DIGITALIZATION INDICATORS AND THE STRUCTURAL TRANSFORMATION OF THE BANKING SECTOR: EVIDENCE FROM THE EUROPEAN UNION

DOI: https://doi.org/10.53486/dri2026.47
UDC: [336.71:061.1EU]:[004.056.5+004.78]

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Abstract: *This paper investigates whether selected digitalization indicators reflect the structural transformation of the banking sector in the European Union. The analysis is based on four complementary dimensions: the share of individuals using internet banking, the number of secure internet servers, the Digital Economy and Society Index (DESI), and the cybersecurity index. Methodologically, the study relies on a comparative longitudinal approach using country-level evidence for EU member states over partially overlapping periods determined by data availability. The findings show that digital banking transformation in the EU is strong, cumulative, and structurally relevant, but uneven across member states. Northern and Western countries display mature digital banking ecosystems, characterized by widespread online banking adoption, robust digital infrastructures, higher digital readiness, and stronger cybersecurity capabilities. By contrast, several Southern and Eastern member states continue to face persistent structural barriers linked to weaker digital infrastructure, lower digital skills, reduced trust in online services, and slower institutional adaptation. The paper argues that banking digitalization should be interpreted not only as technological modernization, but also as a broader restructuring of customer interaction, service delivery, operational models, and risk management. The study concludes that digital convergence in EU banking remains incomplete and requires coordinated action in infrastructure, digital literacy, financial education, and cyber resilience.*

Key words: *digitalization, banking sector, online banking, DESI, cybersecurity, European Union*

JEL: G21, O33, O52, C23

Introduction

Digitalization has become one of the strongest forces reshaping the banking sector in the European Union. What initially appeared as a gradual move toward electronic payments, card-based services, and internet banking has evolved into a broader structural transformation affecting customer interaction, service delivery, operational processes, data governance, and risk management. In this broader sense, digitalization is no longer limited to the adoption of isolated technologies, but represents a reconfiguration of how banks create value, organize internal functions, and compete in increasingly data-driven markets (Vial, 2019; Verhoef et al., 2021).

The relevance of this topic is amplified by the growing role of digital finance in economic modernization, financial inclusion, and institutional resilience. Recent studies show that digital transformation in finance is associated with operational efficiency gains, wider access to services, and changes in organizational capabilities, but also with higher exposure to cyber risk, regulatory challenges, and new inequalities in adoption (Mavlutova et al., 2023; Bueno et al., 2024; Wang et al., 2024). In banking, digital transformation increasingly overlaps with broader FinTech-driven change and with the capacity of institutions to redesign products, processes, and customer channels in line with the logic of Industry 4.0 (Gherțescu et al., 2024).

Within the European Union, this transformation remains markedly uneven. Although digital policy has advanced under a common European framework, national performances continue to differ substantially in terms of infrastructure, digital skills, business digitalization, and public service

readiness (Liu, 2022; Paraschiv et al., 2024). These asymmetries are reflected in the banking sector as well, where some member states have already reached mature digital ecosystems, while others remain constrained by limited infrastructure, lower digital trust, and slower institutional adaptation. Online banking adoption, in particular, continues to reveal large cross-country differences shaped by governance, technological progress, and crisis-related adjustment processes (Grigorescu et al., 2023; Iuga, 2025).

Starting from this context, the present paper examines the structural transformation of the banking sector in the European Union through four complementary indicators: individuals using the internet for online banking, secure internet servers, the Digital Economy and Society Index (DESI), and the cybersecurity index. Together, these variables capture the demand-side use of digital financial services, the robustness of digital infrastructure, the national level of digital readiness, and the security environment that sustains digital finance. Their combined interpretation makes it possible to move beyond narrow descriptions of technological adoption and toward a broader understanding of how banking structures evolve under digital pressure.

The main objective of the paper is to assess whether these indicators provide consistent evidence of a structural shift in EU banking and to identify the extent to which this shift differs across member states. Four working hypotheses guide the analysis. First, a higher share of internet banking users reflects a more advanced structural transformation of banking services. Second, stronger secure digital infrastructure supports the expansion of digital banking. Third, better national digital readiness, captured by DESI, facilitates banking transformation. Fourth, higher cybersecurity maturity makes this transformation more sustainable by reinforcing trust and resilience. The contribution of the paper lies in integrating these dimensions into a single analytical framework focused on the European Union and in interpreting banking digitalization as a cumulative structural process rather than as a simple technological upgrade.

Literature review

The literature on digital transformation increasingly emphasizes that digital change should be understood as a systemic process rather than as the simple adoption of new technologies. Vial (2019) defines digital transformation as a process through which digital technologies trigger significant changes in value creation, organizational arrangements, and strategic responses. Verhoef et al. (2021) extend this view by showing that digital transformation alters customer relationships, competitive logic, firm capabilities, and business models. These conceptual contributions are highly relevant to banking because they explain why digitalization affects not only channels of interaction, but also the structural organization of financial intermediation.

A second stream of research focuses more directly on the banking sector and shows that digitalization is linked to operational efficiency, financial inclusion, and strategic repositioning. Mavlutova et al. (2023) argue that digital transformation can support sustainable development in the financial sector by improving inclusion and operational effectiveness. Bueno et al. (2024) likewise demonstrate that digitization in banking is frequently associated with lower transaction costs, process optimization, and new research directions connected to platformization and service redesign. In the same area, Gherțescu et al. (2024) show that the literature on bank efficiency increasingly intersects with digital transformation, FinTech, and Industry 4.0 topics, indicating a growing shift in how banking performance is framed in recent scholarship.

Another important strand examines online banking adoption and digital convergence across countries. Liu (2022) shows that European digital policy outcomes remain heterogeneous even within a common institutional framework, while Paraschiv et al. (2024) confirm that DESI-related dimensions remain strongly associated with broader national progress in digital transformation. At the level of banking behavior, Grigorescu et al. (2023) identify convergence tendencies in e-banking across EU countries, but also persistent differences in adoption patterns. Complementing this perspective, Iuga (2025) highlights the role of governance and technological progress in explaining internet banking adoption

across major crisis periods, confirming that digital banking expansion depends on more than the simple availability of technology.

A fourth stream of literature emphasizes the role of cybersecurity and systemic resilience in digital finance. Wang et al. (2024) argue that data privacy and cybersecurity are central challenges in the digital transformation of banking, especially in highly connected financial systems. Yudaruddin et al. (2023) further show that financial technology can influence bank stability, which suggests that digital progress should not be assessed only through adoption or efficiency, but also through the resilience of the environment in which innovation is embedded. Xu et al. (2025) similarly conclude that FinTech increasingly affects bank performance through multiple channels, including efficiency, innovation, and competitive adjustment. Although the literature is expanding rapidly, fewer studies combine usage, infrastructure, digital readiness, and cybersecurity in a single EU-wide analytical narrative. This paper addresses that gap.

Methodology

The paper relies on a comparative longitudinal research design based on secondary country-level evidence for the member states of the European Union. The analysis is developed around four indicators that capture complementary dimensions of digitalization: individuals using the internet for online banking services, secure internet servers per million inhabitants, the Digital Economy and Society Index (DESI), and the cybersecurity index. The periods covered differ according to data availability: 2013-2024 for online banking use, 2010-2024 for secure internet servers, 2017-2022 for DESI, and 2014-2023 for cybersecurity maturity. This structure allows the paper to capture both demand-side and supply-side aspects of banking digitalization, while also accounting for the broader institutional and security environment in which digital finance evolves.

Methodologically, the study does not claim causal identification. The available evidence is descriptive-comparative and is interpreted through trend analysis, leader-laggard comparisons, regional clustering, and cross-indicator synthesis. The approach is therefore appropriate for identifying the structural direction of change and for highlighting persistent asymmetries between EU member states. The analysis is guided by the idea that digital transformation in banking can be assessed through a cumulative interpretation of four interconnected layers: customer adoption, infrastructure, national digital readiness, and cybersecurity resilience. In this sense, the paper uses the selected indicators as proxies of structural transformation rather than as isolated descriptive statistics.

The interpretation is also shaped by the institutional context of European digital monitoring. DESI remains a core reference point for the period up to 2022, while for later years the shift toward the Digital Decade framework signals a methodological transition in how digital progress is monitored at EU level. A limitation of the study is that the analysis is not based on panel econometric estimation and therefore cannot measure the magnitude of causal effects among variables. However, the comparative evidence remains highly relevant for identifying common trends, persistent divergences, and the broader logic through which digitalization is transforming the banking sector across the European Union.

Results and discussions

Individuals using the internet for online banking services

The first dimension analyzed concerns the share of individuals using the internet for online banking services. This indicator captures the extent to which digital delivery channels have become integrated into ordinary banking behavior and therefore provides a direct signal of structural transformation on the demand side. Between 2013 and 2024, the indicator registered a positive evolution in all EU member states, but the pace and the final levels differed considerably across regions. The data reveal a persistent contrast between the digitally mature systems of Northern and Western Europe and the less advanced systems of Southern and Eastern Europe.

The Nordic and Western countries remain constant leaders, confirming a very high level of digital banking maturity. Denmark, Finland, and Sweden all exceeded the 90% threshold, with Denmark

reaching 97.8% in 2024. Finland surpassed 93%, while Estonia and the Netherlands also recorded values above 90%, which indicates an almost complete integration of digital banking services into everyday financial activity. Luxembourg, Belgium, and Austria maintained high levels as well, generally ranging between 70% and 85%, which suggests a stable and consolidated digital ecosystem. These results point to a model of banking in which online access is no longer an auxiliary channel, but the dominant interface between clients and institutions.

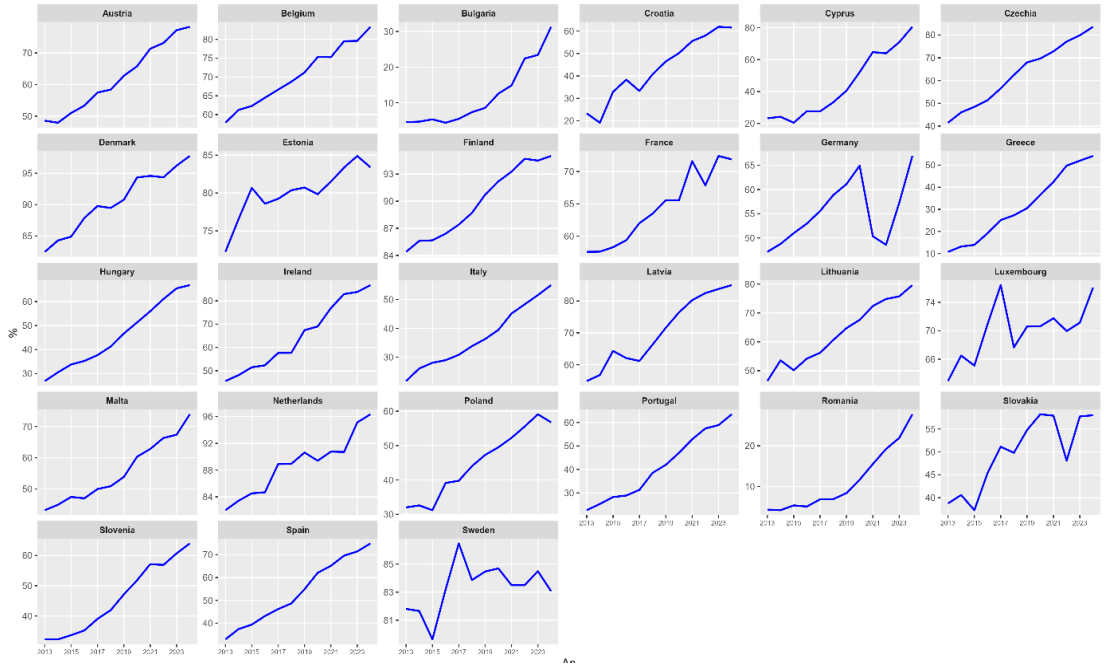

Figure 1. Evolution of the share of individuals using the internet for online banking services in EU member states (2013-2024)

Source: author's own processing based on Eurostat data

Central and Eastern Europe started from lower levels but recorded significant recovery. Lithuania increased from 46% in 2013 to 79% in 2024, while Latvia advanced from 55% to 84%, confirming the dynamic position of the Baltic states in the rapid adoption of digital banking. Poland and Hungary also recorded steady increases and exceeded the 60% threshold in recent years. Nevertheless, Romania and Bulgaria remain far below the EU average, with values of 27.7% and 31.3%, respectively, in 2024. Both countries are more than 40 percentage points below the EU average of 71.7%, which suggests that substantial structural barriers continue to affect digital adoption. These barriers are likely linked to weaker digital infrastructure, lower levels of financial and digital literacy, and reduced trust in online banking services.

Southern Europe displays an intermediate profile, with visible progress especially after 2020. Spain increased from 38% to above 70%, Portugal from 22% to around 60%, and Italy from 28% to 52%. Greece, although starting from extremely low values below 10% in 2013, reached 54.1% in 2024. This pattern suggests that the pandemic acted as an accelerator, forcing a faster transition toward digital banking solutions in countries where face-to-face intermediation had previously remained relatively strong. From a temporal perspective, two key moments are visible: 2015-2017, when acceleration became clear in the Nordic and Baltic states, and the post-2020 period, when Southern and Eastern Europe moved more decisively toward digital service adoption.The comparative distribution in 2024 highlights strong polarization within the European Union. Denmark exceeds the EU average by more than 26 percentage points, whereas Romania and Bulgaria remain more than 40

percentage points below it. Greece occupies an intermediate position, with 54.1%, reflecting meaningful recovery but not full convergence. Overall, the indicator shows that banking digitalization has become a central pillar of financial intermediation in the EU, but also that the process still unfolds at different speeds. In structural terms, the Union continues to function with a two-speed digital banking system: a Northern-Western group close to saturation and a Southern-Eastern group still engaged in a slower and uneven catching-up process.

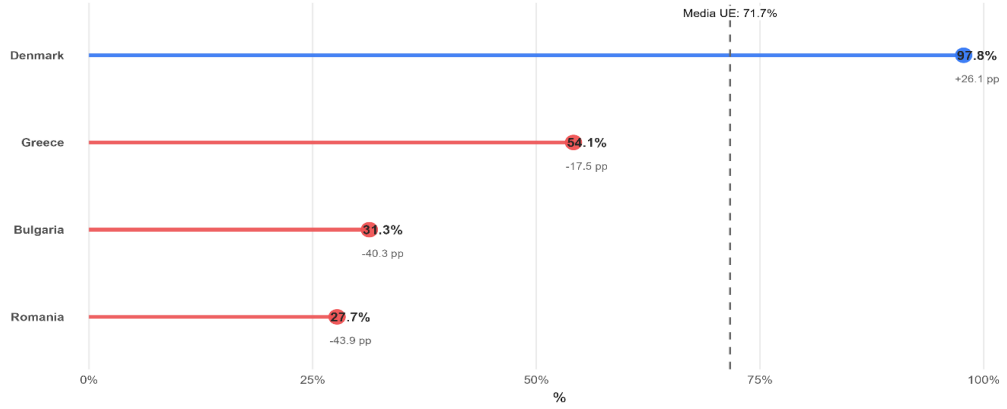

Figure 2. Comparative analysis of the highest and lowest levels of online banking use in the European Union (2024)

Source: author's own processing based on Eurostat data

Secure internet servers

The second indicator concerns secure internet servers, which represent one of the core pillars of digital infrastructure. Online banking, mobile banking, remote onboarding, and digital payments all depend on a secure online environment capable of protecting transactions and user data. For this reason, the number of secure internet servers per population can be interpreted as an indirect but highly relevant measure of the infrastructure that supports digital banking. A larger number of secure servers suggests a stronger technical environment for protected online interaction, which in turn may strengthen user trust and facilitate the expansion of digital financial services.

Between 2010 and 2024, all EU member states recorded growth in this indicator, but the scale of the increase differed widely. Germany stands out very clearly, with more than 12.7 million secure internet servers per million inhabitants in 2024, compared with an EU average of approximately 1.24 million. This result highlights not only Germany's economic and technological strength, but also the fact that digital banking expansion is supported by a very robust security infrastructure. In this setting, the

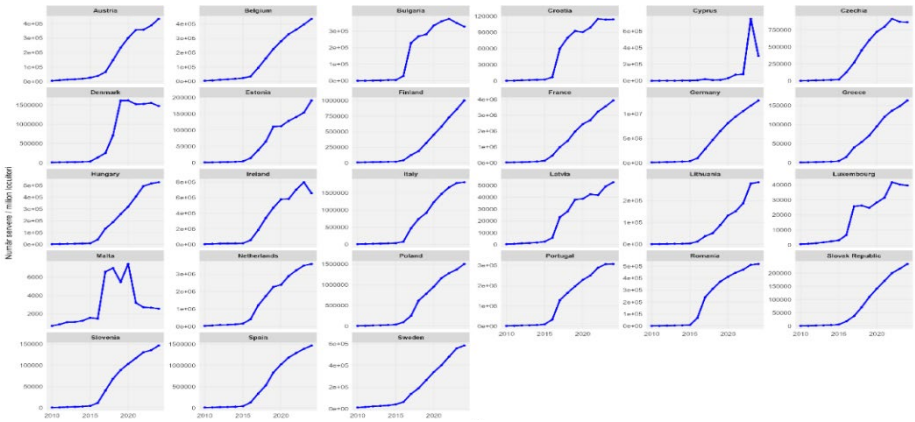

Figure 3. Evolution of secure internet servers per one million inhabitants in EU member states (2010-2024)

Source: author's own processing based on World Bank data

country functions as a hub of digital trust, where secure connectivity and data protection provide favorable conditions for the expansion of online banking services.

At the opposite end of the distribution, small or peripheral states such as Malta, Latvia, and Luxembourg record much lower values. The supplied results indicate values of 2,564 servers for Malta, 52,659 for Latvia, and 39,563 for Luxembourg. In structural terms, these lower values may limit the scale and speed of digital banking expansion, since insufficient security infrastructure can discourage both institutions and users. In Luxembourg, however, the interpretation must remain cautious because the structure of the financial sector and the concentration or externalization of digital services may influence the indicator differently than in larger countries.

The period 2015-2020 marks a particularly visible acceleration in all countries, driven by tighter cybersecurity requirements, the expansion of e-commerce, and the increased use of online banking services. After 2020, the pandemic reinforced this movement because digital delivery became, in many situations, the only practical option. Countries such as Romania, Poland, and Lithuania recovered part of the gap more rapidly, reaching several hundred thousand secure servers and thereby creating more favorable conditions for faster digital banking adoption. Based on the supplied evidence, three broad categories can be distinguished: digital leaders such as Germany, France, the Netherlands, Poland, and Spain; a medium-development group including Italy, Romania, the Czech Republic, and Portugal; and a lower-level group including Malta, Latvia, and Luxembourg.

The indicator confirms that digital banking depends not only on customer demand, but also on the quality and depth of technical infrastructure. A stronger security architecture supports innovation, improves confidence, and enables banks to provide more advanced services. At the same time, the persistence of major asymmetries across countries shows that digital convergence within the EU banking sector is still incomplete and continues to depend on unequal national investments in infrastructure and cyber protection.

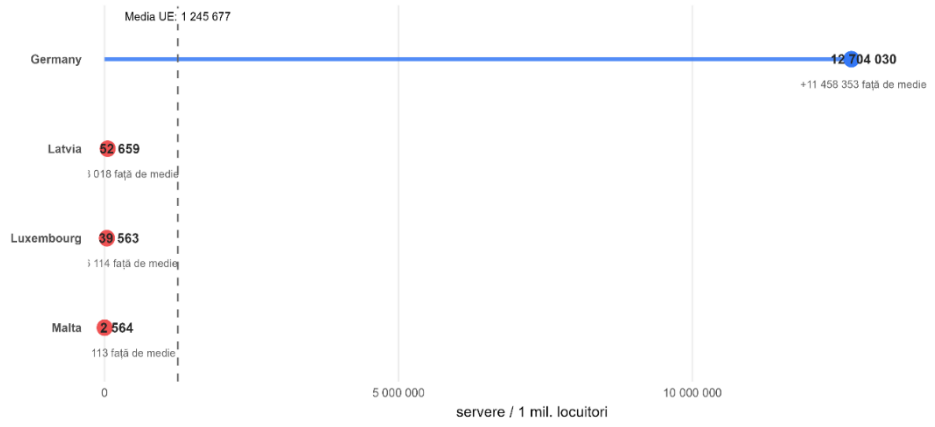

Figure 4. Comparative analysis of secure internet servers reported to population in EU member states with extreme levels (2024)

Source: author's own processing based on World Bank data

Digital Economy and Society Index (DESI)

The third dimension is represented by DESI, which provides a synthetic picture of digital development in EU member states and is therefore essential for understanding the broader environment in which banking digitalization takes place. Up to 2022, DESI was structured around four analytical components: human capital, connectivity, integration of digital technology, and digital public services. From 2023 onward, the classic DESI format was integrated into the Digital Decade monitoring architecture, which preserves analytical continuity but changes the reporting structure.

This methodological transition is relevant for banking studies because it affects the comparability of long-run digital readiness measures.

The supplied results show that the total DESI index followed an upward trajectory in all member states between 2017 and 2022, although at different speeds. The Nordic countries, namely Denmark, Finland, and Sweden, recorded the highest values and exceeded 65 points in 2022. These performances are associated with strong digital infrastructure, a high level of digital skills, sustained investments in innovation, and broad integration of technology into strategic sectors. The Netherlands and Ireland also positioned themselves at an advanced level, confirming structural convergence with the traditional digital leaders. In Western Europe, progress was positive but more moderate: Germany, France, Austria, and Belgium reached values in the range of 50 to 53 points. Central and Eastern Europe displays a mixed but generally improving pattern. Estonia and Lithuania exceeded 50 points and approached the values of several Western states, while the Czech Republic followed a similar path. Poland, Slovakia, and Hungary remained in the interval of 40 to 44 points. Romania and Bulgaria stayed below 40 points, although with a steady growth rate, which suggests a gradual but incomplete narrowing of the digital gap. Southern Europe also evolved unevenly. Spain stands out through a rapid advance beyond 60 points in 2022, Italy approached 50 points, Portugal exceeded 50, while Greece, Cyprus, and Croatia continued to improve from lower absolute levels.

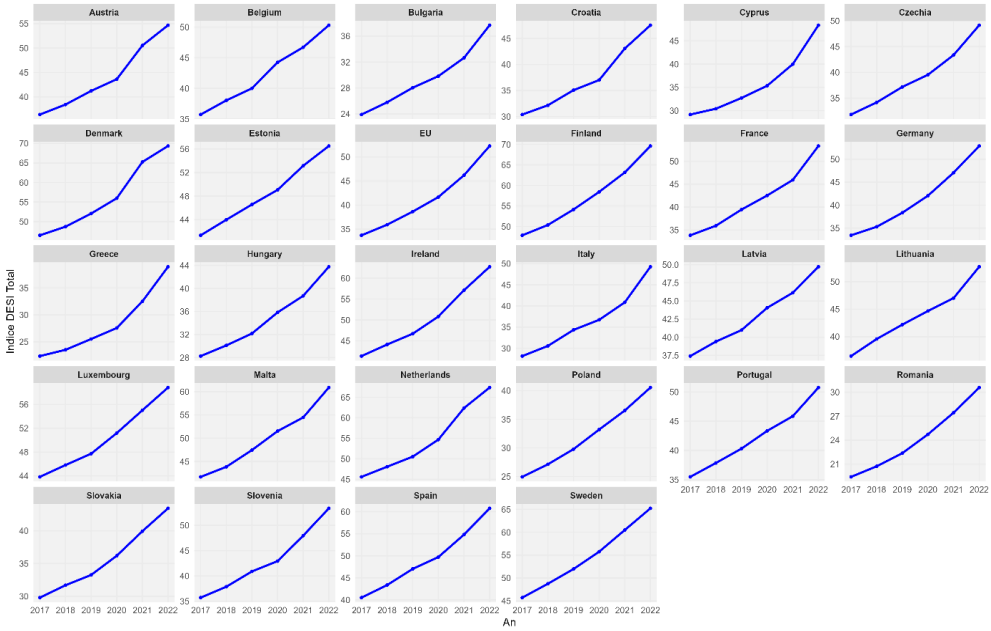

Figure 5. Evolution of the total DESI score in EU member states (2017-2022)

Source: author's own processing based on European Commission DESI data

The comparative pattern reveals two broad clusters: a group of states characterized by high digital maturity, relatively stable values, and structural convergence, and another group still in a recovery stage, where progress is visible but the gap persists. For the banking sector, this result is especially important because it shows that digital transformation is embedded in a wider national context. Where digital skills are stronger, connectivity is better, business digitalization is deeper, and public services are more digitalized, banks are more likely to benefit from a supportive environment for structural transformation. DESI therefore works as a contextual indicator of the national ecosystem within which digital banking develops.

Cybersecurity index

The fourth dimension concerns the cybersecurity index, which reflects the maturity of national systems of digital protection and the capacity of institutions to respond to cyber threats. In banking, this dimension is fundamental because the expansion of digital channels increases exposure to cyber risk and makes trust inseparable from security preparedness. The period 2014-2023 indicates accelerated convergence across the EU, supported by the harmonization of the regulatory framework, the strengthening of national cybersecurity strategies, and growing investments in critical infrastructures.

The time series suggest that during 2014-2016 the values of the index were moderate, generally ranging between 40 and 70 points in most countries. Between 2017 and 2020, however, the indicator increased sharply, with some states advancing by 20 to 30 points in a short interval. This phase can be interpreted as a period of accelerated institutional and technological adjustment. After 2020, the curves tend to flatten, and in many cases the values stabilize between 85 and 95 points. This plateau does not indicate stagnation, but rather a shift from rapid capacity-building toward consolidation, optimization, and the adoption of more sophisticated technologies.

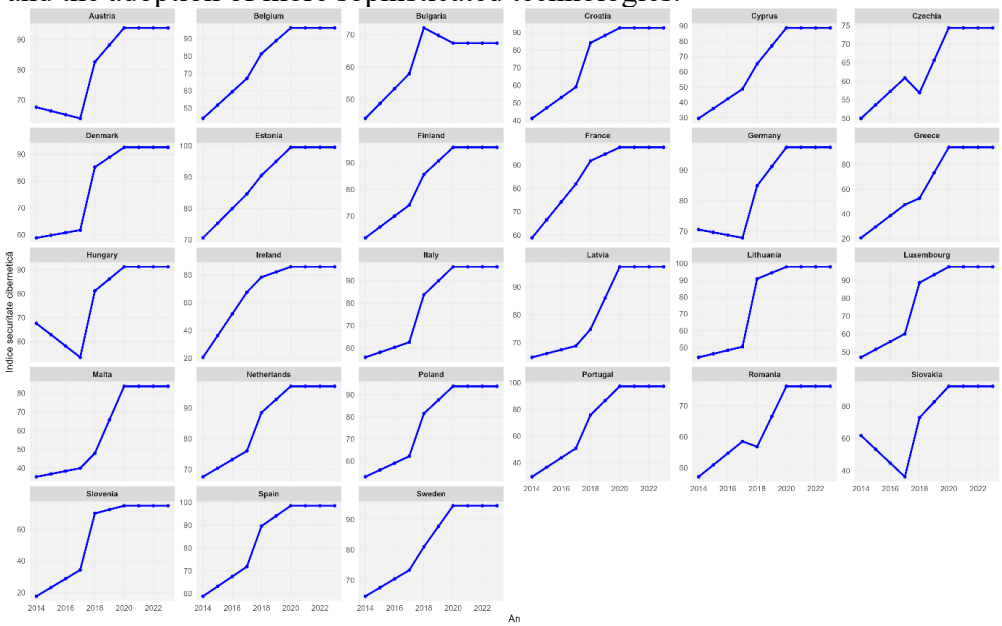

Figure 6. Evolution of the cybersecurity index in EU member states (2014-2023)

Source: author's own processing based on cybersecurity monitoring data

The best-performing countries include Estonia, Finland, Portugal, and Spain, each reaching 100 points in the supplied data. France and Germany also maintain high values, generally between 90 and 95 points, although their growth slows after 2020 as their systems approach maturity. At the lower end of the distribution, Romania, Bulgaria, Croatia, and Greece remain below the EU leaders, despite recording visible improvements. This confirms the persistence of a structural asymmetry: even when late adopters improve rapidly in absolute terms, the relative distance from the most advanced digital systems often remains significant.The results indicate three broad phases in the evolution of cybersecurity across the EU: a stage of moderate values and high variation during 2014-2016; a stage of accelerated growth and statistical convergence during 2017-2020; and a stage of plateauing and maturation during 2021-2023. The supplied evidence also reports an average annual growth rate for the EU of around 5.8% between 2014 and 2020, followed by a rate below 2% after 2020, which reinforces the interpretation of saturation. At the same time, the persistence of lower scores in South-Eastern Europe suggests that financial resources, institutional capacity, and human capital continue to shape the pace of cybersecurity convergence.

From the perspective of banking transformation, the cybersecurity index is particularly important because it connects digitalization with resilience. A banking system may digitalize rapidly, but if cyber protection remains weak, that progress becomes more fragile and less sustainable. The findings therefore suggest that structural transformation in banking is strongest where customer adoption, infrastructure, digital readiness, and cybersecurity mature together. Taken as a whole, the four indicators confirm that digitalization in EU banking is not a marginal or purely technical process, but a broader structural reconfiguration of how financial services are produced, delivered, and secured.

Conclusions

The paper examined whether selected digitalization indicators capture the structural transformation of the banking sector in the European Union. The answer is affirmative. The increasing use of online banking, the strengthening of secure digital infrastructure, the upward evolution of DESI, and the improvement of cybersecurity maturity all indicate that banking in the EU is moving toward a more digital, more remote, and more data-driven model of intermediation. At the same time, the results clearly show that this transformation remains uneven across member states and continues to be shaped by significant structural differences.

From a policy perspective, the findings suggest that digital convergence in banking cannot be achieved through financial-sector measures alone. It requires coordinated efforts in digital infrastructure, digital skills, financial education, cybersecurity capacity, and institutional support for innovation. The evidence also shows that trust is a decisive factor. Even where technical infrastructure improves, the adoption of digital banking may remain limited if users lack confidence in the security and reliability of online services. For this reason, digital banking policy should integrate both technological and social dimensions of transformation.

The paper has several limitations. First, it is based on descriptive and comparative evidence rather than on causal econometric estimation. Second, the time windows differ across indicators, which constrains perfect synchronic comparison. Third, secure internet servers and the cybersecurity index capture the broader digital environment rather than bank-level variables only. Nevertheless, these limits do not weaken the central conclusion of the study: digitalization in EU banking is cumulative, structurally significant, and still characterized by incomplete convergence. Future research may extend this analysis by integrating panel econometric techniques, efficiency indicators, profitability measures, and more detailed banking variables in order to test the magnitude and direction of the relationships suggested here.

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