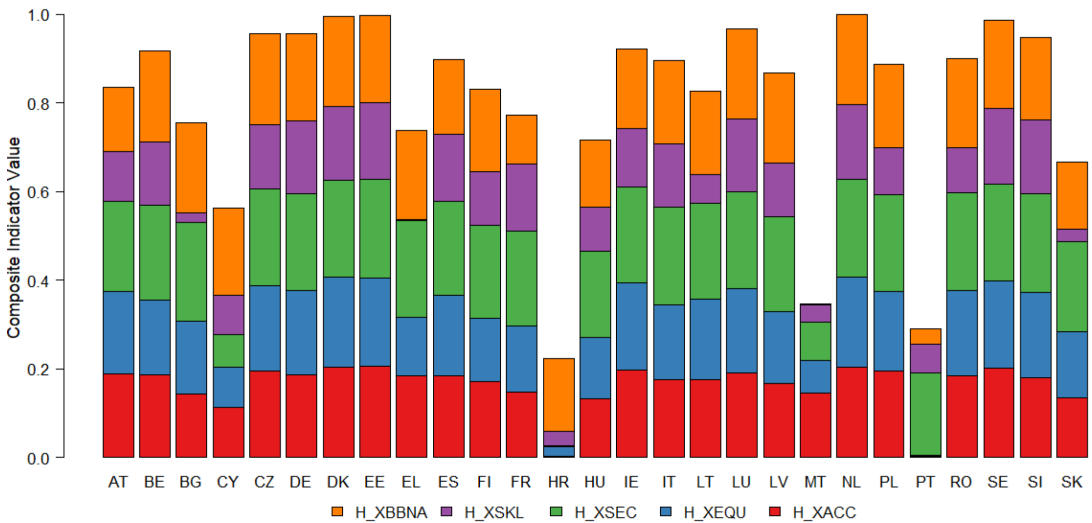


Figure 15: Digital Inclusivity (re-polarized barriers) composite sub-indicator using PCA

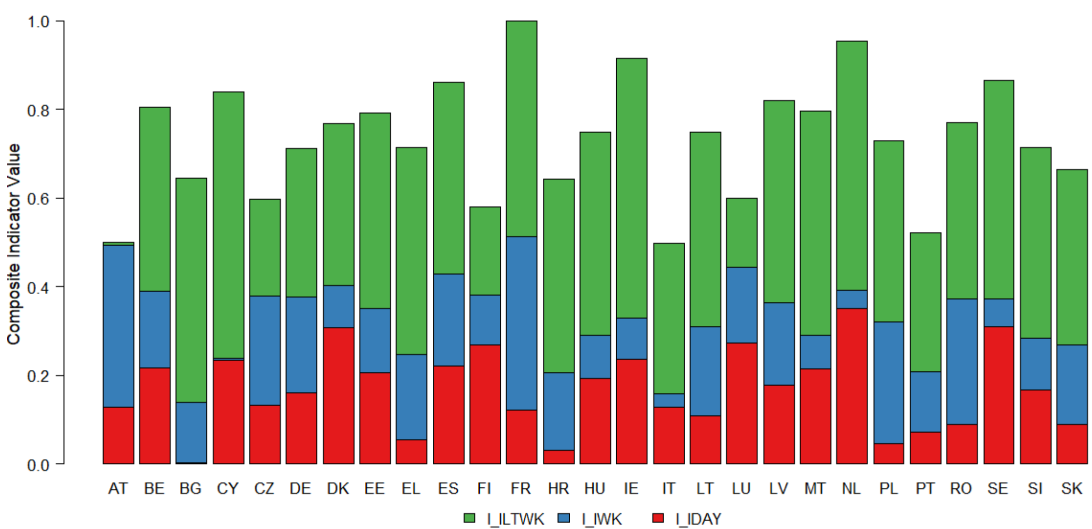


Figure 16: Digital Frequency composite sub-indicator using PCA

For the indicators that are composed of the repolarized variables, namely **digital security permissiveness** and **digital inclusivity**, figures 14 and 15 illustrate the distribution of the respective composite sub-indicator scores. The results show there are some important differences related to the two sub-indicators across EU Member States. For example, the scores for digital security permissiveness vary substantially across some countries with a number of countries showing a high level of security permissiveness and other countries' scores reflecting a much more conservative approach to online security. However, this indicator should be interpreted with a degree of caution as factors other than online security awareness could have a significant impact on countries' scores. For example, beyond security attitudes, other relevant factors could include educational levels, digital skill levels, available internet access infrastructure and even cultural attitudes or political environments. With respect to Luxembourg, the component accounting for the largest portion of the indicator score is online government benefit applications (I_SBGOV). Recalling that this indicator has been repolarized, the interpretation is that Luxembourg citizens have a relatively low degree of security concerns about online government applications for benefits. This could reflect the quality and/or security of the service offered or even the fact that online applications for benefits has become a standard process[23]. The interpretation of this indicator could be complicated by the fact that security permissiveness could also result from a nonchalant approach towards online security.

The digital inclusivity sub-indicator is overall quite high across all EU countries. Notably, however, a number of countries score well below their peers including Croatia (HR), Malta (MT) and Portugal (PT). A detailed analysis of the factors driving digital financial

[23] In Luxembourg, for example, MyGuichet.lu is used for a wide array of online government interaction.

inclusion at Member State level is beyond the scope of this work[24]. However, in the case of Luxembourg, the Digital Inclusivity score is among the highest of the EU Member States with the individual components of the score being relatively uniformly distributed and suggestive that there are relatively low barriers to digital financial inclusion in Luxembourg. Given the repolarized nature of this indicator, for those countries that exhibit lower scores, the most significant barriers are those that are not represented in the score (i.e. they have low values) and tend towards lack of broadband availability (H_XBBNA) for MT and PT, high access costs (H_XACC) for HR and PT, high equipment costs (H_XEQU) for HR and PT, low digital skill levels (H_XSKL) for CY, HR and PT and security concerns (H_XSEC) for HR and CY. Addressing these low contributing components could increase the sub-indicator scores for these countries. Figure 17 shows the EU Member States ranked by their respective $Y^{inclusivity}$ scores.

For the **frequency of digital engagement** or access indicator, Y^{freq}, shown in figure 16 the interpretation of the country scores should take into account that the variable for internet usage less than once a week (I_ILTWK) has been repolarized. Therefore a higher contribution of this variable to the sub-indicator should be interpreted positively. When I_ILTWK significantly contributes towards the sub-indicator score, it implies that individuals access the internet less than once a week *very infrequently.* In other words, individuals frequently access the internet. Most countries' scores suggest that individuals engage in relatively frequent internet access on either a daily or weekly basis. This possibly reflects the ease with which individuals can access the internet either at home or away from home using a mobile device. For Luxembourg, the largest contribution to the Y^{freq}

[24] The European Commission publishes country-level progress reports on the state of implementation of the EU's Digital Decade program. The country-level reports and other information can be found here: `https://digital-strategy.ec.europa.eu/en/factpages/digital-decade-2024-report-country-fact-pages`

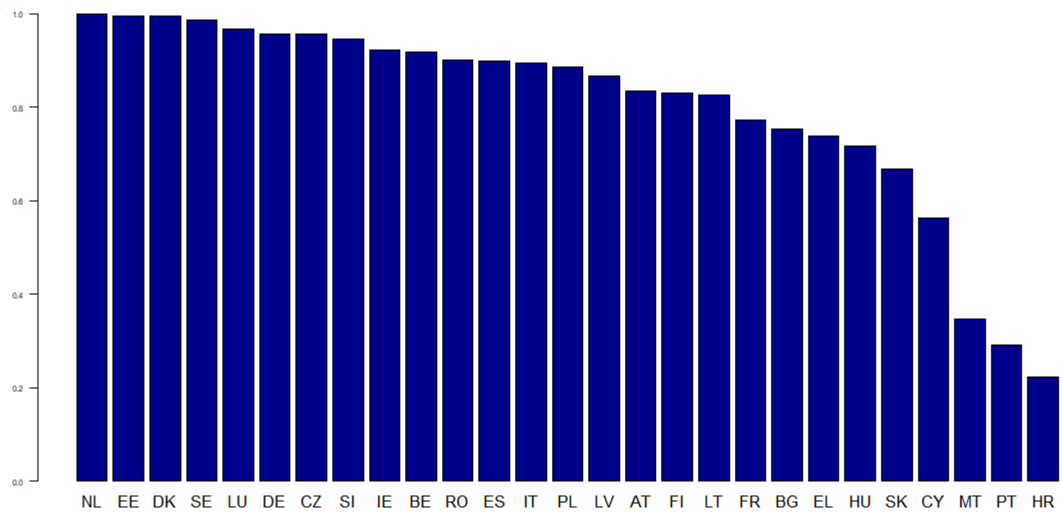


Figure 17: EU Member State countries ranked by their respective $Y^{Inclusivity}$ composite sub-indicator scores.

sub-indicator score comes from the variable for individuals' daily internet access (I_IDAY).

Having constructed the seven composite sub-indicators, we can apply the second PCA step, which consists of repeating the first step but using the country-level composite sub-indicator values in combination with equations 1, 3 and 4. The weights of the composite sub-indicators in the final composite indicator are again computed according to 3. The PCA results, including the composite sub-indicator weights of this final step are shown in tables 5 and 6.

Over 97% of the variance of the original data is explained by the first two principal components for the final composite indicator as shown in table 5. For the principal components themselves, the values for the first principal component are relatively evenly distributed across the seven composite sub-indicators as illustrated in table 6, which is desirable in the context of a composite indicator. Of notable interest is that the largest value of the first principal component is associated with the inclusivity indicator, $Y^{inclusive}$,

Princ. Comp.	Cum. Var. Explained
PC_1	0.9394
PC_2	0.9708
PC_3	0.9842
PC_4	0.9926
PC_5	0.9964
PC_6	0.9989
PC_7	1

Table 5: Cumulative variance explained by the principal components for the final composite indicator.

Variable	PC_1	PC_2	PC_3	PC_4	PC_5	PC_6	PC_7	weight
Composite Indicator of Digital Financial Participation								
Y^{Skills}	-0.3806	-0.2784	0.4729	0.0135	-0.3396	0.4664	-0.4701	*0.1468*
$Y^{Activity}$	-0.3039	-0.3730	0.0958	-0.3770	0.3641	0.3273	0.6144	*0.1206*
Y^{Access}	-0.3889	-0.0007	0.1584	0.7362	-0.2007	-0.1886	0.4537	*0.1457*
Y^{Device}	-0.3126	-0.4622	-0.0276	-0.3095	-0.1551	-0.7418	-0.1337	*0.1278*
$Y^{Permissive}$	-0.3857	0.7435	0.3345	-0.3879	-0.0642	-0.1543	0.0906	*0.1377*
$Y^{Inclusive}$	-0.5001	0.1195	-0.7932	-0.0379	-0.2036	0.2388	-0.0809	***0.1943***
$Y^{Frequency}$	-0.3390	0.0517	0.0164	0.2608	0.8014	-0.0935	-0.4039	*0.1271*

Table 6: Principal components of the final composite indicator.

suggesting that digital inclusivity plays an important role in the composite indicator of digital financial participation. In addition, the *inclusivity* sub-indicator is also associated with the highest weight.

The second principal component has its largest value associated with the security permissiveness composite sub-indicator, $Y^{Permissiveness}$, suggesting that the repolarized variables play a key role in determining the level of digital financial participation within the framework of our indicator. The *activity* and *device* composite sub-indicators also add information useful for explaining digital financial participation and the second component therefore seems to capture the ability to access digital financial activities. The third principal component is also strongly associated with inclusivity and reinforces the idea that inclusivity plays a key role in digital financial participation.

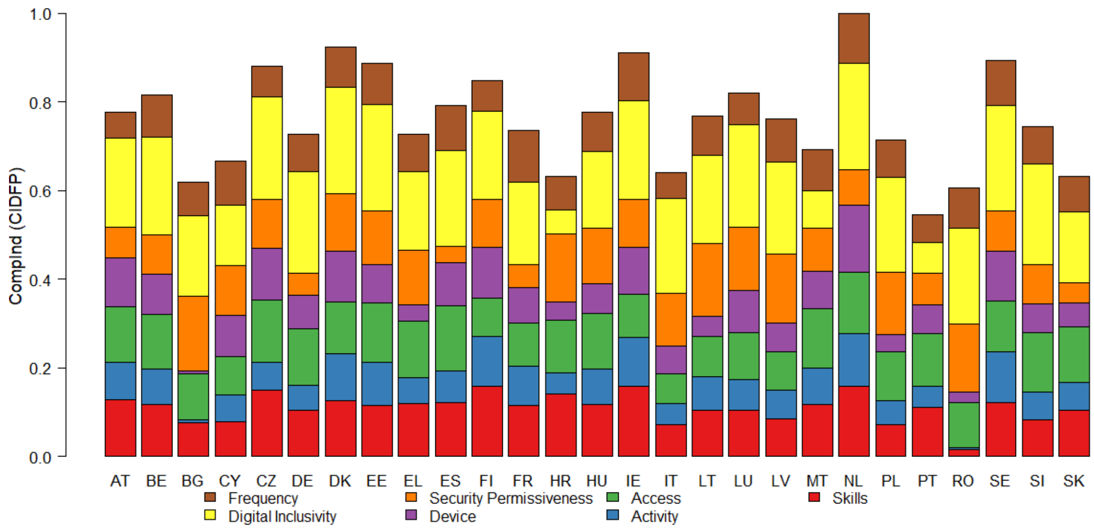


Figure 18: CIDFP with weighted components using two-stage PCA approach

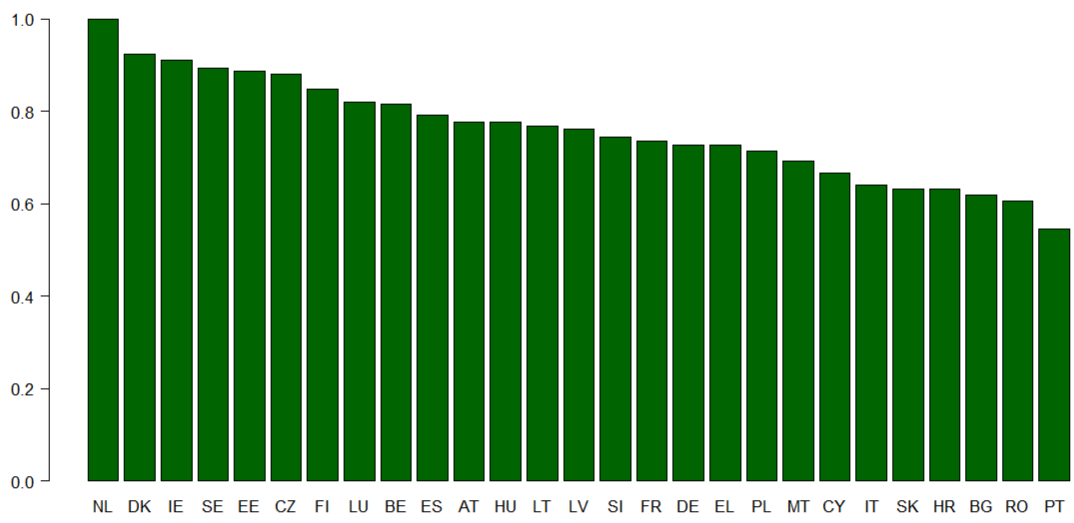


Figure 19: Ordered CIDFP using two-stage PCA approach

The final composite indicator of digital financial participation (CIDFP) for all 27 EU Member States is shown in figure 18. The indicator is shown in terms of its constituent components and the sub-indicator for digital inclusivity clearly accounts for the largest portion of the sub-indicator scores in the final indicator value. In the context of the total indicator value, other important contributions to a country's overall value come from the security permissiveness sub-indicator and the digital skills sub-indicator. Figure 19 shows the countries ranked from the highest scoring to the lowest scoring, with The Netherlands standing out as a benchmark country. Luxembourg scores within the higher end of the indicator range, but ranks below NL, DK, IE, SE, EE, CZ and FI, suggesting that Luxembourg has scope to improve its CIDFP score particularly along the policy lines detailed above.

6.2 Multidirectional Benefit of the Doubt (MDBoD) Results

The Composite Indicator of Digital Financial Participation was also constructed using the Multidirectional Benefit of the Doubt approach. In addition to offering a second method for constructing the indicator which is independent from the two-stage PCA approach, the MDBoD construction also allows for identifying policy directions to improve the indicator score at country level. For the policymaker, these improvement directions offer policy guidance that can be used to tailor programs intended to facilitate digital financial participation.

In addition to the composite indicator values and weights, the MDBoD output includes directional improvement values. These directional improvements represent the directions along which a DMU can expand its constituent indicators in order to increase its efficiency. From a policy perspective, they represent the areas of priority that a policymaker can take into account in order to improve a DMU's composite indicator score. Tables 7 through

12 show the directional scores for each country according to the seven different composite sub-indicators.

Country	I_DSK2_AB	I_DSK2_B	I_DSK2_LW	I_DSK2_X
AT	0.1474	0.0721	**0.2971**	0.1895
BE	0.3409	0.1794	**0.4949**	0.2042
BG	**0.9900**	0.4023	0.3870	0.5885
CY	0.6320	0.6217	**0.9900**	0.2215
CZ	-	-	-	-
DE	0.4247	0.0998	**0.6100**	0.2267
DK	0.1684	0.1428	**0.6333**	0.0740
EE	0.4207	0.3878	**0.5271**	0.1778
EL	**0.4235**	0.0936	0.1550	0.2729
ES	0.3393	0.3424	**0.3602**	0.2387
FI	-	-	-	-
FR	0.4444	0.3108	**0.4754**	0.2398
HR	-	-	-	-
HU	0.3709	0.2037	**0.5262**	0.1441
IE	-	-	-	-
IT	**0.6906**	0.6859	0.5915	0.5089
LT	**0.6120**	0.4549	0.4493	0.2740
LU	0.2632	0.1038	**0.5591**	0.3828
LV	0.7650	0.3396	**0.9005**	0.2607
MT	0.3751	**0.4720**	0.4712	0.1203
NL	-	-	-	-
PL	0.7369	0.6388	**0.7565**	0.3762
PT	**0.5257**	0.5053	0.2942	0.2593
RO	0.9737	**0.9900**	0.6304	0.9900
SE	0.2535	0.2181	**0.6476**	0.0891
SI	0.7618	0.4038	**0.7776**	0.3682
SK	0.5937	0.2856	**0.6449**	0.1992

Table 7: Y^{skills} MDBoD improvement directions.

Country	I_ECOM	I_IUBK	I_IUSELL	I_IGOVBE	I_BFIN_CR	I_BFIN_IN	I_BFIN_SH
AT	0.2655	0.2447	0.2211	0.1368	0.3569	**0.5631**	0.5517
BE	0.3320	0.2183	0.3202	0.4238	0.2924	0.4401	**0.6060**
BG	**0.9900**	0.9792	0.8894	0.9908	0.8908	0.8401	**0.9900**
CY	0.3772	0.3190	**0.6677**	0.0505	0.5486	0.4666	0.4716
CZ	0.3097	0.2161	0.6663	**0.8903**	0.4882	0.6897	0.6597
DE	0.3179	0.5205	0.6601	**0.8398**	0.5898	0.7283	0.5058
DK	-	-	-	-	-	-	-
EE	0.2952	0.0264	0.0455	0.0648	0.1148	0.0376	**0.3593**
EL	-	-	-	-	-	-	-
ES	0.4657	0.3254	0.5600	0.2009	0.5516	**0.7177**	0.6492
FI	-	-	-	-	-	-	-
FR	-	-	-	-	-	-	-
HR	0.5425	0.4002	0.5058	0.6875	0.4454	**0.9990**	0.7329
HU	0.3455	0.3504	0.0146	**0.4643**	0.1502	0.0121	0.2624
IE	-	-	-	-	-	-	-
IT	0.7505	0.5987	0.6669	0.2670	0.6719	**0.9175**	0.7157
LT	-	-	-	-	-	-	-
LU	0.2685	0.3374	0.6510	0.2849	0.6360	**0.9810**	0.7304
LV	0.6389	0.1111	0.5978	0.5085	0.5532	0.3602	**0.6671**
MT	0.3064	**0.3793**	0.0803	0.2947	0.1609	0.2915	0.2967
NL	-	-	-	-	-	-	-
PL	0.6234	0.4969	0.7535	0.4272	0.7370	0.7213	**0.9046**
PT	0.7244	0.5023	0.8444	0.3406	0.8040	**0.8916**	0.7947
RO	0.9412	0.9900	0.9627	0.9891	0.9515	**0.9997**	0.9817
SE	-	-	-	-	-	-	-
SI	0.4642	0.3567	0.2831	0.4556	0.1607	**0.7042**	0.1511
SK	0.3309	0.5163	0.3404	**0.7068**	0.4004	0.5252	0.6100

Table 8: $Y^{activity}$ MDBoD improvement directions.

Country	I_IUG_DKPC	I_IUG_MP	I_IUG_TPC	I_IUG_LPC
AT	-	-	-	-
BE	**0.5820**	0.5392	0.4107	0.2435
BG	0.9806	**0.9900**	**0.9900**	0.8722
CY	0.3640	0.3772	0.2392	**0.5624**
CZ	-	-	-	-
DE	0.5088	**0.7650**	0.3054	0.5122
DK	**0.4550**	0.2191	0.1609	0.1446
EE	0.2698	0.6478	**0.6892**	0.2863
EL	0.6508	**0.9860**	0.6616	0.8124
ES	0.3714	0.1183	0.3840	**0.4775**
FI	**0.3339**	0.2705	0.3069	0.1051
FR	0.5443	**0.6619**	0.5010	0.3229
HR	0.6504	0.8604	**0.9336**	0.5566
HU	0.4365	0.6100	**0.8605**	0.4483
IE	**0.4257**	0.3356	0.2086	0.2881
IT	0.5493	**0.7530**	0.5502	0.5951
LT	**0.8697**	0.7592	0.7539	0.5252
LU	0.3327	0.3476	0.3485	**0.4867**
LV	0.4637	0.6496	**0.7457**	0.5442
MT	**0.5771**	0.4787	0.4034	0.3985
NL	-	-	-	-
PL	**0.9789**	0.7363	0.9624	0.4213
PT	0.5202	**0.7149**	0.6869	0.4797
RO	0.9564	0.5306	0.8307	**0.9900**
SE	**0.3787**	0.1916	0.2966	0.1550
SI	0.3831	0.5333	**0.8289**	0.5973
SK	0.6537	**0.8845**	0.6346	0.5078

Table 9: Y^{device} MDBoD improvement directions.

Country	I_SBBANK	I_SBGOOD	I_SBGOV
AT	**0.7234**	0.6188	0.4601
BE	0.4838	0.4355	**0.5267**
BG	-	-	-
CY	0.4615	**0.5276**	0.0892
CZ	**0.8551**	0.2368	0.0125
DE	**0.9900**	0.3868	0.7372
DK	0.1408	**0.4537**	0.1527
EE	0.1797	**0.5832**	0.1443
EL	**0.5976**	0.2367	0.0645
ES	**0.9406**	0.7689	0.6762
FI	0.1204	**0.8045**	0.2157
FR	0.7221	**0.9900**	0.4707
HR	0.1125	**0.1285**	0.0957
HU	**0.3487**	0.1904	0.2514
IE	0.4540	**0.4686**	0.2102
IT	**0.4266**	0.2891	0.2324
LT	-	-	-
LU	**0.2432**	0.1710	0.0986
LV	0.0703	**0.1079**	0.0010
MT	0.3455	**0.5963**	0.3653
NL	0.5724	**0.6504**	0.3989
PL	**0.3257**	0.1559	0.0982
PT	**0.8142**	0.6223	0.3826
RO	0.0340	**0.2256**	0.0757
SE	0.4708	**0.8161**	0.1861
SI	0.6449	**0.6760**	0.1920
SK	0.7603	0.3905	**0.9900**

Table 10: $Y^{Permissiveness}$ MDBoD improvement directions.

Country	H_XACC	H_XEQU	H_XSEC	H_XSKL	H_XBBNA
AT	0.0870	0.0830	0.0853	**0.3479**	0.2953
BE	-	-	-	-	-
BG	-	-	-	-	-
CY	0.4484	0.5560	**0.6658**	0.4883	0.0375
CZ	**0.0251**	0.0160	0.0015	0.1060	0.0002
DE	**0.0917**	0.0577	0.0230	0.0463	0.0314
DK	-	-	-	-	-
EE	-	-	-	-	-
EL	0.1002	0.3456	0.0170	**0.9664**	0.0099
ES	0.0995	0.1051	0.0463	0.1385	**0.1674**
FI	0.1656	0.2970	0.0554	**0.2989**	0.0946
FR	0.2803	0.2704	0.0345	0.1317	**0.4521**
HR	**0.9900**	0.8875	**0.9900**	0.8094	0.2063
HU	0.3512	0.3256	0.1178	**0.4273**	0.2598
IE	0.0352	0.0318	0.0349	0.2360	**0.1184**
IT	0.1474	0.1606	0.0098	**0.1756**	0.0848
LT	0.1450	0.1086	0.0257	**0.6257**	0.0804
LU	**0.0701**	0.0584	0.0157	0.0229	0.0084
LV	0.1891	0.1913	0.0410	**0.2739**	0.0141
MT	0.2890	0.6357	0.6129	0.7733	**0.9900**
NL	-	-	-	-	-
PL	0.0515	0.1155	0.0179	**0.3882**	0.0826
PT	0.9830	**0.9900**	0.1693	0.6212	0.8327
RO	0.1019	0.0453	0.0025	**0.3947**	0.0143
SE	0.0180	**0.0244**	0.0142	0.0056	0.0078
SI	**0.1257**	0.0391	0.0056	0.0412	0.0784
SK	0.3456	0.2602	0.0932	**0.8309**	0.2618

Table 11: $Y^{Inclusivity}$ MDBoD improvement directions.

Country	I_IDAY	I_IWK	I_ILTWK
AT	0.0345	0.0453	**0.8133**
BE	0.1405	0.1921	**0.2325**
BG	**0.8172**	0.5116	0.1116
CY	-	-	-
CZ	0.2546	0.3342	**0.5246**
DE	0.2276	0.3060	**0.3502**
DK	0.0290	0.0418	**0.3157**
EE	0.2270	**0.3102**	0.2127
EL	**0.5654**	0.5060	0.1457
ES	0.0639	0.0874	**0.1740**
FI	0.1123	**0.1636**	0.6067
FR	-	-	-
HR	**0.6685**	0.5525	0.2038
HU	0.3493	**0.4774**	0.2125
IE	-	-	-
IT	0.6310	**0.9033**	0.4287
LT	0.3996	**0.4874**	0.1833
LU	-	-	-
LV	0.2251	**0.3077**	0.1650
MT	0.3249	**0.4440**	0.1408
NL	-	-	-
PL	**0.4401**	0.2973	0.1956
PT	0.6304	**0.6554**	0.4291
RO	**0.3022**	0.2753	0.2092
SE	0.0818	0.1120	**0.1280**
SI	0.3915	**0.5350**	0.2464
SK	0.4962	**0.5458**	0.2679

Table 12: Y^{Freq} MDBoD improvement directions.

The directional improvement results provide some potentially useful policy indications. For the Y^{skills} indicator results in table 7, the values in bold text show those improvement directions that will most effectively move a country's composite indicator score close to the benchmark value. Countries with no values are considered as benchmark countries since they have attained the maximum level of the indicator given the sample of countries (i.e. CZ, FI, HR, IE and NL). The bold values tend to be concentrated in the I_DSK2_LW column, suggesting that for the majority of countries, targeting individuals with low digital skill levels could move countries close to the benchmark. For other countries, such as Romania and Malta, policy efforts would be better focused on improving individuals' basic digital skills level (i.e. I_DSK2_B). In the case of Romania, policy could also focus on individuals with no digital skills (I_DSK2_X). For Bulgaria, Italy, Latvia and Portugal moving the composite skills indicator towards the benchmark value would be best accomplished by efforts to increase individuals above basic digital skills (i.e. I_DSK2_AB).

For the $Y^{Activity}$ composite sub-indicator, the improvement directions are concentrated in more specialized online financial activities such as applications for insurance (I_BFIN_IN) and online share purchases/online trading (I_BFIN_SH). In terms of a policy approach improving country-level indicator scores along these dimensions may not be feasible. The low level of online insurance applications may be due to the fact that such services may not be offered or individuals see no interest in such activity. Similar conclusions can be made for online trading. On the other hand, a number of countries (CZ, DE, HU and SK) could feasibly increase their indicator scores by increasing individuals' participation in online applications for government benefits. Unlike increasing online financial activities, government benefit applications are a public service that could be relatively straightforward to address at national level and falls within the competences of government entities.

The results for the Y^{device} indicator are less conclusive with the most efficient directions being relatively idiosyncratic across countries. The diversity in the improvement directions probably reflects different device preferences, access options and cost-related factors across the Member States. One possible conclusion is that a number of countries could improve their respective indicator scores through the adoption of desktop computers and mobile phones, reflecting the availability of fixed and mobile broadband access options. Increased use of tablet computers could also improve indicator scores for multiple countries.

For the repolarized undesirable indicators $Y^{Permissiveness}$ and $Y^{Inclusivity}$, there are some potentially interesting results. In terms of the "security permissiveness" indicator, countries could improve their online goods purchases and online banking security attitudes. The improvement direction results suggest that only two countries (BE and SK) could improve their indicator score through more conservative attitudes to online government benefit applications, suggesting that in most countries government online services are subject to stringent security protocols. In the case of Luxembourg, improving security attitudes towards online banking would help to move Luxembourg's indicator score closer to the benchmark. The government and the banking sector could potentially undertake public awareness campaigns to illustrate the importance of online security when conducting banking activities via the internet.

The results for the "digital inclusivity" indicator provide a rather clear policy indication for fostering digital inclusivity. In terms of the directional improvements, the majority of countries could move closer to the benchmark score by addressing deficiencies related to individuals' digital skill levels. In some countries (ES, FR, IE and MT) improving broadband availability, possibly in rural areas, could increase these countries' indicator scores. High access costs are also a potential avenue to increase digital financial participation as the directional results suggest that improving internet access affordability in CZ, DE, HR, LU and SI could be an appropriate policy. Reducing the barriers due to high equipment costs and security concerns are relevant policy options for only a handful of countries; PT and SE for the former and CY and HR for the latter.

Combining the seven individual MDBoD composite sub-indicators gives the overall MDBoD CIDFP that is shown in figure 20.

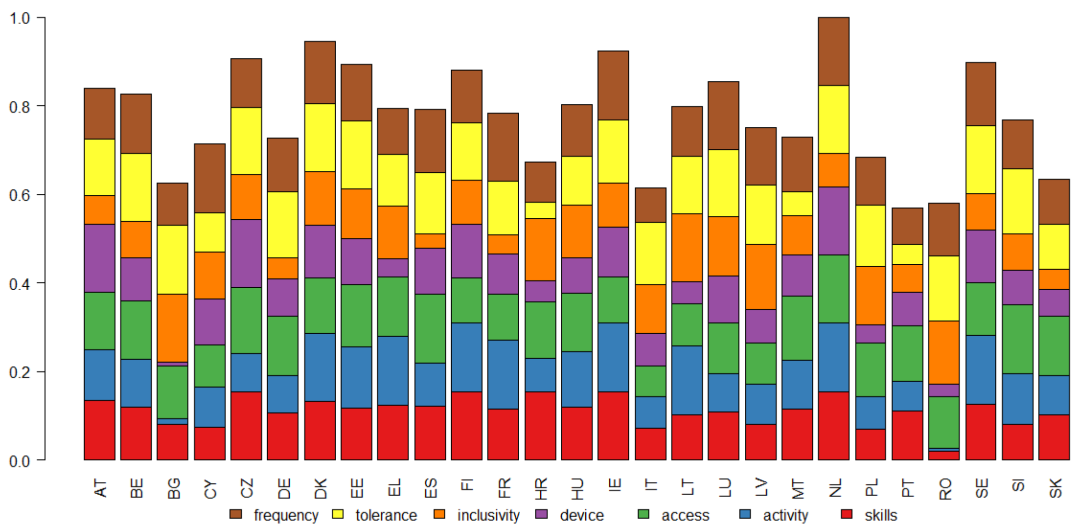


Figure 20: MDBoD derived Composite Indicator of Digital Financial Participation

A comparison with figure 18 shows important similarities in the two independently derived CIs. In both figures, The Netherlands remains the benchmark country for Digital Financial Participation among EU Member States. Table 13 shows the change in country rankings across the PCA and MDBoD composite indicators. There are only limited changes in the country rankings and in the event that a country changes its rank the move is, on average, only by one or two positions in the ranking. There are, however, some countries that change their rankings by up to five positions, for example Greece and Spain. In such cases, the shift in position is due to methodological reasons that result in changes to the contribution of individual composite indicator components.

Country	Rank MDBoD	Rank PCA	Change
NL	1	1	0
DK	2	2	0
IE	3	3	0
CZ	4	6	-2
SE	5	4	1
EE	6	5	1
FI	7	7	0
LU	8	8	0
AT	9	11	-2
BE	10	9	1
HU	11	12	-1
LT	12	13	-1
EL	13	18	-5
ES	14	10	4
FR	15	16	-1
SI	16	15	1
LV	17	14	3
MT	18	20	-2
DE	19	17	2
CY	20	21	-1
PL	21	19	2
HR	22	24	-2
SK	23	23	0
BG	24	25	-1
IT	25	22	3
RO	26	26	0
PT	27	27	0

Table 13: Change in country rank according to the composite indicator values derived from the MDBoD and PCA computations.

The improvement directions can also be graphically illustrated along the various component indicator dimensions. Figures 21 through 26 show the improvement directions illustrated as radar charts. The radar charts can be useful in communicating the potential policy priorities as the extent that the radar line extends along a given variable axis reflects the priority that a policy maker should attribute to that variable in order to increase the composite indicator score closer to the benchmark value.

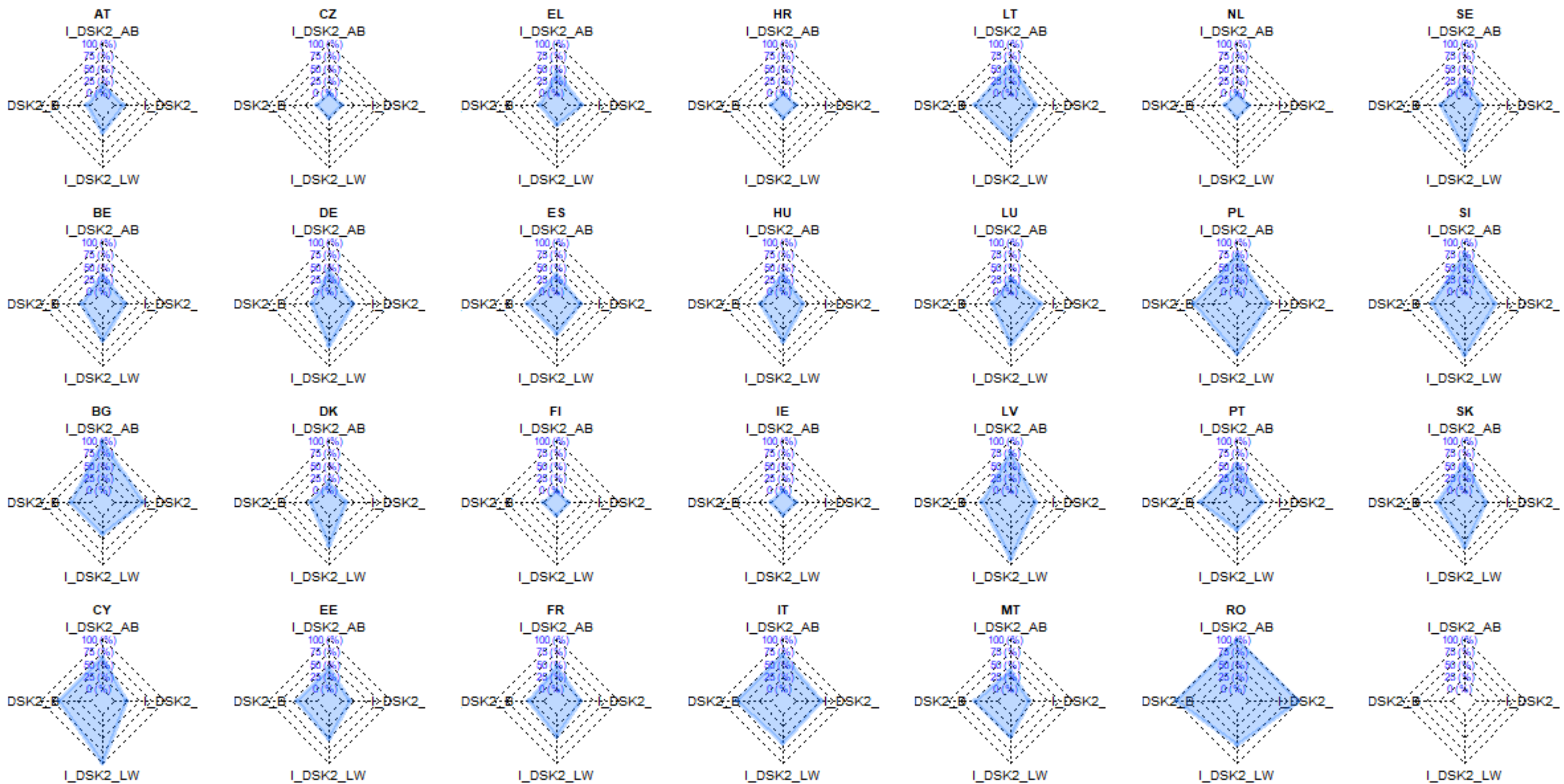


Figure 21: Country-specific improvement directions in the skills indicator based on the MDBoD approach.

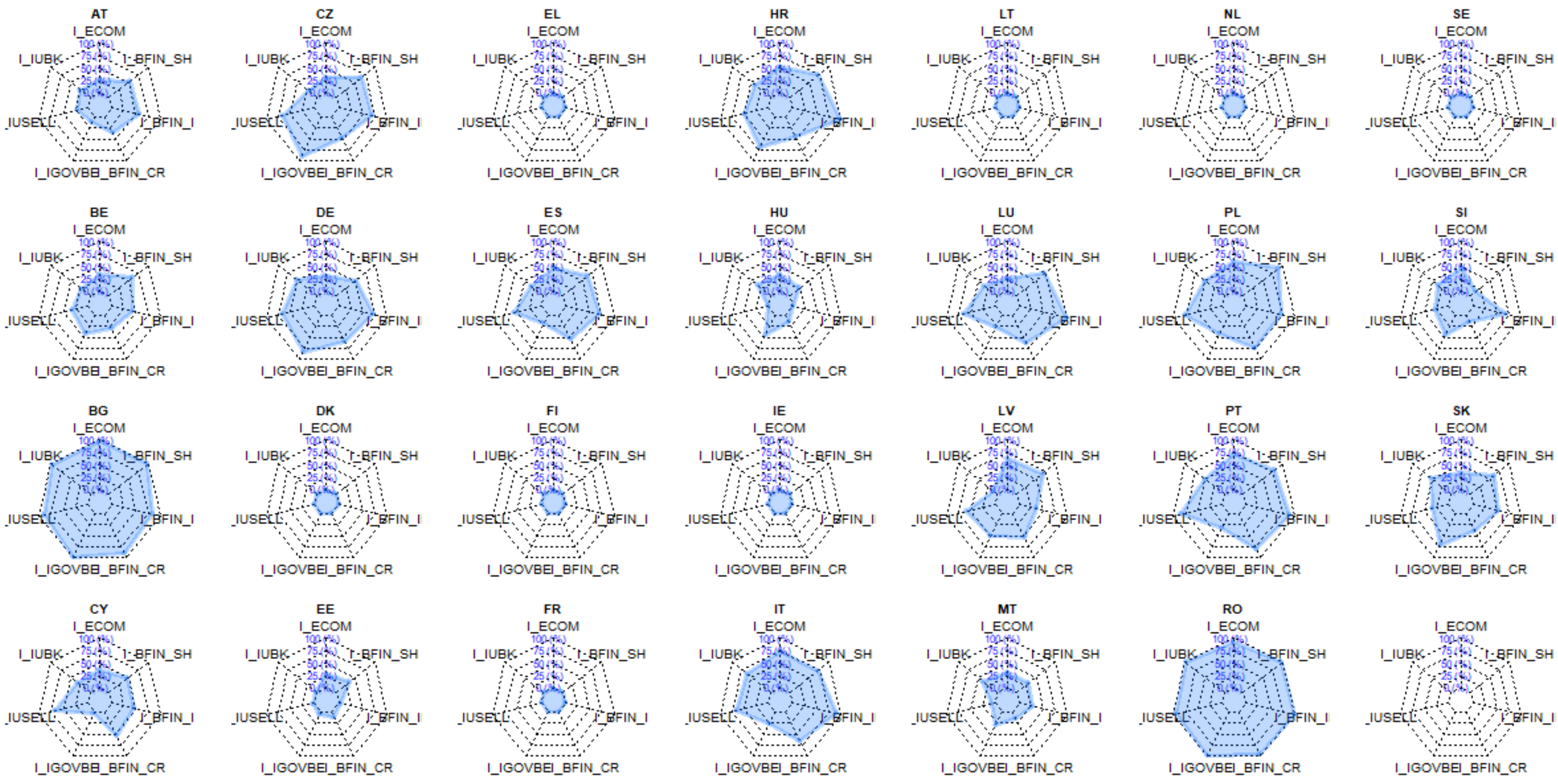


Figure 22: Country-specific improvement directions in the activity indicator based on the MDBoD approach

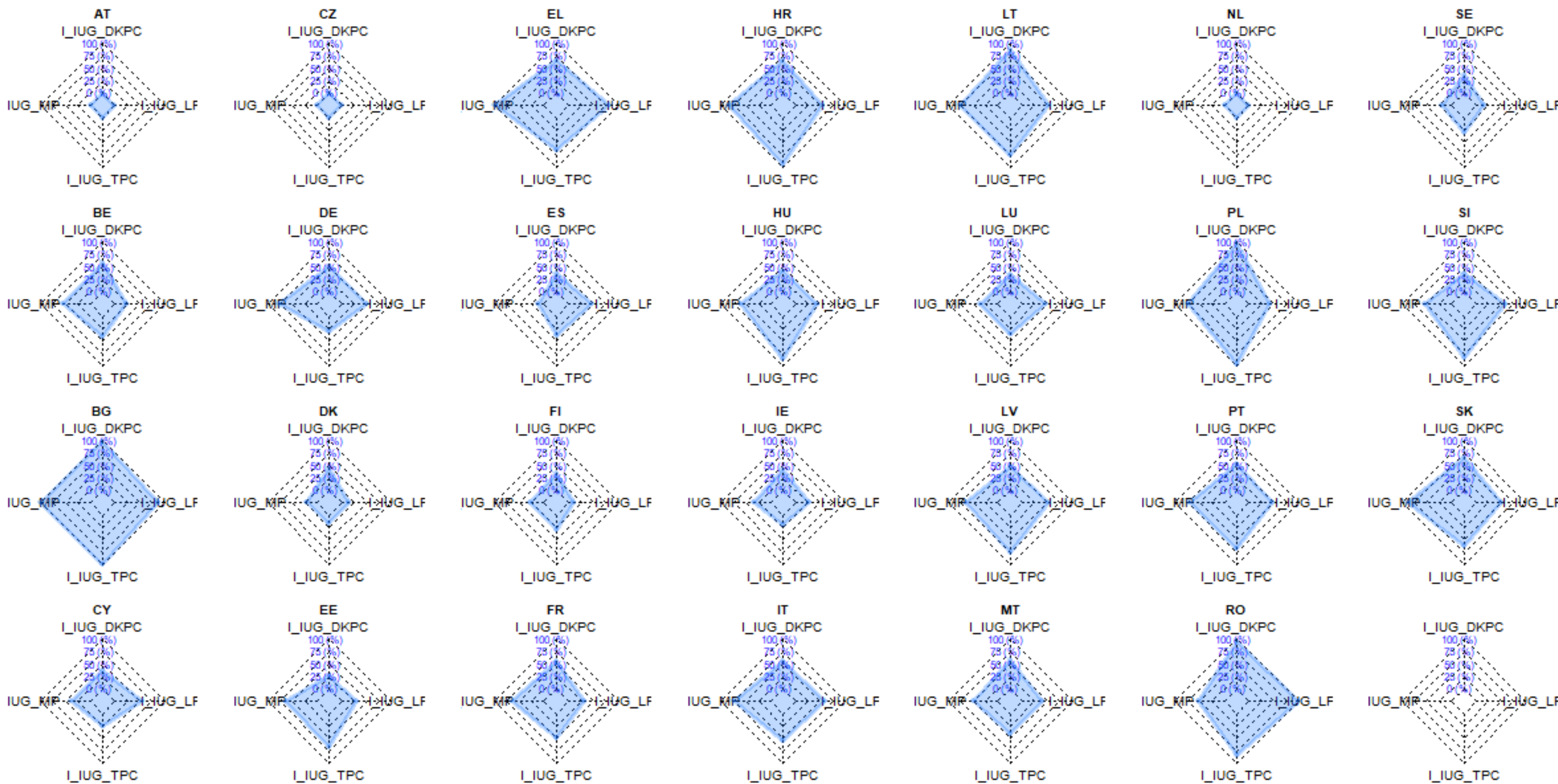


Figure 23: Country-specific improvement directions in the device indicator based on the MDBoD approach

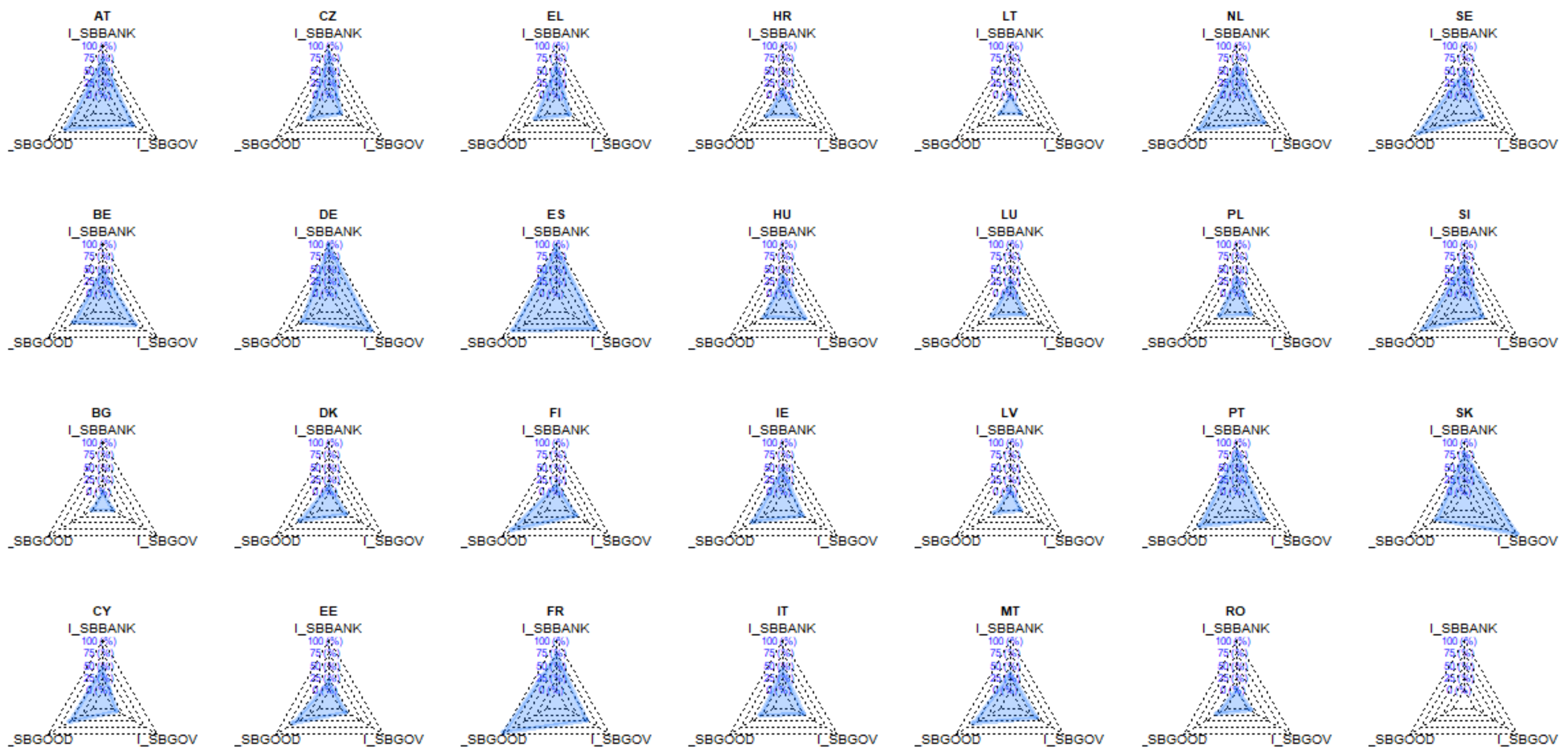


Figure 24: Country-specific improvement directions in the security indicator based on the MDBoD approach

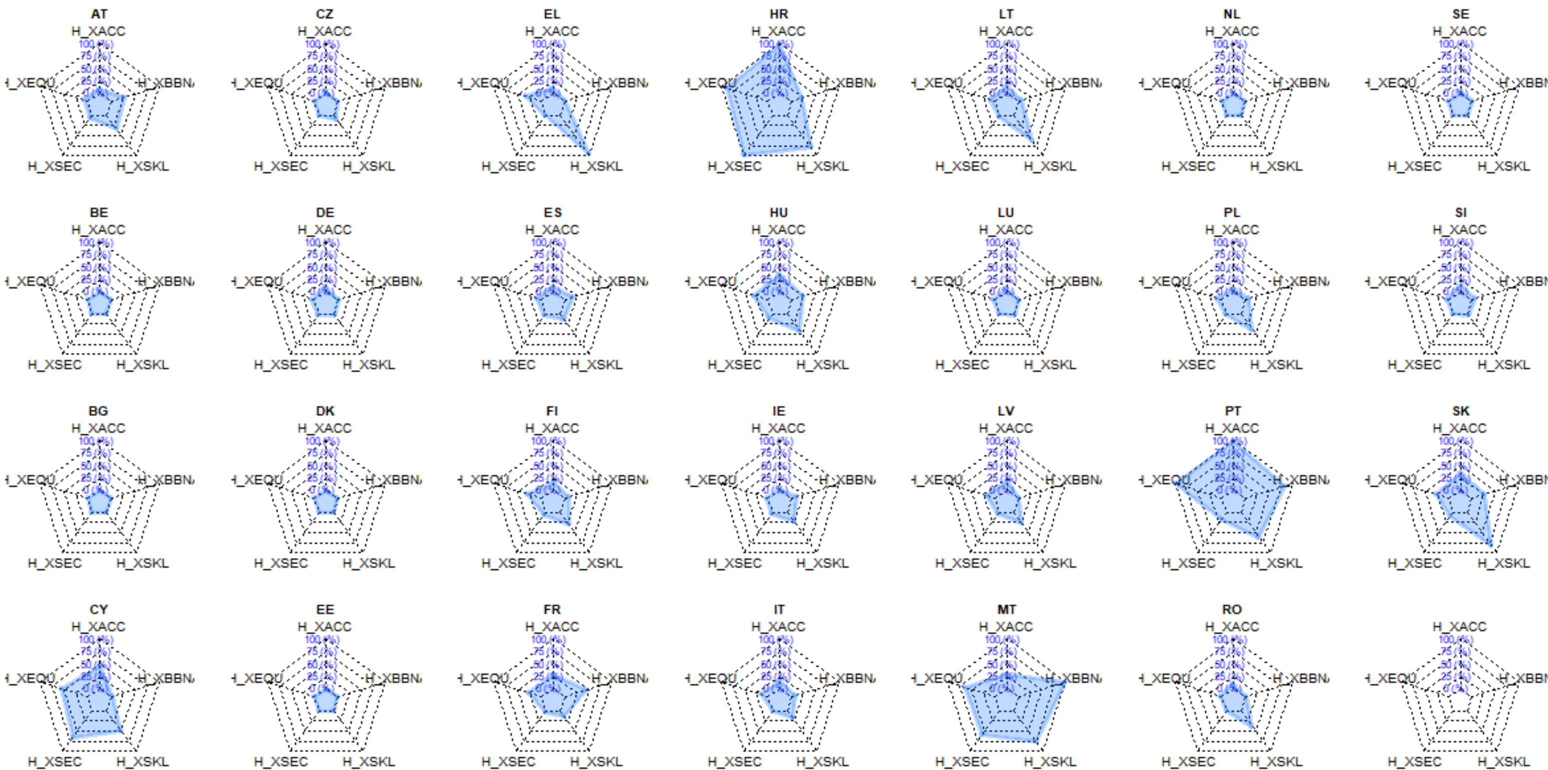


Figure 25: Country-specific improvement directions in the barriers indicator based on the MDBoD approach

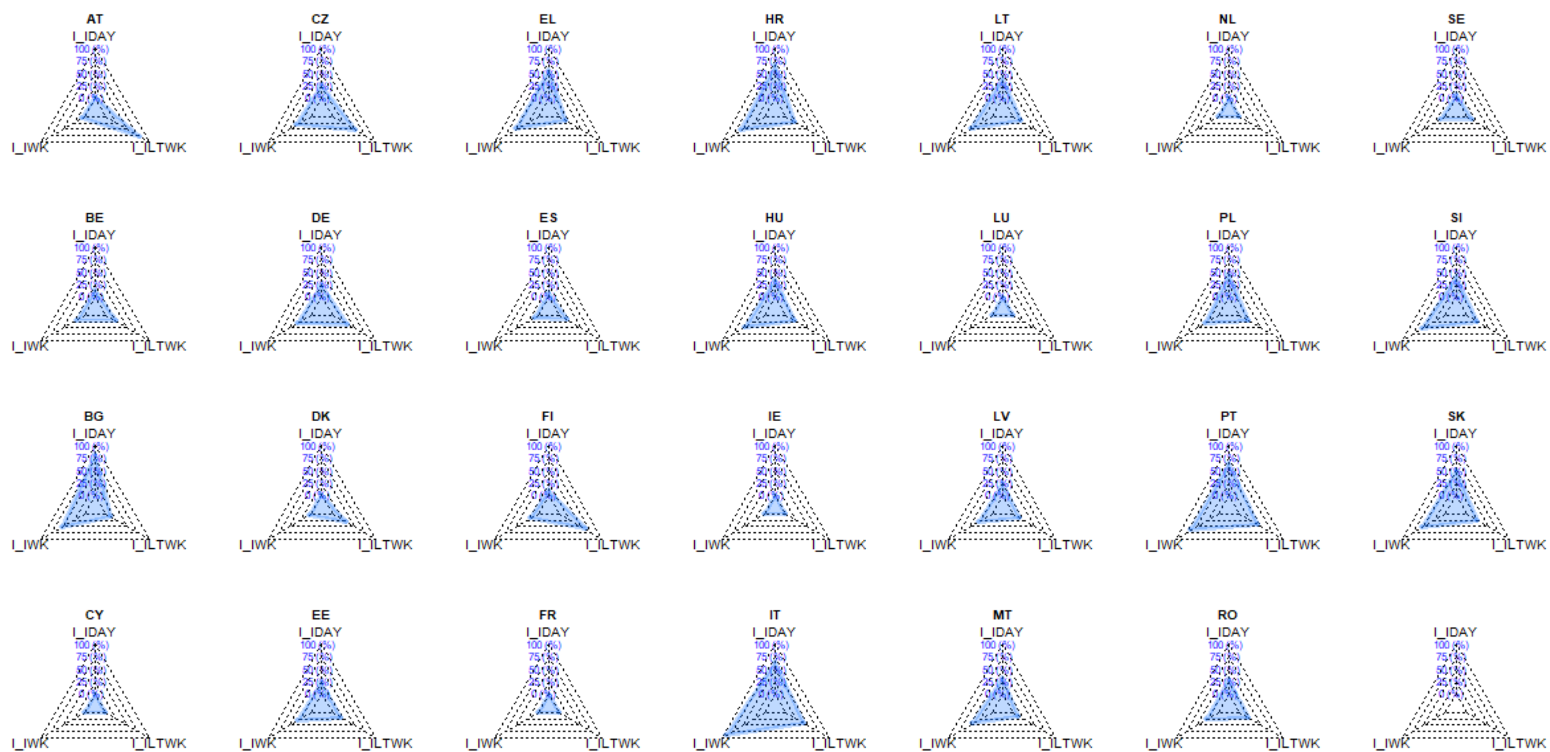


Figure 26: Country-specific improvement directions in the frequency indicator based on the MDBoD approach

7 Digital Financial Participation Policy Improvement Visualization Curves

The information contained in the composite indicator directional improvement scores can also be used to derive policy curves that illustrate where countries are positioned in terms of the policy efforts needed to reach the benchmark score. A useful way of depicting the distance from the benchmark CIDFP score, and thus a measure of the depth of policy required, is to plot the countries on a curve.

The policy curves in this study are constructed by dividing a given country's CIDFP score by area A, the latter quantity calculated as the area under a piece-wise linear function whose values are given by the values of the axis as shown in the radarcharts.

It is important to note that we are not calculating the area of the radar chart as defined by the polygon in the plots as the area measured in this manner will depend upon the ordering of the variables. Rather, we transform the radar chart into a piecewise linear function whose values correspond to the values of the directional improvements. We then compute the area under the curve (AUC) of this function and use the AUC value as the denominator. The results of these computations for the seven composite sub-indicators are shown in figures 27 to 33.

The resulting curves are broadly concave and display a rather consistent country grouping with the benchmark countries for each composite sub-indicator positioned in the upper left of the chart and those countries requiring the most improvement to reach the benchmark composite indicator score grouped towards the bottom right of the charts.

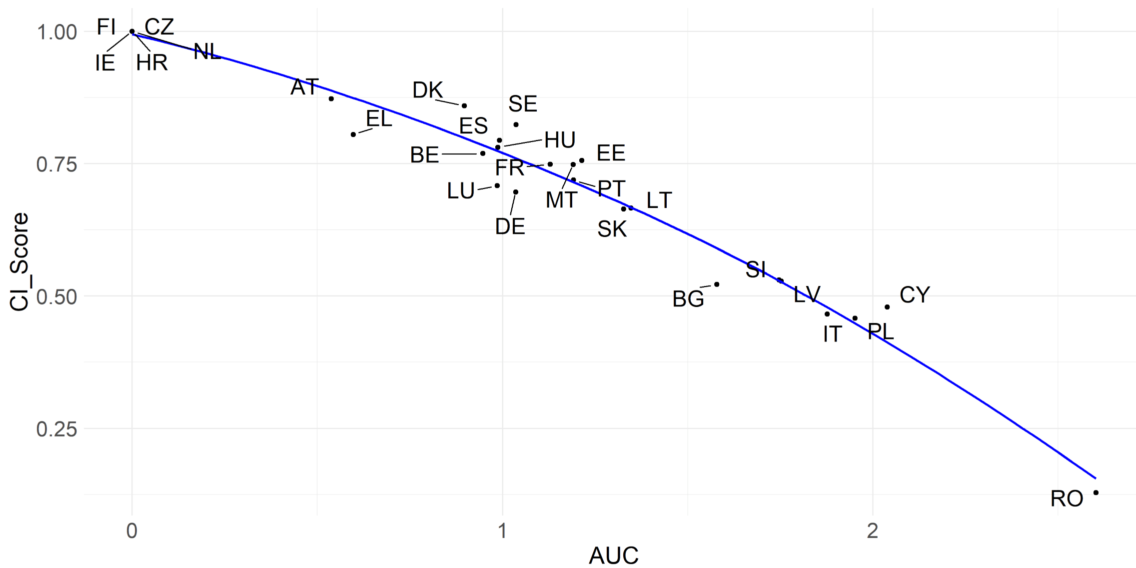


Figure 27: MDBoD composite indicator score versus area under the radar chart for the digital skills composite sub-indicator

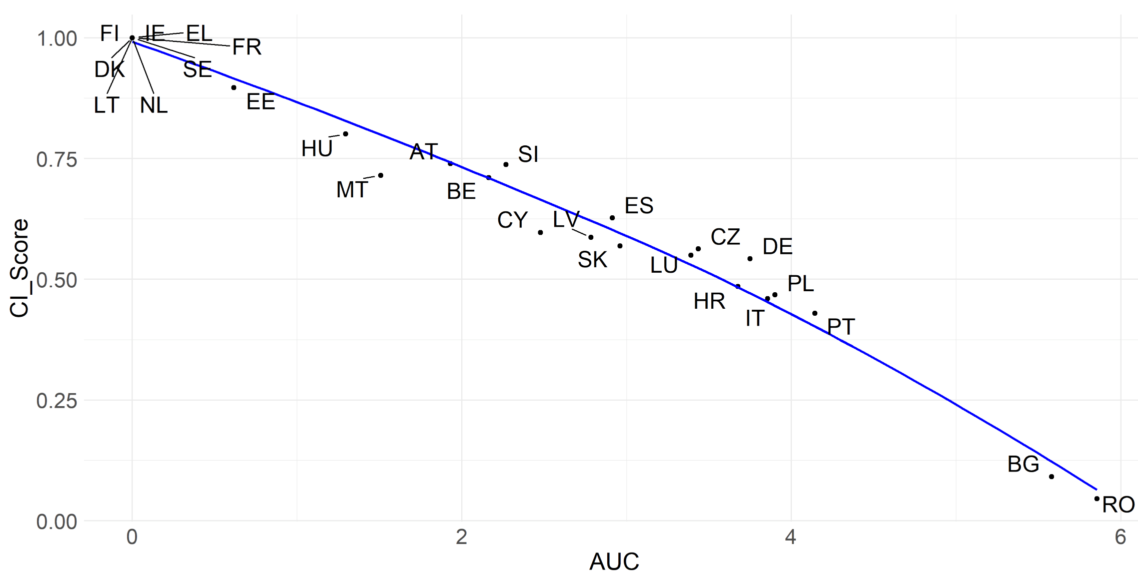


Figure 28: MDBoD composite indicator score versus area under the radar chart for the digital financial activity composite sub-indicator

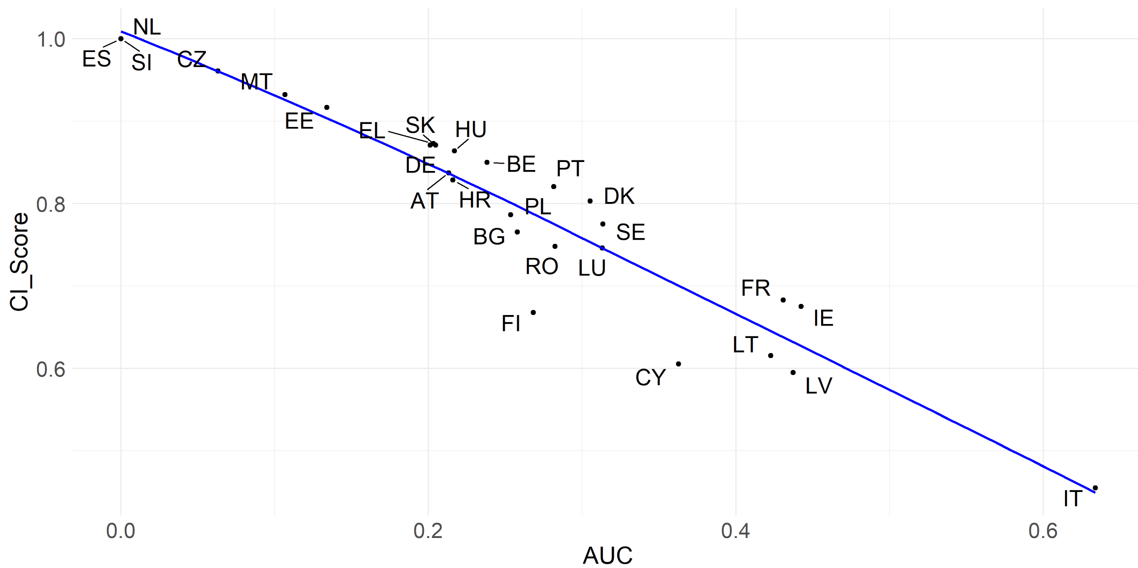


Figure 29: MDBoD composite indicator score versus area under the radar chart for the digital access composite sub-indicator

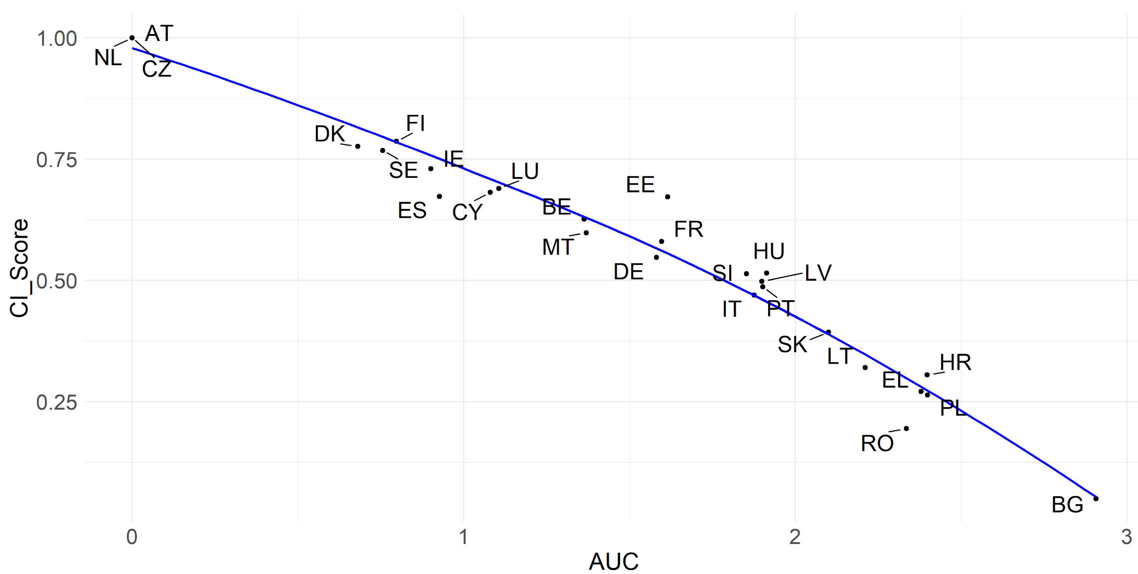


Figure 30: MDBoD composite indicator score versus area under the radar chart for the digital device composite sub-indicator

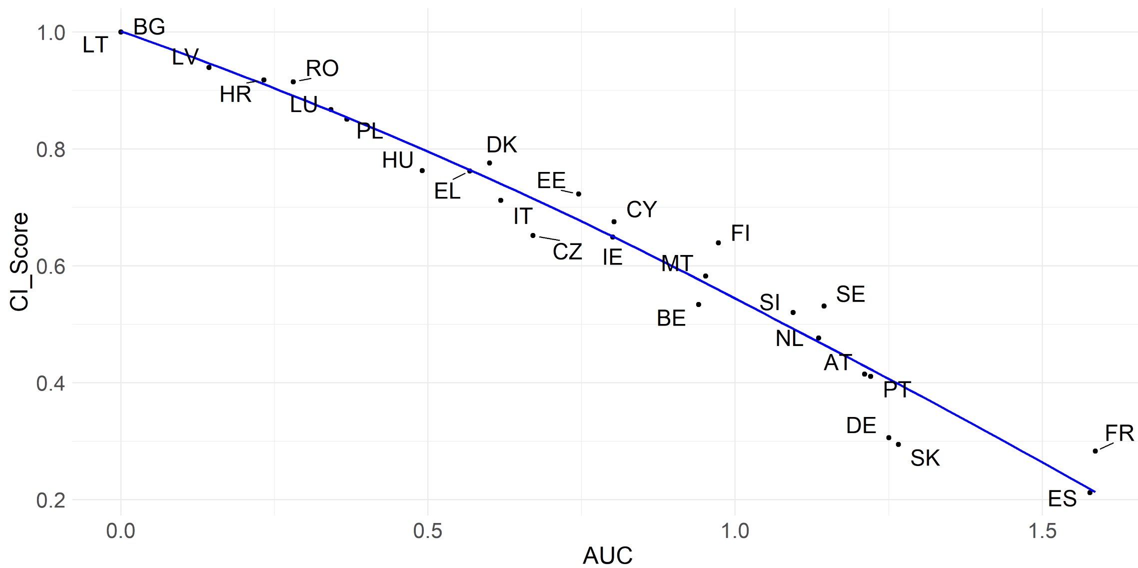


Figure 31: MDBoD composite indicator score versus area under the radar chart for the digital security concerns (permissiveness) composite sub-indicator

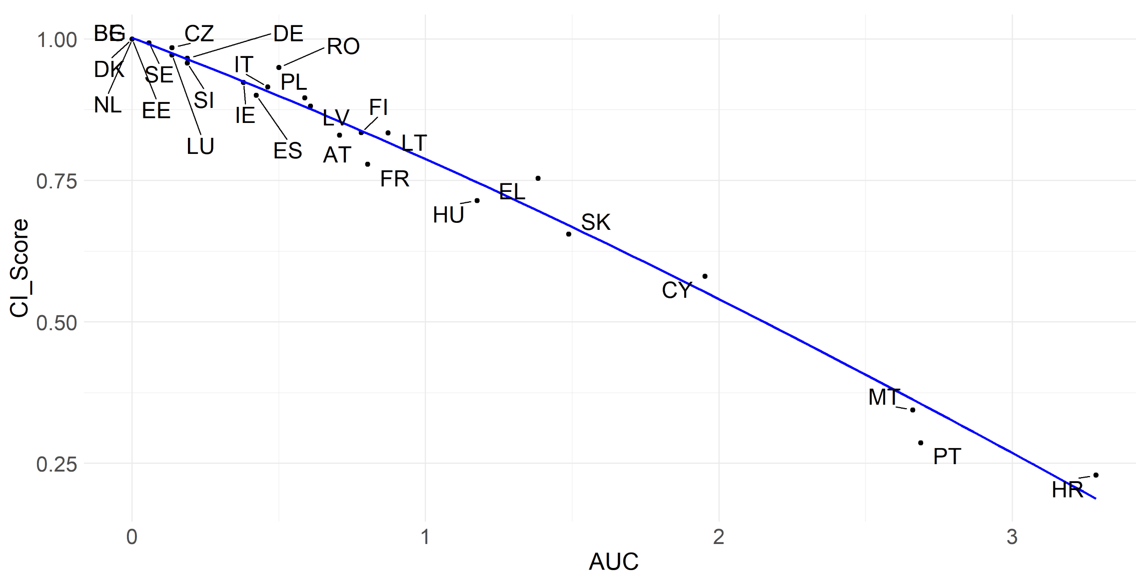


Figure 32: MDBoD composite indicator score versus area under the radar chart for the digital barriers (inclusivity) composite sub-indicator

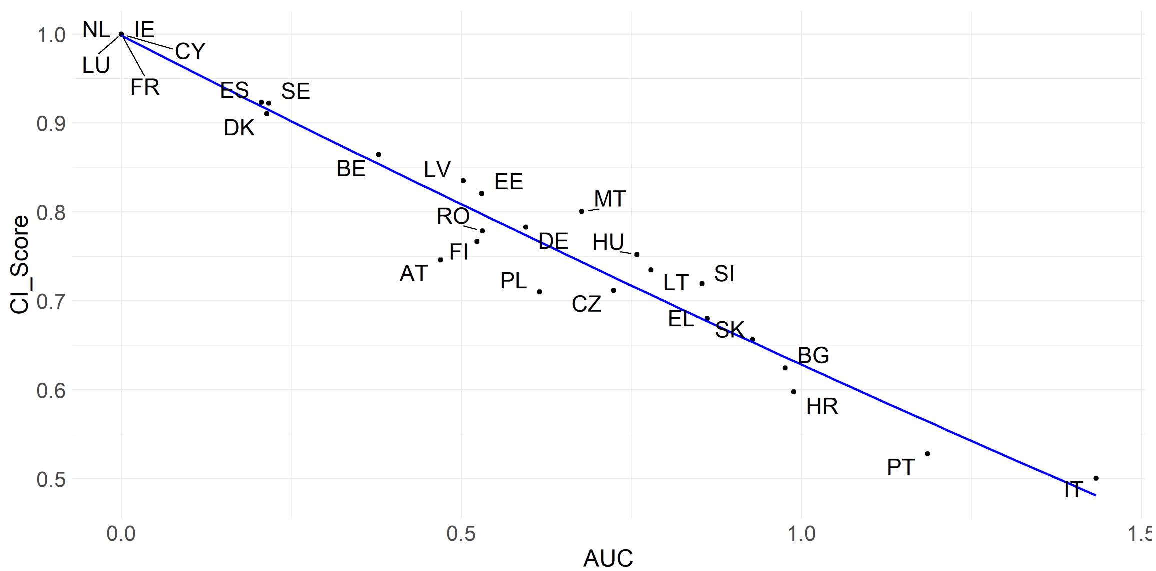


Figure 33: MDBoD composite indicator score versus area under the radar chart for the digital access frequency composite sub-indicator

To identify those countries that can be considered as benchmark countries and those countries that may require additional policy-related efforts to achieve the benchmark score of the CIDFP, we performed a clustering analysis on the CIDFP scores. The results of the clustering analysis are shown in figure 34

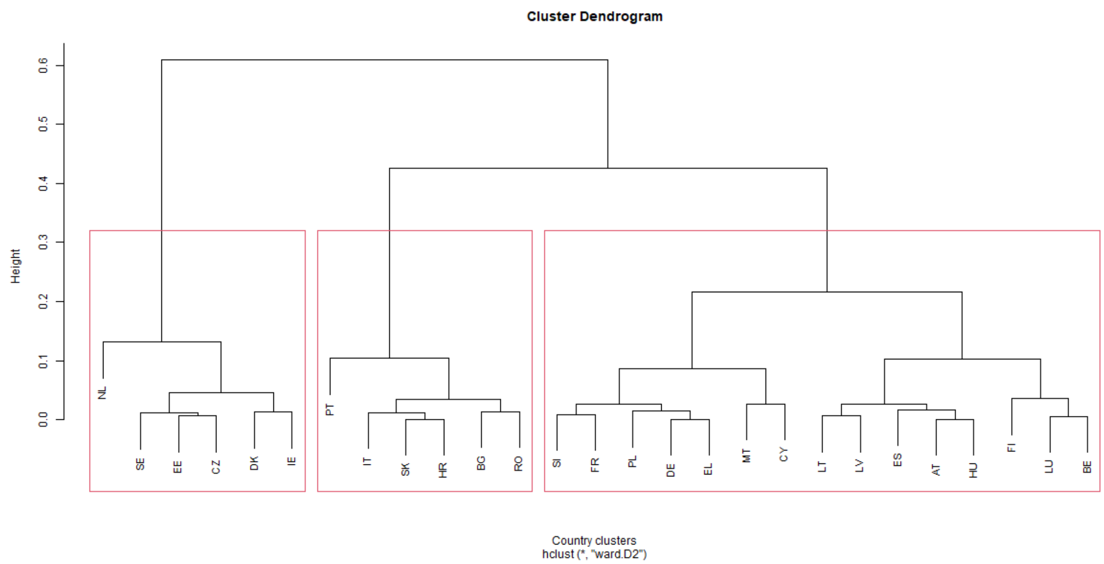


Figure 34: Results of the Ward clustering analysis performed on the CIDFP scores and the resulting three country clusters.

The results of the Ward clustering analysis show three groups of countries that we interpret as benchmark countries (NL, SE, EE, CZ, DK and IE), countries that require potentially important policy efforts to achieve the benchmark score (PT, IT, SK, HR, BG and RO) and those countries that require policy efforts to bring their scores in line with the benchmark countries (SL, FR, PL, DE, EL, MT, CY, LT, LV, ES, AT, HU, FI, LU and BE). The clustering analysis reflects the country rankings as shown in table 13.

8 Visualisation Interface for Composite Indicator Construction

In order to explore and analyse the Eurostat dataset and leverage its multidimensional nature, we have developed a set of visualisation tools in R, heavily based on the R libraries `plotly` and `shiny`. Both tools, as described in subsections 8.1 and 8.2, are interactive web interfaces, allowing data drilldowns, zooming and panning, and data labels on hover (all being native features of `plotly`).

8.1 Exploratory data analysis (EDA) dashboard

We created a web dashboard that allows the user to visualise and summarise a pre-filtered dataset, extracted from the Eurostat database. First, the user pre-filters the Eurostat data (as in figure 35).

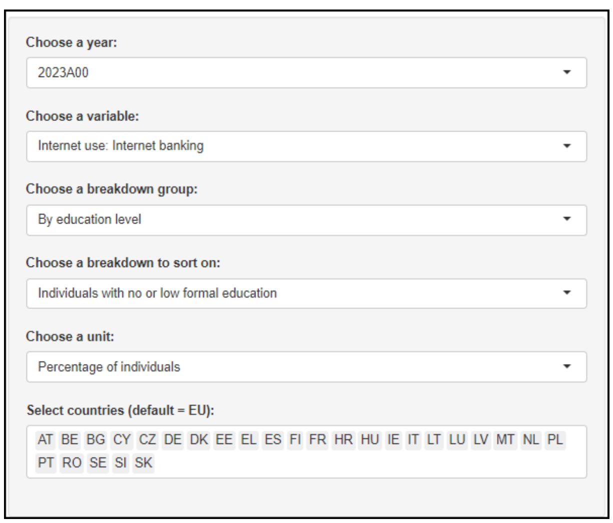
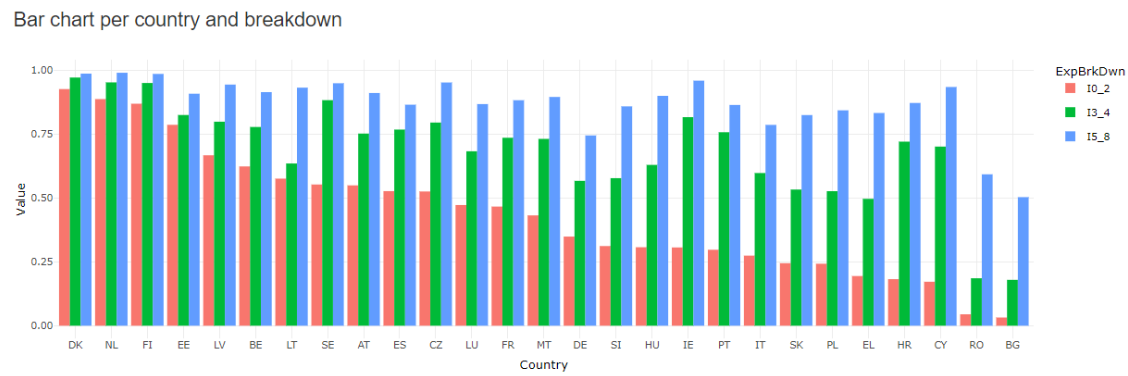


Figure 35: The user pre-filters the Eurostat database via a set of prompts

The visualisation is updated in real-time, and includes a grouped bar chart, basic summary statistics (mean, median, min, max, number of observations, and standard deviation) and a box plot, shown in figure 36, but also a time series plot as in figure 37.



Summary stats, per breakdown

ExpBrkDwn	ExpBrkDwnCaption	n	max	min	sd	average	median
I0_2	Individuals with no or low formal education	27	0.93	0.03	0.25	0.44	0.43
I3_4	Individuals with medium formal education	27	0.97	0.18	0.19	0.69	0.73
I5_8	Individuals with high formal education	27	0.99	0.50	0.11	0.87	0.90

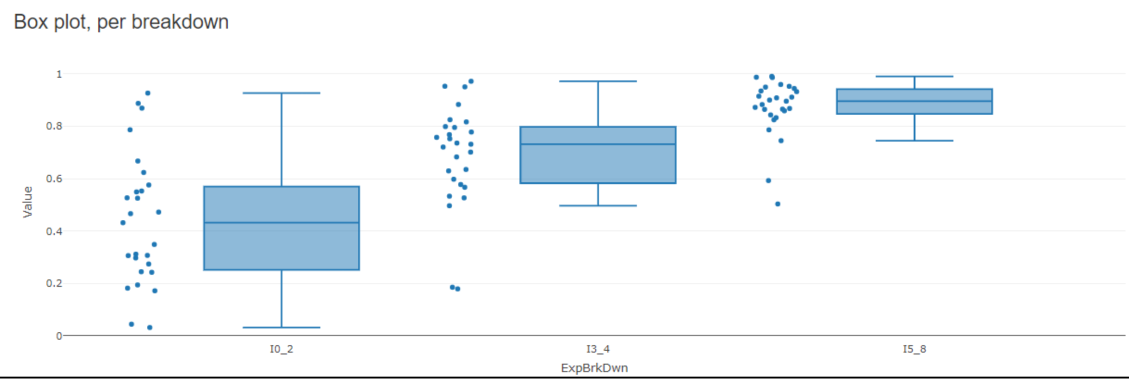


Figure 36: EDA: a grouped bar chart, summary statistics and a box plot, based on prompts in figure 35

The dashboard allowed us to easily spot patterns and relationships in the data. For example, in figures 36 and 37, depicting the percentage of individuals having used internet banking, split by education level, we notice the following:

- there is a high disparity in the use of internet banking across the EU (figure 36)
- the disparity is significantly more pronounced for individuals with no or low education (breakdown `I0_2`) than for highly educated individuals (breakdown `I5_8`)
- the trend is clearly positive across all three education breakdowns (figure 37)

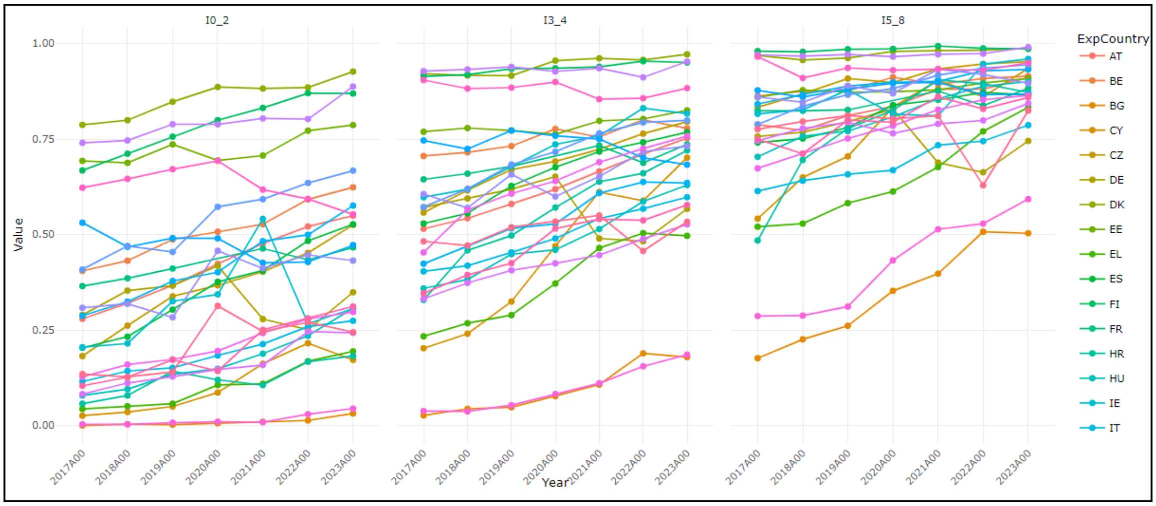


Figure 37: EDA: Time series view of the Eurostat data

- in some countries, when looking at two adjacent education breakdowns, the individuals in the lower education group reach a given level of internet banking usage six years later than the individuals in the higher education group (figure 37)

8.2 Benefit-of-the-doubt and PCA dashboard

For each of the seven sub-indicators in table 1, we also created a dashboard that helps us:

- run the benefit-of-the-doubt (BoD) model, the multi-dimensional BoD model, and the PCA, and plot the resulting scores side-by-side in one bar chart, to see whether the three techniques yield consistent results across countries

- fine-tune the selection of variables in each sub-indicator, to see in real-time the impact of inclusion or exclusion of a variable on the PCA/BoD scores

- constrain the min and max weight for each component variable, and see the impact of the changes in real-time

- plot a PCA biplot with the first two principal components, for the selected list of variables

See figure 38 for an example of the BoD/PCA dashboard for the sub-indicator “skills”.

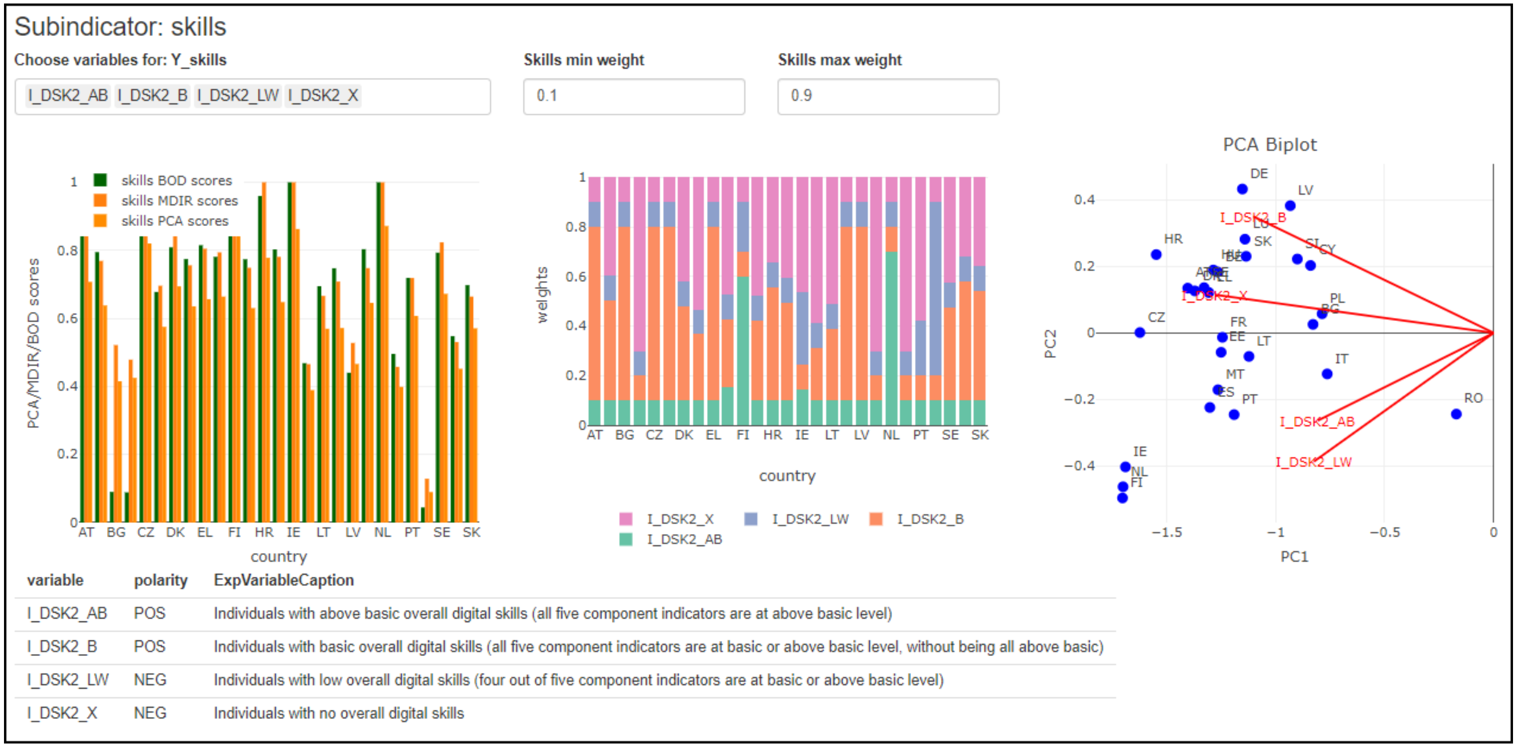


Figure 38: Interactive dashboard: Benefit-of-the-doubt and PCA analysis results for the sub-indicator “skills”

9 Conclusion

In this study we have proposed and constructed a composite indicator of Digital Financial Participation that is an aggregation of seven composite sub-indicators reflecting individuals' digital skill levels, digital financial activity, digital access infrastructure, digital devices used to conduct online financial activities, the frequency of use as well as measures of security attitudes and digital financial inclusion. The composite indicator was constructed using independent approaches that provide nearly identical results. The resulting Composite Indicator of Digital Financial Participation (CIDFP) allows for benchmarking how EU citizens engage in digital financial activities in a comparable manner across EU Member States by leveraging on harmonized data collected through Eurostat.

The weights of the sub-indicators in the final composite indicator suggest that our measure of digital inclusivity plays a key role in determining the degree of participation in digital finance across EU countries. In addition, the directional improvements resulting from the Multi-directional Benefit of the Doubt (MDBoD) methodology provide possible policy insights into how to improve individuals' participation in digital finance. Our results suggest that prioritizing policy programs that involve outreach to individuals with low digital skill levels may increase their digital financial activities, which can bring these individuals within reach of cheaper and more competitive financial services. In addition, the results related to our inclusivity measure suggest that fostering competition in the telecommunications sector can result in a reduction in internet access costs that could assist individuals in accessing online financial services.

We have also used radar charts and policy curves to better visualize and identify those EU Member States that could benefit from proactive policy initiatives targeted towards certain segments of their population. The clustering analysis has identified three categories that consist of benchmark countries, countries with more specific policy needs and countries that may require broader policy programs to achieve benchmark status.

Given the high dimensionality of the Eurostat data and the complexity involved in selecting variables to construct a composite indicator, we have also developed a powerful visualization tool that provides realtime feedback on how the addition or removal of a component variable affects the overall composite indicator score of the countries. The dashboard further allows for the simultaneous visualization of multiple approaches to indicator construction (e.g. BoD, MBoD, etc...) and provides the facility to assess the impact of weight restrictions as well as the removal of DMUs on the overall composite indicator scores.

With a wide range of technological developments in the retail payment market and digital finance coming to fruition, it will be paramount for EU Member States to track their progress in adopting these new innovations and services and to ensure that their respective populations are able to benefit from them to the fullest extent. We hope that the results of this study can assist policymakers in ensuring that all EU citizens can reap the benefits.

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