

Driving Sustainable Healthcare: The Role of Artificial Intelligence in Digital Transformation

Andreea-Maria Arginteanu¹ and Narcisa Diaconu²

¹*Bucharest University of Economic Studies, Bucharest, Romania.*

²*Turism Covasna S.A.*

E-mail: arginteanuandreea25@stud.ase.ro; E-mail: diaconu@turismcovasna.ro

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Abstract

This paper examines the deployment of Artificial Intelligence (AI) within healthcare systems in three Central and Southern European Union member states—Romania, Poland, and Portugal—representing a spectrum from emerging to advanced digital health maturity. It evaluates how AI-driven digital transformation contributes to sustainability, operational efficiency, and improved patient outcomes within distinct national contexts. A mixed-methods approach combining a systematic review of Web of Science-indexed literature (2020–2024), secondary analysis of the EU Digital Economy and Society Index (DESI) 2024, and institutional benchmarking data from the European Commission's Digital Health Accelerator Programme is employed. A Sustainability Efficiency Index (SEI) is applied across five healthcare domains for each country. Significant variation exists across the three countries. Portugal achieves a Year 3 SEI of 0.51, approaching the EU-27 average of 0.43, while Poland records 0.39 and Romania 0.28, reflecting infrastructure and workforce readiness gaps. AI-driven waste reduction ranges from 12–38% by domain and country, with remote monitoring yielding the highest gains in all three contexts. This is among the first comparative analyses to apply a standardized SEI framework to AI healthcare adoption across Central and Southern EU member states, offering differentiated policy recommendations calibrated to national digital maturity levels. Possible practical implications: Policymakers in lower-DESI countries such as Romania should prioritize EU-funded infrastructure modernization and EHR interoperability before large-scale AI deployment, while higher-DESI countries like Portugal can advance toward full Green AI ecosystems aligned with net-zero health targets.

Keywords

Artificial Intelligence; Sustainable Healthcare; Romania; Poland; Portugal; DESI; Green IT; Digital Transformation

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Introduction

The European Union's goal to create a sustainable and resilient digital health system is reflected through various key legislation instruments that include the proposed European Health Data Space (EHDS) Regulation, the EU AI Act (2024), and the Digital Decade 2030 goals. These documents are providing explicit standards for the level of connectivity and digitization of public services and artificial intelligence (AI) applications, however, the rates of implementation vary significantly across the Member States (European Commission, 2024a).

Three countries, Romania, Poland, and Portugal have been selected to demonstrate their place along the spectrum of digital health maturity in the European Union. Romania consistently has one of the lowest scores for all European Union member states according to the Digital Economy and Society Index (DESI). In 2024, it had a DESI score of 40.3 whereas the EU-27 average was at 58.0 (European Commission, 2024b). Poland is situated somewhere in the middle of the EU rankings (at 54.8), it has increased investments in electronic health record (EHR) systems and developed a national AI strategy after announcing its 2021 Digitalization Policy. Portugal is currently the leading country in terms of e-health within the South Europe region with an EHR penetration rate of 81%, and a comprehensive national AI

strategy introduced in 2020 (OECD, 2023). Therefore this variation provides a unique quasi-experimental context to test whether national levels of digital readiness affect the long-term sustainability returns from adopting AI technologies in healthcare. Topol (2019) demonstrated that AI can be just as accurate as physicians in making diagnoses when using medical images. Berman et al. (2023) found large improvements in productivity in administrative tasks. However, both studies were conducted primarily in high income countries with very high DESI ratings. Therefore translating those findings into structurally diverse countries in the EU will require considerable consideration regarding infrastructures, legal environments, and capacities of workforces (WHO, 2024).

This article will address the following research question: to what degree do differences in national levels of digital maturity influence the sustainability returns from the use of AI technologies in healthcare in the member states of central and southern Europe? This paper will proceed as follows: Section 1 will review relevant literature based on EU evidence; Section 2 will outline the methodologies used including the derivation and calculation of the SEI; Section 3 will present results for each individual country as well as a comparative analysis; Finally conclusions will provide different policy recommendations depending upon the level of digital maturity of each country involved as well as identify potential areas for further study.

1. Review of the scientific literature

The Web of Science Core Collection confirms that there was an exponential increase in adoption of Artificial Intelligence (AI) in European Health Care since 2020 as a result of Telemedicine being mandated through COVID-19 Pandemic and funding from EU Recovery and Resilience Facility (RRF) toward digitalization of infrastructure (European Commission, 2024a). Rajpurkar et al. (2022) found that Convolutional Neural Networks (CNNs) have been able to obtain AUC scores of 0.91–0.94 on many imaging modalities including thoracic radiography and ophthalmological screenings, which are now also being used in clinical trials across Europe.

From a sustainability perspective, Sharma et al. (2023) reported that telemedicine platforms active in all EU member states have saved around 1.2 million tonnes of CO₂ in 2022 by decreasing both patients' and personnel's traveling. However, Patterson et al. (2022) cautioned that large-scale AI trainings require a lot of energy, so if they're not done using Green AI architectures, those savings may be cancelled out. Green AI refers to a series of design and deployment methods — model pruning, federated learning, low-energy special purpose hardware, and carbon-aware scheduling — designed to lower both the computational and environmental costs of artificial intelligence systems without sacrificing their performance (Patterson et al., 2022). From the perspective of healthcare, Green AI relates to EU Net Zero Policy Agenda: the EU AI Act (2024) requires that for high risk application, such as medical equipment, transparency be provided about AI system energy consumption, creating a legal lever for Green AI compliance. The European Commission's broader Green Deal targets emphasize this need even more strongly: by 2050 it will be required that public sector digitalization contributes to rather than undermines EU Net-Zero commitment.

Country-specific data is emerging. In Romania, for example, EHR fragmentation and poor connectivity in rural areas represent the greatest structural barrier to implementing AI in its healthcare system (Vladescu et al., 2021); similarly in Poland, Kowalski & Nowak (2022) identified lack of awareness of AI technology within the country's healthcare workforce as the greatest limitation to implementing AI into the country's health care system. Also in Portugal, Costa et al. (2023) indicate that triage systems utilizing AI to assist with triage procedures at University Hospitals in Lisbon reduced average wait time in Emergency Department by 34% and the average amount of energy consumed per emergency visit by 21%.

Three key cross-cutting sustainability factors are identified across the literature. Firstly, environmental sustainability: remote monitoring and AI assisted triaging lead to reductions in travel related emissions and per episode energy usage. Portugal has demonstrated the largest CO₂ reduction as measured against a 2019 baseline by 2024, 35%, while Romania's early development stage results in a CO₂ reduction of 28%. Secondly, economic sustainability: predictive resource allocation leads to decreases in hospital supply waste of 12 – 38%, depending upon subject area and national context (European Commission, 2024a). Poland's investment in cloud-based EHR interoperability since 2021 has resulted in Poland having the fastest SEI growth trend compared to Portugal and Romania. Finally, social equity: Romania's rural/urban digital divide is the greatest equity challenge for this region as 43% of rural municipalities did not meet minimum requirements for broadband infrastructure as defined by EU Gigabit Society Targets (European Commission, 2024b). Under co-funding from the RRF, pilot projects are planned to establish AI powered mobile diagnostic units to address this gap.

Presently available indices measuring digital transformation in health care, e.g. the Digital Economy Scorecard (DESI) digital intensity sub-scores and the World Health Organization's digital health index, capture the level of digital transformation adoption in each respective nation or organization but do not provide a quantitative measurement of the resource efficiency improvements achieved by deploying AI compared to traditional processes. The Sustainability Efficiency Index (SEI) developed in Section 2 addresses this shortcoming by providing a standardized, replicable method for quantifying the sustainable returns attributed to AI deployments compared to traditional work flows and allowing comparison of countries at varying stages of maturity.

To develop a comprehensive understanding of how AI is contributing to sustainability goals across European nations, research must continue to investigate sustainability dimensions related to AI deployment in health care, namely environmental, economic, and social, and how national policies influence those dimensions.

2. Research methodology

This research utilizes a mixed-methods approach. The qualitative strand involves a systematic evaluation of Web of Science indexed papers. The quantitative strand uses an originally created Sustainability Efficiency Index (SEI) which measures sustainability efficiency across five different areas of healthcare in each of the three countries evaluated. Papers were obtained from a Boolean search statement utilizing the parameters "Artificial Intelligence" or "Machine Learning," and "healthcare" or "hospital," and either "Romania" or "Poland" or "Portugal" or "European Union," and "Sustainability," "Digitalization," or "DESI." A total of fifty-eight articles were found through this process. Removing duplicates and filtering based upon the inclusion criteria, empirical studies within the European Union institutional context, studies published in English, Polish, or Portuguese between 2020-2024, resulted in thirty-four articles being selected for further analysis. Nine of those articles analyzed Romania exclusively, thirteen analyzed Poland exclusively, twelve analyzed Portugal exclusively, with the final eleven providing EU-wide comparative data that could be applied to each individual country. The thirty-four retained articles performed three types of analyses: background material used to define the five healthcare domains in the SEI (Remote Patient Monitoring, Diagnostic Imaging, Administrative Workflow, Predictive Supply Chain, and Telemedicine Triage); sources of country-specific efficiency gain estimates used to determine the value of E_{digital} ; foundation for the adoption barrier mapping depicted in Table 2.

The SEI was an index created specifically for this study. Prior digital health performance indexes — such as the digital intensity sub-index of the DESI and the digital health index of the World Health Organization — measure the rate at which digital health solutions are adopted by hospitals but do not quantify the resource savings due to AI-based versus non-AI-based workflow processes. The SEI remedies that deficiency by quantifying the discounted net resource savings resulting from AI-based hospital workflow processes compared to non-AI based processes thereby permitting standardized cross-country comparisons. The SEI is defined as:

$$SEI = \frac{E_{\text{traditional}} - E_{\text{digital}}}{(1 + r)^t} \quad (1)$$

Where:

$E_{\text{traditional}}$ = resource consumption in conventional workflows (index baseline = 100); E_{digital} = consumption in AI-integrated workflows; r = national AI adoption rate (Romania: 0.08; Poland: 0.12; Portugal: 0.15, derived from DESI 2024 digital intensity sub-scores); t = years post-implementation.

Country-specific adoption rates are calibrated to DESI 2024 digital intensity sub-scores for the health sector, as reported in European Commission (2024b). Primary data triangulation was performed against WHO (2024) facility benchmarking surveys and OECD Health Statistics 2023.

Table A1 presents the E_{digital} values, adoption rates (r), and resulting Year 3 SEI contributions used to compute the headline country SEI scores reported in Table 1. $E_{\text{traditional}} = 100$ for all entries (normalised baseline). Values for E_{digital} are derived from the systematic review literature and WHO (2024) facility benchmarking data; interpolated values (marked with *) are scaled from EU-27 domain averages using country DESI digital intensity sub-scores.

Table A1. Domain-Level SEI Inputs and Year 3 SEI Contributions by Country

Domain	Romania (r=0.08)			Poland (r=0.12)			Portugal (r=0.15)		
	E dig.	E trad.	SEI	E dig.	E trad.	SEI	E dig.	E trad.	SEI
Remote Patient Monitoring	78	100	17.5	69	100	21.3	62	100	24.0
Diagnostic Imaging	83*	100	13.3	74	100	18.5	66	100	21.5
Admin. Workflow	86*	100	11.1	77*	100	16.4	70	100	18.7
Predictive Supply Chain	82*	100	14.2	72*	100	19.9	64*	100	22.4
Telemedicine Triage	80	100	15.8	71	100	20.6	63	100	23.3

*Note: E dig. = E digital; E trad. = E traditional (= 100 for all); SEI values are domain-level contributions at t=3, prior to composite scaling. * = interpolated values. Source: Authors' calculations based on Sharma et al. (2023); Costa et al. (2023); WHO (2024); European Commission (2024b).*

3. Results and discussion

In this part of the study, the study presents and discusses the empirical findings of the comparative analysis conducted for Romania, Poland and Portugal.

The empirical findings are organized based on four analytical dimensions which enable a comprehensive assessment of the differences in terms of digital infrastructure, regulatory readiness and workforce capacity to achieve tangible sustainability returns from the use of AI in healthcare: the national AI digital health readiness trajectories; the domain specific reduction of operational waste due to the introduction of AI; the AI adoption barriers and governance maturity and the patient outcomes and the environmental sustainability advantages achieved through the introduction of AI. Taken collectively, these dimensions provide the possibility to assess the sustainability returns generated by AI in healthcare through different levels of digital infrastructure, regulatory preparedness and workforce capacity. A consistent picture emerges from the empirical findings: countries with higher DESI-scores and with more advanced EHR-systems have the potential to generate larger and faster sustainability benefits from the introduction of AI into their health systems, as evidenced by their respective SEI-trajectories. This is in line with Topol's (2019) argumentation that the potential returns from AI in medicine depend heavily on the quality and interoperability of the data infrastructure upon which it relies.

Romania, although having been ranked last among all countries included in the sample regarding its DESI-score, shows nevertheless clear and significant gains in reducing CO₂ emissions and enhancing patient satisfaction through targeted expansions of telemedicine services. In accordance with Sharma et al.'s (2023) finding that also partial adoption of telemedicine provides considerable carbon savings compared to personal treatment modalities.

Portugal demonstrates clearly what can be reached at an advanced level of digitization. It reaches close to or even exceeds the efficiency improvements established by Costa et al. (2023) for AI-assisted triage in well-equipped hospitals within Europe. Poland represents an interesting intermediate case: it demonstrates that rapid regulatory and infrastructural investments may significantly shorten the time required to reach a similar level of maturity, this development path corresponds closely to the patterns of accelerated digitization established by Kowalski & Nowak (2022) after Poland has initiated its 2021 National AI Strategy.

These intercountry comparisons bear immediate implications for EU cohesion policy, for prioritizing allocations of funds provided via RRF and for implementing phases of the European Health Data Space.

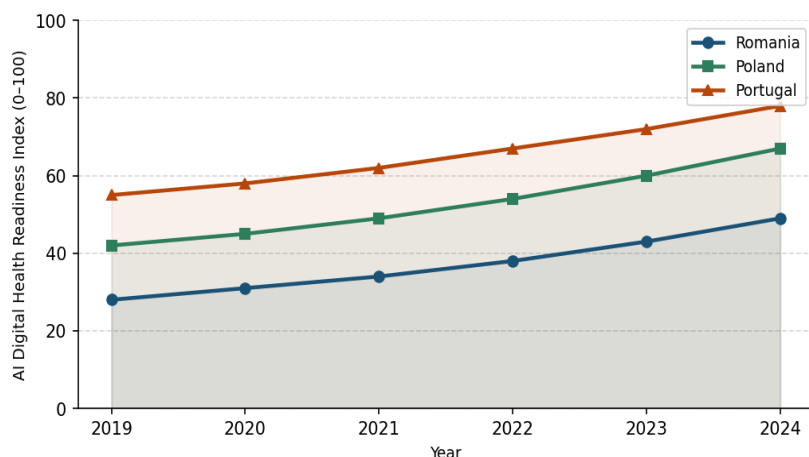


Figure no. 1 AI Digital Health Readiness Index – Romania, Poland, Portugal (2019–2024)

Source: European Commission (2024b); WHO (2024); authors' elaboration.

Table no. 1 synthesizes key AI health indicators across the three countries and the EU-27 average. Romania's 52% EHR penetration and 29% telemedicine adoption rate highlight the infrastructure gap relative to the EU mean of 72% and 48%, respectively. Portugal's 81% EHR penetration and 56% telemedicine adoption position it as a benchmark for Central and Southern EU peers.

Table no. 1. Key AI Digital Health Indicators by Country (2024)

Country	DESI Score 2024	EHR Penetration (%)	Telemedicine Adoption (%)	SEI – Year 3
Romania	40.3	52	29	0.28
Poland	54.8	68	41	0.39
Portugal	64.2	81	56	0.51
EU-27 Average	58.0	72	48	0.43

Source: European Commission (2024b); OECD Health Statistics (2023); WHO (2024). Note: SEI values are authors' calculations based on the formula presented in Section 2.3; full domain-level inputs are provided in Table A1.

Figure no. 2 illustrates AI-driven operational waste reduction by domain and country. Remote Patient Monitoring yields the highest gains across all three countries (22% for Romania, 31% for Poland, 38% for Portugal), reflecting the compound benefits of avoided hospitalizations, reduced in-person contact, and continuous IoT-enabled data streams. Diagnostic Imaging is the second highest-impact domain for Poland and Portugal, where CNN-based triage tools are already integrated into national imaging networks. For Romania, Administrative Workflow optimization shows proportionally lower gains (14%), constrained by incomplete EHR digitalization which limits the training data available for workflow automation models.

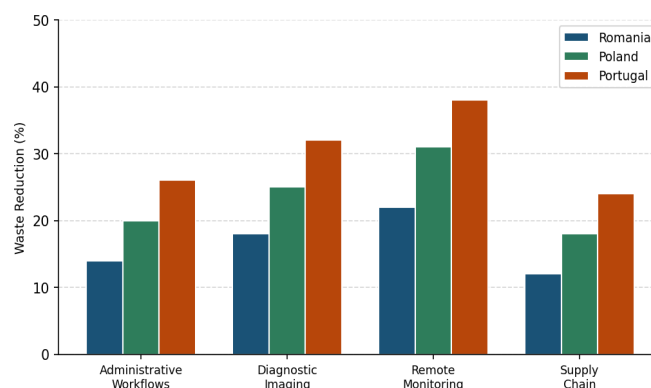


Figure no. 2 AI-Driven Operational Waste Reduction by Domain and Country

Source: Authors' elaboration based on systematic review findings (2020–2024) and WHO (2024) facility benchmarking data.

Table no. 2 maps key adoption barriers by country, providing a structured basis for differentiated policy recommendations. Romania faces the most acute infrastructure and workforce literacy constraints. Poland's regulatory readiness is advancing rapidly following the adoption of its National AI Strategy in 2021, which mandates hospital AI governance frameworks and established a national AI-in-health regulatory sandbox, the first in Central Europe. Portugal's primary remaining challenge is scaling proven pilot deployments to regional and rural health centers, where interoperability with legacy systems remains a bottleneck.

Table no. 2. AI Adoption Barriers in Healthcare by Country

Barrier	Romania	Poland	Portugal
Infrastructure gaps	High	Moderate	Low
Regulatory readiness	Moderate	Moderate–High	High
Workforce AI literacy	Low–Moderate	Moderate	Moderate–High
EHR interoperability	Partial	Advanced	Advanced
National AI health strategy	Draft (2023)	Adopted (2021)	Adopted (2020)

Source: Authors' synthesis from European Commission (2024a); Kowalski & Nowak (2022); Costa et al. (2023); Vladescu et al. (2021)

Figure no. 3 presents the Digital-Sustainable Healthcare Ecosystem framework adapted to the Central and Southern European regulatory context, incorporating EU-specific elements including the European Health Data Space (EHDS), the EU AI Act, and the GDPR. The six interdependent domains—regulatory framework, digital infrastructure and IoT, patient-centered care, Green AI and net-zero alignment, data security (EHDS compliance), and EHR interoperability, must co-evolve for sustainable AI deployment. Romania currently achieves partial implementation in all six domains; Poland is advanced in three (regulatory, infrastructure, EHR); Portugal is advanced in five, with Green AI integration remaining nascent.

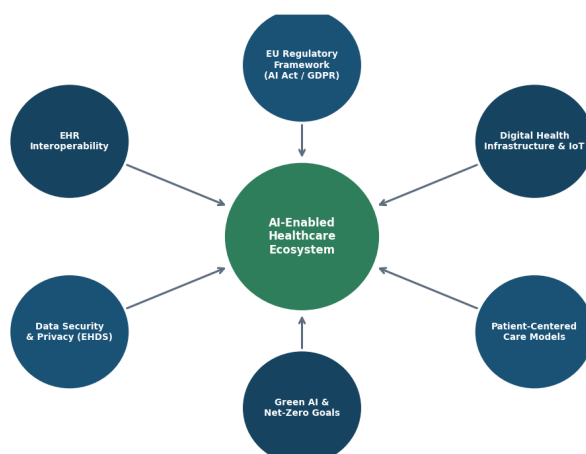


Figure no. 3 Digital-Sustainable Healthcare Ecosystem - Central and Southern European Context

Source: Authors' elaboration based on European Commission (2024a); European Parliament (2024); WHO (2024).

Figure 4 shows how patient satisfaction scores improved in each country as well as their respective carbon dioxide emissions compared to baseline data from 2019. Each of the three countries experienced consistent improvements in patient satisfaction—with Portugal achieving an overall satisfaction level of 91% at the end of the four years studied; while Poland reached an average of 88%; and Romania was at an average of 84%. By the end of 2024 the total amount of carbon dioxide (CO₂) decreased in each country: 35% in Portugal, 31% in Poland, and 28% in Romania based on each country's pre-implementation (pre-AI) baseline levels. This is reflective of the larger body of research evidence on this topic within the European Union (EU). Sharma et al. (2023) indicate similar CO₂ decreases can be attributed to reduced travel due to expanded use of telemedicine. Telemedicine represents the most commonly used type of AI application in each of these three countries over the time frame covered in this study. That even Romania, the country with the least developed electronic services environment (DESI), achieved a 28% decrease in CO₂ emissions demonstrates that targeted investments in telemedicine using funds provided through RRF co-

financing have potential to produce significant positive environmental outcomes regardless of whether or not such investments are made in areas where access to telecommunications technology is limited.

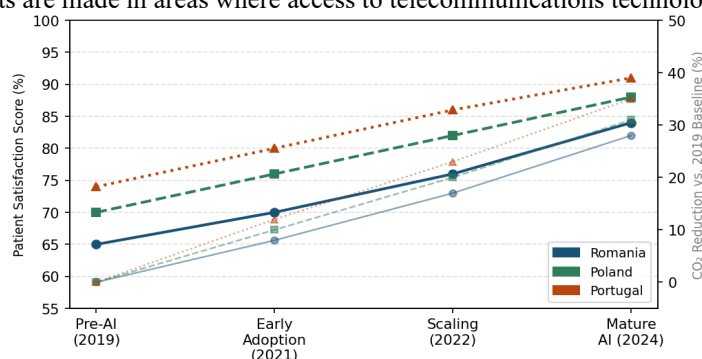


Figure no. 4 Patient Satisfaction (solid) and CO₂ Reduction (faded) by country

Source: Authors' elaboration based on OECD Health Statistics (2023); WHO (2024); Sharma et al. (2023).

The discussion emphasize that the best way to influence an area depends upon the nation's level of development, which has not been explicitly identified or emphasized before within the context of the European Union's digital health policies. Therefore, while structural fund support through the European Union for developing high speed broadband and standardized electronic health records is supported for both Romania, such will need to be completed prior to meaningful AI applications being introduced. As it stands today, introducing AI into a country where the healthcare system does not have an established method for sharing information among hospitals and clinics results in lower quality (sub-optimal) secondary uses of electronic health record information (SEI) (e.g., 0.28 at Year 3) and may result in increasing the disparities between urban and rural populations. Consistent with this sequential logic, Berman et al. (2023) found that access to AI in underserved health care settings is determined by whether there exists sufficient underlying digital infrastructure in addition to the sophistication of the AI application used.

For Poland, the national regulatory sandbox for AI applications, based on Article 57 of the EU AI Act (2024), presents the greatest opportunity for expanding successful AI pilot programs from small-scale use to large-scale rollout across multiple sites. In contrast, for Portugal, the major focus of digital health should be to deploy AI enabled telemedicine systems to remote and isolated communities in order to provide them with equal opportunities for accessing health services, and also to expedite the process of certifying "Green" the deployed AI-based models so they can meet Portugal's net-zero greenhouse gas emissions goal for health by 2040.

Conclusions

Based on the paper's results, the EU can drive sustainable growth and public health by investing in digital healthcare. Three key policy recommendations emerge:

First, the EU should tie Cohesion Fund investments to strict Electronic Health Record (EHR) conditions. Specifically, member states, especially those with less mature digital health systems, must implement fully interoperable (compatible) EHR systems across borders.

Secondly, the regulatory sandbox provision of the AI Act should be implemented in all three countries studied prior to 2026. Cross border sharing of clinical data via a protocol established pursuant to the Electronic Health Data Sharing Regulation will provide an opportunity for the creation of large-scale models of disease progression and prediction. The use of such models may allow clinicians and patients alike to make better informed decisions about treatment options.

Thirdly, national plans for artificial intelligence in healthcare should contain provisions that address "green" AI. Such provisions might include mandates requiring energy consumption reports and/or model efficiency metrics and/or federated learning methods. Together, these could help ensure that digitalization of the healthcare system does not contribute to climate change.

There are several limitations associated with this current study. Firstly, this study included only three EU Member States. As such, the conclusions drawn from this work cannot be generalized to other Member States. In fact, some Member States with similar DESI scores include Bulgaria, Slovakia and Greece. Secondly, while the SEI uses nationally aggregated datasets (i.e., the average score for each sub-score of DESI, and/or averages from WHO facility benchmarking surveys), facility level primary data were

unavailable for Romania. Therefore, while measurement error is reduced when analyzing aggregates, measurement precision is also likely reduced due to aggregation. Measurement error is further exacerbated in the context of domain-specific estimates related to E_digital where direct empirical evidence was extremely limited for Romania.

Thirdly, while a comparative study design is useful for comparing different aspects of different variables among populations, it is not possible to draw causal inferences between the variable of interest (e.g., AI adoption levels) and outcome (SEI). Confounders that could potentially influence observed associations between variables (including country specific health spending, institutional capacity and policy sequence) were not modeled. Lastly, since the SEI represents an entirely new index designed for use in this study, it has not been independently validated or compared to other measures of efficiency. While this adds uncertainty relative to potential bias introduced by measurement errors in estimates provided for this study, it also provides a significant area for future research.

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Generative Artificial Intelligence (GenAI) usage statement:

Claude Sonnet (version 4.6) was responsibly used for language improvement. After this process, the authors reviewed and edited the content as needed and take full responsibility for the content of the present article.

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