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Multidisciplinary measuring of maturity and readiness in national digital public health systems: The digital public health maturity index

Dissertation

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Abbreviations

AI	Artificial intelligence
DiPH	Digital public health
DiPHMI	Digital Public Health Maturity Index
eHealth	Electronic health
EHR	Electronic health records
EMRAM	Electronic Medical Record Adoption Model
GDHM	Global Digital Health Monitor
HIS	Health information systems
ICT	Information and communication technologies
IT	Information-technology
ITU	International Telecommunication Unit
mHealth	Mobile health
NICE	National Institute for Health and Care Excellence
OECD	Organization for Economic Co-operation and Development
TAPIC	Transparency, accountability, participation, integrity, and capacity
UHC	Universal health coverage
UN	United Nations
WHO	World Health Organization

Zusammenfassung

Die rasche Digitalisierung der Gesundheitssysteme auf der ganzen Welt hat nie dagewesene Chancen und Herausforderungen mit sich gebracht. Daher besteht ein dringender Bedarf an Instrumenten zur umfassenden Bewertung des Reifegrads nationaler digitaler Public Health (DiPH) Systeme für die strategische Planung, Ressourcenzuweisung und die nachhaltige Entwicklung robuster DiPH-Infrastrukturen. Diese Dissertation zielt darauf ab, diese Lücke zu schließen, indem sie den *Digital Public Health Maturity Index* (DiPHMI) entwickelt. Dieser ist ein ganzheitliches Instrument zur Messung des Reifegrads von DiPH-Systemen aus einer multidisziplinären Perspektive, der die Bereiche Informations- und Kommunikations-Technologien, Recht, Soziales und DiPH-Interventionsanwendungen umfasst.

Alle im Rahmen der Dissertation durchgeführten Studien betonten die Notwendigkeit interdisziplinärer Ansätze in DiPH und identifizierten verschiedene Schlüsseldisziplinen, die hierzu beitragen. In einem Scoping Review zu DiPH-Interventionen wurden die Charakteristika und technischen Merkmale von 179 DiPH-Interventionen erfasst. Dabei zeigte sich eine erhebliche Heterogenität unter den Anwendungen, wobei der Schwerpunkt auf dem klinischen Bereich des Gesundheitswesens lag. In einem Narrativen Review wurden 286 Indikatoren ermittelt, die derzeit zur Messung der digitalen Reife in Gesundheitssystemen verwendet werden. Hierbei wurden wesentliche Lücken in den Instrumenten zur Reifegradsbewertung aufgezeigt. Die letzte Studie war ein Delphi-Prozess, an dem 82 internationale Experten aus verschiedenen Disziplinen beteiligt waren. Sie einigten sich auf 96 grundlegende Indikatoren für die multidisziplinäre Bewertung des Reifegrads von DiPH-Systemen. Die so ermittelten Indikatoren wurden in den DiPHMI integriert, um eine umfassende Bewertung der nationalen DiPH-Systeme und ein differenziertes Verständnis ihres Reifegrades zu ermöglichen.

Die Ergebnisse unterstreichen die Notwendigkeit eines multidisziplinären Ansatzes bei der Bewertung von DiPH-Systemen. Bestehende Instrumente konzentrieren sich überwiegend auf den klinischen Gesundheitsbereich und vernachlässigen die weiteren nicht-klinischen Dimensionen von Public Health. Der DiPHMI füllt diese kritische Lücke, indem er ein breites Spektrum von Indikatoren einbezieht, die die Komplexität und Interdisziplinarität von DiPH-Systemen erfassen. Dieser umfassende Ansatz ermöglicht ein besseres Verständnis der Stärken und Schwächen der nationalen DiPH-Systeme und damit gezielte Interventionen und eine fundierte Politikgestaltung. Somit stellt der DiPHMI einen bedeutenden Fortschritt bei der Bewertung von DiPH-Systemen dar. Zukünftige Forschungsarbeiten sollten sich auf die Validierung des DiPHMI in verschiedenen Umfeldern und seine kontinuierliche Verfeinerung konzentrieren, um seine globale Anwendbarkeit und Relevanz sicherzustellen.

Abstract

The rapid digitalization of health systems worldwide has brought unprecedented opportunities and challenges in public health. There is a critical need for tools to comprehensively evaluate the maturity of national digital public health (DiPH) systems for strategic planning, resource allocation, and the sustainable development of robust DiPH infrastructures. This dissertation aims to address this gap by developing the *Digital Public Health Maturity Index* (DiPHMI), a holistic tool designed to measure the maturity of DiPH systems from a multidisciplinary perspective, encompassing information-communication technology (ICT), legal, social, and DiPH intervention application domains.

All studies that were conducted and contributed to this dissertation emphasized the need for interdisciplinary approaches in DiPH, identifying diverse key disciplines contributing to this domain. A scoping review of DiPH tools mapped out the characteristics and technical features of 179 DiPH interventions, thereby revealing significant heterogeneity among DiPH tools, with a predominant focus on clinical healthcare applications. The narrative review identified and analyzed 286 indicators currently used to measure digital maturity and readiness in public health systems, highlighting gaps in existing maturity and readiness assessment instruments. The final essential study was a Delphi process involving 82 international experts from various disciplines who agreed on 96 fundamental indicators for the multidisciplinary evaluation of DiPH system maturity. The indicators and interventions identified from these studies were integrated to form the composite DiPHMI to provide a comprehensive assessment of national DiPH systems, offering a nuanced understanding of their maturity levels.

The findings underscore the necessity of a multidisciplinary approach in evaluating DiPH systems. Existing maturity assessment tools predominantly focus on clinical health settings, neglecting broader non-clinical public health dimensions. The DiPHMI fills this critical gap by incorporating a wide range of indicators that capture the complexity and interdisciplinarity of DiPH systems. This comprehensive approach facilitates a better understanding of the strengths and weaknesses of national DiPH systems, enabling targeted interventions and informed policy-making. As such, the DiPHMI represents a significant advancement in the evaluation of DiPH systems. Future research should focus on validating the DiPHMI across diverse settings and its continuous refinement to ensure global applicability and relevance.

1 Introduction

1.1 Background

The work on this dissertation started when I reached out to Clayton Hamilton, who leads the World Health Organization's (WHO) Regional Office for Europe's Initiative for Digitalization of Health Systems at the beginning of 2020. I asked him for a potential dissertation topic in digital public health (DiPH) that the WHO would also be interested in. This topic was one of many from his list, highlighting WHO Europe's intense interest in DiPH and a multidisciplinary measurement tool for national DiPH system maturity.

DiPH provides unparalleled opportunities to transform healthcare and promote health at a population level [1, 2]. Additionally, digitalization affects all areas of life, necessitating health systems to become increasingly interdisciplinary and integrated into other systems [3, 4]. Consequently, health systems must broaden their horizons toward the interoperability and integration of other systems, such as social care or information and communication technology (ICT) systems, to achieve a population health impact in a digitized world [5]. Such holistic systems are what I call DiPH systems. These interdisciplinary systems consist of the health system, as well as governmental public health agencies, academia, and additional sectors (like the ICT and social care sector) [6]. The COVID-19 pandemic has highlighted that all of these sub-systems need to collaborate under the umbrella of an interoperable DiPH system for the implemented initiatives and policies to be effective. Integrating digital interventions into a preexisting public health system and fostering interoperability will allow to create integrated online pathways for healthcare, health promotion, disease prevention, and population health surveillance for highly accessible and feasible interventions [5].

In 2018, during the seventy-first World Health Assembly, the WHO advocated for its Member States to evaluate their utilization of digital technologies in health, encompassing health information systems on national and subnational tiers. This assessment aimed to pinpoint areas necessitating enhancement. Furthermore, the WHO urged prioritization of endeavors concerning the advancement, assessment, implementation, amplification, and augmented deployment of digital health technologies and services [7]. Multiple international organizations and governments have recognized such strategies as essential for strengthening health systems to meet the Universal Health Coverage (UHC) and Sustainable Development Goals [8].

The following chapter will display the evolution of terms related to a digitalized health and public health system, ranging from *health telematics* in 1998 [9] to the currently dominating term *digital health* to set the general frame for this dissertation. Further, I will explain why it is

essential to come back to DiPH and include other public health fields rather than exclusively the clinical healthcare setting for maturity and readiness assessments. Displaying the milestones in DiPH governance, primarily driven by the WHO, will additionally explain the global interest in the field and the need for such assessments. This chapter will then present the differences and requirements for digital maturity and readiness assessments and end with the dissertation outline for a broad overview of this thesis.

1.2 From population-centered health telematics to individual clinical settings: Why do we need digital public health (back)

The term *digital public health* was first mentioned by Public Health England [10] in 2017 to describe new methods in public health practice and research with new digital concepts and interventions. However, the WHO coined the term *health telematics* back in 1998 to describe health-related activities, services, and systems by applying ICT to health promotion, disease prevention, healthcare, health research, and health education [9]. This definition continuously evolved until Eysenbach defined *electronic health* (eHealth) in 2001. According to him, eHealth is an evidence-based connection between population-centered public health and individual-focused medical informatics through ICT services. As such, it combines infrastructural changes through digitalization and specific digital interventions related to health. However, this definition already puts physicians and patients in focus and, therefore, the clinical setting of eHealth [11]. Later, *mobile health* (mHealth) became a term to describe mobile devices for medical and public health practice, focusing on monitoring patients [12]. Through this definition, the perspective shifted again toward specific interventions and away from infrastructure tools. Figure 1 displays the interconnection between the four terms where eHealth diffuses into DiPH due to its original population perspective.

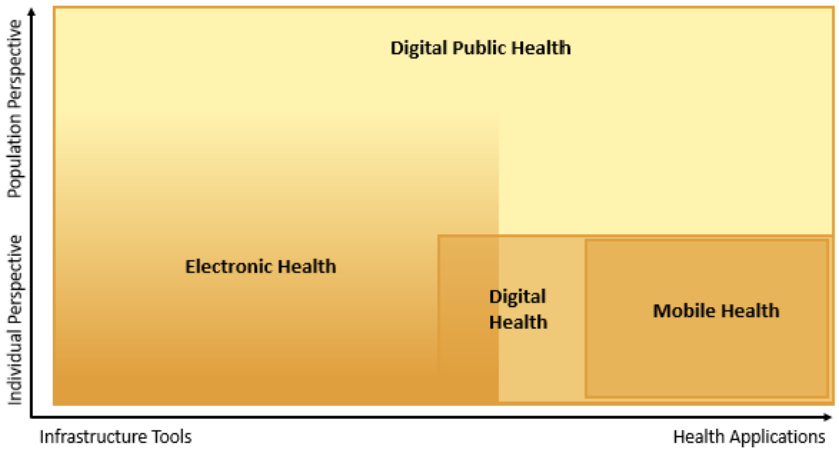

Figure 1. Differences in current terminology to describe digitalization in health. Adapted from Wienert et al. (2020) [13]

Nowadays, the dominating term *digital health* mainly describes the use of mHealth and ICT in individualized and personalized medicine, telehealth, and telemedicine [14], with over 14,000 results in the scientific database PubMed (June 2024). It appears that throughout the years of continuous digitalization in health, the holistic approach of public health (expressed through the initial health telematics terminology) increasingly became excluded from the dominant terminology. Further, a shift toward the digitalization of exclusively clinical healthcare appeared. Only through explicit terminological inclusion will it be possible to put public health back in the digitalization of health.

Following this, DiPH is no new scientific field; instead, it is the use of ICT services to achieve traditional essential public health goals and operations [13, 15, 16]. Thereby, DiPH embraces population-based eHealth and mHealth applications and clinical digital health and infrastructure-focused health telematic approaches. This makes it a population-centric umbrella term for the digitalization of health. Following the *Health in All Policies* approach, DiPH aims to improve population health by applying ICT services on the individual, community-, and global levels [16, 17]. As such, it includes healthcare (like electronic health records or telemedicine), health promotion, and primary prevention through health apps [16, 18-20], as well as the (inter-) national health monitoring and surveillance through digital data to detect disease outbreaks and improve public health responses [1, 16, 21, 22].

Using the principal public health functions as guiding principles, DiPH should follow evidence-based [16, 17], participatory [13, 16, 23], and needs-based technology-development procedures [16, 20]. DiPH technologies are public goods that are accessible to user groups without charges [18], and they include health-specific hardware and software applications such as smartphone apps and wearable technology for recording, monitoring, and evaluating specific health parameters [19]. They should not increase existing inequalities due to different access to and knowledge in using particular technologies in various social groups [10, 16-18, 24]. Additionally, their effectiveness evaluation needs to be analyzed in terms of unintended negative or positive effects [17]. Finally, DiPH must not result in siloed, heterogeneous interventions that lack interoperability and population-health impact (as in unsystematically implemented digital pilot interventions) [24].

1.3 Milestones in digital health and digital public health governance

DiPH governance includes participatory processes, transparency, social accountability, fairness, and effectiveness [25]. It requires a digital strategy and architectural support based on a country's overarching vision for the organization of its (public) health sector. Good DiPH

governance must ensure at all levels of the public health system that equitable access and high-quality, affordable healthcare are supported and the principles of the TAPIC (Transparency, Accountability, Participation, Integrity, Capacity) approach are applied [26]. To achieve this, governance needs stable structures, strategic financing, guarantees for the rights of all stakeholders, and connectivity [25]. The following section will highlight milestones in digital health and DiPH governance that have globally influenced the adoption and regulation of DiPH on a system level primarily driven by the WHO.

The WHO presented its first eHealth strategy during the fifty-eighth World Health Assembly in 2005. With this, they advised their member countries to develop eHealth strategies and digital services for their national health systems. Further, the WHO established the *Global Observatory for eHealth* to guide research on developing eHealth (strategies) in countries, marking the first milestone in digital health governance [27, 28]. The *National eHealth Strategy Toolkit*, published in 2012 by WHO and the International Telecommunication Unit (ITU) [29], marked another milestone in digital health. The toolkit aims to support governments in evaluating their eHealth system and identify areas for improvement (more in Chapter 2.2) [30]. Since then, the toolkit has been used to assess at least two national eHealth systems [31, 32] and inspired the development of the Global Digital Health Monitor (GDHM) that is used to measure the maturity of national digital health systems through standardized indicators [33]. Toolkits of this kind are increasingly used to lead the employment and assessment of digital health and DiPH interventions and systems [34]. Following Barac et al. (2014), toolkits and frameworks are effective knowledge translation strategies applied to message communication, sharing decision support tools, improving health and education outcomes, or positively impacting healthy behavior in target populations, thereby impacting health systems [35].

During the sixty-sixth World Health Assembly in 2013, the WHO appreciated the need for standards in health data, including health data governance, marking the next milestone in DiPH governance. Further, the assembly highlighted the appropriate use of ICT to improve population health outcomes and support sustainable financing [36]. Four years later, the WHO first mentioned using digital technologies for public health in their mHealth report, recognizing the importance of DiPH for sustainable health service delivery, access to health information, and positively impacting preventive health behavior change. This report encouraged member states to seek standardized approaches for applying DiPH services in their health systems. This included focusing on the successful implementation and national upscaling of pilot projects in the health system, improved connectedness between interventions, establishing health information

architectures, implementing standards for a comparative functionality assessment of digital health interventions, and multisectoral digital health approaches in governments [37].

In 2018, the presence of digital health and DiPH governance drastically increased. For instance, it was the year the *Global Digital Health Partnership* was established. This network supports collaboration and knowledge-sharing between 36 countries and territories and three international organizations designing and delivering digital health services for sustainable healthcare [38]. Further, the Broadband Commission for Sustainable Development presented its first policy paper on applying digital health tools for diagnosing and treating non-communicable diseases in low- and middle-income countries [39]. Later, the WHO acknowledged the potential of ICT in public health, resulting in a resolution on digital health during its seventy-first World Health Assembly. This resolution asked the member states to promote UHC and reinforce public health resilience through digital technologies. The report further called for a focus on equity, promoting interoperability between and evidence of digital interventions, workforce development, trust in digital interventions, and protective policies [7].

Another publication by the WHO in 2018 was the first version of the digital health intervention classification framework to categorize the application of eHealth and mHealth technologies in health systems. It was one of the first publications suggesting a standardized vocabulary for digital health interventions [40]. This classification system has since then inspired other frameworks and intervention mapping projects, such as the work by Pernencar et al. (2022) for digital health apps [41], our work on defining DiPH interventions [13], or the National Institute for Health and Care Excellence (NICE) evidence standards framework for digital health technologies to describe digital health technologies that offer benefits to their users and the health system [42].

The *#SmartHealthSystems* study by Thiel et al. (2018) marked another milestone in digital health [43]. This study was among the first to assess national digital health policies and intervention implementation in multiple countries through a standardized procedure. Further, it raised awareness of the importance of digital maturity assessments of national health and public health systems. This work was continued by the GDHM in 2019 and 2023, with the evaluation for 2025 currently ongoing [33, 44], the *Roadmap to Artificial Intelligence (AI) Maturity* by the Broadband Commission (2020) [45], the *Digital Assessment Toolkit Guide* by the World Bank (2021) [46], and the WHO's maturity assessment of the European region in 2022 [47]. All of them paved the way for global interest in digital health and DiPH system maturity and readiness assessments.

1.4 Digital public health system maturity and readiness assessments

In the ever-evolving landscape of disease prevention, health promotion, and healthcare, assessing the digital maturity and readiness of the national DiPH system is a pivotal effort with multilayered advantages. Standardized tools, such as validated indices using public data, allow for an objective and systematic evaluation of the systems' performance. This enables policymakers and healthcare professionals to comprehensively understand the strengths and weaknesses of the system and make data-driven decisions to allocate resources to areas in need (whether it may be funding, technology, personnel, or legislation) [48]. Consequently, inefficiencies will be reduced, and the evaluation will contribute to cost savings from a health economics perspective. Thereby, maturity and readiness assessments support strategic planning to enhance the system's overall efficiency and support the growth and sustainability of robust DiPH systems [49].

Nevertheless, while theoretically, both terms are distinguished, this might not always be true in practice, and this could be why the terms are often used interchangeably. For instance, reaching a basic level of digital literacy among the population will allow a broad group to use digitalized initiatives such as DiPH [50]. However, these skills are also needed for further developing the DiPH system, as the best intervention can fail if nobody is willing or able to use it. Such indicators could then be used for digital maturity and readiness assessments [51].

1.4.1 Digital maturity versus readiness assessments

Maturity assessments have existed since the early '90s, although they started as capability assessments of target areas within specific organizations instead of national health systems [52]. According to Becker et al. (2009) [53], such assessments serve as conceptual frameworks with several distinct maturity levels of specific processes to symbolize concrete development paths. Each maturity level displays a designated degree of more advanced development compared to the previous level. In the health domain, these models are usually applied in healthcare settings to improve the maturity of services and infrastructure [54, 55]. As a result, maturity assessments can describe an organization's or system's current development status, but they lack informative value on the adaptability of a system to change [48, 56, 57]. Suppose one wishes to see beyond the current status and evaluate a system's adaptability and preparedness toward change (e.g., brought by ICT developments and emerging technologies). In that case, readiness assessments should be conducted [58].

1.4.2 Why should we conduct maturity assessments of digital public health systems?

Following the theory of change by Weiss (1995) [59], if nations measure their digital maturity and readiness in DiPH, they can detect gaps and areas for policy development, nationwide upscaling of interventions, and assessments of workforce and financial resources. This will contribute toward countries achieving UHC with improved population health outcomes by creating a setting where health data is available in high quality and can be used to evaluate and track the health system's progress [33, 44].

From a patient perspective, system evaluations through digital maturity or readiness assessments can improve healthcare as the identified gaps (e.g., a lack of workforce and technical infrastructure in rural regions) can be addressed to improve access to health services for the whole population. Assessing their digital maturity would foster access to such services for all (including vulnerable groups) while allowing countries to gain comprehensive overviews of their resources, workforce skills, and knowledge, ultimately leading to standards-based interoperable DiPH programs and systems [7, 29, 33, 60, 61].

Following an interoperability perspective, regular maturity and readiness assessments can identify potential challenges within the DiPH ecosystem. Addressing these can improve data exchange and collaboration among health system components and players (like stakeholders or health services). From a public health lens, a well-developed DiPH system is crucial for timely population surveillance and quick response to disease outbreaks or public health emergencies. Therefore, a regular assessment of the system's capabilities is essential for surveillance planning [22, 62].

Finally, conducting maturity and readiness assessments among various countries through the same tools will allow benchmarking and policy learning. This will facilitate the identification of areas where improvements can be made to align with global norms [33, 43]. Publishing these results may also positively impact public trust in the health system. A mature DiPH system and robust security and privacy measures can uplift the confidence and acceptance of healthcare providers and the general population in the tools and the government. This will result in the successful adoption of DiPH technologies and services among the general population and workforce nationally [63-66].

Nevertheless, challenges for both assessment types remain. Good data quality and availability are essential for a consistent evaluation procedure, as incomplete or unreliable data will impede accurate assessments. Therefore, investing in centralized and interoperable infrastructures is vital to regularly produce and analyze data needed for such evaluations (such as data pipelines

and centralized data hubs) [33, 67]. However, performing these assessments is expensive regarding finances and human resources. Additional costs must be considered as parts of the analysis elements that need representative surveys (e.g., to assess the population's digital literacy or how they perceive DiPH interventions). Nevertheless, recognizing cultural and socioeconomic factors in the assessment process is vital as these will likely influence the adoption and utilization of DiPH technologies [68].

The most critical challenge will be to apply assessment tools capable of measuring all multidisciplinary DiPH fields (e.g., surveillance, health promotion, prevention, governance, workforce, etc.) instead of the more clinical and healthcare-focused digital health. Currently, no measurement tool is available to represent public health needs beyond the clinical aspects [51, 69]. Developed and implemented indicators occasionally target areas that are also captured by public health and DiPH. Such domains often include routine clinical data for public health surveillance or to inform care strategies to support and sustain population health [43, 70-74]. Other indicators address the use of social media for public health concerns or by public health institutions to dispel rumors or misinformation [72]. Additional indicators exist to measure the population health impact of publicly funded eHealth and mHealth interventions [44, 73, 74]. This also applies to regulations on AI-based systems with public health impact [75] or policies on sharing surveillance data in public health emergencies [72]. However, these indicators are usually not combined into a diverse measurement tool, potentially leading to a mismatch between digital health system priorities and actual DiPH requirements [56].

1.5 Cumulative dissertation outline

This dissertation explains the research context of the individually conducted studies. The introduction in **Chapter One** is followed by **Chapter Two,** which describes the theoretical foundations of maturity measurement in health systems. As no ideal model existed, this chapter will introduce a new model that can capture the topic's complexity and interdisciplinarity. Further, the chapter will present the models and frameworks that served as the foundation for this research. Based on this analysis, the chapter closes with an overview of the knowledge gaps addressed by this dissertation and its knowledge relevance. Building on this assessment, **Chapter Three** presents this thesis's overarching research aim and research questions. It lists the five first-authorship publications that fed into this dissertation, including my contributions to the individual projects. The **Fourth Chapter** summarizes the objectives of the articles in this dissertation, their methodology, results, discussion, and conclusion. The **Fifth Chapter** combines the individual publication results to create the overarching Digital Public Health Maturity Index

(DiPHMI). While the chapter will describe the indices' methodology, structure, and applicability, the overview of proposed indicators, including their data sources and description, was moved to Appendix B due to its length. **Chapter Six** discusses the scope and key findings of this dissertation in front of the question of why the DiPHMI measures maturity instead of readiness of DiPH systems and how it can support countries in overcoming implementation barriers. The chapter closes with a discussion of the strengths and limitations of this thesis. The **Seventh Chapter** highlights the implications of this dissertation for future research and public health governance. This chapter also provides an outlook for the further development of the DiPHMI. The conclusion follows in **Chapter Eight.**

2 Theoretical and Empirical Positioning

According to the framework on digital excellence in healthcare (Figure 2) by Cresswell et al. (2019) [48], the continuous evaluation of settings (in the case of this dissertation, DiPH systems) will lead to revised visions of excellence and policy learning across ecosystems to improve systems, and update priorities. It will result in dynamic systems in an ever-changing world. This understanding sets the fundamental assumptions for this dissertation: Evaluating the current digital maturity will support health systems in reaching their desired maturity, which will lead to new reflections, starting another evaluation cycle.

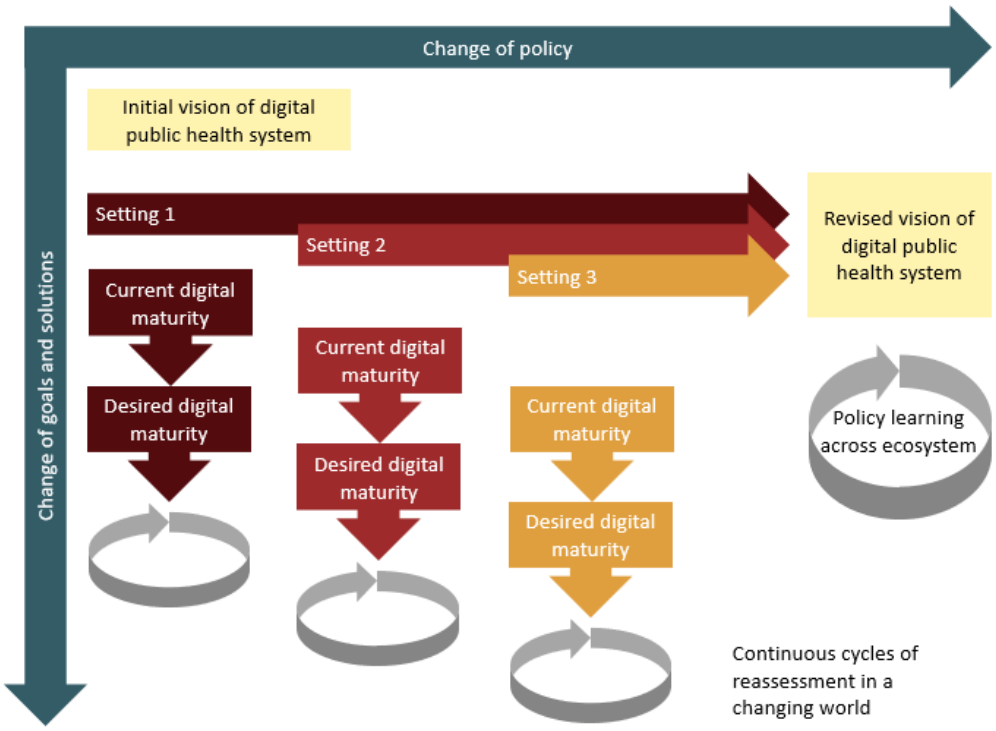

Figure 2. "Evolve in Context" model of digital excellence in healthcare. Adapted from Cresswell et al. (2019) [48]

2.1 A model for describing maturing levels in digital public health systems

Following the WHO (2010) [76], health systems comprise six building blocks: Service delivery, health workforce, health information systems, access to essential medicine, financing, and leadership and governance. Woods et al. (2022) [77] state that models assessing healthcare's digital maturity must also encompass various domains besides those directly targeting health. According to them, this includes IT capability, skill building and technology use, interoperability, national strategies, data analytics, and patient-centered care (Figure 3).

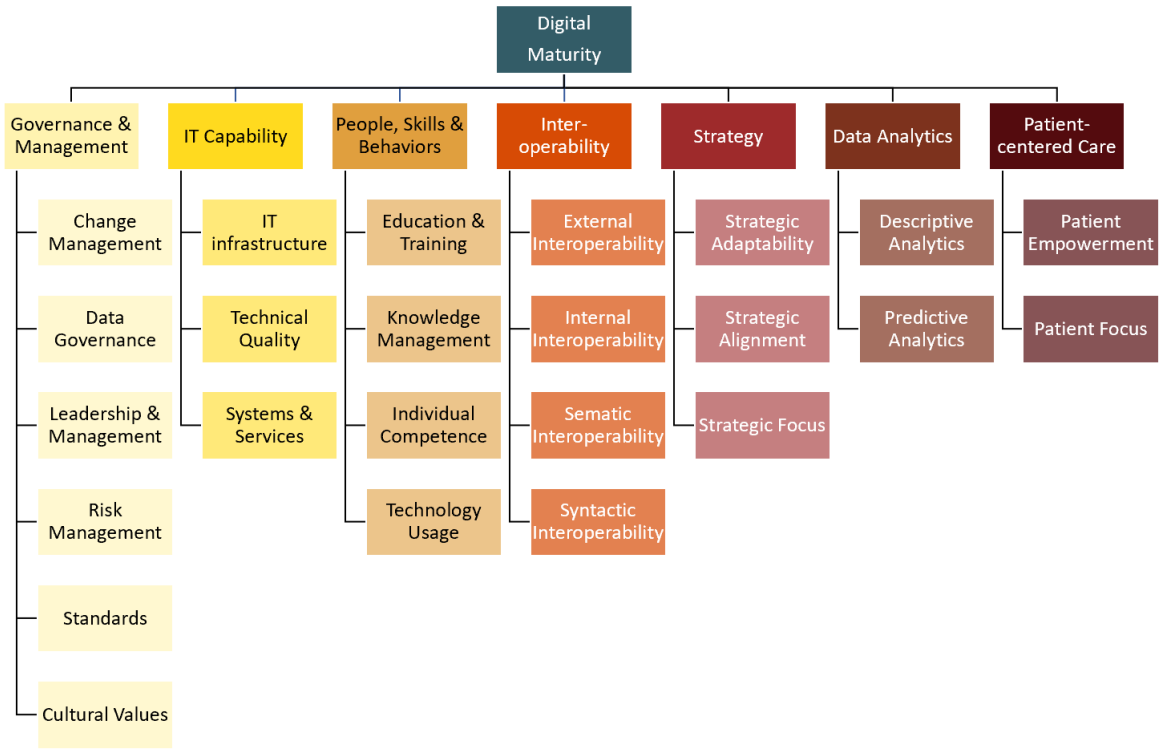

Figure 3. Digital maturity dimensions and corresponding indicators. Adapted from Woods et al. (2022) [77]

However, public health systems need additional blocks as they target clinical healthcare and health promotion, prevention, and population surveillance services, thereby increasing their complexity. For assessing DiPH maturity, these public health blocks need to be developed further and combined with those described by Woods et al. (2022) [77] on digital maturity.

Following, a maturity model that is usable for the case of this dissertation needs to encompass three functions:

1. It must target the digitalization of health on a system level instead of individual organizations or companies.
2. It must encompass different maturity stages for healthcare systems.
3. It must cover general digital healthcare, health promotion, prevention, and surveillance.

Only a few maturity models were identified for digitalizing the health sector. However, none of these fulfilled all three criteria. For instance, the internationally most widely adapted tool for measuring digital maturity is the *Electronic Medical Record Adoption Model* (EMRAM) by the Healthcare Information and Management Systems Society. The EMRAM assesses the digital maturity of hospitals concerning their application of electronic medical records across eight maturity stages [78]. Its medical focus lies on the support of clinicians, patient safety, and satisfaction, making it impractical as a model for measuring national DiPH system maturity inside and outside the clinical context.

Other models might be more practical to the public health setting but not interdisciplinarily enough. An example would be the *Maturity Model for the German Public Health Service* (Öffentlicher Gesundheitsdienst) by Eymann et al. (2023) [79] that targets the information-technology (IT) maturity of health authorities (Gesundheitsamt) and how well they educate their workforce as well as address the citizen needs that access their services. More open regarding the setting but restrictive in terms of its application is the *Mobile Health Readiness Model* by Handayani et al. (2021) [80], which is based on the *Health Belief Model* [81]. However, this model also proved insufficient for this dissertation as it focuses on individual motivation to use mHealth technologies. Lastly, the *Health Information Systems Interoperability Maturity Toolkit* by MEASURE Evaluation (2017) [82] targets the system level. However, its use case lies entirely on interoperability between individual Health Information Systems (HIS), making it less applicable to the complexity of whole DiPH systems.

Eventually, I used the *Digital Health Profile Toolkit* by Liaw et al. (2021) [60] and the *FutureGov's Digital Maturity Assessment* by Holliday and Yin (2019) [83] to create a more applicable model for this dissertation (Figure 4: 12). This five-step model combines different maturity levels with the increased application of digital services and interventions in the total health system. It does not target individual interventions (like EHRs) or use cases (e.g., the clinical context). It operates on the system level, fulfilling all three pre-defined criteria described in Chapter 1.4.3 for a suitable maturity model. As the different levels stem from the toolkit proposed by Liaw et al. (2021) [60], it will be possible to assess each maturity level through specific indicators.

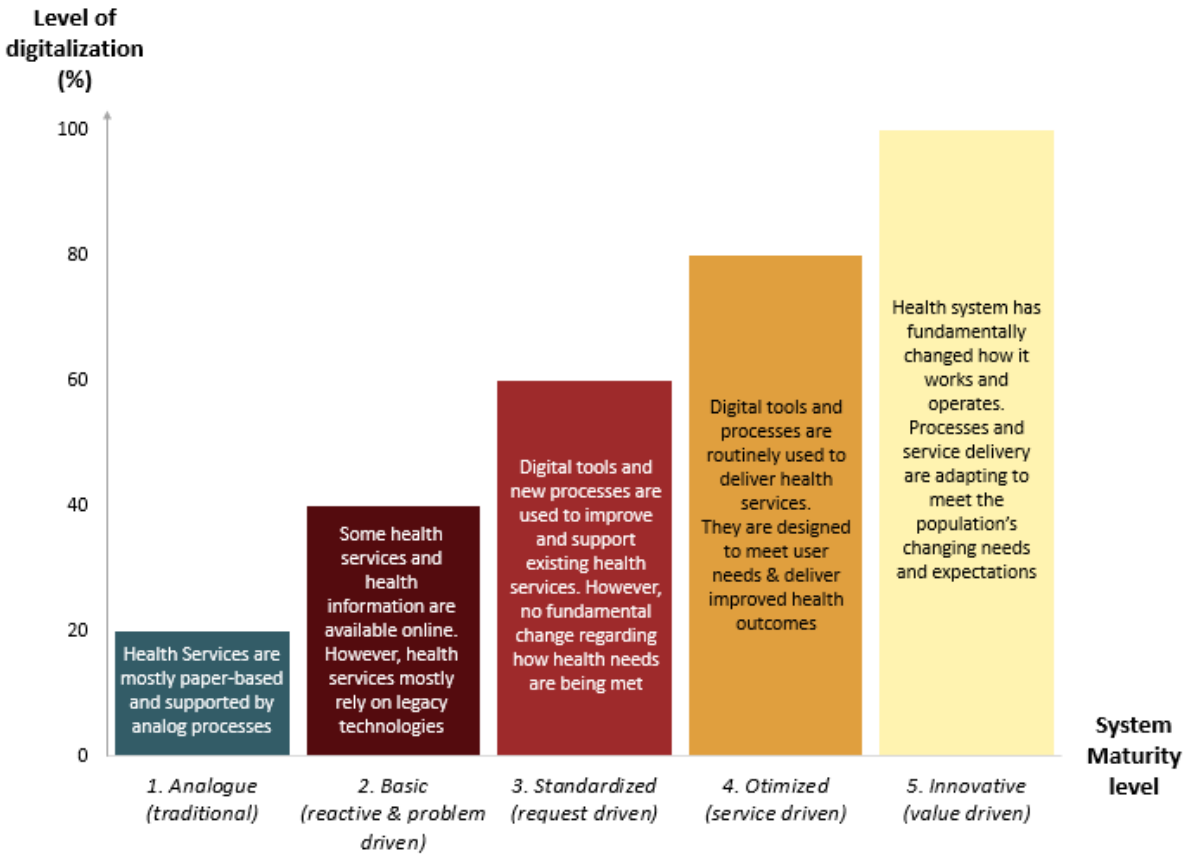

Figure 4. The Digital Public Health Maturity Model. Adapted from Liaw et al. (2021) [60] and Holliday and Yin (2019) [83]

2.2 Dimensions of a maturity assessment for digital public health systems

The research was guided by the *National eHealth Strategy Toolkit* published by the WHO and ITU in 2012 [29], which also served as the guiding framework for the GDHM [33]. The toolkit includes a multidisciplinary governing structure involving leadership and governance, strategy and planning, digital health services and applications, the infrastructure, standards and interoperability, legislation including policies and compliance, and workforce domains. Although serving as a best practice example for holistic policies in DiPH, this toolkit has rarely been uptaken, partly due to its complexity (in June 2024, PubMed listed only six results for "national eHealth strategy toolkit", with the latest being published in June 2020 and one article being a viewpoint from WHO representatives) [30-32, 84-86]. Nevertheless, it had proven to be effective for digital health governance implementation and evaluation in Iran and Argentina [31, 32].

Analyzing the academic fields addressed by the toolkit (according to Rechel et al.'s schematic representation of health information systems [87] and the DiPH field analysis conducted as part of the first publication of this dissertation [88]) revealed that the WHO and ITU policy

recommendation can be categorized across four overarching domains that reflect on its multidisciplinarity (see Table 1). This approach facilitated the later research projects and guided the general structure of the DiPHMI. The complete overview of the color-coded WHO and ITU toolkit is given in Appendix B. Yellow reflects on the *Legal domain*, orange on *ICT-related topics*, red on the *Application perspective*, and brown on the *Social dimension* of the toolkit.

Table 1. National eHealth Strategy Toolkit categorized across overarching domains

Overarching domain	Toolkit category
Legal Topics include the policy, financial, and legislative perspectives of digital public health governance.	- Leadership and governance: Mechanisms - Strategy and planning: Strategy and planning, funding, and investment management - Infrastructure: Identification and authentication services - Legislation, policy, and compliance
ICT Topics include the technical (hard- and software) perspective of digital public health governance.	- Infrastructure: Computing infrastructure and high-speed data connectivity - Standards and interoperability: Data structure standards, clinical and medical terminologies, messaging standards, security messaging standards, and software accreditation standards
Application Topics include the adoption perspective of digital interventions for healthcare, health promotion, surveillance, and other public health functions for digital public health governance.	- Services and applications: Individual electronic health information, healthcare communications and collaboration, healthcare service delivery tools, health information and knowledge, and healthcare management and administration - Infrastructure: Directories, healthcare provider systems, individual electronic health record repositories, and health information datasets
Social Topics include the literacy and workforce availability perspective of digital public health governance.	- Workforce: Health workforce and health IT workforce

Source: Adapted from WHO & ITU (2012)[29]

The four overarching domains presented are directly and indirectly related to one another. Regulations dictate the framework for DiPH intervention's implementation and innovation or using health data for informed-policy approaches [4, 89, 90]. However, new interventions (such as applying big data or AI in healthcare, health promotion, or surveillance settings) force the establishment of updated policies [4, 89, 91-93]. This process is additionally influenced by the *ICT sector*, which constantly creates new infrastructure settings and opportunities for developing new DiPH technologies that require updated regulations [91, 94, 95].

The *Legal domain* is also connected to the *Social area* through instances like trust and ethical use of personal (health) data: Data protection regulations might increase the population's trust

that their data is safe, thereby influencing the uptake of interventions [66, 96, 97]. Additionally, the uptake of interventions among the workforce is influenced by attractive reimbursement regulations [89, 98]. The *ICT domain* also influences the interest and capabilities to use DiPH interventions among the population, as such tools require a stable infrastructure (e.g., electricity, hardware, software, or mobile data) to be used effectively [89, 92, 99]. Further, design strategies can influence the population's interest in using DiPH interventions in both ways. For example, the application of negative design strategies, known as dark patterns that trick the intervention users into doing specific things, can hinder the uptake (examples include unattractive subscription models or risk in data privacy) [100]. In contrast, positive emotion interface designs have supported intervention uptake [101].

Finally, the uptake of DiPH interventions is a direct connection between the *Application domain* and the *Social area*. Specific features of DiPH tools can influence the uptake of interventions among the population or change behavior. The appearance of wearable devices allowing one to monitor one's health impactfully changed how health promotion is perceived and lived among the population and facilitates DiPH intervention acceptance [102-104]. Nevertheless, the uptake of DiPH interventions is also influenced by factors such as the digital and digital health literacy of the general public and workforce or their interest in using DiPH tools [4, 92, 99, 105]. Lastly, ICT can facilitate the distribution of DiPH interventions to reach the target population (e.g., social media or instant messenger services that already have a broad user group among the target population) [99, 106-108].

2.3 Knowledge gap and knowledge relevance

DiPH describes a relatively new term that just recently gained momentum in scientific articles: Before 2020, the database PubMed only listed five results that used "digital public health", whereas in June 2024 already, 174 articles used the term, pointing toward the rising importance in the academic world. However, the most often used term remains "digital health," with nearly 17,000 results on PubMed in June 2024. Nevertheless, questions arise about where these terms separate and what they might have in common [13]. While DiPH is characterized by its inter-disciplinary nature, research on multidisciplinary collaborations within the field has rarely been conducted. Often, papers focus on the collaboration of nurses, therapists, and physicians in the clinical setting [109]. However, DiPH goes beyond this and should include technologists, social scientists, economists, ethicists, and policymakers besides public health professionals. As such, it is relevant to apply multidisciplinary approaches to DiPH intervention development, deploy-ment, and evaluation [110, 111]. This knowledge gap will be addressed in Chapter 4.1.

As I highlighted in previous research [112], interventions of the same tool category (such as health or medical apps) differ in their functions and understanding depending on their deployed setting. Nevertheless, comparable evaluations to benchmark DiPH systems ask for intervention categories (like electronic health records; EHRs) instead of intervention characteristics [43, 113]. However, it remains unclear to which degree such interventions are comparable as terms are not defined precisely enough. This is essential as precise terminology is needed for comparing and regulating interventions [112]. I will talk about this in detail in Chapter 4.2.

Further, a lack of standardized and universally accepted indicators exists to measure the digital maturity and readiness of DiPH systems. While I will show in Chapter 4.3 that numerous assessment tools for digital health systems exist, none of them fulfills the multidisciplinary scope of the maturity model developed in the previous chapters [29, 60, 77, 83]. Many of these existing frameworks and indices use different methodologies and have a varying focus or scope, making comparisons between assessments complicated. Due to their varying scopes, only a minority included indicators from multidisciplinary perspectives [43, 60, 61, 72, 114].

Additionally, no tool has yet been published specifically on DiPH maturity and readiness (only for digital health [43, 60, 113] or other sub-domains of DiPH [71, 72, 113, 115-143]. Thereby, it was unclear until this dissertation which domains are essential for such evaluation approaches. DiPH is characterized by its interdisciplinarity, including socio-economic conditions, the political landscape, the healthcare and ICT infrastructure, cultural differences, and many other aspects that can significantly impact digital readiness and maturity but are often overlooked in ongoing evaluations [47]. This knowledge gap will be the central element answered in Chapter 4.4. A comprehensive, multidisciplinary assessment tool is necessary to capture the full spectrum of factors influencing DiPH system maturity and readiness instead of solely relying on DiPH legislative or ICT infrastructure assessments. This knowledge relevance will play a crucial role in Chapter 5. Based on these assessments, inclusive and informed policy-making can be conducted to engage diverse stakeholders in developing well-rounded DiPH interventions and regulations impacting population health, as explained in Chapter 1.1.

3 Overarching aims and objectives of publications comprised in this dissertation

With the world becoming increasingly digitalized in all aspects of life while populations continue to age and countries experience a shortage of health workforce, health systems globally

turn toward implementing digital services [16, 27]. However, due to *digital health* currently being the leading term for describing this system change, maturity assessment tools and models have been developed primarily to focus on healthcare or the clinical setting. None of these tools can assess the whole complexity of a national DiPH system. As such, this dissertation aims to develop a new tool to describe the maturity of national DiPH systems by incorporating multiple public health perspectives beyond the classic clinical and healthcare lens: The DiPHMI.
This thesis consists of a conceptual consideration on digital public health, a scoping review and its study protocol, one narrative review, and an international multidisciplinary Delphi study to achieve this goal. Below is an overview of all five publications comprising this dissertation.

Paper 1: A conceptual consideration of digital public health as a chapter in an edited book (in press).
Citation: **Maaß L**, Dassow H-H, Diethei D, Freye M, Niess J, Do S (2024). Why is it essential to address digital public health in an interdisciplinary way? In H Zeeb, L Maaß, T Schultz, U Haug, I Pigeot & B Schüz: Digital Public Health – Interdisciplinary Perspectives. Cham: Springer Nature Switzerland AG.

Author contribution: LM and SD conceived and planned the manuscript. The literature search for public health and DiPH disciplines was developed and conducted by LM and SD. Based on the results, LM drafted a model that included all academic fields involved in DiPH (section "definitions of public health and digital public health"). All authors decided to apply the case study of how individual disciplines can contribute to developing, implementing, and evaluating a mobile mental health app. LM conceived and wrote the sections for introduction, implementation sciences, prerequisites for effective and sustainable interdisciplinary collaborations in digital public health, and conclusion. LM critically reviewed the drafts of the other sections and the whole manuscript and acted as the corresponding author. She led the revision of the manuscript based on the reviewers' feedback, compiled the overview of responses, and revised the final manuscript.

Paper 2: A scoping review protocol in a peer-reviewed gold open-access journal (published).
Citation: **Maaß L**, Pan CC & Freye M (2022). Mapping digital public health interventions in practice: Protocol for a scoping review of existing digital technologies and Internet-based interventions to maintain and improve population health. JMIR Research Protocols. 11(3): e33404. DOI: 10.2196/33404.

Author contribution: LM conceived and planned the study protocol. LM conducted the initial literature search in 5 databases. LM and MF independently screened the literature for eligibility. CCP resolved the discrepancies between LM and MF. LM developed the methodology for data extraction and analysis and wrote the first draft of the manuscript. LM acted as the corresponding author and led the revision of the manuscript based on the reviewers' feedback. She compiled the overview of responses and revised the final manuscript.

Paper 3: A scoping review in a peer-reviewed gold open-access journal (published).
Citation: **Maaß L**, Angoumis K, Freye M & Pan C-C (2024). Mapping digital public health interventions in practice: A scoping review of existing digital technologies and Internet-based interventions to maintain and improve population health. Journal of Medical Internet Research. 15/05/2024:53927. DOI: 10.2196/53927.

Author contribution: LM conceived and planned the review. LM updated the initial literature search in 5 databases. LM, MF, and KA independently screened the literature for eligibility. CCP resolved discrepancies. LM conducted the data extraction, interpreted the literature, and wrote the first draft of the manuscript. CCP and KA critically reviewed the manuscript. LM acted as the corresponding author and revised the manuscript based on the reviewers' feedback. She compiled the overview of responses and revised the final manuscript.

Paper 4: A narrative review in a peer-reviewed gold open-access journal (in press)
Citation: **Maaß L**, Badino M, Ihoghosa I, & Holl, F (2024). How advanced is your digital public health system? A narrative review and qualitative analysis of indicators published as grey literature. JMIR Public Health and Surveillance. 18/09/2024:63031. DOI: 10.2196/63031.

Author contribution: LM conceived and planned the review. LM independently conducted the literature search with MB and II. LM performed the data extraction for maturity and readiness indicators with MB and FH. Following the 4-eye principle, LM and FH conducted a preliminary decision process on which indicators to keep for the clustering. LM, FH, MB, and II then clustered the indicators across the four overarching domains and their sub-domains (4-eye principle). LM was responsible for the qualitative analysis of indicators, creating the figures and overview of indicators, and writing the manuscript together with II. LM acted as the corresponding author.

Paper 5: A Delphi study in a peer-reviewed gold open-access journal (published)
Citation: **Maaß L**, Zeeb H & Rothgang H (2024). International perspectives on measuring national digital public health system maturity through a multidisciplinary Delphi study. NPJ Digital Medicine. 7:92 DOI: 10.1038/s41746-024-01078-9.

Author contribution: LM conceived and planned the Delphi study under the supervision of HZ and HR. LM contacted the experts and managed the participants throughout the study. She prepared the panels and conducted the qualitative analysis of responses. LM conducted a literature review for validated indicators to pair with Delphi results and wrote the first draft of the manuscript. HZ and HR critically reviewed the manuscript. LM acted as the corresponding author and led the revision of the manuscript based on the reviewers' feedback. She compiled the overview of responses and revised the final manuscript.

All individual publications will lead to the creation of the DiPHMI, the first tool to holistically assess the digital maturity of national health systems from multidisciplinary perspectives. The index consists of literature-based indicators identified in the fourth publication and empirical indicators from the fifth publication. The research was guided by the *National eHealth Strategy Toolkit* [29], the *#SmartHealthSystems* index [43], and the GDHM [113]. Additional contributions that were produced in connection with this dissertation (presentations, posters, webinars, articles, and book chapters) are listed in Appendix D.

4 Methodology and results of individual publications

Table 2. Structure of the cumulative dissertation

Publication	Publication 1	Publication 2	Publication 3
Title	Why is it essential to address digital public health in an interdisciplinary way?	Mapping Digital Public Health Interventions in Practice: A Scoping Review of Existing Digital Technologies and Internet-based Interventions to Maintain and Improve Population Health	Mapping Digital Public Health Interventions in Practice: A Scoping Review of Existing Digital Technologies and Internet-based Interventions to Maintain and Improve Population Health
Authors	**Laura Maaß**, Hans-Henrik Dassow, Daniel Diethei, Merle Freye, Jasmin Niess and Stefanie Do	**Laura Maaß**, Merle Freye and Chen-Chia Pan	**Laura Maaß**, Konstantinos Angoumis, Merle Freye and Chen-Chia Pan
Guiding questions	- What does interdisciplinarity mean in the context of DiPH*? - What are the advantages of interdisciplinary collaborations in DiPH? - How can we foster multidisciplinary collaborations in DiPH?	- What are DiPH interventions and tools? - Which essential public health functions, as defined by the WHO, do these interventions target? - What are their technical features and non-technical characteristics?	
Methods	Conceptual considerations	Study Protocol for Scoping Review	Scoping Review
Main findings	- DiPH consists of disciplines from Environmental Sciences, Social Sciences, Natural Sciences, Humanities, and Engineering.	- 185 publications were included, describing 179 different DiPH tools. - DiPH tools are highly heterogenetic in total, but also within each intervention group.	
Conclusion	- Good collaboration between and integration of different disciplines is needed for developing effective and sustainable interventions in DiPH. - Students of all involved disciplines need to be taught interdisciplinary approaches as part of their curricula.	- Precise terminology is needed for comparing DiPH interventions. - Instead of comparing "electronic health records", researchers need to compare "interventions with the following characteristics".	
Publication status	Accepted for publication in the *Leibniz ScienceCampus Digital Public Health Bremen Handbook on Digital Public Health; in press*	Published in *JMIR Research Protocols*	Published in *Journal of Medical Internet Research (JMIR)*

** DiPH: Digital Public Health*

Source: Own presentation

Table 2. Structure of the cumulative dissertation (continued)

Publication	Publication 4	Publication 5
Title	How advanced is your digital public health system? A narrative review and qualitative analysis of indicators published as grey literature	International perspectives on measuring national digital public health system maturity through a multidisciplinary Delphi study
Authors	**Laura Maaß**, Manuel Badino, Ihoghosa Iyamu and Felix Holl	**Laura Maaß**, Hajo Zeeb and Heinz Rothgang
Guiding questions	- Which validated indicators exist to measure the DiPH system maturity and readiness? - Can one measure readiness toward emerging technologies without measuring digital maturity in DiPH systems?	- What is the international consensus regarding qualitative indicators to measure the maturity of DiPH systems? - What is the international consensus regarding DiPH services?
Methods	Narrative review	Delphi study
Main findings	- 286 indicators were deemed essential for assessing the maturity and readiness of DiPH systems, with 133 targeting legal domains. - Only 40% of all indicators included a description, and 27% a data source. - Only 14 indicators evaluated readiness in contrast to 110 exclusively on maturity, with the remaining assessing both.	- DiPH tools are public goods (no access fee for users) and target all areas of health promotion, healthcare, prevention, and surveillance. - 96 quality indicators for DiPH system maturity were identified (19-31 per domain). - 48% of indicators were covered through already existing & validated tools.
Conclusion	- As an essential information source for DiPH, grey literature needs to be integrated better into current public health review methods. - Currently, validated indicators focus on the legal domain instead of social domains, which are essential for DiPH. - We require guidelines for indicator reporting to improve transparency and external validity for assessments using indicators.	- Delphi studies are adequate for interdisciplinary research. - Indicators on DiPH need to be developed and validated for domains outside the clinical healthcare setting.
Publication status	Published in *JMIR Public Health and Surveillance*	Published in *NPJ Digital Medicine*
* *DiPH: Digital Public Health*		

Source: Own presentation

4.1 Article 1: Conceptual considerations on the interdisciplinarity of digital public health

4.1.1 Methodology

The book chapter consisted of four parts. In the first, we defined public health and DiPH to map out disciplines involved in both interdisciplinary fields. To do so, we applied acknowledged public health definitions [144-148] supported by DiPH definitions [15, 20, 24, 149-153] to the academic field classification manual by the Organization for Economic Co-operation and Development (OECD) to map linkages between sub-fields in DiPH [154]. The second part was led by the question of what individual disciplines can contribute to DiPH and where they require support from other academic fields to achieve public health impact. We selected epidemiology, psychology, philosophy and ethics, law, computer science, and implementation science as case studies. We used the findings for a proposed action plan regarding ways to initiate and maintain productive collaborations [88].

4.1.2 Results

The discipline mapping resulted in Figure 5: 22. We identified that DiPH includes the relatively clinical concept of digital health and disciplines from social sciences, natural sciences, environmental sciences, humanities, and engineering. However, not only is DiPH interdisciplinary, but also its sub-disciplines. This was especially the case for disciplines related to environmental sciences that also incorporated characteristics from social sciences, natural sciences, and engineering. The second part identified the boundaries and gains of contributing disciplines in the case study of mental health and medical applications in DiPH and where each discipline should be considered best along the process.

4.1.3 Discussion and Conclusion

Due to its interdisciplinary structure, DiPH can adequately address complex problems and questions beyond the methods and aims of just one discipline. Nevertheless, with fields becoming more specialized and eventually breaking apart into smaller disciplines, this research can only serve as a broad orientation of disciplines to be included in DiPH research and practice to enable DiPH to achieve its full potential. Based on our results, we formulated seven requirements for effective and sustainable interdisciplinary collaborations in DiPH, which can be summarized into 1) inclusive communication, 2) informal exchange spaces, 3) empathy toward different approaches, 4) shared mission and vision, 5) mutual trust and respect, 6) team facilitator and balanced team composition, as well as 7) patience that interdisciplinary research takes longer.

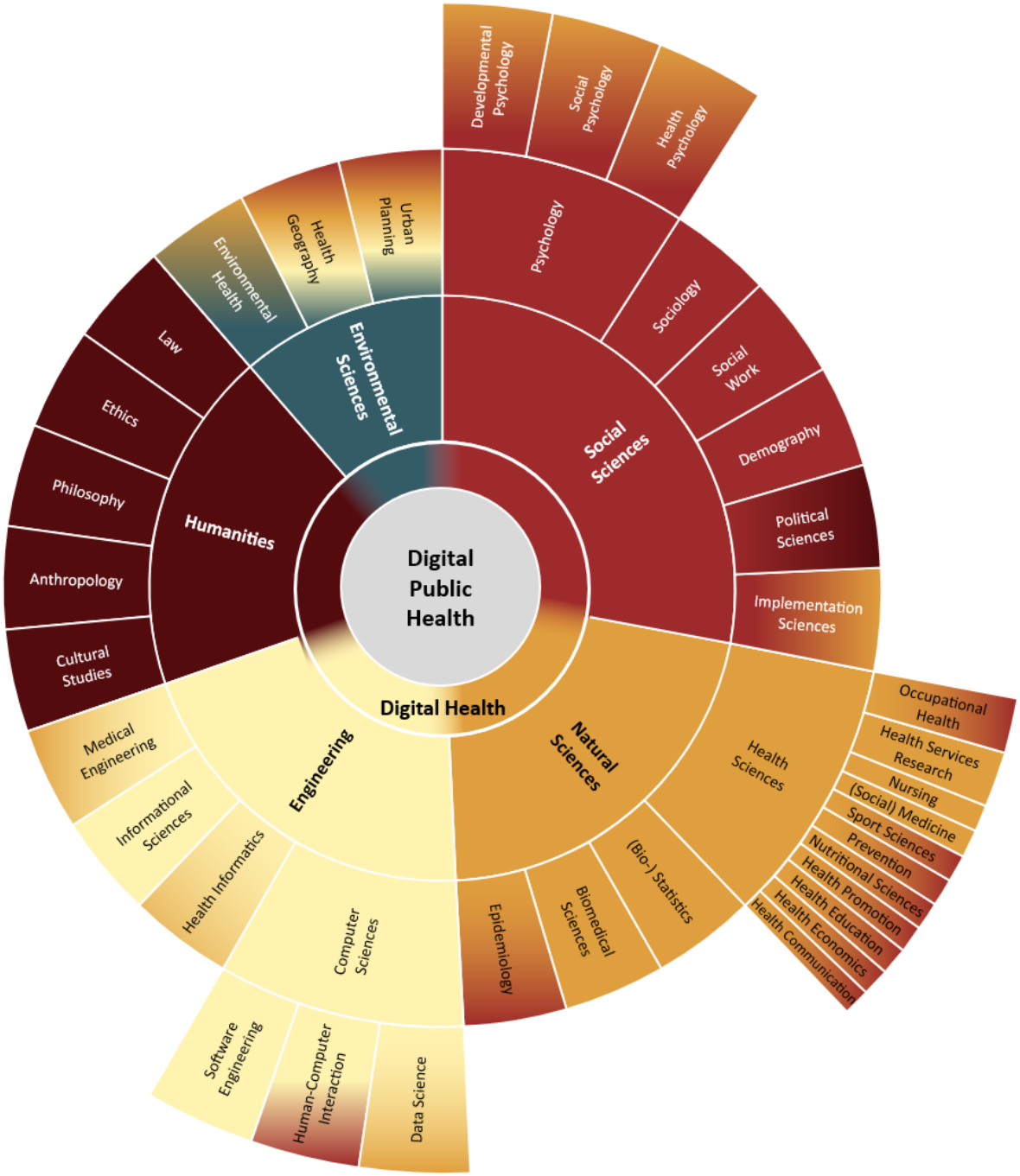

Figure 5. Disciplines in Digital Public Health. Source: Maaß et al. (2024) [88]

4.2 Articles 2 & 3: Scoping Review on characteristics of digital public health tools

4.2.1 Methodology

The protocol for this scoping review has been previously published in JMIR Research Protocols [155]. The study closely followed the *PRISMA Extension for Scoping Reviews* and aimed at mapping interventions to a pre-defined DiPH definition [13, 15, 16] regarding their digital health functions [156], addressed public health function [157], technical features, and non-

technical characteristics (e.g., target population [158] and level of prevention and healthcare [159-162]). The literature search in five academic databases identified 15701 publications, which were screened of which 185 full-text articles were included for the intervention mapping [163-347]. For data extraction, two authors independently extracted data following a pre-defined coding table in a Microsoft Excel 2019 sheet. For the qualitative analysis of technical functions and non-technical intervention characteristics, we used MAXQDA 2022.7 following an iterative coding process [155, 348].

4.2.2 Results

The included publications reported 179 different interventions, of which the majority (n=76) came from Europe or North America (n=47). Overall, interventions were often developed for high-income countries (n=131) rather than low-income countries (n=10). The majority of identified DiPH tools fit the category of telemedical interventions (n=49), followed by health or medical apps (n=28), EHRs (n=23), HIS (n=14), or disease surveillance systems (n=13). An overview of all interventions is displayed in Figure 6: 24. When comparing the public health function and digital health use case in a heatmap, it became evident for the overall intervention cohort that the focus was healthcare from a public health and treatment perspective, diagnostic, communication, and information from a digital health use case perspective. Sub-group analysis for telemedical interventions, health and medical apps, and EHRs displayed that telemedical and EHR tools especially follow this pattern. However, health apps covered a higher number of essential public health functions with the information use case. Nevertheless, the most often addressed public health function remains healthcare. By assessing the technical functions and non-technical characteristics of telemedical interventions and EHRs, we could demonstrate that DiPH interventions' heterogeneity exists between and within intervention types.

4.2.3 Discussion and Conclusion

The spreading of DiPH interventions across countries highlighted the global interest in using technology to improve population health but also pointed out substantial differences in adapting these tools between high- and low-income countries, hinting toward a global digital divide between developed and developing countries [349]. Additionally, our research identified that DiPH interventions often have multiple target groups and settings. Nevertheless, all intervention types reported their applicability in various prevention, healthcare, and research settings, demonstrating flexibility across the healthcare continuum. However, as the heatmap has pointed out, there is room for further exploration of interventions addressing prevention and public health research functions.

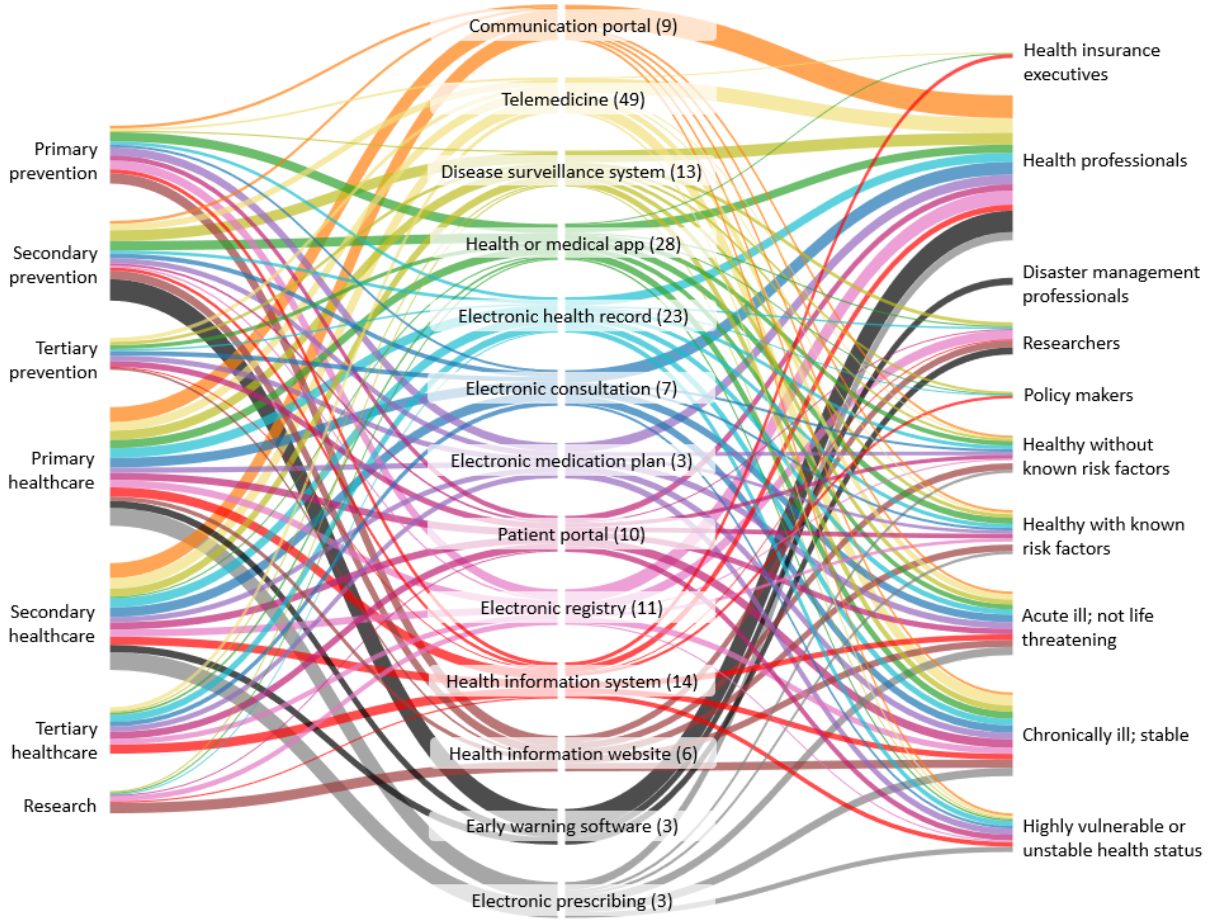

Figure 6. Addressed target groups and level of prevention, healthcare, or research in relative distribution per intervention type. Source: Maaß et al. (2024) [348]

This scoping review has demonstrated the diversity of DiPH interventions regarding their use cases and characteristics. Therefore, using specific terminology when working with or evaluating DiPH interventions is vital. We encourage researchers and practitioners to avoid asking for intervention types (e.g., EHRs). Instead, we should ask for specific technological functions and non-technical characteristics, determine use cases, and define user groups. By doing so, they will facilitate multidisciplinary cooperation among DiPH intervention development and research and foster international comparability across DiPH systems.

4.3 Article 4: Narrative review of existing indicators to measure the maturity of national digital public health systems

4.3.1 Methodology

We applied the approach Godin et al. [350] and Mahood et al. [351] suggested for narrative reviews with pre-defined search terms among search engines and searched for published DiPH system maturity and readiness indicators. The search was primarily conducted using the search engine DuckDuckGo, which claims not to collect any personal data, thereby displaying the

same search results to all its users [352]. The search terms were selected based on the WHO and ITU *National eHealth Strategy Toolkit* [29] dimensions, as presented in Chapter 2. The search terms were chosen to portrait the four overarching domains of the DiPHMI:

1. The ICT domain: To assess the needed digital and technical infrastructure of a country
2. The Legal domain: To analyze the legal framework and political support for DiPH
3. The Social domain: To evaluate the willingness and capability of the general public and workforce to use DiPH tools
4. The Application domain: To estimate the implementation degree and uptake of DiPH tools in the national healthcare system

Additionally, we hand-searched the websites of 19 organizations [353-371] known for engaging in at least one DiPHMI domain for suitable indicators that have not been identified through the primary search.

Two authors individually extracted and screened the references stating "index" or "indicator" for eligibility. We then extracted all 15,806 indicators of the included references. Two authors assessed the indicator's eligibility and screened the remaining for duplications. This reduced the number of indicators to 2,129 distributed across the four DiPHMI domains. All authors voted for their importance on DiPH system maturity and readiness assessment based on a Likert Scale from 1 (not important) to 4 (very important). Indicators were only included if at least three authors ranked them with 3 or 4 on the Likert Scale. Finally, two authors independently categorized the selected indicators into whether they exclusively measured digital maturity, digital readiness, or both concepts. Both terms followed the definition given in Chapter 1.1.1 of this dissertation [51].

4.3.2 Results

The screening and indicator selection process is summarized in Figure 7: 26. The finally selected 286 indicators stem from 90 references [43, 44, 46, 47, 60, 61, 70-75, 80, 114, 115, 117-122, 124-131, 133-139, 141-143, 372-422]. The identified indicators addressed all of the relevant topics deemed essential by the WHO and ITU toolkit (2012) [29] and those by Woods et al. (2022) [77]. For the maturity and readiness assessment, we concluded that only 14 of all 133 indicators exclusively targeted the digital readiness of a DiPH system toward new technologies. These included trust in emerging tools such as AI, financial preparedness in terms of plans for budgeting and reimbursement of new tools as well as plans for implementing and scaling information exchange networks to prepare the uptake of later DiPH interventions [43, 61, 72, 75, 379, 410].

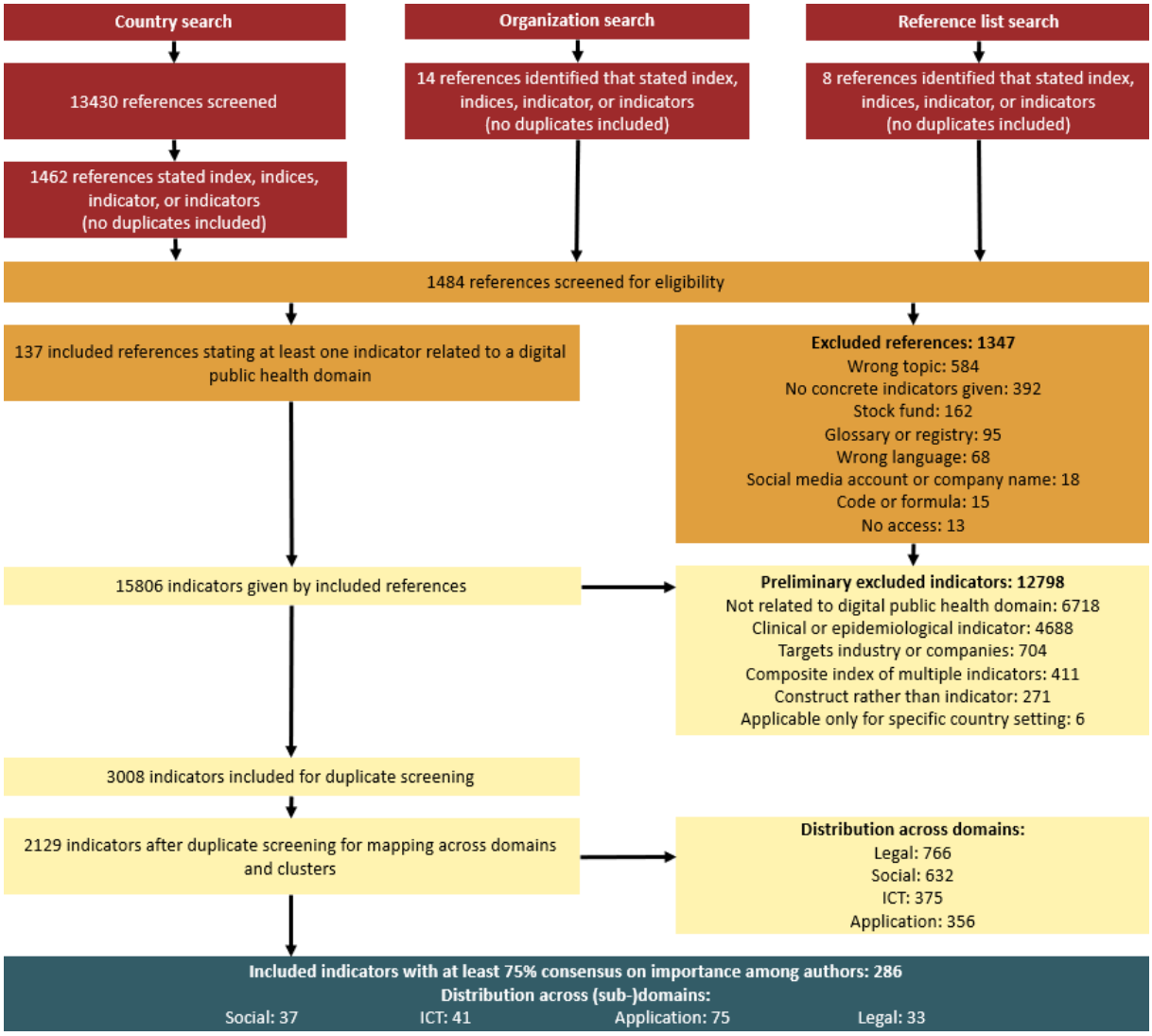

Figure 7. Screening and indicator selection procedure. Source: Maaß et al. (2024) [51]

Another 110 indicators exclusively targeted digital maturity-related topics, including user privacy regulations, the existence of strategies on AI, the implementation degree and user numbers of DiPH interventions, the interoperability between DiPH tools, or the market prices for broadband, mobile data, or handheld devices. The remaining 162 indicators were applicable for both – digital maturity and readiness assessments as they measured the current status concerning change due to new technologies. These included households connected to the Internet, trust in AI and DiPH interventions, digital (health) literacy, the general ICT infrastructure, the use of analytic tools to strengthen the quality and safety across DiPH systems, or the existence of an entity to provide incentives and guidance for innovation of health apps.

4.3.3 Discussion and Conclusion

Our narrative review has shown that grey literature can identify several indicators applicable to the maturity and readiness assessment of DiPH systems. As the vast majority of indicators

targeted the clinical context of DiPH, combining the review results with those from the Delphi study (fifth publication) [69] will result in a multidisciplinary indicator set needed for the DiPHMI. However, to be transferred into a feasible tool, the total number of indicators will need to be reduced, and the selected indicators from this review will need to be discussed by an international and multidisciplinary Delphi panel to achieve an indicator set of global relevance. Additionally, regression analysis is required to test the applicability of such indicators in different settings and identify whether or not they measure the same constructs.

Our findings further support the assumption that readiness assessments of DiPH systems go hand in hand with digital maturity assessments. While some indicators tracked readiness, most aimed at digital maturity or both constructs. Due to the rapid development of digital technologies in the health setting and beyond, assessing readiness dimensions will become challenging [27]. Therefore, evaluating the current development status of a DiPH system through a maturity assessment will most likely produce more sustainable results than exclusively readiness evaluations.

4.4 Article 5: Delphi study on indicators to measure national digital public health system maturity

4.4.1 Methodology

For this study, an online approach with multiple recruitment channels, a pre-study to collect sociodemographic data and assess the eligibility of experts, and three official panel surveys (rounds) were chosen. We asked all experts to which and how many of the four domains (described in Chapter 4.3) they would like to contribute. In total, 82 experts met the inclusion criteria and were invited to the Delphi study, which took place from May to September 2022. Proposed indicators and DiPH tools were kept when they reached at least 70% agreement among the participating experts. We conducted sensitivity analyses to check for biases in the voting results [69].

4.4.2 Results

Overall, 96 indicators (24 for ICT, 31 for Legal, 26 for Social, and 15 for Application) and 25 DiPH tools received at least 70% agreement during the third panel and were finally kept. The indicators were distributed among 21 clusters (see Figure 8: 28), and the DiPH tools were distributed among four groups (digital alternatives to traditional public health tools, mHealth tools, information and education tools, and infrastructure tools). The 25 DiPH tools shared the common characteristic of being free of charge for their user as they are paid for by the government

or health insurance (like a public good) [423, 424]. Additionally, the majority of these interventions target healthcare.

Figure 8. DiPH indicator clusters per sub-dimension after the 3rd Delphi round. Source: Maaß et al. (2024) [69]

In total, 48% of all indicators were covered through existing measures such as the GDHM [33, 44, 113]. However, this rate differed by sub-domains: While 58% of all ICT indicators were already named in published lists, this was the case for only 35% of all indicators from the social dimension. Additionally, several indicators were published for the digital health context but not for DiPH.

4.4.3 Discussion and conclusion

Overall, the online Delphi method proved valuable for achieving consensus among multinational and multidisciplinary expert groups from different geographical regions. The differences in voting behavior by geographic locations regarding the DiPH tools might have come from divergent understandings of public health. For instance, public health in Germany is strongly connected to health promotion and primary prevention, whereas public health in the United Kingdom targets primarily healthcare. This might explain why tools such as telemedicine,

which are not seen as DiPH by German researchers [20], received lower ratings from German experts than from other participants. The range of covered indicators by domain displays different approaches to measuring maturity among the disciplines. For instance, ICT disciplines regularly use indicators for assessments [425], whereas social sciences prefer population surveys to assess how populations think about specific topics.

5 Applying the dissertation results to form the Digital Public Health Maturity Index

5.1 Summary of results that have led to the Digital Public Health Maturity Index

The scoping review and the Delphi study have shown that DiPH interventions are as heterogenetic as the involved DiPH sub-disciplines (see Figure 8: 28) [69, 88, 348]. Their use cases differ from healthcare (diagnostic, treatment, rehabilitation) to health promotion, prevention, surveillance, etc. This is only one reason why assessments of whole DiPH systems are complex. Additionally, the research conducted as part of this dissertation identified that interventions not only differ between intervention groups but also within groups regarding their use case, target population, in their addressed public health function as well as their technical features and non-technical characteristics (see Figure 6: 24). Consequently, multinational assessments of health systems need to consider alternative terminologies when evaluating the implementation status of specific DiPH interventions. Benchmarking results will become more comparable when specific intervention characteristics are recognized for assessing intervention types due to the higher comparability of such DiPH interventions [348].

Apart from the interventions, indicators to measure the maturity and readiness of DiPH systems are of equal importance [51, 69]. Although several indicators to assess sub-disciplines in digital health exist, only a minority of these include maturity and readiness criteria outside the clinical healthcare domain. Further, such tools rarely cover the complexity of DiPH systems and instead focus on one or two sub-dimensions, such as the ICT maturity, interoperability, equity, or DiPH policy [51]. New indicators specifically developed for DiPH are needed to allow a holistic assessment of such a complex system [69].

5.2 The Digital Public Health Maturity Index

The DiPHMI combines this dissertation's collected and developed indicators [51, 69] and distinguishes them across the various disciplines and fields identified in the conceptual considerations of publication 1 [88]. Although relatively resource-intensive, comprehensive tools like the DiPHMI can give reviewers an overview of entire systems [61]. As the narrative review (publication 4) highlighted, no existing tool can currently match the multidisciplinary nature of DiPH [51]. Therefore, applied indices focus on niche topics (such as cybersecurity or ICT infrastructure) but often do not aim to capture the whole DiPH picture [71, 72, 115-123, 125-143, 372]. The DiPHMI will be able to address DiPH system maturity from four perspectives.

5.2.1 Structure of the Digital Public Health Maturity Index

In its current form, the DiPHMI consists of 272 indicators to measure DiPH system maturity from multidisciplinary perspectives. As a composite index, the four sub-dimensions (the *ICT requirements*, the *Legal and political framework*, the *DiPH intervention application*, and the *Social willingness and capability of the population* to use DiPH interventions in prevention, health promotion, and healthcare) can be seen as individual indices. In contrast, their combined analysis forms the holistic DiPHMI [426]. Figure 9 displays the general structure of the DiPHMI.

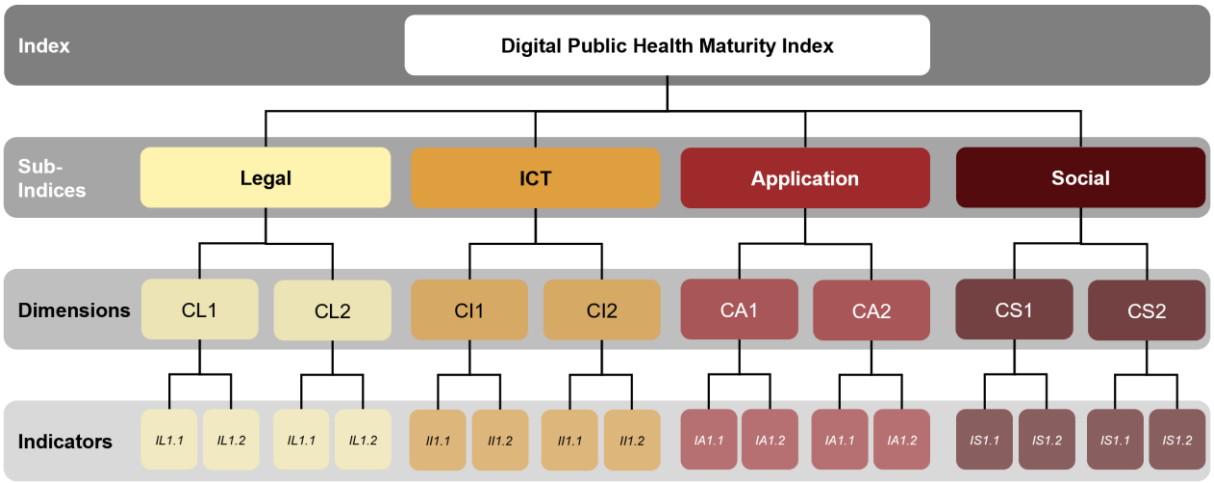

Figure 9. Structure of the Digital Public Health Maturity Index. Source: Own presentation

5.2.2 Methodology of the composite index

The method for the index construction stems from the *Handbook on Constructing Composite Indicators* by the OECD [426]. I will briefly explain the steps needed to construct a composite indicator according to the OECD.

Indicator selection

According to Pencheon (2007, p. 5), "indicators are succinct measures that aim to describe as much about a system as possible in as few points as possible. [They] help us understand a system, compare it and improve it". As such, terminology of indicators and reliable data are crucial for an indicator's value: A poorly formulated indicator with reliable data might be as impractical as a well-described indicator with unreliable data [427], and the quality of the index stems from its selected indicators. The theoretical model for the DiPHMI (see Figure 4: 12) and the WHO and ITU toolkit (see Appendix B) serve as a framework for the index. Selected indicators should, therefore, reflect their importance and the dimensions of the overall DiPHMI [426]. The following criteria guided the indicator selection, which were adapted from Shanahan et al. (2023) [428], Thiel et al. (2018) [43], and Pencheon (2007) [427]:

1. Analytical soundness: The indicator should correctly estimate or describe the construct they are designed to assess.
2. Measurability: The indicator should measure a barrier or an enabler in the take-up of DiPH interventions from the *ICT*, *Legal*, or *Social* perspective or assess the degree of implementation of such interventions (*Application*).
3. Country coverage: The data for each indicator should be available for as many countries as possible (aiming at providing coverage for at least 75% of all countries, like the Mobile Connectivity Index [428]). Therefore, indicators that target specific countries were excluded from this tool.
4. Relevance of the indicators to DiPH systems: The data should be collected consistently over time and relate to DiPH.

Regarding the analytical soundness, one must differentiate between direct, composite, and proxy indicators [123]. While a *direct indicator* can directly measure an aspect of the index (e.g., the number of households covered by a particular Internet connection, as this data can be obtained from public reports), *composite indicators* consist of multiple direct indicators and respond on a scale. *Proxy indicators* are used where original data is limited and direct indicators are impossible (e.g. when asking for user numbers or perceived value through representative surveys). The DiPHMI consists of all three indicator versions, where proxy indicators are primarily used to assess the social dimension, as data in the social sciences is typically collected through representative surveys. Therefore, proxy indicators can only give estimates of the true distribution compared to direct or composite indicators, which can report on hard facts [123]. Where proxy indicators are applied for measuring specific items (such as number of health apps used per individual), surveys are planned for two different target populations: The public health

workforce (including the inner and the broader workforce such as public health practitioners, physicians, nurses, etc.) and the general public. Ideally, these surveys should be conducted paper-based to avoid excluding potential participants based on limited digital skills or the digital divide. However, representative surveys are challenging and resource-intensive, thereby limiting the likelihood of DiPHMI adoption and continuous monitoring through this tool. Due to this issue, well-known indices like the *Exclusive Internet Index* by Economist Impact (2022) [132] or the *#SmartHealthSystems* study by Thiel et al. (2018) [43] do not aim for the representativeness of their survey panels. Instead, they interpret these indicators as qualitative add-ons provided by experts in the field to the more quantitative-oriented direct indicators. This brought me to the decision to follow their approach and define the following minimum required criteria for proxy indicators answered by surveys:

- Minimum sample size: 50 complete respondents (as proposed by Economist Impact)
- Country-specific age distribution but at least 10% of respondents from each category: Gen Z (born 1996-2010), Millennials (born 1980–1995), Gen X (born 1965–1979), Baby Boomers (born 1946–1964)
- Gender: Representative for the country's demographic
- Household income: 50% below and 50% above the country median
- Community type: Mix of urban (major cities) and non-urban (suburban and rural) in each country according to the country's demographic (adapted from Thiel et al. (2018) [43] and Economist Impact (2022) [132])

The dimensions in each sub-index reflect composite indicators to summarize direct and proxy indicators of the same topic. The list of all 272 DiPHMI indicators, including a short description, indicator source, answer, and nominalization scheme, is available in Appendix B.

Nominalization of data

Indicators of the DiPHMI have different measurement units, which limits the comparison of more comprehensive concepts within the DiPHMI and between countries for benchmarking [132]. Some indicators ask for percentages (like the percentage of people who accessed their EHR in the last 12 months [70]), while others have a binary answer scale (e.g., whether or not a specific policy exists [61]). Others apply ranks, for instance, to assess the implementation degree of concrete DiPH interventions in a national system with answer scales from non-existing to nationally implemented [43]. Minimum to maximum values (as goalposts) were chosen for indicators of costs and spending (for instance, the Internet bandwidth capacity per Internet user) as higher values do not necessarily result in a better score (e.g., if a household has to spend

a significant amount of its income to afford broadband at home, this will limit its members on spending money on other essential goods, such as clothing, food, or electricity [391]). On the other hand, if a country invests only a minimum in its ICT infrastructure, this will also tremendously impact the nation's digital maturity.

The calculation for the nominalized scale follows the United Nations' (UN) *Human Development Index* [116] and the *Inclusive Internet Index* by Economy Impact [132]. The ideal scales were chosen based on suggestions from the literature for each indicator (see Appendix C). All indicators are nominalized on a scale of 0 to 100. As a result, 0 always refers to the lowest value, whereas 100 refers to the highest. Table 3 serves as an overview of all types of measurement units in the DiPHMI.

Table 3. Overview of the nominalization process for different indicator measurement units

Measurement unit	Nominalized scale
The percentage (0 – 100%)	0 – 100
Binary scale	0 or 100
Rank (e.g., five ranks)	0, 20, 40, 60, 80, 100
Minimum to maximum	$\text{Indicator} = \frac{\text{actual value} - \text{minimum value}}{\text{maximum value} - \text{minimum value}} * 100$

Source: Economy Impact (2022) [132] and UN (2021) [116]

Weighting and aggregation

In its current form, the DiPHMI can display bar graphs without any interrelation between the individual values (see Figure 10). However, for the DiPHMI to provide its users with comparable results, a weighting scheme will be needed in its updated versions, calculating the total DiPHMI score for a country as the weighted sum of its sub-indicator scores. Choosing the right approach through testing with real-world data is crucial, as weights can tremendously affect the overall index score and rankings [426].

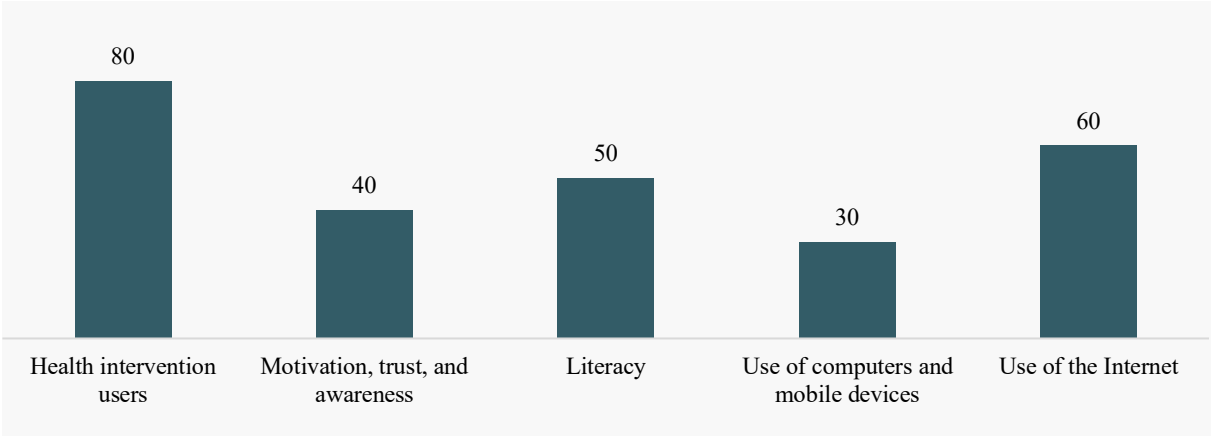

Figure 10. Example bar graph for the Social domain and its sub-dimensions. Source: Own presentation

For composite indices such as the DiPHMI, all weights must be bigger than 0 so as not to make the categories and indicators obsolete. In its current form, the DiPHMI includes no weighting system. However, potential approaches for a weighing system are presented and discussed below (more in Chapter 7).

Neutral weights: Neutral weights assume the same importance to all domains and sub-domains in distributing weights evenly. While this approach is not biased by subjective judgment, is relatively simple, and is neutral to future developments (e.g., a 5G mobile internet might be the gold standard these days but likely be outdated in the upcoming years), the assumption of equal importance of all domains usually does not reflect reality [116, 426].

Equal weights: Equal weights are another option as they assign identical weights to all indicators. Like neutral weight, this has the advantage of eliminating biases based on personal judgment. However, equal weights also share the disadvantage with neutral weights that indicators are usually not equally important in the real world.

Weights by expert-informed panels: For this method, expert-informed panels judge the weight of each category and indicator based on their perspective. This approach has advantages in guiding policy actions due to its strong connection to the real world. However, it is also vulnerable to personal bias by the experts and, therefore, should be accompanied by other evidence regarding indicators and domain importance [132, 140, 426].

Maturity degrees

The individual maturity stages of the DiPHMI are defined by the model based on Liaw et al. (2021) [60] and Holliday & Yin (2019) [83] (see Figure 4: 12). They will be calculated according to the overall score that the country achieved by the assessment. In total, the reachable points for the current DiPHMI version are 27,200. A detailed overview of points is given in Table 4: 35. Following the maturity model defined in Chapter 2.2, countries would need to achieve the following points to be categorized as level 1 to 5 in DiPH maturity:

1. Level: Analogue and traditional public health system: 0 – 5,439 points (0-19%).
2. Level: Reactive and problem-driven DiPH system: 5,440 – 10,879 points (20-39%).
3. Level: Standardized request-driven DiPH system: 10,880 – 16,319 points (40-59%).
4. Level: Optimized service-driven DiPH system: 16,320 – 21,759 points (60-79%).
5. Level: Innovative value-driven DiPH system: 21,760 – 27,200 points (80-100%).

While this approach of nominalization and clustering the indicators across various domains is similar to the GDHM methodology [33, 44], it comes with several limitations due to the current format of the DiPHMI. First, it has to be noted that 48% of the DiPHMI indicators are associated

with the *Legal domain,* which poses a risk of a potential selection bias for the overall assessment of DiPH systems with the tool. Additionally, the informative value of any calculations in the DiPHMI is limited at this stage and needs to be treated with care due to the missing weights for indicators and (sub-) domains. Approaches for an updated DiPHMI version are discussed in the upcoming two chapters of this dissertation.

Table 4. Distribution of achievable points in the Digital Public Health Maturity Index

Domains of the Digital Public Health Maturity Index	Number of indicators	Points in total
Legal domain		
Percentage scale	4	400
Binary scale	4	400
Ranked scale	123	12,300
Total	131	13,100
ICT domain		
Percentage scale	14	1,400
Ranked scale	13	1,300
Min to max scale	1	100
Total	28	2,800
Application domain		
Percentage scale	17	1,700
Binary scale	1	100
Ranked scale	47	4,700
Total	65	6,500
Social domain		
Percentage scale	46	4,600
Ranked scale	2	200
Total	48	4,800

Source: Own presentation

6 Discussion

The findings presented in this dissertation are pivotal in advancing DiPH by providing a comprehensive framework to measure the digital maturity of national public health systems. The development of the DiPHMI addresses a substantial gap in the current landscape of evaluation tools for DiPH domains, which have predominantly focused on clinical and healthcare aspects without fully encompassing the broader public health perspective [33, 71, 140, 377, 380].

This dissertation integrates several theoretical models and frameworks that have guided its development. Notably, the WHO and ITU (2012) *National eHealth Strategy Toolkit* provided the foundational structure for the DiPHMI [29]. Additionally, the central concept of the *Evolve in Context* model of digital excellence in healthcare by Cresswell et al. (2019) has been instrumentalized for the DiPHMI to ensure that the tool remains dynamic and adaptable to evolving

digital landscapes [48]. Further, the maturity models adapted from Holliday & Yin (2019) and Liaw et al. (2021) [60, 83] guided the definition of the individual maturity degrees within the DiPHMI, making it a transparent tool for maturity assessments. Building on this theoretical foundation, the five publications encompassed in this dissertation collectively contribute to the development and validation of the DiPHMI by addressing various dimensions of DiPH maturity from literature and empirical perspectives.

6.1 Discussion of results

The conceptual considerations on the interdisciplinarity of DiPH (publication 1) establishes the theoretical foundation for understanding the interdisciplinary nature of DiPH. By mapping out the various disciplines involved in DiPH, this work creates a framework that underscores the necessity of comprehensive approaches integrating perspectives from environmental, social, and natural sciences, as well as from the humanities and engineering [88]. As such, this publication broadens the scope of digital health maturity to include public health dimensions such as health promotion, prevention, and population surveillance [88]. This comprehensive approach ensures that the DiPHMI can accurately reflect the multifaceted nature of DiPH systems.

The second and third publications, the scoping review protocol and the resultant scoping review, build on this interdisciplinary foundation by systematically mapping DiPH interventions. The identified 179 interventions demonstrate the heterogeneity of DiPH tools, spanning telemedicine, health apps, EHRs, and surveillance systems, and underscore the varied nature of DiPH tools and their deployment. All of these interventions must be included in a holistic evaluation of the DiPH system's maturity. Further, this diversity of intervention types and their characteristics highlight the need for precise terminology and standardization in evaluating DiPH tools, as inconsistencies can hinder comparability and effective policy-making [155, 348]. The methodological rigor of these publications allows the DiPHMI to be grounded in a robust understanding of the current landscape of DiPH interventions.

The fourth publication, the narrative review of existing indicators, further supports the importance of a holistic assessment tool by identifying gaps in existing maturity and readiness indicators that have already been touched upon in the scoping review. The narrative review emphasizes that most identified indicators are biased toward clinical settings, neglecting broader public health dimensions, which was also the case for most DiPH interventions. Consequently, this publication highlights the need for a more holistic approach to evaluating DiPH maturity [51]. This work is crucial for developing the DiPHMI and ensuring it encompasses all relevant dimensions of DiPH.

The fifth publication, the Delphi study on indicators to measure national DiPH system maturity, validates the interdisciplinary and multinational relevance of the indicators identified in the narrative review. These findings reinforce the necessity of the DiPHMI's comprehensive approach, including legal frameworks, ICT infrastructure, general public and workforce attitudes, and the implementation and uptake of DiPH tools. The Delphi study's consensus-building process among experts from diverse backgrounds ensures that the selected indicators are robust, comprehensive, and applicable across various contexts [69]. This publication not only confirms the relevance of the identified indicators but also refines them based on expert feedback, enhancing the credibility and utility of the DiPHMI.

Recent studies emphasize the need for system-level DiPH interventions that integrate public health functions beyond clinical care [3, 48]. This aligns with the DiPHMI's comprehensive approach to evaluating DiPH systems. Moreover, research by other maturity assessment tools underscores the importance of standardized digital maturity assessments for international comparison and policy learning across multiple domains [43, 44, 47], a core objective of the DiPHMI. The tool's inclusion of legal frameworks, ICT infrastructure, and public and workforce attitudes as crucial dimensions, in addition to the implementation degree of DiPH interventions, ensures that these aspects are thoroughly evaluated.

The following sub-sections will discuss the significance of this dissertation for maturity measurement and how the DiPHMI will support overcoming implementation barriers through DiPH governance.

6.1.1 Why does the Digital Public Health Maturity Index target maturity assessments instead of readiness?

Effective DiPH systems can significantly enhance health outcomes by improving data collection, analysis, and dissemination [4, 91]. In this context, digital maturity and readiness play essential roles. With this, digital maturity measures the current status of digitalization and implementation of digital interventions within public health systems. In contrast, digital readiness refers to the degree of preparedness of a system to adapt to emerging technologies [48, 56-58]. While both concepts are vital, assessing digital maturity holds greater importance for several reasons. First, it provides a detailed snapshot of the current capabilities to which digital interventions have been implemented and integrated into existing ICT, regulative, and public health systems. Ideally, this evaluation includes an assessment of the technical infrastructure, workforce skills, data governance, and interoperability of systems, among others [29, 77]. By understanding the current state, policymakers and health administrators can identify strengths and

weaknesses within the system and ensure that the offered health services produce the anticipated outcomes [102]. This knowledge is crucial for developing targeted interventions to enhance system performance and address specific gaps in resource-restricted settings such as public health systems (e.g., financially or due to a lack of available workforce) [27, 43, 44, 47, 61]. Further, allocating resources based on maturity assessments ensures that investments are made in areas with the most significant immediate impact. For example, enhancing data infrastructure or training healthcare workers in digital competencies can immediately benefit the public health system [429]. These improvements also lay the foundation for future advancements, indirectly supporting digital readiness. Focusing on the present state of DiPH systems is critical for immediate decision-making and resource allocation. Given that public health systems often operate under constraints such as limited budgets and urgent crises (e.g., war or global pandemics), understanding the current level of digital maturity enables more effective and timely interventions [430, 431]. On the contrary, focusing on readiness alone may divert resources to potential future needs, which, while necessary, may not address current critical gaps [430].

Additionally, global pandemics such as the COVID-19 pandemic have highlighted the need for high-level maturity in DiPH systems due to shortfalls of in-person delivered health services due to public health actions to mitigate against virus transmission [3, 430, 432, 433]. During the pandemic, countries with better integration and interoperability of digital interventions in the preexisting public health system have proven to be better equipped to handle the surge in cases, manage public health data, and efficiently deploy digital interventions such as contact tracing and vaccination management [434-437]. Nevertheless, interoperability must span the clinical health system and the ICT and social-care systems for a population's health impact [5, 434]. As such, the pandemic underscored that while readiness to adopt new technologies is beneficial, the immediate effectiveness of health responses relies heavily on the current maturity of digital systems [437].

While digital readiness remains essential for future-proofing public health systems, the immediate and practical benefits of measuring digital maturity are more pressing. Comprehensive maturity assessments provide a detailed understanding of current capabilities, facilitate immediate improvements, enable continuous monitoring, and ensure strategic resource allocation [7, 22, 29, 33, 44, 60-62]. Further, the research conducted as part of this dissertation has shown that most existing indicators are designed to measure maturity or both (maturity and readiness), with only a limited number of indicators assessing exclusively readiness-related topics. This overlap suggests that a focus in real-world evaluations on maturity inherently addresses many

readiness aspects. For instance, interoperability, workforce competency, and data governance are crucial for public health systems' digital maturity and readiness [51, 69].

By prioritizing maturity assessments, public health systems can simultaneously enhance their readiness for future technological advancements [430, 438]. This reinforces the need to prioritize the measurement of digital maturity over readiness to ensure DiPH systems are fully prepared to manage current and future health challenges effectively. As such, prioritizing the measurement of digital maturity over readiness is more critical for enhancing the effectiveness and efficiency of national DiPH systems. This approach ensures that health systems are prepared for the future and optimized for present challenges and opportunities [429, 430].

6.1.2 How the Digital Public Health Maturity Index will support countries to overcome barriers toward reaching digital public health maturity

Despite all the opportunities that DiPH offers, it becomes evident that most countries globally are far from reaching a high level of DiPH maturity [16, 44, 47], and questions arise as to how maturity assessments will support them in their digital transmission.

The adoption of DiPH interventions is primarily restricted due to numerous systemic barriers, including a lack of ICT infrastructure (hardware, software, and workforce), missing funding and regulation (or too tight regulation), a substantial digital divide within the country, or a deficiency in the population's digital (health) literacy. Culture also plays a vital role in DiPH uptake if the intervention's supporting effect on the public health system and the population's health is not recognized sufficiently. This also includes the workforce's and the general public's attitude toward DiPH tools [3, 99, 434, 439-441]. The workforce's acceptance is significantly influenced by the workload added due to the implementation of DiPH interventions. A lack of proposed workflows and priorities provided by policy-makers during the national roll-out of such tools could potentially overwhelm healthcare providers and foster their refusal to participate in digitalized health services [440]. Further, ethical uncertainty regarding using digital tools and collecting and accessing personal (health) data often poses a boundary for the deployment and usability of DiPH interventions. Here, policymakers must advocate for the ethical development of DiPH tools and the creation of health data regulations that allow the ethical usage and protection of health data [442, 443].

Additionally, implementing interventions strongly depends on their regulation and funding [3, 99, 434, 439, 440, 444]. For example, video consultations rarely occurred in Germany before 2020 due to strict policies on the circumstances, allowing remote consultations only for precisely defined cases. Numbers drastically increased after the restrictions were lifted with the

introduction of the *Digital-Care-Law* (Digitale-Versorgungs-Gesetz) in December 2019, hinting toward a broad interest by the public in these services during the COVID-19 pandemic [445]. Although the numbers decreased after the pandemic, they remain at a high level compared to pre-pandemic numbers (video consultations among statutorily insured patients in 2019: ca. 4 thousand, 2020: 2.9 million, 2021: 3.5 million, 2022: 2.7 million, 1st half of 2023: 1 million [446, 447]). Other barriers pose limited interoperability and a lack of standards in health data transmission. The relevant applied operating systems can pose a path dependency leading to isolated data silos, which will challenge the change toward an interoperable and inclusive DiPH system with interventions being able to transfer data from one another [433, 448].

While the DiPHMI will not be able to resolve the barriers to DiPH uptake, it will provide an essential first step to holistically identifying blockades that stop countries from progressing further on their DiPH maturity. As determined through standardized evaluations such as the DiPHMI, strategic insights are central to addressing systemic barriers such as inadequate infrastructure, regulatory constraints, and the digital divide [50, 117, 120, 385]. This will be crucial as such procedures allow the development of targeted DiPH interventions and infrastructures [3]. Following a system-level focus, as Gunasekeran et al. (2021) [3] proposed, the DiPHMI can be applied to analyze shortcomings that stem from the challenges mentioned above, amongst others, to identify a solution to these adoption barriers. The DiPHMI will further support policymakers, researchers, and public health experts to create sustainable DiPH interventions that are adopted by the general population and health workforce while being backed up by the ICT and regulative infrastructures. The index will also be applicable for identifying relevant stakeholders and their agenda [43] to create an engagement plan to support intervention uptake [3].

6.2 Thesis strengths

The methods and results presented in this dissertation must be evaluated, considering their strengths and limitations. These are discussed in the following two sections. This dissertation was among the first globally with DiPH as its core topic and compiles five of the first 176 publications on DiPH listed in PubMed (on 16th June 2024, 2 PM). As such, the work conducted as part of this dissertation had a pioneering function and actively contributed toward shaping the global understanding of DiPH.

Further, this cumulative thesis has effectively displayed that Delphi studies (publication 5) are capable of collecting indicators from participants with varying backgrounds (nationally, academically, and culturally) [69]. These qualitative findings were supported by existing literature

through the narrative and the scoping review (publications 2-4) [51, 69, 112, 155]. Consequently, the DiPHMI is based on empirical and literature-based findings, strengthening its validity and applicability to various settings. Additionally, the DiPHMI is supported by recognized concepts of maturity and readiness assessments, distinctions between digital health and DiPH interventions, and the methodologies of established indices for topics related to individual DiPH domains. As such, it is the first evidence-based and theory-guided tool to address and measure the maturity of the DiPH system in a multidisciplinary way.

The work leading to the DiPHMI was conducted following robust internationally recognized methodologies and gold-standard approaches such as the PRIMSA statement on reporting guidelines and its extensions for scoping reviews [449, 450] that were applied to the scoping and narrative review to strengthen the search methodology, the transparency of the search results, and their external validity. This statement has been cited more than 300,000 times across various academic disciplines and research domains (according to Google Scholar, 16th June 2024, 2:40 PM). The qualitative analysis of all publications in this thesis was guided by the groundbreaking work of Braun & Clarke (2006) [451] on thematic analysis, with more than 100,000 citations in Google Scholar (according to Google Scholar, 16th June 2024, 2:50 PM). Due to the missing standards for Delphi studies, our manuscript extensively invested in reporting its methodology to positively influence the methods of upcoming Delphi studies, potentially impacting the development of clear reporting standards in Delphi studies in the future.

Additionally, this dissertation was capable of identifying discrepancies in DiPH. For instance, the scoping review (publication 3) highlighted the need for precise terminologies and reporting of DiPH intervention characteristics instead of reporting intervention types (e.g., instead of using *EHR* ask for an intervention capable to digitally collect, store, and share health data, amongst other functions) [348]. From an indicator perspective (publications 4 and 5), none of the currently publically used indicators follow this scheme [51, 69]. Their reliance on the maturity of intervention types instead of intervention characteristics can limit the benchmarking between countries. Consequently, the DiPHMI will not evaluate the maturity based on intervention types but on intervention characteristics.

6.3 Thesis limitations

While this thesis is characterized by its many strengths, it also has limitations that need to be reported and go beyond the limitations within each publication encompassed in this dissertation. This section will not address the limitations of the individual publications, as these are discussed in detail in the publications available in Appendix A.

Overall, this thesis is based on relatively few publications on DiPH. This is the consequence of the novelty of DiPH and the majority of literature relating more to clinical and individual-centered digital health [51]. Consequently, this might impact the representability of the selected indicators for all domains within DiPH (as identified in the first publication of this thesis) [88] and may have led to a potential selection bias of indicators toward the clinical healthcare setting within DiPH [51]. Nevertheless, as several indicators identified in the narrative review (publication 4) had also been identified in the Delphi study, specifically on DiPH indicators (publication 5), I am confident that these limitations were not strong enough to negatively impact the results of the overall thesis [51, 69]. However, the developed index needs to be tested in a real-world setting to prove its applicability and capability to measure national DiPH maturity.

The second limitation of the DiPHMI is that it is currently a theoretical tool that has not yet been applied. This happened partially due to travel restrictions due to the COVID-19 pandemic but primarily due to missing fundamental research on this topic. As a result, the first two years of this dissertation project were used to define the basic concepts of DiPH [13, 16, 112, 155] before I could explore the requirements for maturity assessments, leaving no time to test the index during the dissertation project. Nevertheless, the DiPHMI has been presented across various international conferences and webinars, thereby raising awareness on the topic and promoting its future uptake (more on that, see Chapter 7 and in Appendix D).

As another result of the currently missing application of the DiPHMI, it is unclear how the currently included 272 indicators interact with each other, whether they measure the same construct or apply to every setting globally. Further, the number of included indicators is potentially too big for the DiPHMI to be a relevant and easy-to-use tool with a potential over-representation of indicators from the *Legal domain*. Nevertheless, DiPH is complex and goes way beyond exclusively the clinical setting. Therefore, it is questionable whether the DiPHMI will be able to provide solid results with only as few as 23 indicators, such as the GDHM [44]. Nevertheless, fewer indicators will likely support the tool's uptake [113].

In addition, the theoretical concepts and models used to develop the DiPHMI represent a limitation. As maturity and readiness assessments are usually conducted for individual organizations or technologies rather than whole public health systems, identifying suitable models and concepts proved challenging. Eventually, this dissertation is not based on one specific concept but on a mixture of various models from academia and business models. However, with no existing models and theoretical concepts for measuring DiPH system maturity, this dissertation may be considered the cornerstone for extensive groundwork on such assessments.

7 Implications for future public health research, practice, and policy

The connection between DiPH maturity and actual health outcomes is currently not well-established. As DiPH tools are no stand-alone interventions but are accompanied by traditional public health assets and measures, assessing their direct impact on health outcomes becomes challenging. Maddah et al. (2023) [436] highlighted that in-depth evaluation studies are missing to evaluate if a correlation exists between an improvement in the population's health and the increasing maturity degree of national DiPH systems. While the DiPHMI will be able to assess digital maturity, future work on the index is needed to connect the DiPH maturity assessment with the health outcomes of the populations. Future research and governance strategies must address questions regarding DiPH's support for countries in achieving the Sustainable Development Goals targeting UHC.

However, further efforts are needed to strengthen the DiPHMI and transform the tool into an easy-to-use measure that can be applied to national DiPH system maturity assessments. As a first step, another Delphi study will be needed to identify those indicators that are applicable and important for the majority of settings globally to reduce the number of indicators to a relevant degree. This will most likely be between 23 indicators, such as the GDHM [113] and 145, like in the *#SmartHealthSystems* study [43]. Building on this, experts will be invited to develop the weighing scheme for the index.

Further, the revised DiPHMI must be tested in a real-world environment to assess its applicability, data availability, and indicators measuring the same constructs. The first dataset will allow linear regression and sensitivity analyses to test for indicators that measure the same construct or intervene with each other.For this, I have already secured partnerships with Malta, the state of Rio de Janeiro in Brazil, the state of British Columbia in Canada, and the Europe Horizon *GerOnte* project, including multiple European countries [452] that have expressed interest in using the DiPHMI for their DiPH systems.

Data availability is also essential for all maturity assessment tools as the assessment's validity correlates with the indicators' data quality and availability. Most data for direct indicators, at least for the *ICT domain*, stems from data sources described in other tools (e.g., data on ICT maturity by Gallup, Speedtest Intelligence® data by Ookla, or data reported to the OECD or ITU by countries). Therefore, there is a high chance that the proposed indicators can be collected through standardized procedures. However, for other indicators, representative surveys among the population and workforce are needed to evaluate most indicators from the *Social*

domain. This will be a cost-intensive assessment, so limiting the indicator numbers first will be crucial. Additionally, data reported from country governments directly might be biased as governments may use different methods for data collection, analysis, and reporting [132]. Other indices further highlighted refraining from data provided by countries in total due to a tendency of governments to report data too optimistic [43].

8 Conclusion

With digitalization increasingly affecting every aspect of our lives, evaluating the preparedness for and implementation of DiPH tools nationally becomes progressively important for health systems. This cumulative dissertation encompasses five peer-reviewed papers published in open-access formats, including a book chapter as interdisciplinary conceptual considerations of digital public health, a scoping review and its study protocol on the complexity of DiPH interventions, a narrative review on DiPH maturity and readiness indicators, and a multinational and multidisciplinary Delphi study on further DiPH indicators. As such, this thesis significantly contributed to the currently limited available data on DiPH systems. All publications were used to develop the DiPHMI as the first tool to analyze the maturity of national DiPH systems holistically.

This dissertation also provided new insights into the potential of DiPH maturity assessments and why it is essential to conduct such evaluations instead of those limited to digital health maturity assessments to see the bigger picture, identify shortcomings, and highlight the strengths of national systems. By that, I identified that assessments necessitate evaluating the ICT requirements and infrastructure for a digitalized public health system. They also require the review of the legal framework and political support toward DiPH, including financing such interventions and protecting sensitive user data. Further, the general public's and workforce's attitudes toward DiPH and their capability to use these tools must be assessed. Finally, the maturity assessment must evaluate the implementation and uptake degree of DiPH tools within the overall public health system.

Additionally, this thesis has proven that Delphi studies are applicable methods for gathering global opinions on complex topics, such as collecting indicators to measure DiPH maturity. Supported by literature-based methodologies, this thesis substantially impacted the international understanding of DiPH interventions and systems while advancing digital health maturity measurements toward more holistic DiPH maturity assessments. Although some research gaps

remain, this thesis is a fundamental building block for further research projects on DiPH maturity evaluations. These gaps will be closed in the upcoming projects.

As the WHO originally initiated this project, the results will be reported to the organization. The WHO already has experience in the field of maturity measurements based on their previous analyses and commitment to the field. Therefore, they have a justified interest in this doctoral thesis's results to develop their procedures further and integrate the DiPHMI into their tools to improve the informative value of DiPH systems. The work on the DiPHMI has not ended with this dissertation. In fact, it has just begun.

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Appendix

A Individual publications

This appendix is not included in the publication of this dissertation. The published individual papers and associated appendices are available under the following links:

A1 Interdisciplinarity in digital public health

Title: Why is it essential to address digital public health in an interdisciplinary way?

Reference: Maaß L, Dassow H-H, Diethei D, Freye M, Niess J, Do S. Why is it essential to address digital public health in an interdisciplinary way? In: Zeeb H, Maaß L, Schultz T, Haug U, Pigeot I, Schüz B, editors. Digital Public Health – Interdisciplinary Perspectives. Cham: Springer Nature Switzerland AG; 2024. Ahead of print.

A2 Characteristics of digital public health interventions – Study protocol

Title: Mapping Digital Public Health Interventions Among Existing Digital Technologies and Internet-Based Interventions to Maintain and Improve Population Health in Practice: Protocol for a Scoping Review

Link: https://www.doi.org/10.2196/33404

A3 Characteristics of digital public health interventions – Scoping review

Title: Mapping digital public health interventions in practice: A scoping review of existing digital technologies and Internet-based interventions to maintain and improve population health

Link: https://www.doi.org/10.2196/53927

A4 Indicators to measure national digital health system maturity

Title: How advanced is your digital public health system? A narrative review of indicators published as grey literature

Link: https://www.doi.org/10.2196/63031

A5 Indicators to measure national digital public health system maturity

Title: International perspectives on measuring national digital public health system maturity through a multidisciplinary Delphi study

Link: https://doi.org/10.1038/s41746-024-01078-9

B WHO and ITU Toolkit for eHealth strategies

C Overview of indicators of the Digital Public Health Maturity Index

The DiPHMI includes 272 indicators spanning the four overarching domains: *Legal*, *ICT*, *Application*, and *Social*. Each domain comprises numerous sub-dimensions filled with individual indicators. All indicators were selected based on this dissertation's narrative review [51] and the Delphi study [69]. The indicator collection aims to transform the DiPHMI into a holistic and interdisciplinary tool for national DiPH maturity assessment.

C1 Legal domain

Digital assets

Indicator ID	**L1-assets**
Indicator	Has the country implemented detailed rules that all health institutions utilize to manage their data assets, including enforcing authentication and access rights to data and compliance with laws and regulations? Health institutions include all institutions providing health services (such as hospitals, pharmacies, or primary healthcare providers).
Indicator source	[61, 69]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (33), yes but only for some health institutions (66), yes for all institutions (100)

Indicator ID	**L2-assets**
Indicator	Is a national list of approved medical devices available for procurement or reimbursement in the country? Medical devices are products or equipment, including objects, substances, and software intended for a medical purpose. They range from low-risk devices (e.g., medical thermometers) to high-risk devices (e.g., implants).
Indicator source	[74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (33), only for specific risk classes (66), yes for all medical devices (100)

Indicator ID	**L3-assets**
Indicator	Did the country consider end-users' needs in developing the electronic health record system? End-users are all people that are using the intervention. This includes healthcare workers (e.g., physicians, nurses, therapists, pharmacists), patients, and representatives. The electronic health record (EHR) is a medical and cross-institutional record or similar documentation of an individual's past and present physical and health mental state in electronic form. EHRs are real-time, patient-centered records that provide immediate and secure information to authorized users. EHRs contain a patient's medical history, diagnoses and treatment, medications, allergies, immunizations, radiology images, and laboratory results. A national EHR system is most often implemented under the responsibility of a national health authority. It will typically make a patient's medical history available to health professionals in healthcare institutions and provide linkages to related services such as pharmacies, laboratories, specialists, and emergency facilities.
Indicator source	[61]
Answer scale and nominalization	Rank; no (0), yes, but not during all development stages (50), yes, participatory approaches were applied across all steps (100)

Indicator ID	L4-assets
Indicator	Are national standards or recommended lists of medical devices available in the country? These lists offer an overview of all medical devices regulated and reimbursed by a country. Medical devices are products or equipment, including objects, substances, and software intended for a medical purpose. They range from low-risk devices (e.g., medical thermometers) to high-risk devices (e.g., implants). This list needs to be publically available.
Indicator source	[74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (33), only for specific risk classes (66), yes for all medical devices (100)

Indicator ID	L5-assets
Indicator	Are technical specifications of medical devices to support procurement or donations publically available in the country? Medical devices are products or equipment, including objects, substances, and software intended for a medical purpose. They range from low-risk devices (e.g., medical thermometers) to high-risk devices (e.g., implants).
Indicator source	[74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (33), only for specific risk classes (66), yes for all medical devices (100)

Indicator ID	L6-assets
Indicator	Do national guidelines, policies, or recommendations on the procurement of medical devices exist in the country? Medical devices are products or equipment, including objects, substances, and software intended for a medical purpose. They range from low-risk devices (e.g., medical thermometers) to high-risk devices (e.g., implants).
Indicator source	[74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (33), only for specific risk classes (66), yes for all medical devices (100)

Indicator ID	L7-assets
Indicator	What percentage of health service providers guarantee compliance with the country's national regulations? Health service providers hereby are software developers and providers of digital health tools that healthcare providers use.
Indicator source	[114]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	L8-assets
Indicator	Does the government participate in cross-border data integration projects to support data transfers between healthcare providers in different countries?
Indicator source	[43]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	L9-assets
Indicator	Does the country run quality checks on the clinical content of electronic patient records?
Indicator source	[43]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L10-assets
Indicator	Are the country's data, algorithm, model, digital technology, and ethical and workforce policies sufficiently robust to achieve the strategic national transformation for a data-driven health future?
Indicator source	[46]
Answer scale and nominalization	Binary; no (0) and yes (100)

Indicator ID	L11-assets
Indicator	Does the country have a policy on using social media for healthcare communication, prevention, and information?
Indicator source	[46]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L12-assets
Indicator	Are organizational performance outcomes shared transparently to inform the public of the impact and value accomplished by the health system?
Indicator source	[70, 74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L13-assets
Indicator	Is there a plan, policy, or program with binding timeframes between set milestones to promote and implement a health information exchange network like electronic health records? The electronic health record (EHR) is a medical and cross-institutional record or similar documentation of an individual's past and present physical and health mental state in electronic form. EHRs are real-time, patient-centered records that provide immediate and secure information to authorized users. EHRs contain a patient's medical history, diagnoses and treatment, medications, allergies, immunizations, radiology images, and laboratory results. A national EHR system is most often implemented under the responsibility of a national health authority. It will typically make a patient's medical history available to health professionals in healthcare institutions and provide linkages to related services such as pharmacies, laboratories, specialists, and emergency and medical imaging facilities.
Indicator source	[43, 61, 69, 73, 74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L14-assets
Indicator	Did the country conduct public awareness campaigns on the importance of health literacy in the last year?
Indicator source	[402]
Answer scale and nominalization	Binary; no (0) and yes (100)

Indicator ID	L15-assets
Indicator	Is there a plan, policy, or program with binding timeframes between set milestones to promote and implement telehealth? Telehealth includes computer-assisted telecommunications to support management, surveillance, literature, and access to medical knowledge. Telemedicine, as a sub-dimension of telehealth, provides healthcare services through ICT when the health professional and the patient (or two health professionals) are not in the same location. It includes the secure sending of health data and information through text, sound, images, or other forms needed for the prevention, diagnosis, treatment, and follow-up of patients.
Indicator source	[43, 46, 74, 391, 413]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L16-assets
Indicator	Is there a plan, policy, or program with binding timeframes to promote and implement electronic prescribing between set milestones? Electronic prescriptions are the prescribing of medicine through software and the electronic transmission of prescription data to a pharmacy where the medicine can be dispensed. Once the medicine has been dispensed, the pharmacy reports the dispensation information using the electronic prescription software.
Indicator source	[43, 46, 74, 391, 413]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

	L17-assets
Indicator	Is there a plan, policy, or program with binding timeframes to promote and implement mobile health interventions between set milestones? Mobile health applications are software programs on mobile devices (e.g., smartphones or tablets) that process health-related data. User groups include health-conscious medical laypersons, family caregivers, or health professionals. They are used to maintain, improve, or manage the users' health.
Indicator source	[43, 46, 74, 391, 413]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L18-assets
Indicator	Is there a plan, policy, or program with binding timeframes to promote and implement health portals between set milestones? Health portals are online applications that foster communication and interaction between patients and their healthcare providers (e.g., physicians or hospitals). The portals can be implemented as stand-alone websites or integrated as modules within a provider's or country's electronic health record system.
Indicator source	[43, 46, 74, 391, 413]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L19-assets
Indicator	Is a multi-sectoral governance (e.g., committee), including the health sector, articulated in the country's national ICT plan, strategy, or policy?
Indicator source	[60]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L20-assets
Indicator	Is there a plan, policy, or program with binding timeframes to promote and implement big data in healthcare between set milestones?
Indicator source	[43, 46, 73, 74, 391, 413]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L21-assets
Indicator	Does the country promote and modernize regulations and policies for using and advancing new ICTs in health that guarantee personal security and privacy?
Indicator source	[75]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L22-assets
Indicator	Does the country's national broadband plan set coverage targets? These targets include the percentage of: - population with broadband - businesses with broadband - schools with broadband - rural population - population with mobile internet - population with PC ownership - population with digital identity - implementation of eGovernment services
Indicator source	[407]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100). The total score will be the average for all targets

Indicator ID	L23-assets
Indicator	Does the country's national broadband strategy to develop a high-speed access network include government investment in infrastructure to make broadband more broadly available?
Indicator source	[396, 397, 407]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	L24-assets
Indicator	Does the country's national broadband strategy to develop a high-speed access network set a minimum download speed Mbps performance target?
Indicator source	[396, 397, 407]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	L25-assets
Indicator	Do legal liabilities for managers of publically funded digital public health projects exist that prohibit them from having additional digital health contracts financed by the private sector that potentially harm the public interest?
Indicator source	[69]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	L26-assets
Indicator	Are the contracts for digital public health projects accessible and transparent to the public for over-sight and law enforcement agencies for anti-corruption purposes
Indicator source	[69]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Digital public health strategy

Indicator ID	L27-strategy
Indicator	Is there a policy for supporting digital (public) health (including hardware and software infrastructure, budgeting, intervention implementation, regulation, evaluation, and data protection) provision and maintenance as part of the national health policy?
Indicator source	[43, 46, 60, 69, 73, 74, 114, 399, 403, 420]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L28-strategy
Indicator	Does the national digital strategy align with Universal Health Coverage's core components? Core components for Universal Health Coverage include systematically addressing the broader determinants of health (social, economic, and environmental factors together with individual characteristics and behavior), empowering individuals and communities to advocate for their health, and meeting the population's health needs through integrated health services focusing on primary healthcare and essential public health functions.
Indicator source	[44, 69, 73]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	L29-strategy
Indicator	Is a legal framework for digital (public) health services established?
Indicator source	[60, 69]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L30-strategy
Indicator	Is health prioritized in national digital transformation and data governance policies?
Indicator source	[44]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)
Indicator ID	L31-strategy
Indicator	Are diversity, gender, equity, and human rights analysis included in national digital (public) health strategies?
Indicator source	[44, 69]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	L32-strategy
Indicator	Does the digital (public) health strategy engage with protecting the fundamental rights of vulnerable groups? Vulnerable groups include those most at risk, including people with disabilities, youth, women, lesbian, gay, bisexual, transgender, and intersex people, ethnic minorities, indigenous people, internally displaced individuals, refugees, asylum seekers, or migrants.
Indicator source	[69]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	L33-strategy
Indicator	Does the population have the legal right to be provided with and access digital (public) health services?
Indicator source	[69]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	L34-strategy
Indicator	Does a policy exist on the need for informed consent to use personal health data from adult patients?
Indicator source	[69]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	L35-strategy
Indicator	Does a policy exist on the need for unique procedures to protect the youth and mentally ill patients who are unable to give their consent for using personal health data?
Indicator source	[69]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	L36-strategy
Indicator	The percentage of all digital (public) health jurisdictions of the country that include criteria and actions related to the inclusive digital health principle. The inclusive digital health principle calls for integrating gender criteria, intercultural perspectives, equity, and solidarity into digital health actions and agendas.
Indicator source	[69, 114]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	L37-strategy
Indicator	Does a governance framework exist for assessing and managing digital (public) health data quality?
Indicator source	[60, 69]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L38-strategy
Indicator	Is a mechanism in place to provide a comprehensive overview of on-going digital (public) health government initiatives?
Indicator source	[69, 121]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L39-strategy
Indicator	Has the country developed and adopted standards or guidelines for the design of digital services?
Indicator source	[121]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L40-strategy
Indicator	Has any political leadership (ministers, party officials, senior government officials) advocated using digital (public) health technologies and applications to reform the national health system in the last five years?
Indicator source	[43]
Answer scale and nominalization	Binary; no (0) and yes (100)

Indicator ID	L41-strategy
Indicator	Has digital (public) health been featured on the platform of a major political party in the last five years (whether in government or not)?
Indicator source	[43]
Answer scale and nominalization	Binary; no (0) and yes (100)

Indicator ID	L42-strategy
Indicator	Does a policy exist that sets standards for transparency and the protection of fundamental rights in using Artificial Intelligence in digital public health?
Indicator source	[69]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)
Indicator ID	L43-strategy
Indicator	Is a big data and Artificial Intelligence strategy related to (public) health in place?
Indicator source	[61]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L44-strategy
Indicator	Are strategies to promote research into the usability of big data for (public) health purposes in place?
Indicator source	[61]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L45-strategy
Indicator	Are strategies to promote the development and use of Artificial Intelligence for (public) health in place?
Indicator source	[61]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L46-strategy
Indicator	Are there (international) coordination and collaboration initiatives aimed at increasing and transferring health-related technology, including between public and private entities?
Indicator source	[74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (20), yes but only on the local level (40), yes but only on the regional level (60), yes on the national level (80), yes on the international level (100)

Indicator ID	L47-strategy
Indicator	Does a policy exist that sets standards for transparency and the protection of fundamental rights in using Artificial Intelligence in digital public health?
Indicator source	[69]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	L48-strategy
Indicator	Does the country have a health workforce strategy to identify fields with insufficient workforce and strategies to address these shortcomings? The health workforce includes those groups that provide health services (such as nurses, midwives, therapists, dentists, or medical doctors) but also those related to public health (including public health experts or social care workers)
Indicator source	[74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (33), only for some health workforce groups (66), yes for the whole health workforce (100)

Indicator ID	L49-strategy
Indicator	Does the national digital (public) health-related strategy aim to improve health workforces' productivity?
Indicator source	[399]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	L50-strategy
Indicator	Does the national digital (public) health-related strategy aim to invest in innovation and develop new tools for the digital (public) health system?
Indicator source	[69, 399]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	L51-strategy
Indicator	Are economic actors (e.g., industry, payers, insurance), civil society (e.g., patient organizations, caregivers, or the general public), or healthcare providers (e.g., physicians or pharmacies) involved in the national planning and implementation of digital health services in addition to government agencies (healthcare system or infrastructure) through regulation and in practice?
Indicator source	[43] [61]
Answer scale and nominalization	Rank; no (0), yes but not during all development stages (50), yes participatory approaches were applied across all steps (100)

Indicator ID	L52-strategy
Indicator	Does a national health information system policy or strategy exist? Health information systems (HIS) are systems designed to manage healthcare data. This includes collecting, storing, managing, and transmitting data from digital health interventions such as electronic health records, hospital operational management systems, systems supporting healthcare policy decisions, and others. HIS commonly access, process, or maintain large volumes of sensitive data, so security is a primary concern.
Indicator source	[61, 73, 74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Financial regulation

Indicator ID	L53-finance
Indicator	Do health insurers (private or national statutory health insurers) use part of their operating budget to reimburse digital health-supported health services?
Indicator source	[43]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L54-finance
Indicator	Is there a regulation allowing public funds for technical infrastructure on-site at the healthcare service provider (e.g., primary care provider offices, hospitals, or pharmacies)?
Indicator source	[43]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L55-finance
Indicator	Does the government sponsor mobile health programs? Mobile health applications are software programs on mobile devices (e.g., smartphones or tablets) that process health-related data. User groups include health-conscious medical laypersons, family caregivers, or health professionals. They are used to maintain, improve, or manage the users' health.
Indicator source	[69, 73, 74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L56-finance
Indicator	Is a national budget for developing Artificial Intelligence-based systems implemented that can impact population health?
Indicator source	[75]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	L57-finance
Indicator	Does the government sponsor electronic health programs?
Indicator source	[69, 73, 74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L58-finance
Indicator	Is there a regulation that provides for financial penalties or subsidies for the introduction of digital health technologies?
Indicator source	[43, 69]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L59-finance
Indicator	Are effectiveness and health-economic evaluations conducted of any government-sponsored telehealth programs? Telehealth includes computer-assisted telecommunications to support management, surveillance, literature, and access to medical knowledge. Telemedicine, as a sub-dimension of telehealth, provides healthcare services through ICT when the health professional and the patient (or two health professionals) are not in the same location. It includes the secure sending of health data and information through text, sound, images, or other forms needed for the prevention, diagnosis, treatment, and follow-up of patients.
Indicator source	[73, 74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	L60-finance
Indicator	What is the share of the digital health budget designated to primary healthcare of the total annual government health budget?
Indicator source	[43, 60, 69, 402]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	L61-finance
Indicator	What is the share of the budget designated to information-communication-infrastructure of the total annual government budget?
Indicator source	[69]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	L62-finance
Indicator	Does the national budget include specific budget-line items to provide a functioning statistics system for all data sources in the national statistics office?
Indicator source	[74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	L63-finance
Indicator	Does the government provide financial incentives for health professionals to offer digital (public) health services?
Indicator source	[69]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (33), yes but not for all health services (66), yes for all health services (100)

Indicator ID	L64-finance
Indicator	Does the national budget include specific budget-line items to provide a sustainable and functioning health information system for all relevant data sources in the Ministry of Health? Health information systems (HIS) are systems designed to manage healthcare data. This includes collecting, storing, managing, and transmitting data from digital health interventions such as electronic health records, hospital operational management systems, systems supporting healthcare policy decisions, and others. HIS commonly access, process, or maintain large volumes of sensitive data, so security is a primary concern.
Indicator source	[61, 69, 74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Health data regulation

Indicator ID	L65-data
Indicator	Do protocols for regulating or certifying devices and health services, including Artificial Intelligence and algorithm provisions, exist?
Indicator source	[44]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L66-data
Indicator	Is a clear definition of the roles and responsibilities of all key stakeholders in the health data governance process (e.g., data managers, IT managers, and senior management staff) available?
Indicator source	[61]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L67-data
Indicator	Is a health data governance or electronic health strategy in place?
Indicator source	[61]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L68-data
Indicator	Is progress reporting on health data governance in place?
Indicator source	[61]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L69-data
Indicator	Is a risk assessment and reporting structure in place concerning the governance risks of health data?
Indicator source	[61]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L70-data
Indicator	Are there specific guardrails for the legal basis for processing personal data for (public) health purposes?
Indicator source	[61]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	L71-data
Indicator	Is there any multistakeholder discourse on the acceptable use of health data for the public or private good?
Indicator source	[61]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L72-data
Indicator	Are available health data analyzed in a structured manner for health policy-making?
Indicator source	[61]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L73-data
Indicator	Are governmental initiatives in place to strengthen the exchange between relevant public institutions regarding the acceptable use of health data?
Indicator source	[61]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L74-data
Indicator	Is a transparent process looping policy-making requirements into health data analytics in place?
Indicator source	[61]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L75-data
Indicator	Is there a long-term vision for using health data in public policy-making (e.g., forecasts for resource planning in healthcare, foresight studies for strategic policy development, or benchmarking to compare and improve the quality of health service delivery)?
Indicator source	[61]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L76-data
Indicator	Is the long-term vision for using health data in public policy-making embedded in multinational initiatives?
Indicator source	[61]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	L77-data
Indicator	Has the government committed public statements, legislation, or a cooperative agreement to share surveillance data during a public health emergency with other countries in the region?
Indicator source	[72]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	L78-data
Indicator	Does the country have a policy or legislation to define medical jurisdiction, liability, or reimbursement of electronic health services?
Indicator source	[74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L79-data
Indicator	Does the national technology transfer strategy with other countries include health-related technologies and relevant capacity-building components?
Indicator source	[74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	L80-data
Indicator	Does the country have up-to-date legislation providing the framework for health information covering specific components? The components include: - Vital registration - Notifiable diseases - Private sector data, including social insurance - Confidentiality
Indicator source	[74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100) for each component

Indicator ID	L81-data
Indicator	Does the country follow international initiatives for the standardization of health data?
Indicator source	[61, 69]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	L82-data
Indicator	Is the guidance provided by international initiatives for health data standardization implemented in the national health data standardization framework?
Indicator source	[61, 69]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	L83-data
Indicator	Are international initiatives for health data standardization used to inform national processes that deviate from international guidance?
Indicator source	[61, 69]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	L84-data
Indicator	Are national interoperability standards developed, maintained, updated, and enforced for relevant health data sets for exchange to coordinate healthcare? Interoperability needs to be distinguished into semantic and technical interoperability. The first refers to computer systems transmitting data with unambiguous shared meaning. It enables machine computable logic inferencing knowledge discovery and data federation between information systems. Therefore, it is concerned with the packaging of data and the simultaneous transmission of the meaning with the data. This is accomplished by adding data about the data linking each data element to a controlled shared vocabulary. Technical interoperability is associated with hardware and software components, systems, and platforms that enable machine-to-machine communication. This kind of interoperability is often centered on (communication) protocols and the infrastructure needed for those protocols to operate.
Indicator source	[60, 69, 73]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (33), yes but not for all health services (66), yes for all health services (100)

Indicator ID	L85-data
Indicator	Have standardized metrics for assessing and reporting risks been implemented in the risk assessment and reporting structure on governance risks of health data?
Indicator source	[61]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L86-data
Indicator	Do regulatory frameworks exist that promote patients' autonomy in using their health information?
Indicator source	[402]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L87-data
Indicator	Do digital assistive technology regulations, standards, guidelines, or protocols exist? Digital assistive technologies include speech recognition or time management software and captioning.
Indicator source	[74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L88-data
Indicator	Do policy guidelines or laws define digital health services' medical jurisdiction and liability?
Indicator source	[43]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L89-data
Indicator	Do legal frameworks allow patient data collection, processing, and disclosure for statistical purposes?
Indicator source	[43]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L90-data
Indicator	Are specific regulations in place for the identification and authentication of healthcare professionals, and who can create and access electronic health records? The electronic health record (EHR) is a medical and cross-institutional record or similar documentation of an individual's past and present physical and health mental state in electronic form. EHRs are real-time, patient-centered records that provide immediate and secure information to authorized users. EHRs contain a patient's medical history, diagnoses and treatment, medications, allergies, immunizations, radiology images, and laboratory results. A national EHR system is most often implemented under the responsibility of a national health authority. It will typically make a patient's medical history available to health professionals in healthcare institutions and provide linkages to related services such as pharmacies, laboratories, specialists, and emergency and medical imaging facilities.
Indicator source	[43]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L91-data
Indicator	Is a legal framework in place for the secondary use of personal health data, such as health data for research purposes or statistics?
Indicator source	[43, 61, 69]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L92-data
Indicator	Are there protocols, policies, frameworks, or accepted processes governing the clinical and patient care use of connected medical devices and digital health services, particularly concerning safety, data integrity, and quality of care?
Indicator source	[46]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L93-data
Indicator	Does a legal data security and privacy framework address the privacy of personally identifiable data?
Indicator source	[43, 60, 61, 69, 73, 74, 114, 375, 383, 402]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L94-data
Indicator	Does a legal data security and privacy framework address the privacy of individuals' identifiable health-related data, such as that generated through health surveillance activities, including mention of protections from cyberattacks (e.g., ransomware)?
Indicator source	[43, 60, 61, 69, 72-74, 114, 375, 383, 402]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L95-data
Indicator	Does a legal data security and privacy framework address civil registration and vital statistics?
Indicator source	[43, 60, 61, 73, 74, 114, 383, 402]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L96-data
Indicator	Does a legal data security and privacy framework exist that addresses national identification management systems?
Indicator source	[43, 60, 61, 69, 73, 74, 114, 383, 402]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L97-data
Indicator	Does a legal data security and privacy framework address digital health data sharing between health professionals through an electronic health record?
Indicator source	[43, 46, 60, 61, 69, 73, 74, 114, 383, 402]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L98-data
Indicator	Does a legal data security and privacy framework grant patients and citizens electronic access to their health-related data?
Indicator source	[43, 44, 46, 60, 61, 73, 74, 114, 383, 402]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L99-data
Indicator	Does a legal data security and privacy framework address patients' and citizens' demands for their health-related issues to be corrected?
Indicator source	[43, 44, 46, 60, 61, 73, 74, 114, 383, 402]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L100-data
Indicator	Does a legal data security and privacy framework address patients and citizens to specify which health-related data can be shared with health professionals?
Indicator source	[43, 44, 46, 60, 61, 69, 73, 74, 114, 383, 402]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L101-data
Indicator	Does a legal data security and privacy framework address patients and citizens to demand the deletion of health-related data?
Indicator source	[43, 44, 46, 60, 61, 73, 74, 114, 383, 402]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L102-data
Indicator	Does a legal data security and privacy framework address cross-border (health) data security and sharing?
Indicator source	[43, 44, 46, 60, 61, 69, 73, 74, 114, 383, 402]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L103-data
Indicator	Does a legal data security and privacy framework address personal and health data sharing between research entities?
Indicator source	[43, 44, 46, 60, 61, 69, 73, 74, 383, 402]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L104-data
Indicator	Do legal frameworks allow patient data collection, processing, and disclosure for research purposes (as opposed to prohibition and suppression)?
Indicator source	[43]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L105-data
Indicator	Are organizational guidelines receptive to value for patients, informed by patient participation, to inform and support digital healthcare systems?
Indicator source	[70, 386]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L106-data
Indicator	Is a training or awareness program for healthcare providers in place for health data governance?
Indicator source	[61]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L107-data
Indicator	Does the training or awareness program for health data governance also target other stakeholders (e.g., public health bodies, non-government organizations, and health insurance systems) and the wider public besides healthcare providers?
Indicator source	[61]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Digital public health authority

Indicator ID	L108-authority
Indicator	Has a public-private commission been created that meets regularly to define and monitor data access and governance to implement Artificial Intelligence strategies in health?
Indicator source	[75]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L109-authority
Indicator	Is a multistakeholder coordination mechanism in place for the development and implementation of a health data governance strategy? The authority can be a public health institute or agency, a department or working group within the Ministry of Health, or another formal authority.
Indicator source	[61]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L110-authority
Indicator	Does a department or working group on digital public health exist in the national Ministry of Health?
Indicator source	[44, 69]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	L111-authority
Indicator	Is an authority in place responsible for health data standards, providing precise criteria, specifications, and rules for defining, creating, storing, and using health data? The authority can be a public health institute or agency, a department or working group within the Ministry of Health, or another formal authority.
Indicator source	[61]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L112-authority
Indicator	Is an authority or multistakeholder platform in place steering initiatives on the quality and accuracy of health data? The authority can be a public health institute or agency, a department or working group within the Ministry of Health, or another formal authority.
Indicator source	[61]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L113-authority
Indicator	Does a regulatory authority propose clinical terminologies (such as SNOMED CT, LOINC, etc.) to facilitate semantic interoperability and data exchange? The authority can be a public health institute or agency, a department or working group within the Ministry of Health, or another formal authority. Semantic interoperability refers to computer systems that transmit data with unambiguous shared meanings. It enables machine computable logic inferencing knowledge discovery and data federation between information systems. Therefore, it is concerned with the packaging of data and the simultaneous transmission of the meaning with the data. This is accomplished by adding data about the data linking each data element to a controlled shared vocabulary.
Indicator source	[43, 60, 61, 69, 399, 403]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L114-authority
Indicator	Does the public health service law include population health monitoring and maintenance of a health information system as a mandatory task of the public health authority? The authority can be a public health institute or agency, a department or working group within the Ministry of Health, or another formal authority. Health information systems (HIS) are systems designed to manage healthcare data. This includes collecting, storing, managing, and transmitting data from digital health interventions such as electronic health records, hospital operational management systems, systems supporting healthcare policy decisions, and others. HIS commonly access, process, or maintain large volumes of sensitive data, so security is a primary concern.
Indicator source	[61]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L115-authority
Indicator	Is an authority in place that conducts independent audits on the governance of health data security? The authority can be a public health institute or agency, a department or working group within the Ministry of Health, or another formal authority.
Indicator source	[61]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L116-authority
Indicator	Is an authority in place that guides data protection and international telecommunication security regarding health data? The authority can be a public health institute or agency, a department or working group within the Ministry of Health, or another formal authority.
Indicator source	[61]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L117-authority
Indicator	Is there a functional central health information system administrative unit in the Ministry of Health to design, develop, and support health-information collection, management, analysis, dissemination, and use for planning and management? Health information systems (HIS) are systems designed to manage healthcare data. This includes collecting, storing, managing, and transmitting data from digital health interventions such as electronic health records, hospital operational management systems, systems supporting healthcare policy decisions, and others. HIS commonly access, process, or maintain large volumes of sensitive data, so security is a primary concern.
Indicator source	[69] [74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L118-authority
Indicator	Is there a functional central health information system administrative authority responsible for population censuses and household surveys that designs, develops, and supports health-information collection, management, analysis, dissemination, and use for planning and management? The authority can be a public health institute or agency, a department or working group within the Ministry of Health, or another formal authority. Health information systems (HIS) are systems designed to manage healthcare data. This includes collecting, storing, managing, and transmitting data from digital health interventions such as electronic health records, hospital operational management systems, systems supporting healthcare policy decisions, and others. HIS commonly access, process, or maintain large volumes of sensitive data, so security is a primary concern.
Indicator source	[69] [74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L119-authority
Indicator	Does a certifying authority exist to validate the systems' regulations, standards, safety, and quality to be implemented in the health area? The authority can be a public health institute or agency, a department or working group within the Ministry of Health, or another formal authority.
Indicator source	[402]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L120-authority
Indicator	Does a technical, political, and administrative authority exist to manage the health information system affairs of a country's health system? The authority can be a public health institute or agency, a department or working group within the Ministry of Health, or another formal authority. Health information systems (HIS) are systems designed to manage healthcare data. This includes collecting, storing, managing, and transmitting data from digital health interventions such as electronic health records, hospital operational management systems, systems supporting healthcare policy decisions, and others. HIS commonly access, process, or maintain large volumes of sensitive data, so security is a primary concern.
Indicator source	[46, 60, 69, 74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L121-authority
Indicator	Does the authority coordinating the health information system have a complete overview of health information needs and what health information is available? The authority can be a public health institute or agency, a department or working group within the Ministry of Health, or another formal authority. Health information systems (HIS) are systems designed to manage healthcare data. This includes collecting, storing, managing, and transmitting data from digital health interventions such as electronic health records, hospital operational management systems, systems supporting healthcare policy decisions, and others.
Indicator source	[61, 69]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L122-authority
Indicator	Does the country have a recognized mechanism (e.g., committee or working group) for reviewing data ethics issues in the national health information system and updating policies, procedures, and laws, as needed? The authority can be a public health institute or agency, a department or working group within the Ministry of Health, or another formal authority. Health information systems (HIS) are systems designed to manage healthcare data. This includes collecting, storing, managing, and transmitting data from digital health interventions such as electronic health records, hospital operational management systems, systems supporting healthcare policy decisions, and others.
Indicator source	[46]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L123-authority
Indicator	Is a regulatory authority responsible for defining digital (public) health standards, overseeing the digital (public) health strategy and investments or implementation of national components of digital (public) health programs, or evaluating digital (public) health applications? The authority can be a public health institute or agency, a department or working group within the Ministry of Health, or another formal authority. Health applications are software programs on mobile devices (e.g., smartphones or tablets) that process health-related data. User groups include health-conscious medical laypersons, family caregivers, or health professionals. They are used to maintain, improve, or manage the users' health.
Indicator source	[43, 46, 60, 69, 74, 377, 403]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L124-authority
Indicator	Does the country have a health technology assessment authority with clear and transparent decision rules? The authority can be a public health institute or agency, a department or working group within the Ministry of Health, or another formal authority. Health technology assessments (HTAs) are methods to systematically evaluate the assets and effects of health technologies (e.g., devices, vaccines, procedures, or programs) at any point during their lifecycle (pre-market, regulatory approval, post-market, disinvestment).
Indicator source	[130]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L125-authority
Indicator	Does the health technology assessment authority assess medical devices, including in vitro diagnostics? The authority can be a public health institute or agency, a department or working group within the Ministry of Health, or another formal authority. Health technology assessments (HTAs) are methods to systematically evaluate the assets and effects of health technologies (e.g., devices, vaccines, procedures, or programs) at any point during their lifecycle (pre-market, regulatory approval, post-market, disinvestment).
Indicator source	[73, 74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L126-authority
Indicator	Is a national authority responsible for regulating medical devices in the country? The authority can be a public health institute or agency, a department or working group within the Ministry of Health, or another formal authority. Medical devices are products or equipment, including objects, substances, and software intended for a medical purpose. The authority can be a public health institute or agency, a department or working group within the Ministry of Health, or another formal authority.
Indicator source	[69] [74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (33), only for specific risk classes (66), yes for all medical devices (100)

Indicator ID	L127-authority
Indicator	Does an authority provide incentives and guidelines for mobile health application innovation, research, and evaluation? The authority can be a public health institute or agency, a department or working group within the Ministry of Health, or another formal authority. Mobile health applications are software programs on mobile devices (e.g., smartphones or tablets) that process health-related data. User groups include health-conscious medical laypersons, family caregivers, or health professionals. They are used to maintain, improve, or manage the users' health.
Indicator source	[43]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L128-authority
Indicator	Does an authority exist to regulate the quality, safety, and reliability of mobile health applications? The authority can be a public health institute or agency, a department or working group within the Ministry of Health, or another formal authority. Mobile health applications are software programs on mobile devices (e.g., smartphones or tablets) that process health-related data. User groups include health-conscious medical laypersons, family caregivers, or health professionals. They are used to maintain, improve, or manage the users' health.
Indicator source	[69] [74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L129-authority
Indicator	Has the country formally assigned an authority responsible for cybersecurity? The authority can be a public institute or agency, a department or working group within the designated ministry, or another formal authority.
Indicator source	[133]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	L130-authority
Indicator	Is it an official policy to conduct regular meetings at healthcare facilities and health administration offices to review information on the health information system and take action based upon such information? Healthcare facilities include primary care facilities (e.g., doctor's practice, community centers), secondary care facilities (e.g., hospitals, clinics, emergency outpatient clinics), and tertiary care facilities (e.g., highly specialized treatment, a referral from primary/secondary care). Health information systems (HIS) are systems designed to manage healthcare data. This includes collecting, storing, managing, and transmitting data from digital health interventions such as electronic health records, hospital operational management systems, systems supporting healthcare policy decisions, and others. HIS commonly access, process, or maintain large volumes of sensitive data, so security is a primary concern.
Indicator source	[74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	L131-authority
Indicator	Are periodic meetings of a community of practice led by the Ministry of Health, where knowledge is shared, awareness and understanding of ICTs in the area of health is increased, and synergies and disseminating best practices are promoted (including free developments to make services available to stakeholders lacking acquisition or development capacity)?
Indicator source	[402]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

C2 ICT domain

The availability of computers and mobile devices

Indicator ID	I1-devices
Indicator	The percentage of healthcare facilities equipped with computers or laptops. Healthcare facilities include primary care facilities (e.g., doctor's practice, community centers), secondary care facilities (e.g., hospitals, clinics, emergency outpatient clinics), and tertiary care facilities (e.g., highly specialized treatment, a referral from primary/secondary care)
Indicator source	[69, 74, 422]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100 for each healthcare facility category.

Indicator ID	I2-devices
Indicator	The percentage of households with a computer or laptop.
Indicator source	[69, 74, 124, 126, 127, 139, 373, 378, 391, 395, 397, 401, 422]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	I3-devices
Indicator	The number of telephone lines per 100 population.
Indicator source	[74]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	I4-devices
Indicator	The percentage of the population that owns a mobile cellular or smartphone. An individual owns a mobile cellular telephone or smartphone if they have a mobile cellular phone device with at least one active SIM card for personal use.
Indicator source	[69, 115, 127, 129, 139, 143, 372, 382, 391, 395, 397, 414, 422]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

The availability of the Internet

Indicator ID	I5-Internet
Indicator	The Internet bandwidth capacity per Internet user (KB/s). International Internet bandwidth refers to the average traffic load (expressed in bits per second) of international fiber optic cables and radio links carrying Internet traffic. More Bits/s indicates better quality.
Indicator source	[60, 136, 379]
Answer scale and nominalization	Minimum to maximum with a minimum defined as 0 Bits/s and maximum defined as 3,000,000 Bits/s

Indicator ID	I6-Internet
Indicator	The percentage of the population within 10 km of a fiber connection point.
Indicator source	[392]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	I7-Internet
Indicator	The number of open public WiFi hotspots per population. The total number of open WiFi hotspots is collected from wifimap.io
Indicator source	[134, 384]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	I8-Internet
Indicator	The percentage of healthcare facilities connected to the internet by available coverage speed. The download speed categories are: - below 30 Mb - 30-299 Mb - 300 MB - 1 GB - above 1 GB Healthcare facilities include primary care facilities (e.g., doctor's practice, community centers), secondary care facilities (e.g., hospitals, clinics, emergency outpatient clinics), and tertiary care facilities (e.g., highly specialized treatment, a referral from primary/secondary care)
Indicator source	[60, 69]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100 for each download speed category and health facility category

Indicator ID	I9-Internet
Indicator	The percentage of households connected to the internet by available coverage speed. The download speed categories are: - below 30 Mb - 30-299 Mb - 300 MB - 1 GB - above 1 GB
Indicator source	[69, 118, 382, 388, 395, 406]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100 for each download speed category

Expenses of and investment in hard- and software

Indicator ID	I10-investment
Indicator	The average costs of an entry fixed and mobile broadband basket (the price of the cheapest broadband tariff to the consumer) as the percentage of the gross national income per capita. The cheapest mobile broadband tariff is a 2 Gigabyte data-only mobile basket, and the cheapest fixed basked is a 5 Gigabyte.
Indicator source	[60, 69, 115, 119, 131, 134, 372, 384, 391, 395, 397, 412, 414, 415, 421]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	I11-investment
Indicator	The ratio between households making less than 35,000 US$ per year without internet and the share of households making 75,000 US$ or more per year without internet access (Internet income ratio). A higher ratio indicates greater internet access inequality between wealthier and lower-income homes.
Indicator source	[120]
Answer scale and nominalization	Percentage with an answer from 0-100%. The nominalized counter value on a score between 0-100 will be used.

Indicator ID	I12-investment
Indicator	The average costs of an entry handset basket (the price of the cheapest internet-enabled mobile device to the consumer) as the percentage of the gross national income per capita. Mobile devices include smartphones, tablets, or laptops.
Indicator source	[129, 131, 375, 384]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Infrastructure and interoperability between ICT systems

Indicator ID	I13-infrastructure
Indicator	Is the existing telecommunication infrastructure sufficient to connect users to the Internet? This includes adequate ICT infrastructure (e.g., computers, internet access, servers, telephones, and e-mail) and adequate ICT support.
Indicator source	[61, 74, 375]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	I14-infrastructure
Indicator	The percentage of healthcare facilities and private households by access to any source of electricity. Healthcare facilities include primary care facilities (e.g., doctor's practice, community centers), secondary care facilities (e.g., hospitals, clinics, emergency outpatient clinics), and tertiary care facilities (e.g., highly specialized treatment, a referral from primary/secondary care). Access is categorized as: - No access - Unreliable supply - Reliable supply
Indicator source	[69, 74, 135]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100 for each access category

Indicator ID	I15-infrastructure
Indicator	Are infrastructure requirements for big data or Artificial Intelligence and data science defined and integrated? The following infrastructure requirements are clearly defined and integrated: - Computing capacity - Storage capacity - Networking infrastructure - Security policies
Indicator source	[61, 129]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100), for all four infrastructure requirements

Indicator ID	I16-infrastructure
Indicator	Is an IT infrastructure in place in the country for storing and processing health data, such as a secure cloud for health data? If data are stored in a cloud, specific security perimeters should be implemented for the cloud, such as secure encryption with encryption keys that the data controller fully manages.
Indicator source	[61]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	I17-infrastructure
Indicator	Are data interoperability standards implemented to ensure that health data is comparable (e.g., ISO standards) across digital (public) health interventions? Interoperability needs to be distinguished into semantic and technical interoperability. The first refers to computer systems transmitting data with unambiguous shared meaning. It enables machine computable logic inferencing knowledge discovery and data federation between information systems. Therefore, it is concerned with the packaging of data and the simultaneous transmission of the meaning with the data. This is accomplished by adding data about the data linking each data element to a controlled shared vocabulary. Technical interoperability is associated with hardware and software components, systems, and platforms that enable machine-to-machine communication. This kind of interoperability is often centered on (communication) protocols and the infrastructure needed for those protocols to operate.
Indicator source	[61, 69, 72, 73, 125]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (33), yes but not for all health services (66), yes for all health services (100)

Indicator ID	I18-infrastructure
Indicator	Are interoperability standards adopted among implemented digitalized (public) health services and applications? Interoperability needs to be distinguished into semantic and technical interoperability. The first refers to computer systems transmitting data with unambiguous shared meaning. It enables machine computable logic inferencing knowledge discovery and data federation between information systems. Therefore, it is concerned with the packaging of data and the simultaneous transmission of the meaning with the data. This is accomplished by adding data about the data linking each data element to a controlled shared vocabulary. Technical interoperability is associated with hardware and software components, systems, and platforms that enable machine-to-machine communication. This kind of interoperability is often centered on (communication) protocols and the infrastructure needed for those protocols to operate.
Indicator source	[69, 72, 402]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Use of ICT for vulnerable groups

Indicator ID	I19-vulnerable
Indicator	Are ICTs being used to improve health outcomes among poor and vulnerable groups? Vulnerable groups include those most at risk, including people with disabilities, youth, women, lesbian, gay, bisexual, transgender, and intersex people, ethnic minorities, indigenous people, internally displaced individuals, refugees, asylum seekers, or migrants.
Indicator source	[69, 115]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	I20-vulnerable
Indicator	Are ICTs used to improve education outcomes for poor and vulnerable groups? Vulnerable groups include those most at risk, including people with disabilities, youth, women, lesbian, gay, bisexual, transgender, and intersex people, ethnic minorities, indigenous people, internally displaced individuals, refugees, asylum seekers, or migrants.
Indicator source	[115]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Workforce

Indicator ID	I21-workforce
Indicator	Do national inclusion strategies exist to address digital skills training for women?
Indicator source	[379]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	I22-workforce
Indicator	Is there a national agenda to prepare the health information workforce for big data or Artificial Intelligence?
Indicator source	[61, 69, 75]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	I23-workforce
Indicator	Do public or semi-public institutions or associations offer electronic health, digital health, or health information training as part of pre-service or in-service education for health professionals? Health professionals are community health workers, nurses, doctors, allied health, health managers/administrators, public health experts, and technologists.
Indicator source	[43, 44, 46, 60, 69, 73, 74, 114, 115, 143]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	I24-workforce
Indicator	The percentage of experts in epidemiology, demography, statistics, and ICT with capacities in health information sciences working at the Ministry of Health.
Indicator source	[74]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	I25-workforce
Indicator	Are there public sector professional titles and career paths in digital health and digital public health?
Indicator source	[44, 46, 69, 74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	I26-workforce
Indicator	Are eLearning programs used in formal education to teach health sciences students and health professionals? eLearning refers to using ICT for learning pre-service (for students) and in-service (for health professionals). It can be used to improve the quality of education, to increase accessibility for geographically isolated persons or those who have poor local learning facilities, and to make new and innovative forms of education potentially available to all. It is increasingly used for training health sciences students and for the ongoing development of health professionals.
Indicator source	[73, 74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	I27-workforce
Indicator	Are eLearning programs for in-service training of health professionals evaluated?
Indicator source	[74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	I28-workforce
Indicator	The number of data science experts per 10,000 population. Data science is a multidisciplinary field that uses algorithms and systems to extract knowledge from data. This includes developing tools to collect and store data, prepare data, explore and visualize data, and apply machine learning algorithms to create data-based predictions.
Indicator source	[69]
Answer scale and nominalization	Nominalized to a score between 0-100

C3 Application domain

Access to digitalized health services

Indicator ID	**A1-access**
Indicator	Are health digital technologies used to ensure the inclusion and participation of vulnerable population groups in healthcare? Vulnerable groups include those most at risk, including people with disabilities, youth, women, lesbian, gay, bisexual, transgender, and intersex people, ethnic minorities, indigenous people, internally displaced individuals, refugees, asylum seekers, or migrants.
Indicator source	[121]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	**A2-access**
Indicator	Is a centralized, secure patient feedback system for all health services available and accessible?
Indicator source	[44]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (33), yes but not for all health information services (66), yes for all health information services (100)

Indicator ID	**A3-access**
Indicator	Does a web or 24/7 telephone service for health information council exist that supports patients in choosing the right treatment path (for instance, whether they should see a primary care provider, emergency department, or wait and see)?
Indicator source	[69, 128]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	**A4-access**
Indicator	Has the national public health authority actively shared messages via online media platforms (e.g., social media, website) to inform the public about ongoing public health concerns or to dispel rumors, misinformation, or disinformation within the agreed time period? The authority can be a public institute or agency, a department or working group within the Ministry of Health, or another formal authority.
Indicator source	[60, 72]
Answer scale and nominalization	Binary; no (0) and yes (100)

Indicator ID	**A5-access**
Indicator	Does the national public health authority have a website with healthcare information and electronic health service functionalities? The authority can be a public institute or agency, a department or working group within the Ministry of Health, or another formal authority.
Indicator source	[69, 379]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	A6-access
Indicator	Does the national public health authority have a website with information on the specific digital (public) health services offered to the population in the country? The authority can be a public institute or agency, a department or working group within the Ministry of Health, or another formal authority.
Indicator source	[69]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	A7-access
Indicator	Are publically funded digital inclusion campaigns on health conducted through multisectoral participation?
Indicator source	[114]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	A8-access
Indicator	Are publically funded digital (public) health services designed in a way that they are accessible to people from vulnerable groups? Vulnerable groups include those most at risk, including people with disabilities, youth, women, lesbian, gay, bisexual, transgender, and intersex people, ethnic minorities, indigenous people, internally displaced individuals, refugees, asylum seekers, or migrants.
Indicator source	[114]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (33), yes but not for all health services (66), yes for all health services (100)

Indicator ID	A9-access
Indicator	The share of health information services for citizens is provided via a health portal. Health portals are online applications that foster communication and interaction between patients and their healthcare providers (e.g., physicians or hospitals). The portals can be implemented as stand-alone websites or integrated as modules within a provider's or country's electronic health record system.
Indicator source	[69, 382]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (33), yes but not for all health information services (66), yes for all health information services (100)

Indicator ID	A10-access
Indicator	Do publicly funded health portals offer appointments and direct communication with doctors and specialists? Health portals are online applications that foster communication and interaction between patients and their healthcare providers (e.g., physicians or hospitals). The portals can be implemented as stand-alone websites or integrated as modules within a provider's or country's electronic health record system.
Indicator source	[43, 128]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	A11-access
Indicator	Is there a comprehensive digital health portal to facilitate patient access to the health system (i.e., accessible format, interactive, offering usable health information, and providing a route to contact healthcare services)? Health portals are online applications that foster communication and interaction between patients and their healthcare providers (e.g., physicians or hospitals). The portals can be implemented as stand-alone websites or integrated as modules within a provider's or country's electronic health record system.
Indicator source	[69, 413]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	A12-access
Indicator	Are there publicly funded health portals to promote health literacy? Health portals are online applications that foster communication and interaction between patients and their healthcare providers (e.g., physicians or hospitals). The portals can be implemented as stand-alone websites or integrated as modules within a provider's or country's electronic health record system.
Indicator source	[43]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	A13-access
Indicator	Do publicly funded health portals offer access to medication plans and electronic prescriptions? Health portals are online applications that foster communication and interaction between patients and their healthcare providers (e.g., physicians or hospitals). The portals can be implemented as stand-alone websites or integrated as modules within a provider's or country's electronic health record system. Electronic prescriptions are the prescribing of medicine through software and the electronic transmission of prescription data to a pharmacy where the medicine can be dispensed. Once the medicine has been dispensed, the pharmacy reports the dispensation information using the electronic prescription software.
Indicator source	[43]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	A14-access
Indicator	Are publicly funded health portals integrated into social media, such as Facebook and LinkedIn? Health portals are online applications that foster communication and interaction between patients and their healthcare providers (e.g., physicians or hospitals). The portals can be implemented as stand-alone websites or integrated as modules within a provider's or country's electronic health record system.
Indicator source	[43]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (100), yes (100)

Indicator ID	A15-access
Indicator	Do all healthcare providers have adequate access to training and capacity building for data governance?
Indicator source	[61]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (33), yes but only for some healthcare providers groups (66), yes for all healthcare providers (100)

Indicator ID	A16-access
Indicator	Is social media used to assist in the clinical management process of appointment scheduling for health services?
Indicator source	[60]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	A17-access
Indicator	The percentage of clinical encounters for patients captured using the electronic record system within the agreed time period.
Indicator source	[394]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	A18-access
Indicator	Does the national public health authority provide a user-friendly website about reproductive and sexual health rights and services for women and girls? The authority can be a public institute or agency, a department or working group within the Ministry of Health, or another formal authority.
Indicator source	[115]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	A19-access
Indicator	Are health system registries of uniquely identifiable providers, administrators, and public healthcare facilities available, accessible, and current? Healthcare facilities include primary care facilities (e.g., doctor's practice, community centers), secondary care facilities (e.g., hospitals, clinics, emergency outpatient clinics), and tertiary care facilities (e.g., highly specialized treatment, a referral from primary/secondary care)
Indicator source	[46]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	A20-access
Indicator	Is an immunization registry of uniquely identifiable individuals available, accessible, and current for health-related purposes implemented? An immunization registry is an information system that collects and processes vaccination data about all persons within a geographic area from multiple data sources (e.g., electronic health records).
Indicator source	[46]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	A21-access
Indicator	Are secure disease registries of uniquely identifiable individuals available, that are fully representative of the population, accessible, and current for use in health-related purposes? Disease registries are collections of secondary data related to patients with predefined diagnoses, conditions, or procedures. They play a vital role in surveillance registries and encompass data from various sources (such as electronic health records).
Indicator source	[44, 46]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	A22-access
Indicator	The percentage of the population with access to their electronic health records. The electronic health record (EHR) is a medical and cross-institutional record or similar documentation of an individual's past and present physical and health mental state in electronic form. EHRs are real-time, patient-centered records that provide immediate and secure information to authorized users. EHRs contain a patient's medical history, diagnoses and treatment, medications, allergies, immunizations, radiology images, and laboratory results. A national EHR system is most often implemented under the responsibility of a national health authority. It will typically make a patient's medical history available to health professionals in healthcare institutions and provide linkages to related services such as pharmacies, laboratories, specialists, and emergency and medical imaging facilities.
Indicator source	[43, 61, 128, 380, 382, 383, 399]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	A23-access
Indicator	Does the country have an electronic prescription system implemented? Electronic prescriptions are the prescribing of medicine through software and the electronic transmission of prescription data to a pharmacy where the medicine can be dispensed. Once the medicine has been dispensed, the pharmacy reports the dispensation information using the electronic prescription software.
Indicator source	[43, 128]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	A24-access
Indicator	The share of the population that is unable to access their digital health data due to at least one of the following reasons: - no access to the Internet - no access to Internet-enabled devices - no sufficient digital literacy skills Adequate digital literacy skills are defined as achieving at least 50% of the maximum reachable points across all dimensions included in the *Digital Competence Framework for Citizens* (DigComp 2.2)[453]
Indicator source	[69]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	A25-access
Indicator	The share of the population that can access digital (public) health services.
Indicator source	[69]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Implementation of digitalized health service

Indicator ID	A26-implementation
Indicator	The percentage of electronic health records that allow the recording of diverse data on patients' social characteristics and medical conditions to support care coordination and chronic disease management. The electronic health record (EHR) is a medical and cross-institutional record or similar documentation of an individual's past and present physical and health mental state in electronic form. EHRs are real-time, patient-centered records that provide immediate and secure information to authorized users. EHRs contain a patient's medical history, diagnoses and treatment, medications, allergies, immunizations, radiology images, and laboratory results. A national EHR system is most often implemented under the responsibility of a national health authority. It will typically make a patient's medical history available to health professionals in healthcare institutions and provide linkages to related services such as pharmacies, laboratories, specialists, and emergency and medical imaging facilities.
Indicator source	[43, 61, 114, 383]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	A27-implementation
Indicator	How many of the following sub-systems are included in the electronic health record system - medical history of the patient - diagnoses and treatment of the patient - medications of the patient - allergies of the patient - immunizations of the patient - radiology images of the patient - laboratory results of the patient? The electronic health record (EHR) is a medical and cross-institutional record or similar documentation of an individual's past and present physical and health mental state in electronic form. EHRs are real-time, patient-centered records that provide immediate and secure information to authorized users. A national EHR system is most often implemented under the responsibility of a national health authority. It will typically make a patient's medical history available to health professionals in healthcare institutions and provide linkages to related services such as pharmacies, laboratories, specialists, and emergency facilities.
Indicator source	[47, 61]
Answer scale and nominalization	Rank; none (0), one (14), two (28), three (42), four (56), five (70), six (84), seven (100)

Indicator ID	A28-implementation
Indicator	Are needs assessments conducted on current technological capabilities for digital (public) health among the population, workforce, and infrastructure nationally?
Indicator source	[60]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	A29-implementation
Indicator	The percentage of health applications adapted for users with disabilities. Health applications are software programs on mobile devices (e.g., smartphones or tablets) that process health-related data. User groups include health-conscious medical laypersons, family caregivers, or health professionals. They are used to maintain, improve, or manage the users' health.
Indicator source	[114]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	A30-implementation
Indicator	Are Artificial Intelligence solutions implemented as a component of the public health system, with outcome reviews built into policy reviews and analyses? Integrating Artificial Intelligence into the system should be streamlined and follow transparently outlined processes, robust guidelines, agile health organizations, and predefined workflows.
Indicator source	[46, 69, 410]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	A31-implementation
Indicator	Were health information system capacity-building activities conducted nationally for health information system staff of the Ministry of Health (including statistics, software and database maintenance, and epidemiology) within the agreed time period?
Indicator source	[74]
Answer scale and nominalization	Rank; no (0), yes but only on the local level (25), yes but only on the regional level (50), yes on the national level (75), yes on the national level (100)

Indicator ID	A32-implementation
Indicator	Has a national terminology infrastructure for semantic interoperability been set up and implemented? Semantic interoperability refers to computer systems that transmit data with unambiguous shared meanings. It enables machine computable logic inferencing knowledge discovery and data federation between information systems. Therefore, it is concerned with the packaging of data and the simultaneous transmission of the meaning with the data. This is accomplished by adding data about the data linking each data element to a controlled shared vocabulary.
Indicator source	[43, 69]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	A33-implementation
Indicator	Are predictive analytic tools used in healthcare delivery with a focus on keeping people well?
Indicator source	[70, 386]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	A34-implementation
Indicator	Are analytic tools used in healthcare to monitor individual health outcomes to inform healthcare decisions that mitigate health risks and optimize public health outcomes?
Indicator source	[69, 70, 386]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	A35-implementation
Indicator	Are analytic tools used to monitor operational performance in real-time to inform leadership choices to strengthen quality, safety, and cost outcomes across the public health system?
Indicator source	[70, 386]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	A36-implementation
Indicator	The share of all publicly funded mobile and electronic health programs evaluated for their population health and public health impact. Mobile health applications are software programs on mobile devices (e.g., smartphones or tablets) that process health-related data. User groups include health-conscious medical laypersons, family caregivers, or health professionals. They are used to maintain, improve, or manage the users' health.
Indicator source	[44, 73, 74]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	A37-implementation
Indicator	The number of publicly funded digital public health services nationally implemented in healthcare per 10,000 population.
Indicator source	[46, 69, 114, 121, 411]
Answer scale and nominalization	Nominalized to a score between 0-100

Indicator ID	A38-implementation
Indicator	Is a publically funded mobile health program with formally defined procedures implemented in the public health system?
Indicator source	[43, 60, 69]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	A39-implementation
Indicator	Are publically funded services for digital assistive technology implemented in the public health system? Digital assistive technologies include speech recognition or time management software and captioning.
Indicator source	[73]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	A40-implementation
Indicator	Is a publically funded telemedicine service implemented in the public health system? Telehealth includes computer-assisted telecommunications to support management, surveillance, literature, and access to medical knowledge. Telemedicine, as a sub-dimension of telehealth, provides healthcare services through ICT when the health professional and the patient (or two health professionals) are not in the same location. It includes the secure sending of health data and information through text, sound, images, or other forms needed for the prevention, diagnosis, treatment, and follow-up of patients.
Indicator source	[43, 60, 69, 380, 410]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	A41-implementation
Indicator	The percentage of healthcare facilities that use standardized electronic health record systems that are interoperable with other health data sets and digital (public) health applications. Healthcare facilities include primary care facilities (e.g., doctor's practice, community centers), secondary care facilities (e.g., hospitals, clinics, emergency outpatient clinics), and tertiary care facilities (e.g., highly specialized treatment, a referral from primary/secondary care). The electronic health record (EHR) is a medical and cross-institutional record or similar documentation of an individual's past and present physical and health mental state in electronic form. EHRs are real-time, patient-centered records that provide immediate and secure information to authorized users. EHRs contain a patient's medical history, diagnoses and treatment, medications, allergies, immunizations, radiology images, and laboratory results. A national EHR system is most often implemented under the responsibility of a national health authority. It will typically make a patient's medical history available to health professionals in healthcare institutions and provide linkages to related services such as pharmacies, laboratories, specialists, and emergency and medical imaging facilities. Health data sets include general information about patients, e.g., name, birth date, gender, etc.), a medical summary with essential clinical data (e.g., allergies, current medical problems, medical implants, or major surgical procedures during the last six months), and a list of the patients' current medication and prescribed medication.
Indicator source	[60, 61, 69, 410]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	A42-implementation
Indicator	The share of patients in need that is covered by digital assistive technology. Digital assistive technologies include speech recognition or time management software and captioning.
Indicator source	[69, 73, 74]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	A43-implementation
Indicator	The share of all implemented digital (public) health services that consider health equity in their planning, implementation, and evaluation.
Indicator source	[69]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Secondary use of health data

Indicator ID	A44-secondary-use
Indicator	Does the national public health system have access to electronic health records of individuals in their country? The electronic health record (EHR) is a medical and cross-institutional record or similar documentation of an individual's past and present physical and health mental state in electronic form. EHRs are real-time, patient-centered records that provide immediate and secure information to authorized users. EHRs contain a patient's medical history, diagnoses and treatment, medications, allergies, immunizations, radiology images, and laboratory results. A national EHR system is most often implemented under the responsibility of a national health authority. It will typically make a patient's medical history available to health professionals in healthcare institutions and provide linkages to related services such as pharmacies, laboratories, specialists, and emergency and medical imaging facilities.
Indicator source	[72]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	A45-secondary-use
Indicator	Are health information systems on the local level integrated into the national-level health information system? Health information systems (HIS) are systems designed to manage healthcare data. This includes collecting, storing, managing, and transmitting data from digital health interventions such as electronic health records, hospital operational management systems, systems supporting healthcare policy decisions, and others. HIS commonly access, process, or maintain large volumes of sensitive data, so security is a primary concern.
Indicator source	[60]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (33), yes but only partially (66), yes completely (100)

Indicator ID	A46-secondary-use
Indicator	Are global positioning system coordinates for each healthcare facility included in the health information system or patient portal? Healthcare facilities include primary care facilities (e.g., doctor's practice, community centers), secondary care facilities (e.g., hospitals, clinics, emergency outpatient clinics), and tertiary care facilities (e.g., highly specialized treatment, a referral from primary/secondary care)
Indicator source	[74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (33), yes but not for all health services (66), yes for all health services (100)

Indicator ID	A47-secondary-use
Indicator	Are health information systems on the regional level integrated into the national-level health information system? Health information systems (HIS) are systems designed to manage healthcare data. This includes collecting, storing, managing, and transmitting data from digital health interventions such as electronic health records, hospital operational management systems, systems supporting healthcare policy decisions, and others. HIS commonly access, process, or maintain large volumes of sensitive data, so security is a primary concern.
Indicator source	[60]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (33), yes but only partially (66), yes completely (100)

Indicator ID	A48-secondary-use
Indicator	The percentage of health information systems whose identification modules address aspects related to gender and cultural issues. Health information systems (HIS) are systems designed to manage healthcare data. This includes collecting, storing, managing, and transmitting data from digital health interventions such as electronic health records, hospital operational management systems, systems supporting healthcare policy decisions, and others. HIS commonly access, process, or maintain large volumes of sensitive data, so security is a primary concern.
Indicator source	[114]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	A49-secondary-use
Indicator	Are health surveillance data on epidemic-prone diseases disseminated and fed back through regularly published bulletins?
Indicator source	[74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	A50-secondary-use
Indicator	Is there a national database that tracks the annual numbers of graduates from all health-training institutions?
Indicator source	[74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	A51-secondary-use
Indicator	Are there digital (public) health services in which the application of international health and medical informatics standards is mandatory?
Indicator source	[43]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	A52-secondary-use
Indicator	The existence of at least one health information system as an integrated data warehouse containing data from all population-based and institution-based data sources (including all key health programs). Health information systems (HIS) are systems designed to manage healthcare data. This includes collecting, storing, managing, and transmitting data from digital health interventions such as electronic health records, hospital operational management systems, systems supporting healthcare policy decisions, and others. HIS commonly access, process, or maintain large volumes of sensitive data, so security is a primary concern.
Indicator source	[60, 74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	A53-secondary-use
Indicator	Are unique identifier codes used in different health data sets to enable legally valid and reliable links in the public health system? Health data sets include general information about patients, e.g., name, birth date, gender, etc.), a medical summary with essential clinical data (e.g., allergies, current medical problems, medical implants, or major surgical procedures during the last six months), and a list of the current medication and prescribed medication that the patient is currently taking. The electronic health record system records clinical data during routine medical care.
Indicator source	[43, 46, 60, 69, 74, 379, 399]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	A54-secondary-use
Indicator	What percentage of all primary care sector, hospitals, pharmacies, and physicians in private practice providers use the same terminology guidelines for electronic health record systems? The electronic health record (EHR) is a medical and cross-institutional record or similar documentation of an individual's past and present physical and health mental state in electronic form. EHRs are real-time, patient-centered records that provide immediate and secure information to authorized users. EHRs contain a patient's medical history, diagnoses and treatment, medications, allergies, immunizations, radiology images, and laboratory results. A national EHR system is most often implemented under the responsibility of a national health authority. It will typically make a patient's medical history available to health professionals in healthcare institutions and provide linkages to related services such as pharmacies, laboratories, specialists, and emergency and medical imaging facilities.
Indicator source	[43, 47]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	A55-secondary-use
Indicator	The percentage of all national electronic health records with the same unique patient identifier. The electronic health record (EHR) is a medical and cross-institutional record or similar documentation of an individual's past and present physical and health mental state in electronic form. EHRs are real-time, patient-centered records that provide immediate and secure information to authorized users. EHRs contain a patient's medical history, diagnoses and treatment, medications, allergies, immunizations, radiology images, and laboratory results. A national EHR system is most often implemented under the responsibility of a national health authority. It will typically make a patient's medical history available to health professionals in healthcare institutions and provide linkages to related services such as pharmacies, laboratories, specialists, and emergency and medical imaging facilities.
Indicator source	[43, 74]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	A56-secondary-use
Indicator	Is patient information transmitted immediately and electronically through a health information exchange network or electronic health record system (either through a federated document repository and document registry or through a centralized depository)? The electronic health record (EHR) is a medical and cross-institutional record or similar documentation of an individual's past and present physical and health mental state in electronic form. EHRs are real-time, patient-centered records that provide immediate and secure information to authorized users. EHRs contain a patient's medical history, diagnoses and treatment, medications, allergies, immunizations, radiology images, and laboratory results. A national EHR system is most often implemented under the responsibility of a national health authority. It will typically make a patient's medical history available to health professionals in healthcare institutions and provide linkages to related services such as pharmacies, laboratories, specialists, and emergency facilities.
Indicator source	[43, 69, 394]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (33), yes but not for all health services (66), yes for all health services (100)

Indicator ID	A57-secondary-use
Indicator	What percentage of the primary care sector, hospitals, pharmacies, and physicians in private practices is connected to a (sub-)national electronic health record system? The electronic health record (EHR) is a medical and cross-institutional record or similar documentation of an individual's past and present physical and health mental state in electronic form. EHRs are real-time, patient-centered records that provide immediate and secure information to authorized users. EHRs contain a patient's medical history, diagnoses and treatment, medications, allergies, immunizations, radiology images, and laboratory results. A national EHR system is most often implemented under the responsibility of a national health authority. It will typically make a patient's medical history available to health professionals in healthcare institutions and provide linkages to related services such as pharmacies, laboratories, specialists, and emergency and medical imaging facilities.
Indicator source	[43, 71, 73, 380, 383, 397, 411, 418]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	A58-secondary-use
Indicator	What percentage of all available national health data sets or electronic health records regularly report on healthcare quality and overall health system performance (efficiency, quality, access to care)? Health data sets include general information about patients, e.g., name, birth date, gender, etc.), a medical summary with essential clinical data (e.g., allergies, current medical problems, medical implants, or major surgical procedures during the last six months), and a list of the current medication and prescribed medication that the patient is currently taking. The electronic health record system records clinical data during routine medical care. The electronic health record (EHR) is a medical and cross-institutional record or similar documentation of an individual's past and present physical and health mental state in electronic form. EHRs are real-time, patient-centered records that provide immediate and secure information to authorized users. EHRs contain a patient's medical history, diagnoses and treatment, medications, allergies, immunizations, radiology images, and laboratory results. A national EHR system is most often implemented under the responsibility of a national health authority. It will typically make a patient's medical history available to health professionals in healthcare institutions and provide linkages to related services such as pharmacies, laboratories, specialists, and emergency and medical imaging facilities.
Indicator source	[43, 46, 74]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	A59-secondary-use
Indicator	Is the electronic health record system connected to other systems through proposed standards allowing for technical linkages and communication with other health systems? The electronic health record (EHR) is a medical and cross-institutional record or similar documentation of an individual's past and present physical and health mental state in electronic form. EHRs are real-time, patient-centered records that provide immediate and secure information to authorized users. EHRs contain a patient's medical history, diagnoses and treatment, medications, allergies, immunizations, radiology images, and laboratory results. A national EHR system is most often implemented under the responsibility of a national health authority. It will typically make a patient's medical history available to health professionals in healthcare institutions and provide linkages to related services such as pharmacies, laboratories, specialists, and emergency and medical imaging facilities. Technical linkages and communication are possible due to technical interoperability, which is usually associated with hardware and software components, systems and platforms that enable machine-to-machine communication. This kind of interoperability is often centered on (communication) protocols and the infrastructure needed for those protocols to operate.
Indicator source	[43, 69]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (50), yes (100)

Indicator ID	A60-secondary-use
Indicator	Does the government operate an electronic reporting surveillance system (e.g., for notifiable infectious diseases)? Disease surveillance systems systematically and continuously collect and analyze data for public health purposes and timely dissemination of information to assess and respond to public health problems (e.g., pandemics). Typically, these systems include components for collecting, analyzing, and using health data.
Indicator source	[61, 71, 72]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	A61-secondary-use
Indicator	Is routine clinical patient data collected once and used for public health surveillance and research or to inform personalized care strategies to support and sustain population health and wellness?
Indicator source	[43, 69-74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (33), yes but not for all health services (66), yes for all health services (100)

Indicator ID	A62-secondary-use
Indicator	Is routine clinical patient data (for direct care) collected once and used to evaluate healthcare services?
Indicator source	[69]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (33), yes but not for all health services (66), yes for all health services (100)

Indicator ID	A63-secondary-use
Indicator	What percentage of data from different sources is integrated into the national health repository? Data sources include data collected by digital healthcare applications such as electronic health records, wearables for continuous monitoring, or health portal data transmitted by the patient.
Indicator source	[43, 402]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	A64-secondary-use
Indicator	Is a written set of procedures for data management implemented throughout the country, including data collection, storage, cleaning, quality control, analysis, and presentation for target audiences?
Indicator source	[47, 61, 74]
Answer scale and nominalization	Rank; no and it is not planned (0), no but it is planned (25), yes but only on the local level (50), yes but only on the regional level (75), yes on the national level (100)

Indicator ID	A65-secondary-use
Indicator	What percentage of patient data is connected to other information sources to support personal and health systems performance and quality assessment programs? Other information sources include
Indicator source	[43, 47, 61]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

C4 Social domain

Health intervention users

Indicator ID	S1-users
Indicator	The percentage of healthcare providers using Artificial Intelligence technologies as part of their work.
Indicator source	[410]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S2-users
Indicator	The percentage of clinical provider encounters entered into the electronic health record system within the agreed time period by healthcare facility category. The electronic health record (EHR) is a medical and cross-institutional record or similar documentation of an individual's past and present physical and health mental state in electronic form. EHRs are real-time, patient-centered records that provide immediate and secure information to authorized users. EHRs contain a patient's medical history, diagnoses and treatment, medications, allergies, immunizations, radiology images, and laboratory results. A national EHR system is most often implemented under the responsibility of a national health authority. It will typically make a patient's medical history available to health professionals in healthcare institutions and provide linkages to related services such as pharmacies, laboratories, specialists, and emergency and medical imaging facilities. Healthcare facilities include primary care facilities (e.g., doctor's practice, community centers), secondary care facilities (e.g., hospitals, clinics, emergency outpatient clinics), and tertiary care facilities (e.g., highly specialized treatment, a referral from primary/secondary care)
Indicator source	[43, 47, 60, 69, 72, 394, 411]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S3-users
Indicator	The percentage of the population using a health-related mobile application within the agreed time period. Health-related applications include at least one of these functions: - consult with a doctor - buy medicine - look for articles or health information - look for disease information - displays information on daily activity - displays health status - look for the location of a healthcare facility. Healthcare facilities include primary care facilities (e.g., doctor's practice, community centers), secondary care facilities (e.g., hospitals, clinics, emergency outpatient clinics), and tertiary care facilities (e.g., highly specialized treatment, a referral from primary/secondary care).
Indicator source	[69, 80, 409, 417]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S4-users
Indicator	The percentage of teleconsultations of all consultations by primary care providers or hospitals for diagnosis, consultation, or intervention within the agreed time period
Indicator source	[43, 47, 387, 397, 408, 409, 411]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S5-users
Indicator	The percentage of patients and healthcare providers satisfied with virtual healthcare by specific intervention.
Indicator source	[386, 411]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S6-users
Indicator	The percentage of the population that would be interested in accessing any digital health service for health promotion, healthcare, prevention, or surveillance.
Indicator source	[69, 411]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S7-users
Indicator	The percentage of patients recorded in nationally networked health data sets. Health data sets include general information about patients, e.g., name, birth date, gender, etc.), a medical summary with essential clinical data (e.g., allergies, current medical problems, medical implants, or major surgical procedures during the last six months), and a list of the current medication and prescribed medication that the patient is currently taking. The electronic health record system records clinical data during routine medical care.
Indicator source	[43]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S8-users
Indicator	The percentage of the population that has accessed their electronic health records within the agreed time period.
Description	The electronic health record (EHR) is a medical and cross-institutional record or similar documentation of an individual's past and present physical and health mental state in electronic form. EHRs are real-time, patient-centered records that provide immediate and secure information to authorized users. EHRs contain a patient's medical history, diagnoses and treatment, medications, allergies, immunizations, radiology images, and laboratory results. A national EHR system is most often implemented under the responsibility of a national health authority. It will typically make a patient's medical history available to health professionals in healthcare institutions and provide linkages to related services such as pharmacies, laboratories, specialists, and emergency and medical imaging facilities.
Indicator source	[43, 69, 70, 374, 386]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S9-users
Indicator	The percentage of the population that has and is using new technologies in general. New technologies include software such as Artificial Intelligence and smart devices (e.g., wearables, smartphones, virtual-reality glasses).
Indicator source	[375]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S10-users
Indicator	The percentage of individuals who use digital tools to manage their health and wellness on their own. This measures the use of personalized digital tools, technologies, and platforms to support people in self-managing their health and care, supported by meaningful communication with care providers (informal and formal). Individuals and families choose technologies, tools, and care approaches that best suit their personal preferences and unique life circumstances (e.g., in-person care settings, virtual, online, and wearables) to support and enable self-management access to care providers when and where needed.
Indicator source	[69, 70, 386]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S11-users
Indicator	The percentage of healthcare professionals in the country who have used any digital health tool within the agreed time period to improve health and healthcare delivery, by reasons. Reasons are: - for digital treatment - for consultations - for daily practice routines - for real-time access to patient data - for digital fitness and well-being - to enable collaboration with other clinicians, including secure messaging
Indicator source	[69, 70, 386, 411]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100 for each reason

Indicator ID	S12-users
Indicator	The percentage of healthcare providers who have exchanged patient data with other healthcare providers within the agreed time period
Indicator source	[43, 374]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S13-users
Indicator	The percentage of patients and healthcare providers that have visited a publicly funded health portal within the agreed time period. Health portals are online applications that foster communication and interaction between patients and their healthcare providers (e.g., physicians or hospitals). The portals can be implemented as stand-alone websites or integrated as modules within a provider's or country's electronic health record system.
Indicator source	[43, 69, 409]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S14-users
Indicator	The percentage of the population that uses digital services to communicate with a social welfare or healthcare professional within the agreed time period.
Description	"Others" is defined as outpatient general practitioners, outpatient specialist doctors outside their practice, or hospitals.
Indicator source	[69, 374, 408, 411]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	**S15-users**
Indicator	The percentage of participants who started a publicly funded digital health promotion or prevention program and finished it.
Indicator source	[69]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	**S16-users**
Indicator	The percentage of all patients with a specific condition (as classified by ICD-10) that participated in publically funded online health training programs for this condition within the agreed time period.
Indicator source	[69]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	**S17-users**
Indicator	The percentage of all healthcare providers participating in publically funded online health training programs within the agreed time period.
Indicator source	[69]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	**S18-users**
Indicator	The percentage of all prescriptions that were electronic prescriptions within the agreed time period. Electronic prescriptions are the prescribing of medicine through software and the electronic transmission of prescription data to a pharmacy where the medicine can be dispensed. Once the medicine has been dispensed, the pharmacy reports the dispensation information using the electronic prescription software.
Indicator source	[43, 387]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Literacy

Indicator ID	**S19-Literacy**
Indicator	The percentage of the population that has achieved at least a minimum level of proficiency in health literacy skills. Adequate digital literacy skills are defined as achieving at least 50% of the maximum reachable points across all dimensions included in the *Health Literacy Questionnaire* [454]
Indicator source	[69]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S20-Literacy
Indicator	The percentage of the people working in the health information system (e.g., Ministry of Health, public health institute, statistical office, healthcare facilities) other than dedicated ICT staff (e.g., civil servants, scientific staff, medical staff) who have achieved at least a minimum level of proficiency in ICT skills. Health information systems (HIS) are systems designed to manage healthcare data. This includes collecting, storing, managing, and transmitting data from digital health interventions such as electronic health records, hospital operational management systems, systems supporting healthcare policy decisions, and others. HIS commonly access, process, or maintain large volumes of sensitive data, so security is a primary concern. Adequate ICT skills are defined as achieving at least 50% of the maximum reachable points across all dimensions included in the *Digital Competence Framework for Citizens* (DigComp 2.2)[453]
Indicator source	[61, 69]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S21-Literacy
Indicator	The percentage of the population that has achieved at least a minimum level of proficiency in digital health literacy skills. Adequate digital literacy skills are defined as achieving at least 50% of the maximum reachable points across all dimensions included in the *eHealth Literacy Scale* [455]
Indicator source	[69]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S22-Literacy
Indicator	The percentage of the population that has achieved at least a minimum level of proficiency in digital literacy skills. Adequate digital literacy skills are defined as achieving at least 50% of the maximum reachable points across all dimensions included in the *Digital Competence Framework for Citizens* (DigComp 2.2)[453]
Indicator source	[69, 80, 117, 122, 142, 376, 387, 393, 404, 405, 419]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Motivation, trust, and awareness

Indicator ID	S23-motivation
Indicator	The percentage of the population that trusts medical and health advice from the government.
Indicator source	[72]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S24-motivation
Indicator	The percentage of the population that trusts digital interventions provided by public health authorities.
Indicator source	[69]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S25-motivation
Indicator	The percentage of the population that trusts non-government websites and apps.
Indicator source	[114]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S26-motivation
Indicator	The percentage of the population that trusts government websites and apps.
Indicator source	[114, 129]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S27-motivation
Indicator	The percentage of health professionals who believe digital health technologies are best for improving patient care in the next five years
Indicator source	[410]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S28-motivation
Indicator	The percentage of health professionals who believe that, in ten years, most of their decisions will be based on support tools that utilize Artificial Intelligence.
Indicator source	[410]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S29-motivation
Indicator	The percentage of health professionals who believe in the value of health data sharing.
Indicator source	[69]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S30-motivation
Indicator	The percentage of the population that is aware of digital health services (e.g., electronic health records, telemedicine, electronic prescription, etc.)
Indicator source	[69]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100 for each intervention type

Indicator ID	S31-motivation
Indicator	The percentage of the population that trusts medical and health advice from health professionals.
Indicator source	[72, 380]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S32-motivation
Indicator	The percentage of patients and healthcare professionals who are comfortable with Artificial Intelligence being used as a tool in healthcare
Indicator source	[410, 411]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S33-motivation
Indicator	The percentage of patients who are more satisfied with online consultations compared to in-person consultations.
Indicator source	[69]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S34-motivation
Indicator	The share of the population that classifies digital interventions (like electronic health records, telemedicine, online consultation, electronic prescriptions, wearables, etc.) at least as "useful". Usefulness is assessed for all intervention types on a four-point Likert scale from "not useful", "somewhat useful", "useful", and "very useful". Interventions with at least 50% votes for "useful" are perceived as useful by the population.
Indicator source	[69]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Use of computers and mobile devices

Indicator ID	S35-devices
Indicator	The percentage of the population using a computer, laptop, or tablet within the agreed time period.
Indicator source	[373, 382, 391, 395, 397, 422]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S36-devices
Indicator	The percentage of the population that uses a mobile cellular or smartphone in general within the agreed time period. Mobile telephones refer to portable phones subscribing to an automatic public mobile telephone service provider using cellular technology. Using a mobile telephone does not mean it is owned or paid for by the person; rather, it should be reasonably available through work, a friend or family member, etc. It excludes occasional use, such as borrowing a mobile phone to make a call. The percentage of individuals using a mobile telephone is calculated by dividing the total number of in-scope individuals using a mobile phone by the total number of in-scope individuals.
Indicator source	[69, 74, 422]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S37-devices
Indicator	The share of a household's monthly income that is used for information and communication equipment (hardware).
Indicator source	[391, 397, 400]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S38-devices
Indicator	The share of a household's monthly income that is used for information and communication services (software).
Indicator source	[397] [391, 400]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S39-devices
Indicator	The percentage of all patients that use a mobile cellular or smartphone to access digital healthcare and health promotion services. Mobile telephones refer to portable telephones subscribing to an automatic public mobile telephone service using cellular technology, which provides access to the PSTN. Using a mobile phone does not mean it is owned or paid for by the person; rather, it should be reasonably available through work, a friend or family member, etc. It excludes occasional use, such as borrowing a mobile phone to make a call. The percentage of individuals using a mobile telephone is calculated by dividing the total number of in-scope individuals using a mobile phone by the total number of in-scope individuals.
Indicator source	[69]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S40-devices
Indicator	The share of a household's monthly income that is used for software, excluding games and computer software packages.
Indicator source	[391, 397, 400]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S41-devices
Indicator	The share of a household's monthly income that is used for ICT games, toys, and hobbies,
Indicator source	[391, 397, 400]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Use of the Internet

Indicator ID	S42-Internet
Indicator	The average monthly mobile data usage per individual mobile broadband subscription in Gigabytes.
Indicator source	[69, 388, 400]
Answer scale and nominalization	Rank; below 10 Gigabytes (0), 10-29 Gigabytes (25), 30-49 Gigabytes (50), 50-69 Gigabytes (75), at least 70 Gigabytes (100)

Indicator ID	S43-Internet
Indicator	The percentage of the population using the Internet in general within the agreed time period.
Indicator source	[69, 135, 137, 141, 386, 400, 422]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S44-Internet
Indicator	Internet access tariffs (20 hours per month), in US$, and as a percentage of per capita income
Indicator source	[139]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S42-Internet
Indicator	The percentage of urban and rural households with mobile and fixed Internet connections by type and download speed. Rural areas are defined as those with less than 100 people per km^2. Urban areas are defined as those with at least 100 people per km^2. Mobile broadband download speed categories include: - At least 2G - At least 3G - At least 4G (LTE) - At least 5G Fixed broadband includes the technologies FTTH, FTTB, Cable Docsis 3.0, and VDSL with the following download speed categories: - below 30 Mb - 30-299 Mb - 300 MB - 1 GB - above 1 GB
Indicator source	[60, 61, 72, 124, 126, 127, 129, 131, 134-136, 138, 139, 143, 372, 375, 379, 381, 382, 384, 389-391, 395, 400, 401, 409, 414-416, 421, 422]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100 for each download speed category.

Indicator ID	S46-Internet
Indicator	The percentage of individuals in the country using the Internet for at least one health-related purpose within the agreed time period. Health-related purposes are: - to post or read a healthcare review - to share personal medical information - to make an appointment with a health practitioner - to ask a question of their healthcare provider - to access their electronic health record - to schedule an appointment with their healthcare provider - to monitor disease symptoms - to seek health-related information
Indicator source	[69, 376, 382, 400, 414, 417]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S47-Internet
Indicator	The percentage of health professionals who provided health consultancy services through online platforms within the agreed time period.
Indicator source	[114, 376]
Answer scale and nominalization	Percentage with an answer from 0-100% nominalized to a score between 0-100

Indicator ID	S48-Internet
Indicator	The number of searches per 10,000 population for specific digital public health interventions was measured on Google Trends. Digital public health interventions include the national terms for implemented interventions such as electronic health records, mobile health and medical apps, telemedicine, online consultation, electronic prescription, etc.
Indicator source	[69, 413]
Answer scale and nominalization	Nominalized to a score between 0-100

D Overview of additional publications connected to this dissertation

Poster presentations at conferences

1. **Maaß L**, Badino M, Iyamu I & Holl F (2024). How advanced is your digital public health system? A qualitative analysis of suitable indicators. Poster presentation at the 17th Public Health Conference, 13.-15.11.2024, Lisbon.
2. **Maaß L**, Albrecht J, Tokgöz P, Hrynyschyn R, Wrona KJ, Stark AL, Dunsche C, Fischer A, Schmidt A & Dockweiler C (2024). How much digital public health is taught in German public health programs? A qualitative analysis. Poster presentation at the 17th Public Health Conference, 13.-15.11.2024, Lisbon
3. **Maaß L,** Freye M & Pan CC (2022). Mapping core characteristics of internet-based tools to maintain and improve population health. Poster presentation at the 15th European Public Health Conference, 12.10.2022, Berlin.
4. **Maaß L**, Freye M, Pan CC, Dassow HH, Niess J & Jahnel T (2022). Health and medical apps - Same same but different? A review of definitions in public health and law. Poster presentation at the 15th European Public Health Conference, 12.10.2022, Berlin.
5. **Maaß L** (2021). The Digital Public Health Maturity Index to measure maturity in European health systems. Poster presentation at the Digital Public Health meets Malta networking event, 19.10.21, Valletta.

Oral conference presentations and workshops

1. **Maaß L**, Duplaga M, Saleem M & Macedo Silva A (2024). Why do we need clear understanding of digital public health interventions? Moderation of the workshop at the 17th Public Health Conference, 13.-15.11.2024, Lisbon.
2. Hrzic R, **Maaß L**, Albrecht J & Buttigieg S (2024). Developing curricula that empower the public health workforce: to lead the digital transformations in health. Moderation of the pre-conference at the 17th Public Health Conference, 12.11.2024, Lisbon.
3. **Maaß L**, Zeeb H & Rothgang H (2023). Holistically assessing digital public health systems: The Digital Public Health Maturity Index. Presentation at the 16th European Public Health Conference, 8.-12.11.2023, Dublin.
4. **Maaß L**, Zeeb H & Rothgang H (2023). An international and interdisciplinary Delphi study to measure digital public health system maturity. Presentation at the 16th European Public Health Conference, 8.-12.11.2023, Dublin.

5. **Maaß L**, Staines A, Brînzac M & Hrzic R (2023). „Digital public health in Europe – What is the new normal? Presentation and moderation of the workshop at the 16th European Public Health Conference, 8.-12.11.2023, Dublin.
6. Forberger S, Buttigieg S, Freye M & **Maaß L** (2023). Helping countries to learn from each other by comparing digital health systems. Presentation in the panel "Digital Public Health Governance – navigating complex structures" at the 17th World Congress on Public Health, 2.-6.5.2023, Rome.
7. **Maaß L**, Holl F & Hrynyschyn R (2023). How to evaluate health and medical apps – what are alternatives to randomized controlled trials? Moderation of the workshop at the 17th World Congress on Public Health, 2.-6.5.2023, Rome.
8. Pan CC, **Maaß L**, Iyamu I, Holl F & Buttigieg S (2023). Learning from digital public health interventions in practice: Challenges we embraced. ECRA: An interdisciplinary early career research academy for digital public health. Presentation and panel discussion at the 17th World Congress on Public Health, 2.-6.5.2023, Rome.
9. **Maaß L** (2023). How to measure digital public health system maturity on a national level: An international interdisciplinary Delphi study. Presentation at the 17th World Congress on Public Health, 2.-6.5.2023, Rome.
10. **Maaß L**, Freye M, Pan CC, Pédros Barnils N (2023). How to achieve effective interdisciplinarity in digital public health practice. Moderation of the workshop at the 17th World Congress on Public Health, 2.-6.5.2023, Rome.
11. Alessi C, Buttigieg S, Laurila T, Martikainen J, **Maaß L**, Saele L, Selbie D & Solomon A (2023). The Public´s Health Demystifying Health Security and Digital Public Health. Presentation and panel discussion at the Radical Health Festival Helsinki, 12.-14.06.2023, Helsinki.
12. **Maaß L**, Wöhlke S, Hocke-Bolte Z, van Gils-Schmidt HJ & Posselt J (2023). [The role of statutory health insurers in promoting digital health literacy among their members]. Moderation of the expert forum at the Kongress Armut und Gesundheit, 07.03.2023 (virtual).
13. **Maaß L**, Pan CC, Freye, M & Niess, J (2022). How can we achieve effective interdisciplinarity in digital public health practice? Moderation of the workshop at the 15th European Public Health Conference, 12.10.2022, Berlin.

14. **Maaß L**, Pan CC, Zeeb, H, Muellmann, S, Wong, BLH & Buttigieg S (2022). Better DiPH – To plan, implement, evaluate, and the future of digital public health interventions. Moderation of the workshop at the 15th European Public Health Conference, 12.10.2022, Berlin.
15. **Maaß L** (2022). How can we measure national Digital Public Health Maturity? Presentation and podium discussion in the panel "The Power of Digital Transformation for Global Health Equity" (with Lazarus J, Mateen B & Venkateswaran M) at the HIMSS22 European Health Conference & Exhibition, 16.06.2022, Helsinki.
16. Rachadell J, Buttigieg S, Rodrigues EF & **Maaß L** (2021). The German perspective of digital public health to tackle the COVID-19 pandemic. Presentation and podium discussion in the panel "Digital innovation to fight the pandemic, what is here to stay?" at the 14th European Public Health Conference, 12.11.21 (virtual).

Webinars

1. **Maaß L** (2023). Was ist eigentlich Digital Public Health? Webinar by #Gesundheit e.V., 09.03.2023.
2. **Maaß L** (2022). Messen des digitalen Reifegrades eines Gesundheitssystems: Der Digital Public Health Readiness Index. Lecture as part of the training series "Methoden in der Versorgungsforschung" of the Center for Healthcare Research and the Institute for Medical Biometry and Epidemiology at the University Medical Center Hamburg-Eppendorf (UKE), 27.07.2022.
3. **Maaß L** (2022). Messen des digitalen Reifegrades eines Gesundheitssystems: Der Digital Public Health Readiness Index. Lecture at the University of Applied Sciences Hamburg (HAW), 29.06.2022.
4. **Maaß L** (2022). The German Perspective on Contact Tracing Apps. Presentation at the webinar "Digital and Innovative Tools: The Challenges of Contact Tracing in Public Health" by Population Health Information Research Infrastructure (PHIRI), 17.02.2022.
5. Jahnel T, Shrestha R & **Maaß L** (2021). [Impulse: The relationship with and trust in Digital Public Health using the German Corona Warn and Luca apps as examples]. Keynote at the annual Leibniz ScienceCampus Digital Public Health Bremen meets Stakeholder Advisory Board, 16.12.21.

Articles and book chapters

1. Gille F, **Maaß L**, Ho B & Srivastava D (2024). We need to discuss the economics of trust-building in digital health. JMIR. 02/04/2024: under review.
2. **Maaß L**, Wong BLH, Hrzic R, Põld A, Rachadell JJ, Delgrange M, van Kessel R & Buttigieg S (in press). Digital public health in Europe: Was the COVID-19 pandemic an enabler for healthcare digitalization? In I Pigeot, H Zeeb, T Schultz, B Schüz & **L Maaß**: Digital Public Health – Interdisciplinary Perspectives. Cham: Springer Nature Switzerland AG.
3. Albrecht J, **Maaß L**, Tokgöz P, Hrynyschyn R, Stark AL, Wrona KJ, Fischer F, Schmidt A, Schultz H, Hidding S, Dunsche C, Hocke-Bolte Z & Dockweiler C. (2024). Wie viel Digital Public Health steckt in Public-Health-Studiengängen? Eine systematische Modulhandbuchanalyse von Vollzeitstudiengängen an öffentlichen Hochschulen und Universitäten in Deutschland. Bundesgesundheitsblatt – 67: 339-350. Doi: 10.1007/s00103-024-03844-2
4. **Maaß L,** Hrynyschyn R, Palacios A, Orbinski J, Restivo V, Vella G, Grieco V, Gorga A, Löwe A, Lange M, Hacem M, Burdenski K, Lang A-L, Varnfield M, Button K & Holl F (2023). Challenges and alternatives to evaluation methods and regulation approaches of medical apps as mobile medical devices: An international and multidisciplinary focus group discussion. JMIR. 24/07/2024:54814 (forthcoming/in press). Doi: 10.2196/54814
5. **Maaß L**, Freye M, Pan CC, Dassow HH, Niess J & Jahnel T (2022). The Definitions of Health Apps and Medical Apps from the Perspective of Public Health and Law: Qualitative Analysis of an Interdisciplinary Literature Overview. JMIR Mhealth Uhealth, 10(10): e37980. Doi: 10.2196/37980
6. Wong BLH, **Maaß L,** Vodden A, van Kessel R, Sorbello S, Buttigieg S, Odone A & European Public Health Association (EUPHA) Digital Health Section. (2022). The dawn of digital public health in Europe: Implications for public health policy and practice. The Lancet Regional Health – Europe, 14: 100316. Doi: 10.1016/j.lanepe.2022.100316
7. Wienert J, Jahnel T & **Maaß L** (2022). What are Digital Public Health Interventions? First Steps Towards a Definition and an Intervention Classification Framework. Journal of Medical Internet Research. 24(6): e31921. Doi: 10.2196/31921

E Declaration of originality

I hereby declare, that …

- … it is my original work and it is conducted without unauthorized assistance.
- … only the referenced sources and tools were used for this dissertation.
- … I made due references to all published or unpublished work either quoted or used as the basis for ideas.

I permit, this dissertation to be checked for plagiarism using appropriate software.

Laura Maaß

Bremen, 18.09.2024