Digital Public Infrastructure: a framework for conceptualisation and measurement

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David Eaves and Krisstina Rao

Abstract

Digital Public Infrastructure (DPI) is an emerging concept in public administration and digital governance, referring to shared digital systems that support service delivery, foster innovation, and enable social and economic development. This paper develops a conceptual framework to define and measure DPI, addressing its growing global policy relevance. Using a grounded theory approach, the study integrates insights from literature and expert interviews to provide two key contributions. First, it offers a normative framework to trace the attributes of the concept, discussing its qualities in terms of its technology, public-interest values, and adoption context. Second, it offers a measurement framework to evaluate the presence of these attributes in real-world DPI implementations. Second, it offers a measurement framework to evaluate the presence of these attributes in real-world DPI implementations. The insights from this conceptual and measurement framework contribute to the 'DPI Map,' an ongoing global research project by the authors, aiming to document how countries build their DPI functions globally. The paper bridges theory and practice on DPI, providing concrete guidance for government officials, technical implementers, civil society organisations and researchers to advance their work in this evolving field.

Reference

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Contents

1. Introduction

DPI is a term that is growing in popularity, with Google Trends reporting an uptick in interest around the term worldwide, especially since early 2023 (Google Trends, 2024). Late in 2023 and following several claims that lauded its potential in influencing large-scale development and digital transformation, it was formally adopted into the global policy lexicon at G20. The New Delhi Declaration acknowledged DPI to be an 'evolving concept', describing it as a set of shared digital systems for the 'delivery of services at societal-scale' (G20 India Presidency 2023).

The term itself has been **used only in practice-oriented literature, typically by public administrators and technologists**, as discussed below. These practitioners refer to the innovative way in which some governments have designed their information architectures in a way that reduces duplication, prevents an unreasonable amount of dependence on private vendors, and makes citizen-centric service delivery by states more efficient. Interestingly, this approach was positioned by its authors as being prevalent in countries of the Global South, explaining the co-option of the term by stakeholders in the development field.

Despite its popularity in global policy forums like the G20 and the field of development policy more generally, **DPI as a concept seems to lack definitional consensus**. The multitude of actors involved in shaping the design and deployment of DPI across the world has meant differences in the normative and empirical weights of its features. While some actors have **emphasised the technical design of the infrastructure itself** (like interoperability and decentralised storage) (CDPI 2024), **others emphasise public-interest norms that inculcate public values** (like ownership and accountability) (UNDP 2024). This difference in normative emphasis is detrimental to its potential. If relevant stakeholders fail to agree on what serves as digital public infrastructure (and by extension, what does not), the north star will keep shifting.

On looking closer, it is also evident that while **its etymology may be new, the term is underpinned by robust theoretical contributions from several fields of study** – economics (Bukht and Heeks 2017, Oakland 1987, Frischmann 2012, Mazzucato et al. 2024), public administration and digital government (Mergel et al. 2019, Mazzucato et al. 2024), media studies (Zuckerman 2020), socio-technical studies (Larkin 2013) and innovation studies (Sestino et al. 2020). As the paper goes on to discuss, making sense of the term has been less about investigating the emergence of a new term and more about investigating the complementary ways in which terms related to DPI have been explained. That is, the etymology of the **term DPI as a culmination of related terms ('infrastructure', 'public infrastructure', 'digital infrastructure', 'shared resources')** – emphasising the different values inherited by the term DPI.

Intending to contribute a framework to understand and discuss digital public infrastructure, this paper offers an **exploratory conceptual framework**, describing how its normative attributes interact with other attributes that ground it in a government's practice. Further, it proposes **a measurement framework** for these dimensions through a comprehensive list of indicators or metrics. In doing so, it uses a largely inductive methodology to arrive at the attributes of digital public infrastructure, triangulating the normative qualities of the terms ("attributes") from

literature and expert interviews. This is followed by steps to deduce and standardise metrics ("indicators") that allow the prevalence of DPI to be studied in a country's context.

While this paper intends to further the narrative on digital public infrastructure by grounding its discussion in theory, we value **leveraging the outputs of this paper to study real world digital systems** in the public sector. We house this investigation in an open-access tool called the **'DPI Map'**, which leverages the framework discussed below to ask how existing systems exhibit characteristics of the 'normative' DPI concept. In doing so, we aim to directly support stakeholders who engage with digital public infrastructure: public sector officials, technical implementers, and researchers offering them a benchmark for their work. Simultaneously, the needs of these users have also shaped the research questions and scope of this paper.

The three sections of this paper have been laid out as follows. The first situates the term DPI theoretically, discussing how it has been conceptualised across different fields and what that means for the normative qualities derived towards its use in the field of public administration and digital government. The second section provides the analytical framework based on empirical research conducted through document analysis and expert interviews and consultations. Given the practice-oriented nature of the term's use, and the lack of published academic research on the topic, this section aims to contribute a grounded understanding of the topic through a set of attributes and indicators. The derivations from this research and its limitations have been laid out in the third and final section of this paper.

2. Theoretical background

2.1. Situating digital public infrastructure in literature

The term digital public infrastructure appears to be novel before we consider how ubiquitously it has been used as related terms in adjacent fields. While 'infrastructure' has been largely used to refer to physical infrastructures since its first use by French engineers in the 19th century (Mazzucato et al. 2024), using 'digital' as a qualifier for infrastructure helps us segment the scope of infrastructure studied in this paper quite clearly.

Digital infrastructure can further be segmented into hardware (data centres, security hardware, infrastructure equipment like cables and power supply units) and software components (cloud services, operating systems, database management systems, middleware, data) that facilitate information flows and in turn, service delivery. The fields of information science, computer science and infrastructure studies emphasise protocols, networked environments, interoperability and heterogeneity to understand how infrastructures form and operate digital ecosystems like the internet (Hanseth and Lyytinen 2010, Edwards et al. 2009). Practice-oriented literature in the field of DPI confirms this, highlighting certain common good use cases (authentication, transactions, assets) that are fulfilled by digital infrastructures (Centre for Trustworthy Technology 2024, Mazzucato et al. 2024).

Digital infrastructure is often discussed in the field of innovation studies as an enabler for innovation itself, given its ability to restructure business processes, products and services (Sestino et al. 2020). This offers a competitive advantage to its adopters, in public sectors as much as private sectors (Du and Wang 2024).

Infrastructure and its governance have been especially analysed in the fields of science and technology studies and media studies. STS scholars view infrastructure as complex socio-technical systems, investigating the interplay between infrastructure and human organization (Harvey 2012, Larkin 2013). In analysing these systems, Bowker et al. (2010) hat-tip to the technology stack discussed in practice-oriented DPI literature, highlighting the role of data directories, computing services, protocols and standards that serve as infrastructure to society. Musiani (2024) has further unpacked the governance of one such socio-technical system– the internet, highlighting its role as a "general-public" technology, and alluding to its public value, as highlighted in economics literature. Further, Zuckerman's (2020) work in the related field of media studies offers a lens on the role of large media corporations in controlling and operating public digital service spaces, tools and resources. His work speaks to the issues of monopolisation and competition, and how tools in these policy spaces may be used to create more decentralised and autonomous versions of digital public infrastructure. While these bodies of work address some governance discussions around DPI, they do not adopt the same definition of DPI as has been adopted in practice-oriented literature on the topic.

Two fields contribute more specifically to conceptualising digital public infrastructure: economics (due to their position as common or public goods, defined by their relation to markets and their production rationales) and public administration (due to the primary role of governments in building and using them). These contributions have been discussed below.

2.1.1. Literature from economics

The field of economics has long been analysing the role of data and digital technologies in the economy. The now-commonly understood term 'digital economy' has witnessed a consensus in its understanding only in the past decade. Bukht and Heeks (2017) defined it as that part of economic output derived solely or primarily from digital technologies with a business model based on digital goods or services. In this realm, digital infrastructure refers to the foundational digital technologies and systems that support the digital economy. This includes the hardware, software, networks, and services that enable the storage, processing, and transmission of data, which are essential for modern economic activities (Bukht and Heeks 2017, Constantinides et al. 2018).

The value of digital technologies here was viewed as crucial for reducing various economic costs such as search, replication, transportation, tracking, and verification costs, thereby enhancing economic efficiency (Goldfarb and Tucker 2017). This value justifies the popularity of digital technologies in influencing development goals, especially in the Global South, which reports faster growth rates of digital infrastructures despite having a smaller share of the growth in comparison to the Global North (Bukht and Heeks 2017).

Infrastructure and its provision can also be analysed through the theory of public goods, which stipulates that public goods are meant to be non-excludable and non-rivalrous (Oakland 1987). In reality, most goods understood to be public goods (roads, knowledge, law enforcement) are considered to be impure public goods due to being rivalrous or excludable to an extent (Mazzucato et al. 2024). Nonetheless, the role of the government is considered essential to the provision of public goods because of its implicit production externalities. The supply of public goods is hampered if its negative externalities disadvantage private producers i.e. if the private benefits are small relative to the social benefits, but the private costs to produce them are large (Helbling 2010).

A separate segment of literature discusses the infrastructure through the lens of commons management and social value. Frischmann (2012) describes infrastructure as a 'shared means to many ends'. This definition values infrastructure's social, institutional and digital attributes. It also emphasises the uniqueness of 'infrastructure', which lies in its value as an input into a wide range of goods and services, which may include private goods, public goods and social goods (Mazzucato et al. 2024).

The public value of digital public infrastructure has been discussed in prior work (Mazzucato et al. 2024), which highlights the 'publicness' of digital public infrastructure being articulated through its public-interest governance rather than public ownership of the digital asset. Further, there is an emphasis on this publicness being value-laden and normative, offering a *direction* in which the infrastructure can and should be leveraged.

2.1.2. Literature from public administration and digital government

The adoption of digital technologies for value delivery by the public sector alludes to its 'public' value. Governments have commonly leveraged these technologies to increase efficiency and productivity (Katsonis and Botros 2015), enable citizen engagement and participation (Sivarajah, Irani, and Weerakkody 2015), public management reform (Asgarkhani 2005), as well as address social exclusion (Metaxiotis, Larios, and Assimakopoulos 2010). This adoption has been catalytic for the field of public administration, with research on the movement from digital services in the government quickly evolving into 'digital transformation' and service delivery at scale (Huang and Karduck 2017). Mergel et al. (2019) define digital transformation as a comprehensive process that involves the integration of digital technologies into various aspects of an organisation, fundamentally altering how it operates and delivers value. Further, Zhang and Kimathi (2022) explore the stages of e-government development from a public value perspective, explaining the three kinds of public value: transparency, efficiency, and engagement identified in the public management paradigm and how they can be understood through the three stages of evolution in e-government, namely the information stage, transaction stage, and engagement stage.

Public value theory also offers a useful lens to discuss the role played by digital technologies in the public sector by offering innovative ways to plan, design, and implement digital government initiatives (Bannister and Connolly 2014, Cordella and Paletti 2019, Cordella and Bonina 2012). Panagiotopoulos et al. 2019 purport that it shifts the focus of public sector management

from internal efficiency to value creation processes that occur outside the organization. They specifically emphasise that digital government implementations support public value creation by integrating various services and technologies, rather than enhancing individual innovations. Meijer and Boon (2021) further explain the relationship between technology, governance, users and societal outcomes through a set of three configurations that involve different actors interacting to create public value. These configurations include (1) a closed platform controlled by a private sector organisation, (2) an open platform controlled by a government organisation and (3) an open platform run by a civil society organisation. More recent research also extends this configuration to explain citizen-led digital innovation, and its role in public value creation (Chohan 2023).

2.2. Theoretical contributions as a starting point for research

The term 'digital public infrastructure' is still novel, its boundaries being negotiated through current deployments in the real world. Recognising its derivation from related terms across several fields of study, we discuss how precursory concepts and theories offer a direction to discuss practice-based contributions to understand the term. Table 1 summarises these contributions.

Table 1. Precursory contributions to the term 'digital public infrastructure'

Field	Concept / Theory	Contribution
Economics	Digital economy	The part of economic output derived solely or primarily from digital technologies with a business model based on digital goods or services (Bukht and Heeks, 2017)
	Public good(s)	Public goods are meant to be non-excludable and non-rivalrous (Oakland 1987)
		Most commonly understood public goods are considered to be impure public goods due to being rivalrous or excludable to an extent (Mazzucato et al. 2024)
	Social value of infrastructure	Infrastructure as a shared resource that should be managed collectively rather than through strict private control (Frischmann 2012)
Public administration	Digital transformation	A comprehensive process that involves the integration of digital technologies into various aspects of an organisation, fundamentally altering how it operates and delivers value (Mergel et al. 2019)
	Public value	Creation and governance of digital systems that serve the common good. DPI should not only be regulated but actively designed to maximise public value, which involves a collective effort focusing on outcomes and processes that benefit society as a whole (Mazzucato et al. 2024)
Information studies	Digital infrastructure	Information infrastructures form and operate digital ecosystems like the internet, through protocols, networked environments, interoperability and heterogeneity (Hanseth and Lyytinen 2016)

Field	Concept / Theory	Contribution
Media studies	Digital public infrastructure	Infrastructures that let us engage in public and civic life in digital spaces (Zuckerman 2020)
Socio-technical studies	General public technology	Technologies that have a broad range of applications across various sectors and can significantly impact economic and social structures (Larkin 2013)
Innovation studies	Digital innovation	Enabler for innovation, given the ability to restructure business processes, products and services (Sestino et al. 2020)

3. Research Design

3.1. Research questions and scope

Given the multifaceted nature of the term 'DPI', as discussed above, the scope of this research was defined broadly so as to inductively contribute to practice. First, it focused on harmonising raw information on the concept from various sources, attempting to derive themes that are common across them. Second, recognising the novelty of the term and its use in practice-oriented literature, feedback and validation on these 'induced' insights were sought through practitioners and experts in the digital government and digital public infrastructure ecosystem, who in turn helped shape the research scope. Accordingly, two research questions were identified:

1. What are the norms of digital public infrastructure?
2. How can these norms be measured in real world deployments?

3.2. Methods

Based on the open-ended nature of research, qualitative and interpretive methods of data collection and analysis were adopted. It has been recognised that descriptive-interpretive research is valuable to qualitative analysis that relies on real world observations. This is because these methods derive theories from the observed data rather than test pre-existing hypotheses (Elliott and Timulak 2015). This allows the adoption of a sense-making approach to data analysis rather than one that is based on hypothesis testing. Further, grounded theory (Glaser and Strauss 1967) shaped this research design extensively by allowing us to leverage its focus on real world observations. Given that the concept of DPI has not been academically investigated so far, grounded theory helped shape an iterative process by which data collection, data analysis and theory development to conceptualise and measure DPI took place. The steps of data collection, data analysis and sense-making to articulate a grounded theory about DPI were informed by Gioia et al.'s (2013) methodology.

3.3. Data collection

3.3.1. Documentary evidence

Initial document analysis for the DPI values relied on publications from credible practice-oriented sources. Credibility was established through source evaluation, where 'content' was filtered based on authorship, publication avenue, and recency of publication. Further, the quality of the text was scrutinised based on the purpose and audience it was framed for and the avenue where it was published. These parameters to conduct interpretative document analysis were supported by Bengtsson (2016), who further emphasised the contextual relevance of the content. The documents speaking to the concept of digital public infrastructure were inherently considered contextually relevant, given the broad research question being pursued. Further, given the nascent nature of the field, most literature came from non-academic sources and grey literature, including working papers, project and technical reports, emails and public presentations that were published by the public sector, private sector, civil society and research organisations. While these sources may not be rated highly on credibility in other fields, they may be treated as foundational documents in the context of academic literature being premature or non-existent. Literature selected to be a part of this stage of analysis was written by a relevant organisation working in the DPI ecosystem – such as a development partner, technical advisor or funding partner. It was also selected only if it had relevance to the scope of this research, in the sense of speaking to the research questions specifically rather than broadly relating to the topic of DPI itself. Accordingly, an initial conceptualisation of DPI emerged through 8 textual sources (digital blogs, websites, and published reports).

These documents were accessed directly if they were hosted publicly, or indirectly through the authors of the documents. A complete list of content that was consulted is available in the bibliography.

3.3.2. Semi structured expert interviews

In addition to the documents accessed initially for content analysis, data was collected from experts through interviews. These interviews were semi structured and open-ended, where the research method focused on extracting real world insights and observations from experts and practitioners, as a panel or individually, to validate the findings from the document analysis.

Dexter (2006) defines an expert as any person who has specialized information on or who has been involved in the political or social process of interest. They are distinguished from elites, who may be situated in a role that allows them to have an opinion about the subject of study rather than having real knowledge about it. Instead, experts are understood to be academics, practitioners, and managers who hold "real knowledge" on the subject of study (Von Soest 2023). Accordingly, for their participation in independent interviews or panel consultations, experts were identified based on their contributions to practices in the field, either through publishings, presence at subject matter conferences, or qualification, as well as recommendations from identified experts. These experts typically occupied leadership-level roles in their respective

functions and/or organisations. Given the novelty of the field of digital public infrastructure, many of these experts were practitioners in adjacent or subsumed fields of development and subject areas like banking and finance, information technology, and economics. Attempts were made to ensure a diversity of participants across geography and organisational type, but the final list of participants represented both– those who could be accessed through networks of the authors, as well as those who were available and interested in participating in the interview or consultation. No remuneration for participation was provided, but participants were able to leverage the consultations for their reputational and networking interests.

Semi-structured interviews were favoured to obtain information from these experts. This format allowed selected experts to respond to the exploratory questions, while also contributing to the research direction by offering real world insights that more structured interview questions could not have anticipated. In the same vein as Gioia et al. (2013), anonymity instead of confidentiality was promised. For those experts who participated in panel consultations, their anonymous input was sought offline via e-mail, if it was not shared in the presence of other experts.

Table 2: Distribution of experts participating in research interviews, grouped by affiliated organisations and geographical regions

	Region					
Type of organisation	North America	Europe	Asia	Africa	Caribbean	Latin America
Government	4	2				1
Private Sector		2	1			
Civil society/ think tank			2	2	1	
Research/ Academia	1	6				
International organisations	16	2	5			2

Interviews with these experts were conducted independently as well as in groups through consultations. These were also arranged iteratively, based on the topic of expertise and the stage of data analysis that their insights informed. Appendix 1 provides an illustrative list of questions that guided these research interviews, grouped into the parameters that were considered critical to the research scope.

3.4. Data analysis

To address the two research questions, the analysis focused on first– inductive, and then deductive methods of coding and content analysis. This was in line with the iterative nature of the grounded theory approach, which encouraged the use of open codes (looking for initial patterns)

and then axial coding (grouping observations based on similarities in coding). The inductive methods addressed the open-ended sections of the research scope.

Coding for data analysis followed the guidelines by Kleinheksel et al. (2020). They articulate a four-step process to inductive content analysis: (1) identifying units of meaning (2) labelling equivalent units with a code (3) grouping similar codes with a category and (4) describing similar categories with a theme. Based on a set of groups and categories that emerged from the content analysis and research interviews, a follow-up stage of analysis was carried out to address gaps in the findings from the first stage. Accordingly, stages 1 and 2 of the data analysis involved inductive analysis that was open-ended and led to an exploratory set of dimensions that helped conceptualise the term DPI. Based on an initial set of dimensions that were arrived at through axial coding, indicators to measure these dimensions were developed inductively through another round of content analysis. The final stages of the data analysis – stages 3 and 4 – were carried out deductively. This allowed us to paint a comprehensive picture of the dimensions of DPI across its fundamental blocks and through a uniform set of indicators. The stages of data analysis have been summarised in Table 3.

The initial documentary analysis was supported by semi-structured interviews with relevant practitioners and subject matter experts, who validated the initial content analysis and provided feedback on findings through real world observations. As these stages were iteratively conducted, they informed a grouping and prioritisation of the attributes and indicators of DPI, where those attributes or indicators that did not find consensus among experts interviewed were excluded from consideration. This allowed every subsequent stage of data analysis to validate the insights previously gathered. Given that documentary analysis was followed by expert interviews and consultations, the insights from the research exercise were generally grounded in practitioner and expert experiences.

Table 3. Stages of data analysis through inductive and deductive methods

Stage	Methodology	Analysis method	Output	Research scope
1	Documentary analysis	Inductive	Attributes	Conceptualisation
2	Expert semi-structured interviews and consultation	Inductive	Validated list of attributes	Conceptualisation
3	Documentary analysis	Inductive, deductive	Metrics/ indicators	Measurement
4	Expert semi-structured interviews and consultation	Inductive, deductive	Validated list of metrics/ indicators	Measurement

4. Results

4.1. Conceptualisation of DPI

The literature highlights that the term 'digital public infrastructure' discussed in practice-oriented texts finds parallels in adjacent concepts discussed in the fields of economics, public administration and others (table 1). Further, there emerges an organic set of categories among attributes of DPI that have high consensus among the documents consulted), as presented in table 4.

Table 4. Documentary analysis for DPI attributes

Document	1st order codes	Category for common codes
DPI Overview (Centre for Digital Public Infrastructure, CDPI)	▪ Foundational categories: identifiers and registries; data sharing and AI/ ML models; trust infra; discovery and fulfilment; and payments. ▪ Foundational blocks for digital economies ▪ Market innovation ▪ Governance ▪ Open tech standards	technology design, societal outcomes, market innovation, foundational categories, openness
DPI Tech Architecture principles (Centre for Digital Public Infrastructure, CDPI)	▪ Interoperability ▪ Minimalist, reusable building blocks ▪ Diverse, inclusive, innovation ▪ Federated, decentralised ▪ Security and privacy by design	technology design, governance by technology, societal outcomes
'What is Digital Public Infrastructure?', (Co-Develop)	▪ Inclusive ▪ Foundational ▪ Interoperable ▪ Publicly accountable	technology design, foundational, societal outcomes
The DPI Approach: A Playbook (UNDP)	Technology ▪ Interoperability ▪ Modularity and extensibility ▪ Scalability ▪ Security and privacy by design Governance ▪ Public benefit, trust, transparency ▪ Grievance Redressal ▪ Intellectual property protection Ecosystem ▪ Inclusivity ▪ Human rights ▪ Collaboration ▪ Sustainability	technology design, societal values, ecosystem, societal outcomes

Document	1st order codes	Category for common codes
Framework for the governance of DPI (Aapti Institute)	▪ Inclusivity, access, equality ▪ Robust privacy and security measures ▪ Collaboration and co-creation ▪ Transparency, accountability and grievance redressal	societal values, societal outcomes
Digital public Infrastructure, building blocks, and their relation to digital public goods (Govstack)	▪ Foundational component ▪ Open source or proprietary ▪ Functional role in facilitating delivery of public services: registration, authentication, payments, messaging ▪ Autonomous ▪ Generic ▪ Interoperable ▪ Iterative evolvability	foundational, technology design, functional outcomes, societal values, sector-agnostic, dynamic evolution
Digital Public Infrastructure (Gates Foundation)	▪ Economic value ▪ Safety and inclusivity ▪ Trust between governments and citizens ▪ Essential for functions ▪ Core elements: digital identity system, digital payment system, data exchange system ▪ Emerging elements: consent, credentials, registries, digital signatures	societal values, foundational categories, emerging categories, technology design
Defining the Digital Public Infrastructure Approach (T20 Task Force 2 Report, G20 2023)	▪ Interoperable technology ▪ Robust governance with values of privacy by design, inclusivity, and security into the technology ▪ Private sector engagement	technology design, societal values, market engagement

4.2. Synthesis of attributes

The norms of DPI as derived from the research procedure are captured herein as 'attributes', regarding these norms to be inherent to the nature of the concept. Based on the stages of content analysis and iterative expert interviews conducted through the stages described above, these attributes were coded and grouped based on the type of reflection they offer about the term DPI.

Table 5 offers a summary of inductive codes that were identified based on an open-code process. These were eventually grouped into categories to make sense of how they related to the concept of DPI, or which aspect of the DPI phenomenon the codes seemed to explain. These produced 1st order and 2nd order codes, as well as aggregate dimensions, to respond to the research question, 'What are the norms of digital public infrastructure?'. The encoded data has been presented in the form of a data structure (adapted from Gioia et al. 2013) in table 5.

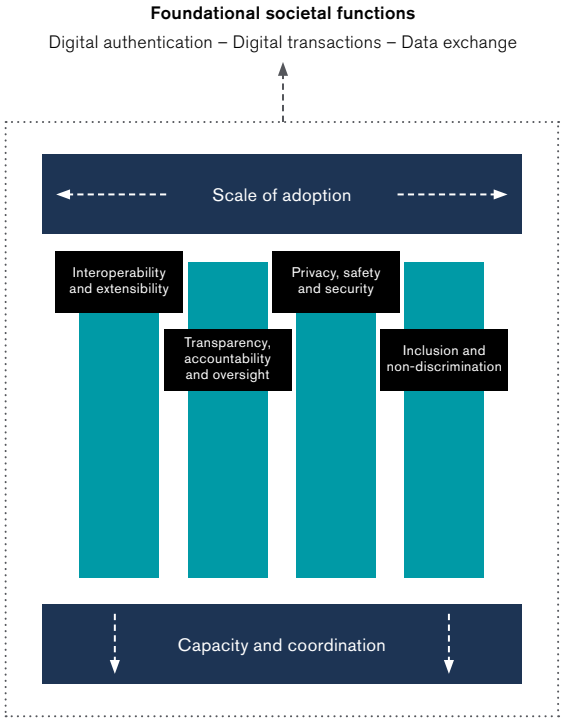
Table 5. Encoded data on the attributes of DPI

1st order codes, grouped by category	2nd order themes	Aggregate dimensions
▪ Foundational categories: identifiers and registries; data sharing and AI/ML models; trust infra; discovery and fulfilment; and payments. ▪ Foundational blocks for digital economies ▪ Functional role in facilitating delivery of public services: registration, authentication, payments, messaging ▪ Foundational ▪ Foundational component ▪ Essential for functions ▪ Core elements: digital identity system, digital payment system, data exchange system ▪ Emerging elements: consent, credentials, registries, digital signatures ▪ Economic value	• Identification/ authentication • Payments/ transactions • Data exchange	Functions or Foundational value to society
▪ Diverse, inclusive, innovation ▪ Inclusive ▪ Publicly accountable ▪ Public benefit, trust, transparency ▪ Grievance Redressal ▪ Intellectual property protection ▪ Human rights ▪ Inclusivity ▪ Inclusivity, access, equality ▪ Safety and inclusivity ▪ Trust between governments and citizens ▪ Robust governance with values of privacy by design, inclusivity, and security into the technology	• Public accountability • Inclusivity and equality • Trust and transparency	Public-interest values
▪ Interoperable ▪ Security and privacy by design ▪ Modularity and extensibility ▪ Robust privacy and security measures ▪ Open source or proprietary ▪ Autonomous ▪ Interoperable ▪ Iterative evolvability ▪ Generic ▪ Interoperable technology ▪ Robust governance with values of privacy by design, inclusivity, and security into the technology	• Interoperability • Modularity, extensibility, • Open source or proprietary base	Technology norms
▪ Collaboration ▪ Sustainability ▪ Collaboration and co-creation ▪ Transparency, accountability and grievance redressal ▪ Private sector engagement	• Societal values, Societal outcomes	Adoption context

This encoding process was subject to certain validation processes to determine a coherent set of attributes that normatively describe the concept of digital public infrastructure. Specifically, any 1st order concepts derived from literature that did not occur commonly, or were not validated by more than one expert, were not filtered into the list of 2nd order codes. These norms are instead subsumed within the final list of attributes, as a feature of some DPI systems rather than a norm for all DPI systems. Additionally, the aggregate dimensions derived from this data structure were visualised and validated through expert interviews to identify any missing norms of the concept that might not have been documented in the literature.

Figure 1 captures the final set of attributes, as derived collectively through the literature review and consultation with experts. The attribute of 'Capacity and Coordination' was identified through expert interviews, where DPI's need to be *housed* within an institutional capacity and its need to have access to an implementation budget was also underscored.

Figure 1. Attributes of DPI



The diagram captures the norms of DPI as 'attributes' – framed through the first 2 stages of data analysis. Broadly, there exist some inherent attributes – categories of DPI's norms that can reflect both the technology features, as well as the features of societal value. These include 4 categories of norms (in no specific order): interoperability and extensibility; transparency, accountability and oversight; privacy, protection and non-discrimination; and inclusion and non-discrimination. Another set of norms operationalise the stated norms, situating them in the context of a state's capacity to implement and scale DPI-based projects for public service delivery. Capacity and coordination (represented as a foundational norm at the bottom of the diagram) signify that DPI's technology and societal value features should be grounded in an institutional capacity, and its ability to coordinate for DPI's adoption with other capacities. A

similar attribute on the top of the diagram signifies that DPI is meant to grow in scale, through its adoption by more actors that use it for public service delivery. Finally, what is encompassed within the frame of DPI is expected to be designed and used for foundational societal functions, namely three: digital authentication, digital transactions and data exchange.

Table 6 elaborates on each of these norms, describing how mould DPI, and summarising subsumed features that may have been identified in the first 2 stages of data analysis.

Table 6. Synthesis of attributes of digital public infrastructure

Category	Attribute
Functions	**Foundational societal functions** Designed to serve foundational functions for society, DPI is designed towards certain commonly understood functions of a digital society. This includes three functions in particular 1) digital authentication, 2) digital transactions and 3) data exchange. These societal functions are understood to be achieved through three interconnected systems respectively – digital identity, digital payment and data exchange systems. The fundamental functions of DPI may be leveraged to generate economic value for its adopters and implementers, which speaks to the realised potential of digital economies.
Technology	**Interoperability and extensibility** Interoperability refers to the ability of digital systems and components to communicate with each other, reflecting the 'infrastructure' nature of the technology. Extensibility refers to the ability of the technology to be foundational and bare-bones, such that it can be stretched to build its functionality as needed. It reflects the relevance of the technology to a diverse set of public and private actors using it as infrastructure to serve societal outcomes. DPI can also favour modularity, reflecting its composition of a set of building blocks that can be put together or broken apart as necessary. It can also be federated and decentralised, to allow an amalgamated set of services to serve one function. Technology with both open as well as closed (or proprietary) source code can be interoperable and extensible. However, the norm of interoperability favours open standards so as to facilitate higher adoption among more actors in a consensus-driven way.
Public-interest values (in no specific order)	**Transparency, accountability and oversight** Transparency reflects the quality of DPI being open and accessible regarding its processes and outputs throughout the design and adoption process. Accountability and oversight reflect the role of system operators and governors in ensuring that the digital technology, now essential to the functions of society, can be trusted by its users and by society at large. It implies accountable design through technology's design features, as well as external accountability as ensured through oversight by legal actors in society.
	Privacy, safety and security Given the inherent access that DPI has to personal information and data, protecting this information against threats to privacy, safety and security of individuals is a necessary norm for DPI to be trusted by its users.
	Non-discrimination and inclusion DPI can exacerbate existing issues around individual access to basic services, curtailing human rights. For DPI to be inclusively designed, it needs to not only accommodate peripheral access, but keep inclusive design at the centre of its philosophy.

Category	Attribute
Adoption context	**Capacity and coordination** Reflects the institutional arrangement within which the implementation of DPI is housed. For states, this refers to the novel and existing capacity that needs to be developed to respond to the DPI mandate. This capacity could house the DPI itself or be tasked with coordinating with non-state actors to implement the DPI.
	Scale of adoption The adoption of DPI by multiple agencies for public service delivery is an intrinsic DPI norm because it reflects the success of its 'infrastructure' potential. This attribute also hints at the interoperability, reflecting whether agencies (state or non-state) other than the one where the DPI is housed, can communicate with this piece of infrastructure.

4.3. Synthesis of indicators to measure DPI

To respond to the research question, "How can the norms of DPI be measured in real world deployments?", the subsequent stages of data analysis became increasingly deductive. This allowed for a degree of specificity to be articulated through the metrics and indicators.

Accordingly, the initial synthesis of DPI attributes was adopted at the inception of this phase (stage 3 of data analysis in table 3). This meant that indicators to measure DPI sought to measure the foundational functions of DPI and their systems – digital identity, digital payment and data exchange (hereafter, 'components of DPI') wherein national-level deployments of these systems were treated as the unit of analysis. Further, measurement of real world deployments of DPI focused on assessing the technology and societal-value attributes of these systems (see table 6).

An initial list of indicators was identified for each attribute of DPI, further customised to how it may be observed across DPI's components. The initial stage of this investigation was inductive (stage 3 of data analysis, see table 3). Using desk-based sources (see appendix 2), we sought the following types of indicators for each attribute and DPI component:

- *Policies and processes* that indicate the presence of DPI-specific state mandates
- *Facilities and infrastructure* that allow this mandate to be operationalised
- *Risk-mitigation and proactive measures* that uphold the attributes of DPI as systemic features of a deployment

This initial set of indicators was treated to a validation process through an expert review (stage 4 of data analysis, see table 3). Experts, through independent interviews as well as panel consultations, offered feedback to address gaps in desk research. They also used some grounding conditions to facilitate greater reliability and validity of the indicators of them involved. These conditions included:

- **Outcome orientation:** ensuring that the language of the indicator adopted an outcome orientation, not specifying the channel or method of achieving a certain metric, but focusing on the outcome that a suggested intervention should try to achieve.
- **Contextual relevance:** ensuring that the language of the indicator had global relevance in terms of the terminology and context of its use.

These conditions were considered crucial to shape how the measurement framework (grouped attributes and indicators) was absorbed by potential users – government stakeholders interested in self-assessments in their DPI journeys, and facilitators leveraging this as a tool to develop a DPI roadmap. Tables 7–9 provide the validated list of indicators grouped by the attribute they seek to measure.

Table 7. Indicators to measure digital identity systems as DPI

Attribute	#	Indicator
Interoperable and extensible	1.1	Individuals can authenticate themselves or their documents digitally
	1.2	Policy preference for a government-wide digital and interoperable ID system exists
	1.3	Vision and strategy of the interoperability of the ID system as DPI conveyed transparently
	1.4	Documentation for services to use ID system architecture is publicly disclosed
	1.5	Procurement guidelines for technical vendors specify interoperability through data, standards, APIs
	1.6	Technical standards and specifications of the ID system are compliant with international standards
Transparency, accountability and oversight	2.1	The ID serves as a legal proof of an individual's identity
	2.2	Institutional governance structure and its accountability are established
	2.3	ID authority is subject to general oversight of the courts
	2.4	Accountability of the ID executors to the ID authority is established
	2.5	Legally-binding redressal framework for ID-related malpractice is established
	2.6	Procedural rules for collection, storage and sharing of personal data related to ID system are established
	2.7	Government exceptions for using ID system and its data for national security, public order or other government interests are codified in law
	2.8	Credentials issued by the DID are treated as legal proof of the elements recorded by the ID
	2.9	Accountability of institutions recording personal data and their responsibility for digitalisation are established
	2.1	ID system and its operations are under the purview of relevant Freedom of Information Laws, towards addressing corruption
	2.11	ID system is informed by a multi-stakeholder group of representatives (especially from civil society, domain experts)
	2.12	ID authority performance and ID system governance is regularly reviewed and reported

Attribute	#	Indicator
Privacy, safety and security	3.1	Personal data linked to the ID is under the purview of the DPA and protected by law
	3.2	Procedural rules for the ID (enrolment, data processing, issuing credentials, etc.) are established
	3.3	There exists a process to notify individuals and general public about personal data related to ID system leaks or threats
	3.4	ID-related personal data collection, processing and sharing is based on individual consent
	3.5	Data protection authority regulates ID data collected and shared by the ID Authority and executors
	3.6	Data and system security standards are publicly disclosed
	3.7	ID system data and cyber resilience are regularly reviewed and strengthened
Non-discrimination and inclusion	4.1	Processes to access, review, edit and delete one's ID data are transparent
	4.2	Enrolment in DID is possible without discrimination
	4.3	DID is not the only legal document to serve as a credential for accessing basic human rights
	4.4	Cost of enrolling for the DID is affordable
	4.5	DID is designed with inclusive access features
Capacity and coordination	5.1	Processes to leverage the ID system across all levels of government are established
	5.2	Budget for management of identification is dedicated, reliable and sufficient.
	5.3	Strategy for skills training and retention is established
	5.4	DID use across government is facilitated through a coordination body
Scale of adoption	6.1	Public entities (that are not the same as the architect of the ID layer) use the ID infrastructure
	6.2	ID infrastructure is used across more than 1 sector
	6.3	Private entities use the ID infrastructure
	6.4	Civil society actors use the ID infrastructure
Glossary *DID Digital identity* *KYC Know your customer*		

Table 8. Indicators to measure digital payment systems as DPI

Attribute	#	Indicator
Interoperable and extensible	1.1	Payment system policy prefers interoperability between PSPs
	1.2	Payment system facilitates cross-domain and/or domain-specific interoperability
	1.3	Payment system has the infrastructure to facilitate (near) real-time settlement of transactions between users
	1.4	Documentation for PSPs to use RTPS architecture is publicly disclosed
	1.5	Technical standards/ specifications are compliant with international standards/ specifications

Attribute	#	Indicator
Transparency, accountability and oversight	2.1	RTPS is governed by a central bank/ financial regulator
	2.2	RTPS is transparent about the rules and conditions of participation
	2.3	Non bank RTPS services are subject to payment system rules
	2.4	Payment system operator performance is regularly reviewed and reported on
	2.5	Payment system design is informed by a multi-stakeholder group of representatives
Privacy, safety and security	3.1	Procedural rules for the RTPS's data handling are established
	3.2	Fraudulent transactions on the RTPS are proactively prevented and managed
	3.3	RTPS is subject to relevant security compliance and consumer protection laws
	3.4	There exists a process to notify individuals and general public about personal data related to the RTPS data leaks or threats
	3.5	Personal data linked to RTPS is protected by law
	3.6	RTPS uses unique aliases to encrypt personal information
	3.7	Merchants accepting retail payments are subject to security and fraud prevention compliance measures
	3.8	There exist laws and institutions that individuals can seek protection under if their rights are infringed or they are discriminated against through the payment system
	3.9	Data and system security standards are publicly disclosed
Non-discrimination and inclusion	4.1	RTPS enables key transaction types for financial inclusion: P2P, G2P payments
	4.2	Transactions are enabled through multiple access channels and non-digital means
	4.3	Transaction fee for retail users is low/none
Capacity and coordination	5.1	Budget for management of payment system is dedicated, reliable, sufficient
	5.2	Strategy for skills training and retention (improving the interoperability and efficiency of the payment system) is established
Scale of adoption	6.1	Public entities (that are not the same as the architect of the payment system) use the payment system for G2P/P2G transactions
	6.2	Private entities use the payment infrastructure to accept retail payments (P2M)
	6.3	Private entities use the payment infrastructure (B2B)

Glossary
AML Anti money laundering
API Application programming interface
ATM Automater teller machine
B2B Business-to-business
CB Central bank
DNS Deferred net settlement
DPA Data protection authority
G2P Government-to-person
NPS/A National payment system Policy/Act
P2G Person-to-government
P2M Person-to-merchant
P2P Peer-to-peer
PoS Point of sale
PSP Payment service provider
QR Quick response
RT Real time
RTGS Real time gross settlement
RTPS Real time payment system

Table 9. Indicators to measure data exchange systems as DPI

Attribute	#	Indicator
Interoperable and extensible	1.1	Semantic interoperability within the DES is facilitated through either policy or technical means
	1.2	Data is shared in (near) real-time through the DES
	1.3	Technology architecture of the DES is scalable
	1.4	Data exchange has a federation capability
Transparency, accountability and oversight	2.1	A public-interest entity governs the development and operations of the DES
	2.2	Use of the DES is subject to transparent enrollment and participation conditions
	2.3	Data exchange instances within the DES can be monitored in public-interest
		Data exchange governance is regularly reviewed and reported on
	2.5	Data exchange governance is informed by a multi-stakeholder group of representatives (especially from civil society, domain experts)
Privacy, safety and security	3.1	Procedural rules for the DES (access restrictions, protections, etc.) are established
	3.2	Personal data on the exchange is protected by law
	3.3	Data and system security standards are publicly disclosed
	3.4	Data exchange is regularly reviewed for data protection and cyber resilience
Capacity and coordination	4.1	Data exchange across government is implemented by a coordination unit
	4.2	Strategy for skills training and retention is established
	4.3	Budget for management of the data exchange is dedicated, reliable, sufficient
Scale of adoption	5.1	Public entities (other than the operator of the DES) leverage the data exchange
	5.2	Data exchange is cross-sectoral
	5.3	Private entities leverage the data exchange
	5.4	Civil society entities leverage the data exchange
Glossary *DES Data exchange system*		

5. Discussion and conclusion

This research paper aims to conceptualise and measure digital public infrastructure – a term that is gaining popularity in the fields development and digital government but has witnessed little investigation that is robust and empirical in a way that harmonises existing knowledge on the topic. Despite a steady rise in its co-option by a diverse set of actors, there is a missing consensus on its definition – adversely affecting how states adopt and implement DPI to pursue their respective growth and development goals. In this context, this research paper makes several contributions.

In **addressing these two research questions, regarding the qualities of digital public infrastructure and its measurement, a qualitative-inductive approach to research is undertaken**. This methodology relied on content analysis of data collected through grey literature in the field, as well as research interviews with functional and subject matter experts. The research analysis, conducted in four iterative stages, contributed a framework for conceptualising the term 'digital public infrastructure'. In addition, it contributed a measurement framework for foundational components of DPI– identified to be the digital identity system, digital payment system and data exchange system of a country's digital infrastructure. This measurement framework not only provided indicators to measure DPI but translated a previously theoretical framework into one that can be subject to real world assessment.

The contribution of foremost value in this paper is the conceptualisation of DPI offered through its analysis, based on a set of 'attributes'. An **attributes-based definition of DPI regards DPI as a digital system that is meant to be leveraged by diverse actors (both state and non-state) to pursue foundational societal functions like digital authentication, digital transactions and the exchange of information**. This insight is specifically framed in the context of participating in a digital society, rather than unsurping more Inherently, digital systems would be regarded as DPI if they are: interoperable and extensible; facilitate transparency, accountability and are subject to oversight; value privacy and safety; and promote inclusion. As such, the paper identifies six attributes, identifying an organic set of groups related to technology, societal value and the adoption context of DPI. It is worth clarifying that these attributes were not identified or presented in any order of importance. Instead, the paper favoured filtering out those norms that did not find as much consensus as the rest, across literature and expert interviews.

The measurement framework offered by this paper is another crucial contribution, guiding DPI adoption and development across a variety of stakeholders – governments, technical builders, civil society organisations, and private sector partners. In providing **a set of indicators to measure a given attribute of DPI, this paper offers a lens to discern digital systems as DPI or not, based on the degree to which they fulfil these indicators**. The results of the paper are thus meaningful to the subsequent development of the field, both in research and in practice, given that the lack of consensus on the term hinders its potential adoption and benefits.

This investigation **evidences a departure from digital transformation as typically discussed in practice**. With DPI, there emerges an emphasis on the foundational value of specific DPI components in creating social value by its interoperable nature – not a norm that

is common to all digital transformation efforts. In this emphasis, DPI also managed to **prioritise certain functions of a state's digital infrastructure in relation to the functions it plays, summarised as (1) authentication, facilitated by digital identity systems (2) transactions, facilitated by digital payment systems and (3) exchange of information, facilitated by data exchange systems**. Simultaneously, it shifts the discussion on DPI to move from a techno-centric one to one that is closely related to public-interest values. The measurement framework based on a set of common attributes quickly highlights that DPI adoption requires its own set of institutional capacities and policy processes that are unique to DPI specifically, and not all digital transformation state projects.

Critically, the framework offers a template that allows meaningful investigation of the state of DPI in the world, in a way that speaks to real world evidence for its measurement. It also streamlines how practitioners, designers and users of DPI can articulate successes and challenges in the field, not only making apparent what a country looking to build DPI needs to consider but also being able to learn from other contexts that may have overcome similar challenges.

It's worth noting that this research also lays bare the premature state of literature on the topic of digital public infrastructure. This gap has directly translated to some attributes and indicators being abstract. In the absence of clear documentation on how a certain attribute can be fulfilled through a set of action-oriented outcomes, the attribute itself remains aspirational.

5.1. Limitations

Despite our best efforts to make this research robust and comprehensive, the investigation remained a product of our resource constraints. This has required us to adapt the rigour of our methodology as well as our findings.

The most notable limitation may be reflected in a sampling bias. Given that the content scanned through grey literature and research interviews reflected the knowledge and experts that were known, and accessible to us, the findings reflected those of a highly-conforming group of experts. Our ability to address this bias is further challenged by the scant literature available on the subject. At a later stage, we would like to review this sampling by scanning for counter-evidence against certain assumptions made by our investigation.

A second limitation lies in the coding of the attributes and indicators of DPI, where there is less transparency about the dismissal of some attributes or indicators. While this reflects our limited research capacity, the dismissal of some indicators may be misleading to governments using this framework to self-reflect on the state of their evidence for building DPI. To address this to an extent, we have cautiously framed the indicators as outcome indicators, to not impose specific methods on achieving some outcomes.

Further, our ability to be exhaustive about measuring DPI reflected the state of evidence on existing DPI deployments across the globe. Since a consolidated view on real world deployments of DPI has been missing, we have simultaneously sought to address this gap by building the

DPI Map (dpimap.org). Given that this picture of the state of DPI is still incomplete, and has less information to report on under-resourced countries, the input of these countries may have been organically discounted in framing and benchmarking the indicators.

5.2. Further research questions

We believe that DPI is an emerging concept. While this paper progresses the discussion on the concept of DPI, its dimensions and its impact, it can only serve as a formative framework in response to this agenda. More research will be necessary to investigate how DPI as a concept measures up against actualised forms of this infrastructure. Further, there may be merit in diving into differences among countries developing DPI, investigating if there are regional, component-level, or outcome-level variability in how DPI evolves.

Further research is necessary to investigate how the conceptual framework provided by this paper can be made useful for DPI's implementers and users. Specifically, the exploratory conceptual framework proposed by the paper will organically lead to questions around weighing one dimension of DPI against another. These queries can be addressed by potentially analysing the state of real world deployments of DPI and how countries view DPI development in accordance with their economic, social and political goals.

As with digital transformation, there is room for a correlational analysis between digital public infrastructure and its relation with factors like state capacity, public finance, role of the private sector in successfully adopting DPI. These analyses will positively contribute to a rich and complex picture of digital public infrastructure, and frame a more realistic path for many countries looking to adopt the DPI approach.

Appendix

Appendix 1: Guideline for consultations and interviews at stages 2 and 4 of data analysis

Parameter	Question
Clarity, Comprehension	▪ Does the attribute convey the value we straightforwardly ascribe to DPI?
	▪ Does the language of the attribute make it accessible to a broad audience of users?
Completeness	▪ Does the list of attributes signify a complete list of values that are of importance to framing global DPI development?
	▪ Are there any design features, or governance risks that the suggested list of attributes does not address?
	▪ Do the indicators for a specific dimension convey a complete picture of the outcome being pursued?
Evidence and justification	▪ Is there evidence for the relevance of the attribute to a country's DPI context?
	▪ Is it justifiable why a certain attribute is imposed as being relevant to a country's DPI context?
Flexibility, adaptability	▪ Can the attribute be adapted to different contexts of use?
	▪ Is the language of the attribute broad enough to include an expansive list of indicators?
	▪ Are the indicators achievable, or do they represent inaccessible benchmarks?
Relevance, applicability	▪ Does the attribute convey a relevant feature related to the technology, governance or adoption practices of DPI in a country?

Appendix 2:
List of documents consulted to frame the indicators of DPI

Documents consulted	Data analysed
Principles of digital development (UNDP, Accessed on Jan 18, 2024)	Provides 9 principles for designing digital programmes like inclusion, participation, sustainability, and openness.
Model Governance Framework for Digital Legal ID System (UNDP, Accessed on Jan 22, 2024)	Provides key considerations for a rights-based implementation of national legal IDs across 8 elements: 1) Equality and non-discrimination 2) Accountability and rule of law 3) Legal and regulatory framework 4) Capable institutions 5) Data protection and privacy 6) User value 7) Procurement and anti-corruption 8) Participation and access to information
Digital Standards (UNDP, Accessed on Jan 18, 2024)	Provides 10 design standards for digital transformation projects
ID4D practitioner's guide- Credentials and Authenticators (World Bank, 2019)	Provides insight on credentials, authenticators and its types, to ascertain governance considerations
Technical architecture of credentials, and uses of digital ID (CDPI, Accessed on March 5, 2024)	Explains what technical attributes digital IDs should have
The State of Instant and Incusive Payment Systems in Africa 2022, 2023 Reoirts SIIPS report (Africa Nenda, 2022 and 2023)	Mapping IPS + IIPS in Africa, understanding how digital payment customer behaviour is evolving, and outlining opportunities for investment and development
Technical Note – Interoperability in digital financial services (CGAP, 2021)	Key components of IPS- roles (oversight, scheme mgmt., switch operator, settlement agent)
Fast Payments- Enhancing the speed and availability of retail payments (Committee on Payments and Market Infrastructure, BIS, 2016)	1) FPS models and their implications 2) Settlement models 3) Risks around fast payments 4) Issues relevant to central banks
Future of Fast Payment Systems (World Bank, Oct 2023)	Typical evolution of FPS; overlay services on FPS; market trends and forces that drive FPS evolution
Technical Note on Payments (CDPI, Accessed on March 5, 2024)	DPI intervention in payments: 1) Interoperable QR codes 2) Interoperable authentication 3) Financial Address Mapper 4) Cash in cash out 5) Interoperable bill payments protocol
Private expert submission (Co-develop internal presentation, May 2023)	Digital payments and its infrastructure components; payment cycle; stakeholder management for interoperability in payments
Private expert submission (E-mail, Nov 2023)	Context setting on treating payment system components as DPI
Meeting the needs of end users: The three layers of cross-border payment solutions (Visa Economic Empowerment Institute, Feb 2023)	Pitch for multilateral cross-border payment systems rather than closed-loop ones (e.g. SIPA, SWIFT)
Fast payments: design and adoption (BIS, Mar 2024)	Design features of FPS system affecting adoption of FPS

Documents consulted	Data analysed
Data sharing, credentials and models (CDPI, Accessed on May 20, 2024)	Definition Data Sharing, Credentials, Models Personal Data Sharing eLockers Verifiable credentials
DPI Playbook (UNDP, 2023)	Instances of data sharing
X-Road Data Exchange Layer (NIIS, Accessed on May 20, 2024)	X-road deep dive

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