

Multidimensional Digital Inclusiveness Index: Dimensionality Reduction for Improved Applicability in Digital Agri-solutions

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ABSTRACT

This report introduces the refined Multidimensional Digital Inclusiveness Index (MDII), developed to assess and promote inclusiveness in digital innovations within agricultural systems. Developed through iterative consultation with experts and stakeholders, the MDII integrates structural and experiential dimensions of digital inclusiveness. It distinguishes between inclusion — ensuring access and usability — and inclusivity — fostering a sense of belonging and meaningful engagement among diverse underserved groups. By applying theoretical frameworks such as the Capability Approach and the Technology Acceptance Model, the MDII captures the multifaceted nature of digital inclusiveness, addressing both tangible and psychological aspects. The revised framework (Version 3.0) evaluates inclusiveness across seven core dimensions, including accessibility, stakeholder relationships, and the social impacts of digital innovations. Significant refinements have been made to reduce complexity, eliminate redundancies, and introduce actionable core and extended indicators.

Piloted across multiple regions, the MDII demonstrates adaptability and effectiveness in assessing inclusiveness within varying socio-economic and cultural contexts. The report highlights the importance of user-centric design and culturally responsive approaches to ensure digital tools are accessible, equitable, and relevant. By addressing critical challenges such as digital illiteracy, device affordability, and socio-cultural constraints, the MDII aims to empower underserved communities and foster resilience within agricultural systems.

This refined framework provides actionable insights for policymakers, innovators, and development organizations, supporting the creation of inclusive digital ecosystems that bridge the digital divide. Future steps involve expanding the MDII's application through multi-country pilots, incorporating empirical feedback to refine the framework further, and developing user-friendly tools to enable real-time evaluation and deliver impactful recommendations.

INTRODUCTION

Digital inclusion is increasingly recognized as a critical, yet complex, factor in achieving equitable growth and sustainability within today's agri-food, water, and land systems, offering significant potential if addressed with deliberate, inclusive strategies. Ensuring that marginalized groups, including women, indigenous communities, and rural youth—have equal access to digital innovations is essential for creating resilient agricultural systems. The Multidimensional Digital Inclusiveness Index (MDII) was developed to address these challenges and promote inclusiveness in digital agricultural solutions, aiming to ensure that these tools are accessible, usable, and beneficial for all stakeholders (Opola et al., 2023; Martins et al., 2023). Recent research (see Box 1) has demonstrated the positive impacts of digital inclusiveness on

Box 1. What is digital inclusiveness in agricultural developments and why is it important to assess?

Digital inclusiveness, while frequently discussed, has yet to gain a universally accepted definition in the academic field. According to FAO (Hernandez et al., 2024), inclusive digital transformation can drive social and economic development, enhance productivity, and improve food security, especially in underserved rural areas. Research shows that increasing digital inclusiveness offers multiple benefits for agricultural development. Inclusive digital platforms expand market access for smallholder farmers, improve information flow, and reduce post-harvest losses, supporting food security (Akinwale & Grobler, 2023) and provide access to agricultural machinery, particularly in areas with regional disparities (Lin et al., 2022). These platforms also improve agricultural production quality by facilitating land circulation (redistribution or transfer of land management rights to optimize usage) and upgrading infrastructure in regions with strict environmental regulations (Xiong et al., 2024). Beyond economic drivers, inclusive digital interventions offer underserved groups, the opportunity to participate equitably in sustainable food systems (Udisha & Philomina, 2024; Ndege et al., 2024). Interactive voice response (IVR) systems, for example, make agricultural knowledge accessible by delivering information in local languages to farmers who may be less comfortable with text formats (Ananda et al., 2024). These inclusive tools can boost productivity and income by incorporating user-centric design (Agunyai & Ojatorotu, 2024), accessible content for low-literacy users (Aker et al., 2016), and content localization (Alemu et al., 2024). Inclusive digital interventions also require adequate training and infrastructure support to help farmers fully leverage these resources (Agunyai & Ojatorotu, 2024). In Cambodia, integrating digital literacy initiatives within environmental sustainability efforts has shown promise, as higher digital literacy and technology access are related with better sustainable practices and lower environmental impacts

(Ly et al., 2024). However, not all information is created equal, requiring adapting digital information to be both accessible and contextually relevant (Aker et al., 2016). In the case of complex agricultural practices, such as fertilizer dosage and intercropping, more detailed instructional methods, such as digital imagery or in-person training, are required to be fully effective (Aker et al., 2016). Despite the transformative potential of inclusive digital interventions, significant gaps in digital access and inclusiveness persist in LMIC agricultural sectors (Beanstalk AgTech, 2023). These challenges are evident through limited infrastructure in rural areas, high device and data costs that restrict access for small-scale farmers, and digital tools that are often not user-friendly or adapted to the needs of marginalized groups (Beanstalk AgTech, 2023). Addressing these disparities is essential for social stability, as inclusive digital tools can help mitigate socio-environmental conflicts—such as those between farmers and herders in climate-stressed regions—through culturally responsive and linguistically inclusive design (Song et al., 2024). Furthermore, initiatives like living labs have shown that co-created, community-centered solutions can iteratively refine digital tools to meet the unique needs of rural communities, ensuring these tools are both accessible and practical (Gardezi et al., 2024; Alemu et al., 2024).

In this report, digital inclusiveness refers not only to the structural act of inclusion — providing underserved groups with equitable access to digital resources — but also to the extent to which these groups experience a sense of belonging and active participation within digital spaces. This approach distinguishes between inclusion (the provision and accessibility of digital opportunities) and inclusivity (the individual feeling of being valued and included within digital environments).

promoting equitable access to technology, enhancing market opportunities, and fostering resilience (Xiong et al., 2024).

However, achieving inclusiveness requires addressing more than just access to technology. Research suggests that inclusive digital interventions must also overcome barriers like digital illiteracy, limited connectivity, social norms and unequal power dynamics that create barriers for certain communities and individuals from fully benefiting from digital innovations (Warschauer, 2004; Steinke et al., 2024; Ndege et al., 2024). To address these issues, the MDII framework goes beyond merely evaluating access; it includes dimensions that assesses social impacts, governance, and ethical considerations in the use of digital agricultural tools. Without intentional inclusiveness, digital solutions risk reinforcing existing inequities (Hernandez et al., 2024; Steinke et al., 2024), especially given the current lack of standardized measures for assessing

inclusiveness (Scheerder et al., 2017). Addressing these disparities necessitates tools that integrate responsible digital design principles throughout every stage of development (Faik et al., 2024; Steinke et al., 2024; Ndege et al., 2024).

A key issue of the conceptual MDII version (version 2) was the complexity and redundancy in the original index structure, where multiple indicators measured overlapping aspects of digital inclusiveness. This resulted in an unnecessary level of complexity and challenges in data collection, particularly among underserved groups, where specific indicators proved difficult to measure consistently across diverse contexts. We addressed these concerns and refined the MDII to enhance its effectiveness. This report outlines the revised MDII and presents the comprehensive methodology for assessing digital inclusiveness across multiple dimensions. The subsequent sections detail the theoretical background, framework

structure, refinement phases, and findings of the MDII, with a particular focus on evaluating the inclusiveness of digital agricultural solutions in diverse contexts.

MAPPING DIGITAL INCLUSIVENESS FOR AGRICULTURAL DEVELOPMENT

Digital tools are potentially transformative technologies in agricultural contexts, designed not only to enhance productivity but also to improve resource management and promote sustainable practices. These tools encompass a diverse range of technologies, including software applications, mobile devices, sensors, drones, satellite imagery, and data

analytics platforms, all of which contribute to more efficient and responsive agricultural systems (Daum et al., 2022; Camacho-Villa et al., 2023). As these technologies become increasingly integrated into agricultural operations, it is essential to understand the dual dynamic at play: not only how people access and use these digital tools, but also their broader impact particularly on those in communities experiencing digital gaps (see Box 2).

A Multi-Theory Lens on Experience and Inclusiveness

Understanding digital inclusiveness in agricultural systems requires integrating multiple theoretical perspectives to address both technological and social dimensions. The MDII framework draws on key dimensions informed by established

Box 2. Findings from Bangladesh study

In Bangladesh, agriculture makes a vital contribution to the national economy as well as to smallholder livelihoods. However, the sector's contribution to the GDP has been declining in recent years – from 15.35% in 2014 to 11.63% in 2021 (Chowhan et al., 2021). Also, food and income insecurity result in an increasing (seasonal and more permanent) out-migration of mostly adult men (age groups of 20-50) from farming to alternative livelihoods in the capital Dhaka and other urban centers (Al-Maruf et al., 2022).

A large exodus of adult males in an agrarian society results in what is known as a feminization of agriculture. The term implies many things, but essentially a growing presence, visibility, and involvement of women in all agricultural activities. Various studies point out that women's increasing engagement in productive agricultural work (de Brauw et al., 2021), are often not associated with positive outcomes. There are more traditional challenges related to women's lack of access to, and ownership of land, necessary assets, credit, services, markets, as well as access to and use of digital technologies. As Bangladesh transitions to digitization of all sectors, including agri-food systems – the latter in order to reenergize the sector and enable improved public-private-farmer entrepreneur interventions across food systems value chains – there are also real concerns of a digital gender and social inclusion gap.

A study conducted in 2022 included secondary data review, as well as quantitative and qualitative research in three divisions (Barisal, Kurigram, Mymensingh and the Dhaka metropolitan area) with 1,161 respondents (women and men) from 435 households, across the age groups of 19–65. While Bangladesh is reported to have a high gender gap in mobile internet usage amongst low and middle-income countries (GSMA, 2022), our data showed that the digital divide is not just about access to the internet or technology. The divide also includes disparities

in social norms and economic capacity and agency to access and use technology for personal and other purposes. One key finding was that while a high proportion of households (97.76%) in the study areas had access to, and used electricity at home, access to the internet was generally low across households (12.75%) with sharp differences across regions. Wi-fi connectivity was highest in Barisal (17.25%) nearer Dhaka, and lowest (4.9%) in Mymensingh in the hilly regions of the country. Most respondents (90.7%) reported access to a feature phone, but only 31.52% of respondents also reported ownership and use of a smart phone. 79.14% of women reported a lack of access to, and use of a smart phone. While more than 90% of the male respondents reported using a mobile phone (mostly feature phones) to access information, a similar number of female respondents reported relying on friends, neighbors, and family to access information. In our discussions, women reported that they faced social and cultural constraints in marketing agricultural products, including using available e-commerce platforms from their homes. Domestic care work responsibilities also played a key role in women being unable to find time and acquire knowledge and information about these digital services. These findings echo the GSMA 2020 study on gender inequalities in accessing digital devices/tools. Among the respondents, only 2.30% of female respondents reported some training on using internet-based applications, compared to 15.41% of males. Of this group, only 9.45% of female respondents reported that they were fully aware of and could independently use digital devices compared to 23.52% of men who reported digital expertise. Sociocultural norms and practices, lack of digital education, skills and training were some key constraints for women. A key finding was that not a single woman respondent we interviewed in these 3 districts reported independent use of digital devices for getting agriculture input or advisory related information.

theories of user acceptance and social inclusion, even if not explicitly defined (Davis et al., 1989; Venkatesh et al., 2003; Sen, 1999; Teles & Joia, 2011). Early discussions of digital inclusiveness often emphasized basic access to technology and resources, focusing on infrastructure and connectivity as primary indicators of inclusion (Warschauer, 2004; van Dijk, 2005). However, recent research suggests that inclusiveness extends beyond mere access to encompass disparities in digital skills, usage patterns, and the broader social impacts of technology adoption (van Dijk, 2005; Steinke et al., 2024; Faik et al., 2024). These broader perspectives emphasize the importance of addressing both structural and experiential factors affecting digital engagement.

To address these challenges, the MDII also incorporates social inclusion frameworks like the Capability Approach (Sen, 1999) and the Dynamic Digital Inclusion Model (2iD) (Teles & Joia, 2011). These approaches highlight the need to overcome barriers such as “device poverty” and “digital illiteracy” to ensure equitable access and effective use of digital tools. Enhancing digital literacy and addressing these barriers can significantly improve outcomes for underserved communities (Faik et al., 2024; Ali et al., 2023; Díaz Andrade & Techatassanasoontorn, 2020). To complement the effort on overcoming these barriers, technology adoption models in Information Systems, such as the Technology Acceptance Model (TAM) (Davis et al., 1989) and the Unified Theory of Acceptance and Use of Technology (Venkatesh et al., 2003), inform which psychological and social conditions are necessary for sustained user engagement. These models explore key factors like perceived usefulness, ease of use, and social influence, which shape individuals’ experience with digital tools, influencing their perception, adoption, and continued use (Davis et al., 1989; Venkatesh et al., 2003). In agricultural contexts, these models help explain the initial acceptance and sustained use of digital tools like mobile applications, sensors, and data analytics (Camacho- Villa et al., 2023). Figure 1 illustrates how these models conceptualize the progression from individual reactions to digital tools, to users’ intention to adopt, and ultimately their actual usage of these technologies (Venkatesh et al., 2003, p. 427).

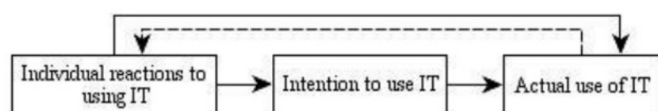


Figure 1. Basic Concept Underlying User Acceptance Models (Venkatesh et al., 2003, p. 427)

By integrating these perspectives, the MDII addresses both the technical and social dimensions of digital inclusiveness. This dual approach acknowledges that for digital tools to be inclusive, they must be accessible, usable, and beneficial to users and cause no harm to stakeholders, particularly those in vulnerable positions. Achieving inclusiveness, therefore, involves not only adopting new technologies but also ensuring

that social and contextual factors are addressed through culturally sensitive interventions (Alemu et al., 2024; Ndege et al., 2024; Song et al., 2024).

Key Pillars of Inclusiveness

The results of our literature review, beta test and expert consultations identified three central pillars for the framework of measuring inclusiveness in digital innovation: Innovation Usage, Stakeholder Relationships, and Social Consequences. To develop indicators within each of these pillars, we integrated insights from both social sciences and information systems (IS) research, focusing on key factors such as motivation, material access, digital skills, perceived ease of use, co-creation, and social influence, which play critical roles in shaping technology adoption behaviors. Broadly, digital inclusion encompasses equitable access, usage, and meaningful impact. It emphasizes overcoming barriers like digital illiteracy, device poverty, and connectivity poverty (Warschauer, 2004; Selwyn, 2004). These barriers align closely with adoption factors identified in IS/ICT models, such as digital literacy in populations with low levels of internet experience (Ali et al., 2023) and perceived usefulness (Díaz Andrade & Techatassanasoontorn, 2020). This integration creates a symbiotic relationship between adoption and inclusiveness: adoption efforts must prioritize vulnerable groups to be genuinely inclusive, while achieving inclusiveness in the adoption process leads to greater digital inclusion overall.

Structural Digital Inclusiveness Framework - Overview

As a human-centered tool designed to index digital inclusiveness in agricultural solutions, the baseline framework provides a method for underserved users, downstream beneficiaries, and domain-specific experts to score the barriers and enablers faced by underserved communities in LMIC settings when accessing and utilizing digital agricultural innovations (Opola et al., 2023). Additionally, it offers recommendations for enhancing inclusiveness. The MDII’s hierarchical structure is divided into three levels: dimensions, categories, and indicators, each serving as specific layers of evaluation (see Figure 2).

The MDII’s Dimensions of Digital Inclusiveness

The MDII framework (see Figure 3) is organized around three key pillars and seven core dimensions, each representing a key theme of digital inclusiveness: (1) Innovation Usage (which includes dimensions of Accessibility, Usage Effectiveness, and Supportive Ecosystem); (2) Stakeholder Relationships (includes dimensions of Ethical & Responsible Innovation and Co-creation & Governance); and (3) Social Consequences (include dimensions of Beneficial Impact and Risks & Harms).

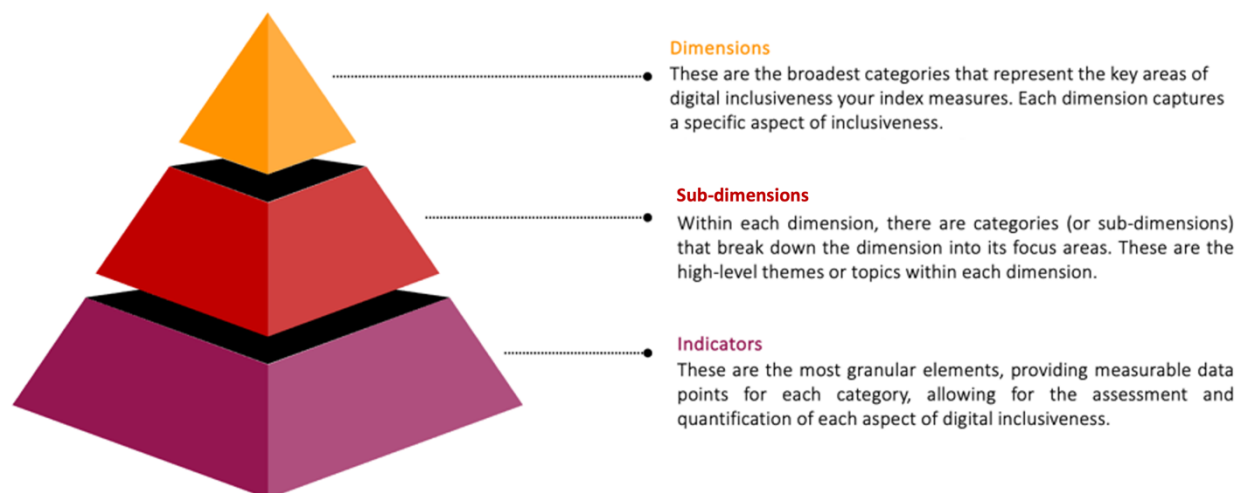


Figure 2. Breakdown of components of the MDII (Source: Authors)

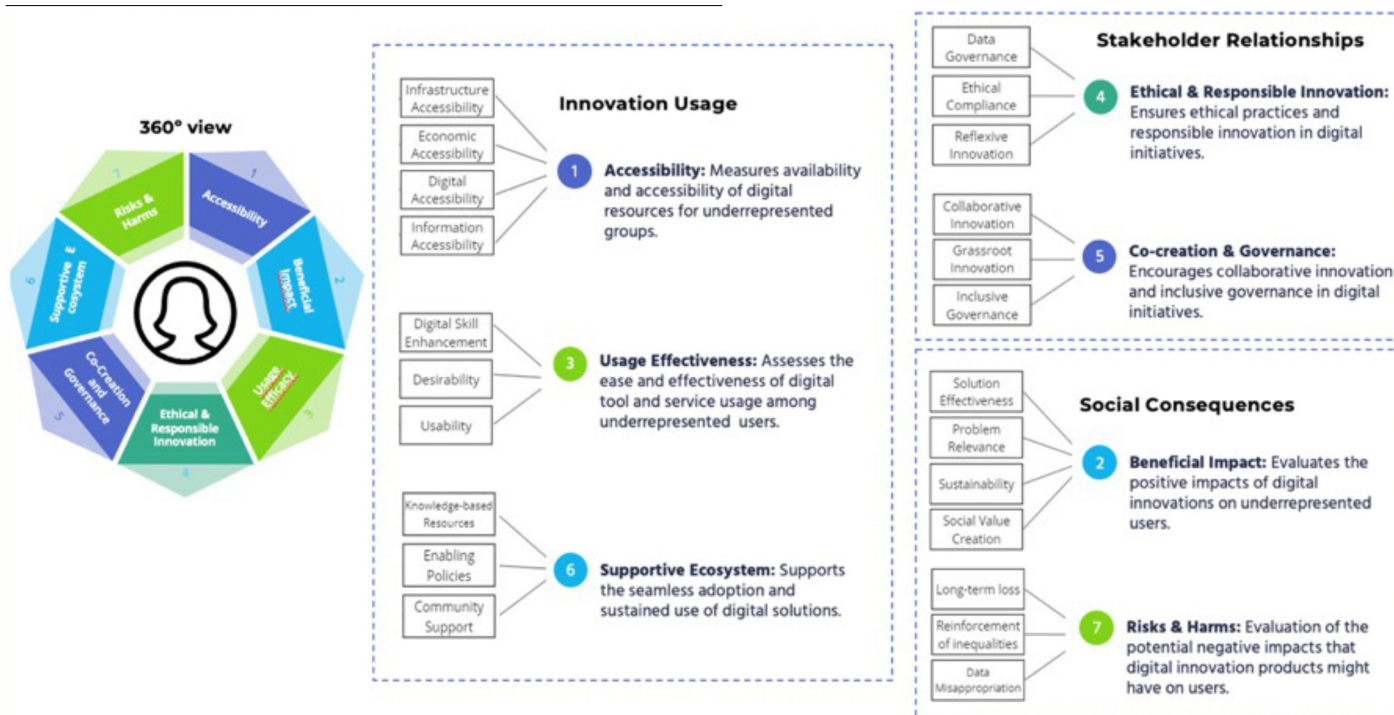


Figure 3. MDII Framework with 7 core dimensions and sub-dimensions (Source: Authors)

These dimensions guide the assessment of inclusiveness across multiple contexts. Specifically, within the Accessibility dimension, we included subdimensions such as Digital Accessibility and Infrastructure Accessibility to assess whether underserved groups have access to essential digital tools (Warschauer, 2004; Selwyn, 2004). Examples of indicators in this dimension include “Quality and Functionality of Devices” and “Affordability of Internet Access”. Indicators such as “Community Impact” and “Economic Sustainability” ensure that digital innovations foster both social and economic benefits. Within the Ethical and Responsible Innovation

dimension, we added statements about ethical considerations, including “Data Privacy” and “Bias Monitoring,” to address potential risks of inequality exacerbation (Taylor, 2017; Villarino et al., 2022), placing value on how digital tools adhere to ethical guidelines and responsible practices. Sub-dimensions like Data Governance include indicators such as “Data Privacy” and “Bias Monitoring,” reflecting the need for ethical considerations as discussed by Taylor (2017) and Villarino et al. (2022). For the co-creation and governance dimension, we focused on the collaborative aspects of digital inclusiveness. In line with Kleine (2013) and Sen (1999),

which highlight the importance of inclusive governance in achieving meaningful social and economic outcomes, we included indicators in sub-dimensions such as Grassroots Innovation Collaboration.

Specifically, we added statements about “Local Knowledge Utilization” and “Inclusive Decision-Making,” which measure the extent to which local insights are integrated into digital innovation strategies. Similarly, in the usage efficacy domain, we included indicators to measure how effectively digital tools are utilized by their intended users. Sub-dimensions like Digital Skill Enhancement and Desirability encompass indicators such as “Tool Proficiency” and “Appeal and Engagement,” capturing factors identified by Venkatesh et al. (2003) as key to sustaining user engagement through perceived usefulness and ease of use. To ensure that the MDII also assesses the broader context that supports these tools, we created the supportive ecosystem dimension. Here, we added sub-dimensions like Knowledge-Based Resources, incorporating indicators such as “Training Availability” and “Community Support,” reflecting the need for supportive systems to enhance digital inclusiveness (Warschauer, 2004).

Finally, recognizing the potential challenges associated with digital innovations, we included indicators within the risks and harms dimension. Sub-dimensions like Reinforcement of Inequalities and Data Misappropriation include indicators such as “Algorithmic Fairness” and “Unauthorized Data Commercialization,” which address concerns around potential biases and the misuse of user data (Taylor, 2017; Villarino et al., 2022).

Contextual Considerations for Measuring

Consistently with previous work (Opola et al., 2023; Martins et al., 2023), we developed statements to assess the manifestations of each indicator, capturing individual perceptions and experiences of inclusion regarding digital agricultural tools. These perceptions can vary widely across different contexts and cultures. This is critical, as there is no single, official definition of inclusion, and understanding personal perspectives can guide more effective inclusion strategies (Scheerder et al., 2017). Additionally, individual experiences to using digital tools are central to the process of technology adoption, as they capture each user’s unique perceptions of the benefits and challenges of the technology (Faik et al., 2024; Venkatesh et al., 2003). In this context, the MDII’s approach emphasizes individual experiences of the inclusiveness of digital agricultural solutions. Data about personal experiences is critical for evaluating inclusion, as it captures personal experiences and perceptions that are essential for understanding its multifaceted nature (Ndege et al., 2024). Such insights can inform policy and practice, ensuring that interventions are more responsive to the diverse needs of communities. This can significantly enhance community indicators by reflecting lived experiences, providing a more comprehensive view of social progress and

well-being. This approach ensures that indicators are relevant and accountable to community members’ realities, promoting inclusiveness and social equity (Faik et al., 2024; Warschauer, 2004; Ndege et al., 2024).

Individual Experience and Objective Evidence

Distinct measurement approaches were applied to capturing both the objective presence of digital resources and individual experiences of inclusiveness. This dual approach aligns with social inclusion theories that emphasize the importance of tangible evidence and individual experience (Sen, 1999; Warschauer, 2004), which are crucial for the sustainable adoption of digital tools in underrepresented communities (Faik et al., 2024; Kleine, 2013). Objective presence refers to the actual existence of digital resources, programs, and initiatives, which are verifiable and measurable (van Dijk, 2005; Warschauer, 2004). Categorical measures were applied to metadata, such as connectivity needs, device type or applied technologies. In contrast, perceptual indicators used a 5-point Likert scale to capture nuanced perceptions, reflecting engagement and personal relevance. Respondents rated how well the digital tool meet each statement, ranging from “Not at all” to “Fully Agree”, with an additional “Don’t know” option for items where sufficient information was lacking. On other instances, the Likert scale also allowed to evaluate objective presence and individual experience. For example, indicators such as “Subsidy Availability,” use statements such as “There are financial support programs available to help cover the cost of acquiring necessary digital devices and/or internet access.”, capturing not only the existence of support but also users’ awareness.

Types of Survey Statements

Furthermore, while the combination of individual perceptions and objective evidence guides the creation of evaluative statements, it is not sufficient to comprehensively assess digital inclusiveness. Due to the multifaceted nature of this phenomenon, we also focused on the intent and type of information we sought to measure. Therefore, we aligned our work with theoretical perspectives that distinguish between descriptive and injunctive norms (Lapinski & Rimal, 2005) and emphasize expanding users’ capabilities to achieve meaningful outcomes (Sen, 1999). To capture this range, we categorized statements into several groups: (1) descriptive statements confirm the presence or availability of a resource (e.g., “Mobile network coverage is sufficient to use this tool.”); (2) perceptual statements that target users’ subjective experiences (e.g., “I think it is important and valuable for me to use this tool.”); (3) injunctive or normative statements that measure adherence to norms or expectations (e.g., “I’m made aware of and consent to the information and data being collected from me.”); and (4) outcome-oriented statements assess whether the digital tools enable users to achieve their personal and community-based goals (e.g., “The training resources enable me to confidently use this tool”).

Adapting Indicators for Diversity in Evaluation

In the architecture of our assessment, we realized that the total of indicators possibly would not be able to be answered by all our evaluation groups (especially by end-users, downstream beneficiaries from underserved communities). Consequently, to accommodate the diversity of evaluators, we had to adjust the evaluation to be inclusive of all evaluators regardless of their level, while minimizing discomfort. We decided to split the indicators (and their statements) in two subsets: Core and Extended. The Core Subset consists of universally applicable statements designed for both domain-specific experts and underserved groups, capturing essential aspects of digital inclusiveness. The Extended Subset, on the other hand, targets domain-specific experts, focusing on specialized topics requiring deeper knowledge or technical expertise. Evaluators with expertise in fields like IT, Data, Economics, or Gender Equality and Social Inclusion (GESI) address these more specialized questions to provide a comprehensive assessment.

Version 3.0

The MDII started with a theoretical version (Opola et al., 2023), has evolved into a conceptual version that expanded on the previous version (Martins et al., 2023) through literature review and expert consultation. Our goal with all versions of the MDII has been guided with a strong focus on ensuring that the tool would ultimately serve the needs of underserved communities. While direct engagement with these groups was not feasible in the initial stages, the development process involved extensive consultations with domain experts from IWMI, other CGIAR-affiliated institutions, and digital innovation stakeholders from both public and private sectors in partner countries. Throughout the development process, emphasis was placed on understanding the barriers and challenges faced by underserved groups in accessing an adopting digital tools and innovations. Accounting for the range of development stages and possible digital solutions in agricultural development, we designed the Index to be adaptable and inclusive to different tools, once pilot testing began.

The current version of the MDII, Version 3 (see Figure 4), reflects significant refinements compared to its previous version. This version addresses key challenges from the previous iteration, focusing on improving clarity, reducing redundancy, and ensuring that all indicators provide distinct, actionable insights.

This new version is currently being piloted within several organizations including Farmerline, a social enterprise in Ghana that requested an MDII inclusiveness assessment. Farmerline specializes in making agricultural services such as irrigation technologies, market information, and credit facilities accessible and useful to smallholder farmers in rural Ghana. Box 3 highlights some key findings from this pilot test.

The Design Science Research Methodology (DSRM) was adopted as our processual framework (Peppers et al., 2007) to refine the Index components for a reduced version. The DSRM is widely used in information systems to systematically develop and evaluate innovative solutions (Hevner et al., 2004). In our case, we were able to identify and address limitations in the previous version by focusing exclusively on elements that were robustly measured and that exceeded defined cut-off points, which led to a 30% decrease from our previous version (V2). The reduction in the number of indicators has not compromised the depth of the analysis.

Our results pointed to the need to keep the MDII original seven dimensions. Additionally, we maintained equal weighting across all dimensions and indicators, valuing the simplicity, and non-subjectivity it offers. After conducting the piloting phase, we intend to analyze the collected data to explore potential weighting refinements.

METHODOLOGY

Initial Assumptions

During the development of the original conceptual version of the MDII (see Figure 5), we conducted comprehensive deliberations on the index's scope and applicability. These discussions involved consultations with CGIAR experts across domains, including specialists from the Women's Empowerment in Agriculture Index (WEAI) and Human-Centered Design.

Further enriching our understanding and approach, a National Consultation Workshop was convened in New Delhi, India (see Box 4). This workshop provided a platform for incorporating valuable feedback from a broad spectrum of relevant stakeholders from the public and private sectors, enabling the integration of diverse perspectives into the refinement process.

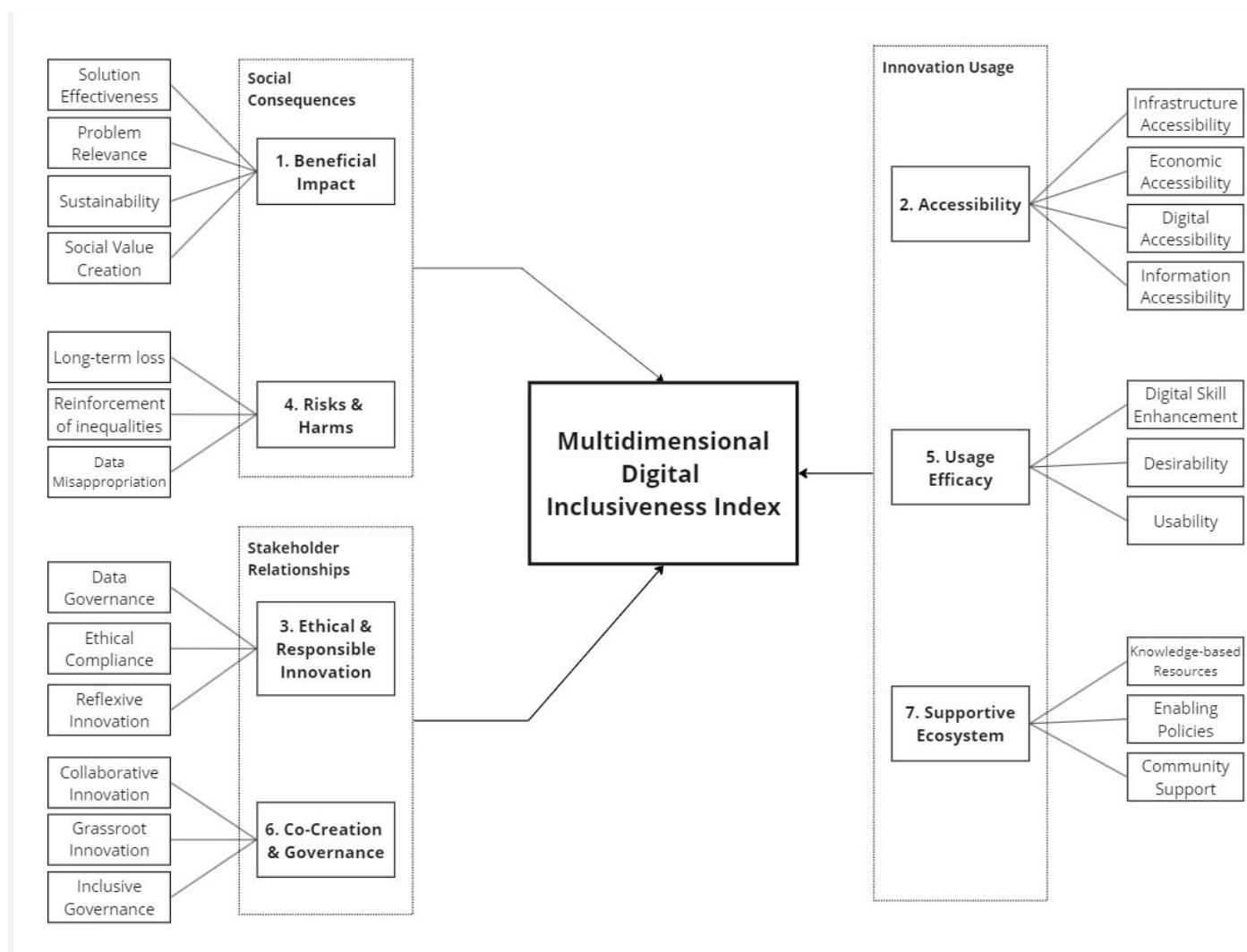


Figure 4. MDII Version 3.0 (Source: Authors)

Box 3. Findings from the first implementation in Ghana

Since 2013, Farmerline, a social enterprise in Ghana, has been using digital tools such as a data platform and call center to link smallholder farmers in Northern Ghana to quality and affordable agricultural products and services. The company requested an MDII review of its business-to-farmer services, with the aim of understanding their social impact, and enhancing the reach and benefit of their services. Based on the MDII assessment, the innovator was found to perform exceptionally well in the usability dimension of inclusiveness. The company leverages on pre-existing technologies among rural communities, such as basic phone calls and IVR services, and presents its services in over 10 local languages, making its services highly usable. It also compliments its digital services with offline options such as the use of village-based agents to

enhance accessibility. The biggest area of concern, according to the MDII review, is in the co-creation and governance dimension. Though the firm developed its digital tools with a human-centered design approach, there are no deliberate efforts to continuously include smallholder farmers, and farmer associations in decision-making and tool iterations. This could for instance be through 'Farmerline innovation committees' that is composed of representatives from Farmerline, smallholder farmers as well as other stakeholders such as government extension departments. Once the MDII assessment is completed, a half-day feedback session will be arranged with Farmerline to discuss findings and actionable strategies to enhance the inclusivity of their services.

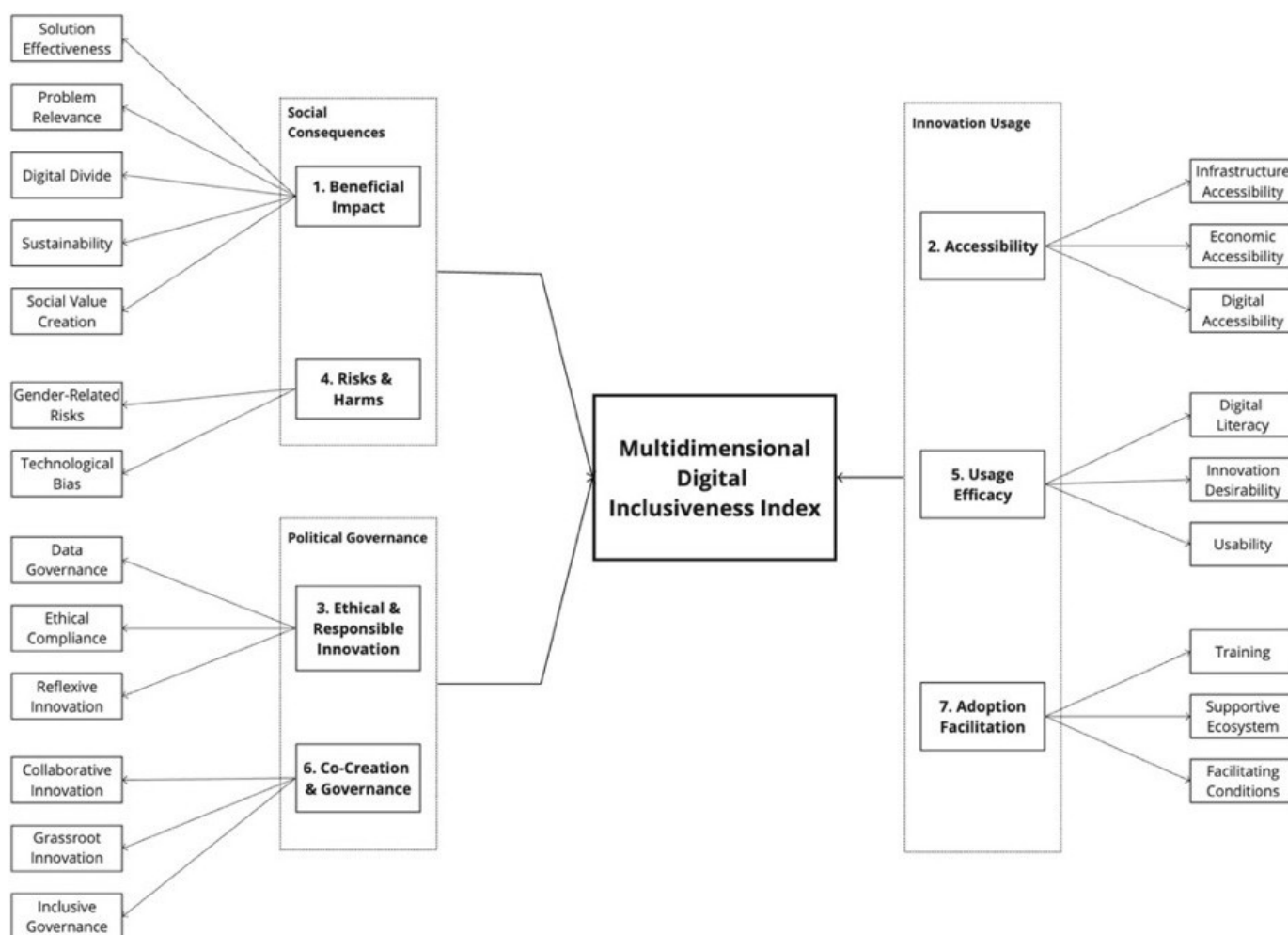


Figure 5. MDII Version 2 (Source: Authors)

Box 4: Summary of national stakeholder consultation workshop conducted in India

The National Stakeholder Consultation Workshop on Digital Innovation and Inclusion in New Delhi highlighted the need for inclusive digital practices in agriculture. Held on December 4, 2023, by CGIAR's Digital Innovation Initiative with IMWI, IRRI, and CRISP, the workshop convened 38 stakeholders from NGOs, research institutions, and policy bodies to foster collaboration and gather feedback for refining the MDII. Presentations outlined the MDII's purpose in addressing the digital divide and assessing digital inclusiveness. Participants reviewed the MDII's indicators, focusing on accessibility and impact, and identified key areas for improvement.

Major findings included the need to adapt the MDII to local contexts, add metrics for economic sustainability, and enhance usability for varied digital literacy levels in rural areas. Discussions with stakeholders emphasized the importance of gender-sensitive content, multilingual support, and the importance of focusing on practical issues like connectivity and device access during tool implementation. They also stressed data integration and quality assurance as essential for informed decision-making.

The refinement process was guided by several foundational assumptions:

- **Assumption 1, Inclusiveness as a Priority:** It was assumed that digital inclusiveness, particularly for underserved communities, is not solely dependent on access to technology but also on the adaptability of digital tools to meet specific social, economic, and cultural needs (Warschauer, 2004).
- **Assumption 2, Data Availability and Feasibility:** We assumed some indicators may be theoretically ideal but practically challenging to measure, considering that barriers to data collection are often more pronounced when engaging with underserved communities (Heeks, 2010). The Index was designed based on the assumption that data collection in underserved contexts would present significant challenges. Therefore, refinement should consider that the MDII would remain functional even with limited data inputs.
- **Assumption 3, Redundancy and Uniqueness:** We assumed that minimizing redundancy was essential to maintain the MDII's focus, as overlapping indicators might not effectively capture the nuanced aspects of their digital inclusiveness experiences.
- **Assumption 4, Representativeness of Underserved Groups:** We assumed that the MDII should accurately reflect the experiences of underserved users to drive effective policy and intervention.

Refinement Methodology

The DSRM's structured approach (see Figure 6) to creating and evaluating artifacts is particularly effective for refining indices, as it enables the development of comprehensive, user-centric frameworks. Its iterative process allows for continuous improvement, ensuring the index remains relevant and effective in practice (Peffer et al., 2007), especially in contexts where the index must evolve with changing requirements and technological advancements (Haryanti et al., 2023). This includes defining the problem, the objectives of a solution, developing the solution, demonstrating the solution in a real-world scenario, evaluating outcomes and

communicating them (Haryanti et al., 2023; Venable et al., 2017). Additionally, on the design & development stage, we have paired several methods (both quantitative and qualitative) to strengthen the robustness of the refinement.

DSRM Applied to MDII Refinement

Stage 1: Problem(s) Identification

The initiation of the MDII refinement was marked by an in-depth identification and analysis of existing challenges within the MDII framework. For this step we followed Hevner's et al. (2004) guidelines which emphasize that the demonstration of the utility, quality and efficacy of an artifact must be done with rigorous demonstration of well-executed evaluation methods. A multidisciplinary team of experts in Digital Inclusion, Human-Centered Design, Gender Equality, and Data Science conducted a collaborative review of the index, identifying three key issues. First, the analysis revealed redundancy among indicators, resulting in unnecessary complexity and overlapping data. Secondly, expert feedback and insights from consultation workshops indicated that some sub-dimensions lacked clarity and alignment with the evolving digital inclusion landscape. Finally, practical challenges in data collection were noted, with certain indicators proving difficult to measure consistently, particularly within underserved communities in LMIC contexts. Our findings reinforced the need for a refined, context-sensitive index to enhance both theoretical robustness and practical applicability.

Stage 2: Objectives Definition

Based on our previous findings, we defined the primary objective as enhancing the index's clarity, relevance, and usability to support deeper knowledge and better understanding, ultimately enabling the development and adoption of technology-based solutions in food, land, and water systems. This focus aims to ensure that the MDII not only assesses digital inclusiveness but also drives impact by providing actionable recommendations for iterative improvement. Such an approach aligns with design science principles in Information Systems (Hevner et al., 2004; Venkatesh & Davis, 2000; Peffer et al., 2007). To achieve this

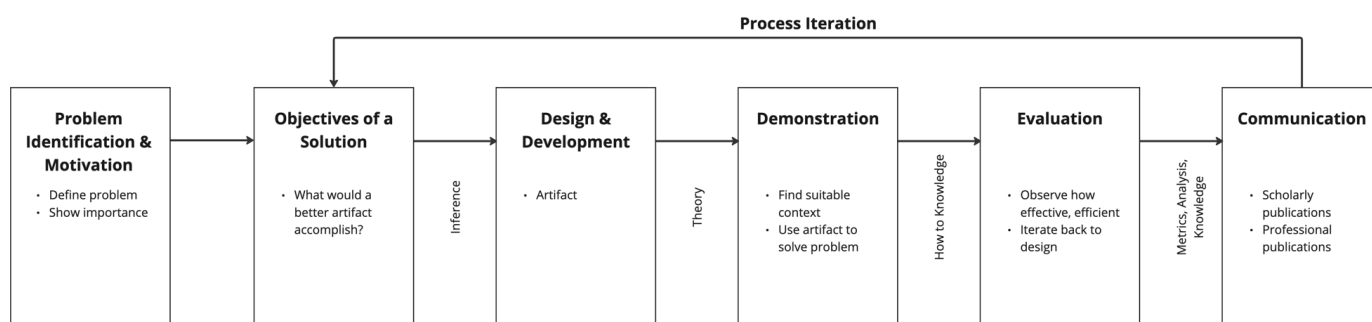


Figure 6. DSRM Process Model (Source: Peffer et al., 2007)

primary objective, we set a derived goal of identifying and prioritizing the most impactful indicators while maintaining the comprehensiveness and integrity of the index. The emphasis was on selecting indicators that deliver meaningful insights without introducing unnecessary complexity.

Stage 3: Design and Development

Building on the objectives defined in Phase 2, we adopted the Analytic Hierarchy Process (AHP) as the primary methodology in this stage. AHP provided a structured framework to guide the prioritization and selection of indicators based on their relative importance (Saaty & Vargas, 2012). This approach systematically refined the MDII, addressing our secondary goal of identifying and prioritizing impactful indicators while upholding clarity, relevance, and usability (see Figure 7).

The preceding phases laid the foundation for applying AHP (see table 1). Phase 1 ensured content validity through expert consensus, refining the initial set of sub-dimensions and indicators. In Phase 2, co-occurrence analysis reduced redundancy by merging or removing overlapping indicators, enhancing thematic clarity. Phase 3 measured each indicator's

accuracy, directness, and specificity to further refine relevance, while Phase 4 allowed a more methodologic approach to the indicators, culminating on the application of the AHP with a more reduced set of indicators.

In constructing a systematic approach for evaluating and refining indicators, we have integrated established methodologies from measurement theory, qualitative analysis, and decision-making frameworks, with each phase built on the results of the previous one.

Phase 1: Content Validity Index

We applied Lynn's (1986) Content Validity Index (CVI) methodology to evaluate and refine the relevance and importance of sub-dimensions within the MDII. This method, which relies on expert judgment, is widely used to assess the validity of measurement tools (Polit & Beck, 2006). The CVI systematically evaluates each item to determine its contribution to the overall construct, leading to the removal of items that fail to meet an agreed-upon threshold (Lynn, 1986; Polit & Beck, 2006).

The primary objective at this stage was to ensure that each sub-dimension contributed validly to digital inclusiveness. This

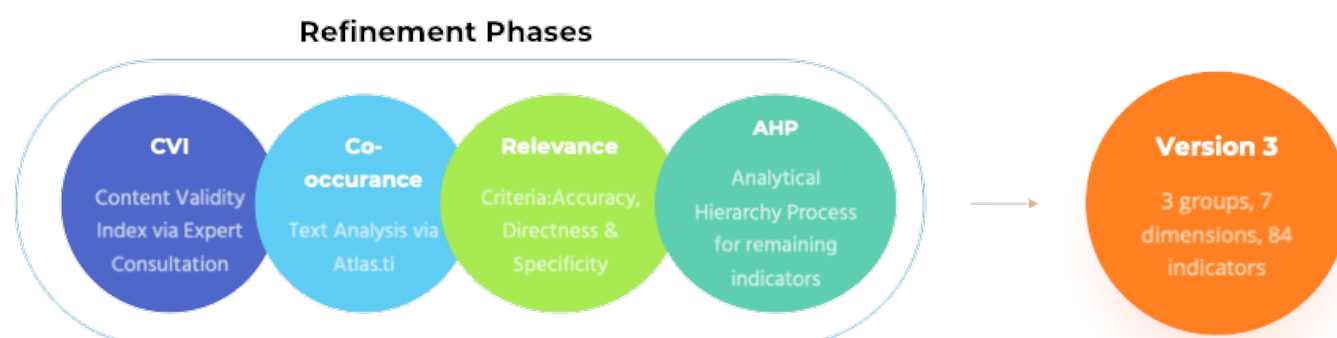


Figure 7 - MDII Refinement Phases (Source: Authors)

Table 1 - Summary of Applied Methodologies in MDII Refinement.

Phase	Methodology	Summary of application
1	Content Validity Indexing (CVI)	Applied to evaluate and refine the relevance and importance of sub-dimensions within the MDII, ensuring the retention of only the most relevant items (Lynn, 1986).
2	Co-Occurrence Analysis via Atlas.ti	Used to identify thematic overlaps and redundancies among indicators, enhancing their clarity and distinctiveness within each sub-dimension (Friese, 2019).
3	Relevance Assessment	Conducted a structured evaluation of each indicator's specificity, directness, and alignment with the sub-dimension, setting the stage for their subsequent prioritization in the AHP process (Nunnally & Bernstein, 1994).
4	Definition of Core and Extended Statements	Differentiated between core statements, applicable to all users, and extended statements for domain-specific experts, ensuring the MDII captures essential aspects of digital inclusiveness. This distinction supports focused yet comprehensive evaluations.
5	Final Indicator Prioritization with AHP	Employed AHP as the culminating step to systematically prioritize the refined indicators (Saaty & Vargas, 2012), reflecting the most critical elements of digital inclusiveness.

approach was essential for (1) establishing content validity through expert validation and (2) reducing complexity by eliminating sub-dimensions below the required relevance threshold. To assess each sub-dimension, we used a 5-point Likert scale ranging from ‘Not relevant’ (1) to ‘Highly relevant’ (5), allowing for nuanced evaluation. Experts were selected based on their domain knowledge in digital inclusiveness, following the criteria of Zamanzadeh et al. (2015). Each expert rated the sub-dimensions and provided suggestions for improvement, ensuring adherence to best practices in item clarity and relevance (Lynn, 1986).

CVI Calculations

After collecting expert ratings, we conducted several CVI calculations to ensure robust content validity of the sub-dimensions, following Zamanzadeh et al.’s (2015) methodology. The first calculation was the Item-CVI (I-CVI), ensuring that each sub-dimension is individually evaluated for its contribution to the overall construct. In our case, the I-CVI measures the proportion of experts who rated each sub-dimension as relevant (score of 4 or 5). The I-CVI is represented by the following formula:

$$I - CVI = \frac{\text{Number of experts rating 4 or 5}}{\text{Total number of experts}}$$

This approach helps filter out sub-dimensions without a strong consensus, with an I-CVI score of ≥ 0.78 considered acceptable (Zamanzadeh et al., 2015). Next, we assessed the scale’s overall validity using the Scale- Level Content Validity Index (S-CVI). The S-CVI offers a broader measure of content validity by looking at how well the entire set of sub-dimensions reflects the construct under analysis. The S-CVI can be calculated through two primary methods: the S-CVI/Ave and S-CVI/UA. The S-CVI/Ave averages the I-CVI scores for all sub- dimensions, offering a general view of content validity:

$$S - CVI_{Ave} = \frac{\sum I - CVI}{N}$$

This approach is widely used due to its simplicity and ability to give a clear indication of the overall content validity across all items. A threshold of ≥ 0.90 indicates strong alignment of the sub-dimensions with the overall construct (Zamanzadeh et al., 2015). In the case of the MDII, a high S-CVI/Ave score indicates that the sub-dimensions consistently capture the core elements of digital inclusiveness, which is crucial for a multidimensional tool. This score ensures that sub-dimensions are not only individually valid but also cohesively reflect the complexity of the construct, aligning with the tool’s goal of providing a comprehensive evaluation of digital inclusiveness.

The second method (S-CVI/UA) focuses on Universal Agreement, which is more stringent and measures the proportion of sub-dimensions that received a perfect agreement (a score of 4 or 5 from all experts):

$$S - CVI_{UA} = \frac{\text{Number of items with universal agreement}}{N}$$

The more stringent S-CVI/UA method measures the proportion of sub-dimensions receiving a perfect agreement score (4 or 5 from all experts), with a threshold of ≥ 0.80 (Zamanzadeh et al., 2015). This conservative approach guarantees full consensus on retained sub-dimensions. For the MDII’s refinement, we chose the more stringent S-CVI/UA method, as its strictness provided a robust measure of content validity (see Box 5 for findings).

Box 5: Findings of CVI Analysis

The analysis showed that all dimensions achieved an I-CVI of 0.78 or higher (see Table B2 in the annex), indicating strong agreement among expert on the relevance of each dimension’s indicators. Additionally, at the dimension level, the S-CVI/UA reached 1.00, indicating full consensus among experts. However, at the sub-dimension level, the S-CVI/UA scored 0.79, slightly below the 0.80 threshold recommended by Zamanzadeh et al. (2015). This minor deviation was deemed acceptable given the planned post-pilot refinements. The marginal gap allowed for a strategic examination of the Index’s performance, with particular attention to the implications of retaining sub-dimensions that slightly fell below the target threshold. We hypothesize that by selectively removing sub-dimensions with I-CVI scores at or below 0.78, the total S-CVI/UA will align more closely with the optimal threshold.

To enhance content validity, six sub-dimensions with I-CVI scores below 0.75 were removed (see Table B3 and B4 in the annex), resulting in the exclusion of 27 indicators (Table B5 in the annex). The selection of 0.75 as the cutoff value for I-CVI scores was guided by established best practices in content validity assessments, balancing the need for rigorous evaluation with practical feasibility (Zamanzadeh et al., 2015). This threshold provided a conservative measure, ensuring that retained sub-dimensions demonstrated strong expert consensus. Phase 1 concluded with 23 sub-dimensions comprising 109 indicators, reduced from an initial set of 136.

Phase 2: Co-Occurrence Analysis

Building on the content validation conducted in Phase 01, we began by gathering comprehensive descriptions for each of the remaining indicators, ensuring that all relevant information was included. These descriptions were then systematically imported into Atlas.ti, a qualitative data analysis software noted for its ability to manage large datasets, identify relationships between codes, enhance thematic distinctiveness and ensure a cohesive data structure in complex frameworks (Frieze, 2019). The advanced co-occurrence functions of Atlas.ti allowed us to explore and resolve thematic overlaps among the indicators retained from the previous phase, thereby preserving the clarity and relevance of each sub-dimension. Following the principles of structured qualitative analysis

(Friese, 2019), we systematically coded the indicators in Atlas.ti. Each indicator description was assigned a unique identifier (ID) and linked to its corresponding sub-dimension to maintain alignment with the MDII framework. We then conducted a concept analysis, creating a “Stop List” to exclude irrelevant or commonly repeated words. Finally, each indicator was coded with key concepts related to digital inclusiveness, ensuring consistent coding across all sub-dimensions.

Next, we used Atlas.ti’s “Code Co-Occurrence” feature to assess overlaps among indicators and to determine whether they were addressing similar concepts or phenomena. We identified indicators that shared a significant number of similar codes, categorizing these overlaps into three levels: critical, moderate, and low (see Box 6 for findings).

- Critical overlaps indicated substantial redundancies that necessitated the removal or merging of indicators.
- Moderate overlaps highlighted similarities that required adjustments or justifications for retention.
- Low overlaps reflected slight similarities but were distinct enough to justify retention, with minor adjustments noted if necessary.

Box 6: Findings of co-occurrence analysis

Our detailed co-occurrence analysis identified indicators with overlapping themes, leading to a refinement of the initial set of 109 indicators, which was streamlined to 92. Indicators were categorized by the level of overlap—critical, moderate, or low—informing decisions for inclusion, modification, or removal. This approach provided a clear framework for consolidating similar indicators and documenting the rationale behind each adjustment (see Table C1 in the annex). Out of the 109 initial indicators, 11 were merged due to critical overlaps, 6 were removed, and 3 were retained with modifications to clarify their distinct contributions. One new indicator was introduced to capture dimensions previously underrepresented. Additionally, a new sub-dimension termed “Digital Accessibility” was created to better represent indicators related to efficacy, usability, and desirability, reflecting key aspects identified during the refinement process (see Table C2 in the annex).

Accounting for the need for clear thresholds and coding rules to maintain consistency and reliability (Friese, 2019) and ensuring that only relevant and distinctive indicators are retained, we applied specific rules for manual validation of indicators:

- Critical Overlap:
If (Total Co-occurrence > 3) AND (Dimension Overlap ≥ 3) OR If (Intra/Inter-subdimension Overlap ≥ 3)

- Moderate Overlap:
If (Total Co-occurrence ≤ 3) AND (Dimension Overlap = 3)

For indicators identified as critically overlapping, we conducted a detailed comparison to analyze the nuances of each indicator’s focus, identifying similarities and differences to determine whether consolidation or retention of both indicators was the most appropriate course of action.

Phase 3: Relevance Assessment

In the relevance assessment phase, we applied foundational psychometric principles as outlined by Nunnally and Bernstein (1994) to evaluate each indicator’s accuracy, directness, and specificity. This step was crucial for establishing validity and reliability, aligning with Hand’s (2010) emphasis on precision in quantitative frameworks. We defined criteria (see table 2) for relevance — accuracy, directness, and specificity — guided by the following questions:

Table 2. Criteria for relevance

Criteria	Reasoning
Accuracy: Does the indicator have a verified association with the aspect of digital inclusiveness it is intended to measure?	Accurate indicators confirm reliable and trustworthy data, reducing measurement errors (Nunnally & Bernstein, 1994).
Directness: Is the indicator a direct measure of a key element, or does it rely on multiple proxies?	We aimed to minimize distortion from external factors, yielding clearer and more interpretable insights.
Specificity: Does the indicator measure a precise concept, or does it encompass multiple elements?	High specificity allows for more targeted interventions and a deeper understanding of specific areas within digital inclusiveness.

Using these criteria, each indicator was rated on a scale from 1 to 3, where 1 indicated ‘not relevant’ and 3 denoted ‘highly relevant.’ Indicators scoring below two-thirds of the maximum possible score (i.e., below 7 points) underwent a manual review to determine their suitability for retention. Low-scoring indicators often exhibited indirect measurement, ambiguity in focus, or weak alignment with digital inclusiveness (see Box 7 for findings).

Phase 4: Categorization of Statements

Following Phase 3, we identified a key challenge: certain technical or data-related questions within the MDII could be difficult for underserved users to answer accurately due to their specialized nature. This process was guided by the indicators’ relevance and complexity, ensuring that a set of statements would be operational for all evaluators, while another set would be tailored for those with specific expertise, such as in

areas like data governance or ICT infrastructure. To achieve this, each remaining indicator and its corresponding statement were systematically categorized into either the Core or Extended subset through expert consultation (see Table E1 in annex):

Core Indicators: Essential indicators designed to gauge digital inclusiveness across all user demographics, accessible to both underserved individuals and domain-specific experts.

Extended Indicators: Additional indicators providing finer granularity or addressing specialized dimensions of inclusiveness, targeted towards specific segments with relevant expertise.

For Extended Indicators, domain-specific experts are provided with supplementary data/evidence (by the Innovator), to support evaluation (see Box 8 for findings).

Phase 5: Analytic Hierarchy Process (AHP) for final selection

The final phase involved applying AHP to prioritize indicators and ensure the MDII accurately reflects critical aspects of digital inclusiveness. This structured decision-making framework, based on Saaty & Vargas' (2012) principles, enabled us to establish a systematic hierarchy of indicators aligned with our overall goal. We defined our objective as selecting the most relevant indicators for the Index. A three-tiered hierarchical structure was created: (1) top level: overarching goal of identifying the most pertinent indicators; (2) middle level: criteria for evaluation, including data availability, ease of data collection, and uniqueness; and (3) bottom level: indicators themselves.

We conducted pairwise comparisons for each criterion to determine the relative importance of indicators. This involved direct comparisons between pairs to assess which was more crucial for digital inclusiveness. AHP's systematic approach converted these comparisons into quantitative scores, establishing priority rankings objectively. We used AHP's standard 1-9 scale, where a score of 1 indicates equal importance and 9 indicates extreme importance.

We focused on three primary criteria to evaluate each indicator: data availability, ease of data collection, and uniqueness. Data availability was chosen as the first criterion to address the practical challenge of working with underserved groups in LMICs, where data scarcity often poses significant barriers (Villarino et al., 2022). Therefore, selecting indicators with existing and accessible data was essential to ensure the MDII could be effectively implemented without substantial obstacles. However, the availability of data alone does not guarantee its practicality for collection, leading us to establish ease of data collection as the second criterion. While data may exist, the ability to gather it efficiently is influenced by various factors such as geographical constraints, social norms, or economic barriers. Thus, indicators with data that were more straightforward to collect were prioritized, ensuring that the MDII remains feasible and scalable in real-world applications.

Box 7: Findings of relevance assessment

The relevance assessment led to the removal of 10 indicators that fell below the established threshold of two-thirds of the maximum score. These indicators, which often exhibited indirect measurement, ambiguity in focus, or insufficient alignment with digital inclusiveness, were excluded to enhance the framework's precision and clarity (see Table D1 in the annex). This refinement resulted in a final set of 83 indicators, representing a 9.8% reduction from the previous phase, highlighting a further refinement in accuracy and specificity. The average relevance score across the retained indicators was 8.53 out of 9, indicating a high level of alignment with the established criteria of accuracy, directness, and specificity.

Box 8: Findings of statements categorization

During Phase 4, we successfully categorized all remaining indicators and their corresponding statements into two subsets: Core and Extended. Our analysis revealed that the Extended subset was necessary for indicators requiring specialized expertise in domains such as IT, Economics, Data, and GESI (Gender Equality and Social Inclusion). Out of the total indicators, 54 were classified as Core Indicators, ensuring their universal applicability across diverse contexts and user groups. In contrast, the remaining 29 indicators were categorized as Extended Indicators, which targeted domain-specific experts (see Table E1 in the annex). This separation allowed for a more nuanced assessment, enabling comprehensive evaluations without compromising inclusiveness. The expertise domains identified for the Extended Indicators included IT, Data, Economics, GESI, Human-Centered Design and Country Experts.

Lastly, uniqueness was also deemed as a fundamental criterion to ensure that each indicator offered distinct insights into digital inclusiveness.

To derive priority weights for each criterion, we calculated priority vectors using Goepel's (2018) AHP framework, which converted subjective comparisons into quantitative values. These priority weights were then used to compute a composite score for each indicator, representing its relative significance (table F1 in the annex). Throughout this process, we maintained a transparent justification for each decision by systematically comparing and scoring each element, ensuring objectivity and consistency. To verify the reliability of our comparisons, we calculated the consistency ratio (CR), with all evaluations achieving a CR below the threshold of 0.10, confirming the reliability of our assessments. Given the large number of indicators, the AHP was applied within each sub-

dimension to allow for more focused comparisons, reducing cognitive load and improving accuracy. Indicators were grouped by their corresponding sub-dimensions, and separate AHP analyses were conducted, ensuring consistency and integrity in the prioritization process.

Once the Index was reduced, we manually reviewed the remaining indicators and proceed with minor adjustments in domain, sub-domain and indicators names and descriptions to improve clearness (see Box 9 for findings).

Stage 4 and 5: Demonstration and Evaluation

To validate its performance the Index will be applied in a multi-country pilot study which includes the evaluation of 9 tools developed by IWMI in partnership with FAO and based on WaPOR (Water Productivity through Open access of Remotely sensed derived data) project in 6 countries (one tool in Mozambique, Jordan, Kenya and Pakistan, two tools in Tunisia, and three tools in Ethiopia). The feedback loop from pilot testing will be instrumental in informing necessary adjustments to the indicators, including refinement, expansion, or reduction, to optimize accuracy and utility.

Stage 6: Communication

Findings, insights, and the refined MDII will be documented and disseminated, contributing to academic knowledge and practical application in digital inclusiveness measurement.

CONCLUSION AND NEXT STEPS FOR IMPLEMENTATION

Through a comprehensive approach to indicator selection, systematic refinements, and an extensive piloting phase, the MDII aims to serve as a dependable tool for assessing digital inclusiveness in agricultural innovation. Following the principles of DSRM, the MDII's development has prioritized iterative improvement and empirical validation. The forthcoming pilot testing phase on WaPOR tools being developed by IWMI, will enable us to iterate on the Index based on much needed empirical evidence and support our focus on evaluating practical applicability, ensuring construct reliability, and statistically assessing indicator significance. Indicators that lack measurable impact will be systematically excluded to maintain the MDII's precision and statistical rigor.

As next steps, we will expand on the MDII's recommendations and ability to provide actionable insights and equipping policymakers with evidence to support gender- and inclusion-responsive innovations. A user-friendly dashboard is also being developed to ensure that the MDII is accessible across diverse settings, with both online and offline data collection options to accommodate varying connectivity levels. Data collection will be conducted through digital forms, and an Excel-based tool for areas with limited internet access for offline implementation. Additionally, it is our goal that the

Box 9: Findings of AHP

Phase 5 used the AHP to systematically prioritize indicators based on weighted criteria. Data Availability received the highest weight (49%), reflecting its critical role in ensuring feasibility, followed by Uniqueness (44%) and Ease of Data Collection (7%). The prioritization process demonstrated consistency, with all pairwise comparisons achieving a Consistency Ratio (CR) below the 0.10 threshold, confirming the reliability of the assessments. Overall, indicators with high scores in Data Availability and Uniqueness achieved higher total weights. For instance, indicators such as 'Data Accessibility' and 'Transparency and Communication' received a total weight of 100%, highlighting their comprehensive alignment with all three criteria. Conversely, indicators like 'Cost of Transition' and 'Cost Predictability' had lower total weights due to challenges in data availability and collection, confirming the need for careful selection in the final index version. Despite varying weights, all indicators were retained in the preliminary version of the MDII to allow empirical validation in upcoming testing phases.

MDII and its dashboard can allow real-time comparison and analysis of scores and generate a comprehensive report will provide detailed insights for each tool, organized by dimension and indicator, combined with AI-generated recommendations will draw from the latest agricultural research, offering targeted suggestions for improving digital inclusiveness in alignment with best practices. To support efficient evaluation and provide comprehensive guidance, we plan to elaborate essential resources, such as structured evaluation forms and implementation guides, and the automatic generation of an evaluation support document that compiles information from the evaluated tools.

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REFERENCES

- Agunyai, S. C., & Ojakorotu, V. (2024). Data-driven innovations and sustainability of food security: Can asymmetric information be blamed for food insecurity in Africa? *Sustainability*, 16(20), 8980. <https://doi.org/10.3390/su16208980>
- Aker, J. C., Ghosh, I., & Burrell, J. (2016). The promise (and pitfalls) of ICT for agriculture initiatives. *Agricultural Economics*, 47(S1), 35–48. <https://doi.org/10.1111/agec.12301>
- Akinwale, Y., & Grobler, W. (2023). Research and Technology Innovation, food security and economic growth in Nigeria: Implications for Agripreneurs and policymakers. *African Journal of Food, Agriculture, Nutrition and Development*, 23(04), 23220–23237. <https://doi.org/10.18697/ajfand.119.21255>
- Al-Maruf, A., Pervez, A. K., Sarker, P. K., Rahman, M. S., & Ruiz-Menjivar, J. (2022). Exploring the factors of farmers' rural–urban migration decisions in Bangladesh. *Agriculture*, 12(5), 722. <https://doi.org/10.3390/agriculture12050722>
- Alemu, S., Kosmowski, F., Stevenson, J. R., Mallia, P., Taye, L., & Macours, K. (2024). Studying inclusive innovation with the right data: An empirical illustration from Ethiopia. *Agricultural Systems*, 219, 103988. <https://doi.org/10.1016/j.agsy.2024.103988>
- Ali, A., Raza, A. A., & Qazi, I. A. (2023). Validated digital literacy measures for populations with low levels of internet experiences. *Development Engineering*, 8, 100107. <https://doi.org/10.1016/j.deveng.2023.100107>
- Ananda, K. R., Saikanth, D. R. K., Chaudam, V., Sravani, S., Nayak, S. H., Dam, A., & Shukla, A. (2024). Impact of mobile technology on Extension Service Delivery in remote farming communities: A Review. *Journal of Scientific Research and Reports*, 30(3), 1–13. <https://doi.org/10.9734/jsrr/2024/v30i31853>
- Beanstalk AgTEch. (2023). (rep.). State of the Digital Agriculture Sector. Harnessing the Potential of Digital for Impact Across Agricultural Value Chains in Low- and Middle-Income Countries. Retrieved from <https://static1.squarespace.com/static/61f723d2d47f140c4200a1d9/t/65557be9c2f23404d1576704/1700101355494/State+of+the+Digital+Agriculture+Sector+in+LMICS+-+Whole+Report.pdf>
- Camacho-Villa, T. C., Zepeda-Villarreal, E. A., Díaz-José, J., Rendon-Medel, R., & Govaerts, B. (2023). The contribution of strong and weak ties to resilience: The case of small-scale maize farming systems in Mexico. *Agricultural Systems*, 210, 103716. <https://doi.org/10.1016/j.agsy.2023.103716>
- Chowhan, S., Rahman, Md. M., Sultana, R., Abdur Rouf, Md., & Islam, M. (2023). Contribution of agriculture sector in the GDP growth of Bangladesh. *Food and Agri Economics Review*, 3(2), 51–54. <https://doi.org/10.26480/faer.02.2023.51.54>
- Daum, T., Ravichandran, T., Kariuki, J., Chagunda, M., & Birner, R. (2022). Connected cows and cyber chickens? Stocktaking and case studies of digital livestock tools in Kenya and India. *Agricultural Systems*, 196, 103353. <https://doi.org/10.1016/j.agsy.2021.103353>
- Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1989). User acceptance of computer technology: A comparison of two theoretical models. *Management Science*, 35(8), 982–1003. <https://doi.org/10.1287/mnsc.35.8.982>
- de Brauw, A., Kramer, B., & Murphy, M. (2021). Migration, labor and women's empowerment: Evidence from an agricultural value chain in Bangladesh. *World Development*, 142, 105445. <https://doi.org/10.1016/j.worlddev.2021.105445>
- Díaz Andrade, A., & Techatassanasoontorn, A. A. (2020). Digital Enforcement: Rethinking the pursuit of a digitally- enabled Society. *Information Systems Journal*, 31(1), 184–197. <https://doi.org/10.1111/isj.12306>
- Faik, I., Sengupta, A., & Deng, Y. (2024). Inclusion by design: Requirements elicitation with digitally marginalized communities. *MIS Quarterly*, 48(1), 219–244. <https://doi.org/10.25300/misq/2023/17225>
- Friese, S. (2019). *Qualitative data analysis with atlas.ti*. SAGE Publications.
- Gardezi, M., Abuayyash, H., Adler, P. R., Alvez, J. P., Anjum, R., Badireddy, A. R., Brugler, S., Carcamo, P., Clay, D., Dadkhah, A., Emery, M., Faulkner, J. W., Joshi, B., Joshi, D. R., Khan, A. H., Koliba, C., Kumari, S., McMaine, J., Merrill, S., Zia, A. (2024). The role of Living Labs in cultivating inclusive and responsible innovation in Precision Agriculture. *Agricultural Systems*, 216, 103908. <https://doi.org/10.1016/j.agsy.2024.103908>

- Global System for Mobile Communications Associations (GSMA). (2020). The State of Mobile Internet Connectivity 2020. Retrieved from <https://www.gsma.com/r/wp-content/uploads/2020/09/GSMA-State-of-Mobile-Internet-Connectivity-Report-2020.pdf>
- Global System for Mobile Communications Associations (GSMA). (2022). The State of Mobile Internet Connectivity 2022. Retrieved from <https://www.gsma.com/r/wp-content/uploads/2022/12/The-State-of-Mobile-Internet-Connectivity-Report-2022.pdf>
- Goepel, K. D. (2018). Implementation of an online software tool for the Analytic Hierarchy Process (AHP-OS). *International Journal of the Analytic Hierarchy Process*, 10(3). <https://doi.org/10.13033/ijahp.v10i3.590>
- Hand, D. J. (2010). *Measurement theory and practice: The world through quantification*. Wiley.
- Haryanti, T., Rakhmawati, N. A., & Subriadi, A. P. (2023). A comparative analysis review of digital transformation stage in developing countries. *Journal of Industrial Engineering and Management*, 16(1), 150. <https://doi.org/10.3926/jiem.4576>
- Heeks, R. (2010). Do information and communication technologies (ICTs) contribute to development? *Journal of International Development*, 22(5), 625–640. <https://doi.org/10.1002/jid.1716>
- Hernandez, K., Flynn, J., He, J., & Alsahi, H. (2024). Towards digital inclusion in rural transformation. Rome, FAO. <https://doi.org/10.4060/cc9816en>
- Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design science in information systems research. *MIS Quarterly*, 28(1), 75. <https://doi.org/10.2307/25148625>
- Kleine, D. (2013). *Technologies of choice?: ICTs, development, and the capabilities approach*. MIT Press.
- Lapinski, M. K., & Rimal, R. N. (2005). An explication of social norms. *Communication Theory*, 15(2), 127–147. <https://doi.org/10.1111/j.1468-2885.2005.tb00329.x>
- Lin, Q., Dai, X., Cheng, Q., & Lin, W. (2022). Can digital inclusive finance promote food security? evidence from China. *Sustainability*, 14(20), 13160. <https://doi.org/10.3390/su142013160>
- Ly, B., Dem, T., Ly, R., Sorn, S., & Doeur, B. (2024). Exploring the nexus of digital inclusion and Environmental Sustainability: Insights from Cambodia. *Information Technology for Development*, 1–18. <https://doi.org/10.1080/02681102.2024.2345381>
- Lynn, M. R. (1986). Determination and quantification of content validity. *Nursing Research*, 35(6). <https://doi.org/10.1097/00006199-198611000-00017>
- Martins, C. I., Opola, F., Jacobs-Mata, I., Garcia Andarcia, M., Nortje, K., Joshi, D., Singaraju, N., Muller, A., Christen, R., Malhotra, A. (2023). Development of the conceptual framework (version 2.0) of the Multidimensional Digital Inclusiveness Index. Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Initiative on Digital Innovation. 36p. <https://hdl.handle.net/10568/138705>
- Ndege, N., Marshall, F., & Byrne, R. (2024). Exploring inclusive innovation: A case study in operationalizing inclusivity in digital agricultural innovations in Kenya. *Agricultural Systems*, 219, 104033. <https://doi.org/10.1016/j.agsy.2024.104033>
- Nunnally, J. C., & Bernstein, I. H. (1994). *Psychometric theory*. McGraw-Hill.
- Opola, F., Langan, S., Singaraju, N., Arulingam, I., Schumann, C., Jacobs-Mata, I., Nortje, K. (2023). An index for enabling socially inclusive digital innovation processes in food, land, and water systems. Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Initiative on Digital Innovation. 13p. <https://hdl.handle.net/10568/134556>
- Peffer, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A design science research methodology for information systems research. *Journal of Management Information Systems*, 24(3), 45–77. <https://doi.org/10.2753/mis0742-1222240302>
- Polit, D. F., & Beck, C. T. (2006). The content validity index: Are you sure you know what's being reported? critique and recommendations. *Research in Nursing & Health*, 29(5), 489–497. <https://doi.org/10.1002/nur.20147>
- Saaty, T. L., & Vargas, L. G. (2012). *Models, methods, concepts & applications of the analytic hierarchy process*. Springer.
- Scheerder, A., van Deursen, A., & van Dijk, J. (2017). Determinants of internet skills, uses and outcomes. A systematic review of the second- and third-level digital divide. *Telematics and Informatics*, 34(8), 1607–1624. <https://doi.org/10.1016/j.tele.2017.07.007>
- Selwyn, N. (2004). Reconsidering political and popular understandings of the digital divide. *New Media & Society*, 6(3), 341–362. <https://doi.org/10.1177/1461444804042519>
- Sen, A. K. (1999). *Development as freedom*. Knopf.
- Song, C., Petsakos, A., & Gotor, E. (2024). Linguistic diversity, climate shock, and farmers-herder conflicts: Implications for inclusive innovations for agro-pastoralism systems. *Agricultural Systems*, 216, 103883. <https://doi.org/10.1016/j.agsy.2024.103883>
- Steinke, J., Schumann, C., Langan, S., Müller, A., Opola, F. O., Ortiz-Crespo, B., & van Etten, J. (2024). Fostering social inclusion in development-oriented digital food system interventions. *Agricultural Systems*, 215, 103882. <https://doi.org/10.1016/j.agsy.2024.103882>

- Taylor, L. (2017). What is Data Justice? the case for connecting Digital Rights and Freedoms globally. *Big Data & Society*, 4(2), 205395171773633. [https://doi.org/ 10.1177/2053951717736335](https://doi.org/10.1177/2053951717736335)
- Teles, A., & Joia, L. A. (2011). Assessment of Digital Inclusion via the actor-network theory: The case of the Brazilian Municipality of pirai. *Telematics and Informatics*, 28(3), 191–203. [https://doi.org/ 10.1016/j.tele.2010.09.003](https://doi.org/10.1016/j.tele.2010.09.003)
- Udisha, O., & Philomina, I. G. (2024). Bridging the digital divide: Empowering rural women farmers through mobile technology in Kerala. *Sustainability*, 16(21), 9188. [https://doi.org/ 10.3390/su16219188](https://doi.org/10.3390/su16219188)
- van Dijk, J. (2005). *The deepening divide: Inequality in the information society*. Sage Publications.
- Venable, J. R., Pries-Heje, J., and Baskerville, R. L. (2017). Choosing a Design Science Research Methodology. *ACIS 2017 Proceedings*. 112. <https://aisel.aisnet.org/acis2017/112>
- Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS Quarterly*, 27(3), 425. [https://doi.org/ 10.2307/30036540](https://doi.org/10.2307/30036540)
- Venkatesh, V., & Davis, F. D. (2000). A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Management Science*, 46(2), 186–204. <https://doi.org/10.1287/mnsc.46.2.186.11926>
- Villarino, Ma. E., Tejada, M. G., & Patterson, S. E. (2022). From agricultural statistics to zero hunger: How the 50X2030 initiative is closing data gaps for SDG2 and beyond. *Statistical Journal of the IAOS*, 38(1), 63–73. <https://doi.org/10.3233/sji-210904>
- Warschauer, M. (2004). *Technology and Social Inclusion: Rethinking the digital divide*. Massachusetts Institute of Technology.
- Xiong, Q., Guo, X., & Yang, J. (2024). Digital Financial Inclusion, land circulation and high-quality development of Agriculture. *Sustainability*, 16(11), 4775. [https://doi.org/ 10.3390/su16114775](https://doi.org/10.3390/su16114775)
- Zamanzadeh, V., Ghahramanian, A., Rassouli, M., Abbaszadeh, A., Alavi-Majd, H., & Nikanfar, A.-R. (2015). Design and implementation content validity study: Development of an instrument for measuring patient- centered communication. *Journal of Caring Sciences*, 4(2), 165–178. <https://doi.org/10.15171/jcs.2015.017>

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APPENDIX A. INDICATORS PER DOMAIN AND FOCUS AREAS

Table A1. Granular level of focus and indicators for social consequences group

Beneficial Impact		Risks & Harms	
Solution Effectiveness	Solution Performance	Long-term Loss	Loss of Skills (reversed scale)
	Functionality		Loss of Cultural Identity (reversed scale)
	Problem-Solution Fit		Loss of Agency (reversed scale)
	Adaptive Capability		
Problem Relevance	Problem Identification Accuracy	Reinforcement of Inequalities	Content and Design (reversed scale)
	Relevance to Target Group		Equality and Empowerment (reversed scale)
	Severity Assessment		Algorithmic Fairness
	Engagement in Problem Definition		Data Representation Equity
Sustainability	Local Contextual Understanding	Data Misappropriation	Fraudulent activities (reversed scale)
	Long-term Viability		Inability to Access Collected Data (reversed scale)
	Maintainability		Data Leakage (reversed scale)
	Scalability		Unauthorized Access (reversed scale)
Economic Sustainability	Economic Sustainability		Unauthorized Commercialization of Data (reversed scale)
	Community Impact		
	Individual Empowerment		
	Social Equity		
Social Value Creation	Cultural Sensitivity		
	Social Capital Building		
	Digital Knowledge		
	Perception of Psychological Belongingness		

Table A2. Granular level of focus and indicators for innovation usage group

Accessibility		Usage Effectiveness	
Infrastructure Accessibility	Digital Availability Quality and Functionality Infrastructure Readiness Integration with Existing Systems Resilience and Security	Digital Skill Enhancement	Tool Proficiency
Economic Accessibility	Affordability Cost of Access Cost Transparency Subsidy Availability Cost of Transition Cost Predictability	Desirability	Appeal and Engagement Perceived Value
Digital Accessibility	Ease of Adoption Accessibility Features Adaptation to local context	Usability	Ease of Use Error Management Performance Efficiency
Information Accessibility	Communication Channels and Messaging	Supportive Ecosystem	
		Knowledge-based Resources	Training Availability Training Relevance Performance Monitoring and Feedback Training Affordability Documentation and Guidance Training Support Training Assessment and Feedback
		Enabling Policies	Resource Availability Inclusive Policies Feedback Mechanisms Collaboration Platforms
		Community Support	Community Engagement Community Activeness

Table A3. Granular level of focus and indicators for governance group

Ethical and Responsible Innovation		Co-Creation and Governance	
Data Governance	Data Privacy Data Accessibility Data Accuracy Data Portability Transparency of Data Practices Bias Monitoring and Adaptation	Collaborative Innovation	Collaboration Accessibility Diversity and Representation Collaborative Support Co-creation Opportunities
Ethical Compliance	Ethical Standards Adherence Ethical Oversight Impact Assessment	Grassroots Innovation Collaboration	Grassroots Engagement Community-led Solutions Local Knowledge Utilization Capacity Building Impact Assessment
Reflexive Innovation	Continuous Reflection Feedback Integration Transparency and Communication	Inclusive Governance	Inclusive Decision-making Transparency

APPENDIX B. PHASE 1 – CVI FINDINGS

Table B1. Entire set of sub-dimensions considered for removal

1.1 Infrastructure Accessibility	3.2 Innovation Desirability	5.4 Inclusive Governance
1.2 Economic Accessibility	3.3 Usability	6.1 Training Accessibility
1.3 Informational Accessibility	3.4 Community Networks	6.2 Supportive Ecosystem
1.4 Capacity Development	4.1 Data Governance	6.3 Behavioral Intention
2.1 Solution Effectiveness	4.2 Ethical Compliance	6.4 Facilitating Conditions
2.2. Problem Relevance	4.3 Epistemic Justice	7.1 Gender-Related Risk
2.3 Digital Divide	4.4 Reflexive Innovation	7.2 Job Displacement
2.4 Sustainability	5.1 Intellectual Property Assurance	7.3 Technological Dependency
2.5 Social Value Creation	5.2 Collaborative Innovation	7.4 Technological Bias
3.1 Digital Literacy	5.3 Grassroots Innovation Inclusion	

Table B2. I-CVI per dimension

	1. Accessibility	2. Beneficial Impact	3. Usage Efficacy	4. Ethical and Responsible Innovation	5. Co-Creation and Governance	6. Adoption Facilitation	7. Risks & Harms
I-CVI	1,00	0,88	0,97	0,81	0,84	0,78	0,88

Table B3. I-CVI per sub-dimension

1.1 Infrastructure Accessibility 0,97	1.2 Economic Accessibility 0,94	1.3 Informational Accessibility 0,84	1.4 Capacity Development 0,81	
2.1 Solution Effectiveness 0,94	2.2. Problem Relevance 0,97	2.3 Digital Divide 0,78	2.4 Sustainability 0,78	2.5 Social Value Creation 0,88
3.1 Digital Literacy 0,94	3.2 Innovation Desirability 0,84	3.3 Usability 0,94	3.4 Community Networks 0,69	
4.1 Data Governance 0,94	4.2 Ethical Compliance 0,91	4.3 Epistemic Justice 0,75	4.4 Reflexive Innovation 0,81	
5.1 Intellectual Property Assurance 0,53	5.2 Collaborative Innovation 0,78	5.3 Grassroots Innovation Inclusion 0,84	5.4 Inclusive Governance 0,91	
6.1 Training Accessibility 0,88	6.2 Supportive Ecosystem 0,91	6.3 Behavioral Intention 0,75	6.4 Facilitating Conditions 0,84	
7.1 Gender-Related Risks 0,81	7.2 Job Displacement 0,75	7.3 Technological Dependency 0,75	7.4 Technological Bias 0,78	

Table B4. Removed Sub-Dimensions
(I-CVI < 0.78)

Sub-Dimensions	I-CVI
3.4 Community Networks	0.69
4.3 Epistemic Justice	0.75
5.1 Intellectual Property Assurance	0.53
6.3 Behavioral Intention	0.75
7.2 Job Displacement	0.75
7.3 Technological Dependency	0.75

Table B5. Affected Indicators

Name	Name	Name
Network Formation	Knowledge Inclusion	IP Awareness
Network Engagement	Recognition Justice	IP Protection Mechanisms
Resource Sharing	Communicative Equality	IP Inclusivity
Community Resilience	Knowledge Accessibility	IP Dispute Resolution
Community-driven Innovation	Epistemic Empowerment	IP Education and Capacity Building
Intention to Use	Automation Impact on Rural Employment	Dependency on Continuous Tech Support
Perceived Usefulness	Skill Adaptation for Underserved Communities	Adaptability to Local Technological Infrastructure
Perceived Ease of Use	Support for Traditional Practices	Impact on Traditional Knowledge and Practices
Attitude towards Use	Behavioral Control	Risk of Obsolescence for Underserved Users

APPENDIX C. PHASE 2 – CO-OCCURRENCE RESULTS

Table C1. Co-occurrence results

Co-occurrence Level	Action Taken	Rationale for Action
Critical	Indicator Removed	Indicator removed since it is not related with the innovation but with the infrastructure.
Critical	Indicator Merged with D1.2.7	Both indicators measure cost vs benefits.
Critical	Indicator Merged with D1.2.3	Both indicators measure economic incentives.
Critical	Indicator Merged with D3.2.2	Both indicators measure perceived value.
Critical	Indicator Merged with D3.1.4	Indicator is redundant in terms of digital literacy.
Critical	Indicator Removed	Conceptual and semantic overlap with D3.2.1.
Critical	Indicator Removed	Conceptual and semantic overlap with D3.3.1.
Critical	Indicator Merged with D6.4.4	Both indicators measure effectiveness of community networks.
Critical	Indicator Merged with SD6.1.2	Indicator relates more with FC than Access.
Critical	Indicator Merged with D6.1.1	Both indicators measure continuous learning.
Critical	Indicator Merged with D7.1.3	Both indicators measure the gender gap.
Critical	Indicator Removed	Indicator is redundant with D6.1 which focuses on Learning Support as Facilitating Conditions.
Critical	Indicator Removed	Indicator is redundant with D6.1 which focuses on Learning Support as Facilitating Conditions.
Critical	Indicator Merged with D4.2.4	Both indicators refer to processes. Since collection, analysis and feedback are part of processes, it better aligns with D4.2.4.
Critical	Indicator Merged with D1.1.1	All indicators measure digital infrastructure, however D6.4.1. better merges with digital infrastructure availability (D1.1.1).
Critical	Indicator Removed	Both indicators measure support services. Conceptual overlap with 6.2. Support Services better align with the concept of Supportive Ecosystem.
Critical	Indicator Merged with D3.3.4	Redundancy with D3.3.4 which focuses more on Usability.

Table C2. Other changes outside of co-occurrence

Previous Dimension/Sub-dimension	New Dimension/Sub-dimension	Action Taken
Accessibility, Capacity Development	Adoption Facilitation	Indicators Moved
Usage Efficacy/Innovation Desirability	(NEW) Digital Accessibility	Indicator Moved
Usage Efficacy/Usability	(NEW) Digital Accessibility	Indicator Moved

APPENDIX D. PHASE 3 – RELEVANCE ASSESSMENT TABLE

Table D1. Relevance assessment table

Indicators	01. Accuracy	02. Directness	03. Specificity	Relevance score	Status
Digital Availability	3	2	3	8	
Quality and Functionality	3	2	2	7	
Infrastructure Readiness	2	2	3	7	
Accessibility Features	1	2	1	4	removed
Integration with Existing Systems	3	3	3	9	
Cost of Access	3	3	3	9	
Resilience and Security	3	3	3	9	
Affordability	3	3	3	9	
Cost Transparency	2	2	3	7	
Subsidy Availability	3	3	3	9	
Cost of Transition	2	2	3	7	
Cost Predictability	2	2	3	7	
Ease of Adoption	3	3	3	9	
Accessibility Features	3	3	3	9	
Adaptation to local context	3	3	3	9	
Performance Monitoring and Feedback	3	3	3	9	
Certification and Recognition	2	1	3	6	removed
Solution Performance	3	3	3	9	
Functionality	3	3	3	9	
Outcome Measurement	2	2	2	6	removed
Problem-Solution Fit	3	3	3	9	
Adaptive Capability	2	3	3	8	
Problem Identification Accuracy	3	3	3	9	
Relevance to Target Group	3	3	3	9	
Severity Assessment	3	3	3	9	
Engagement in Problem Definition	2	2	3	7	
Local Contextual Understanding	3	3	3	9	
Digital Gap Reduction	3	3	3	9	
Long-term Viability	3	1	3	7	
Maintainability	3	2	2	7	
Scalability	3	3	3	9	
Resource Efficiency	1	2	3	6	removed

Table D1 (cont. 1)

Indicators	01. Accuracy	02. Directness	03. Specificity	Relevance score	Status
Economic Sustainability	2	2	3	7	
Community Impact	3	3	3	9	
Individual Empowerment	3	3	3	9	
Social Equity	3	2	2	7	
Cultural Sensitivity	3	3	3	9	
Social Capital Building	3	3	3	9	
Skill Acquisition	3	3	3	9	
Assessment and Feedback	1	2	2	5	removed
Appeal and Engagement	3	3	3	9	
Perceived Value	3	3	3	9	
User Satisfaction	2	2	3	7	
Innovation Relevance	3	3	3	9	
Ease of Use	3	3	3	9	
Error Management	3	3	3	9	
Performance Efficiency	3	3	3	9	
Data Privacy	3	3	3	9	
Data Accessibility	3	3	3	9	
Data Accuracy	3	3	3	9	
Data Portability	2	3	3	8	
Transparency of Data Practices	3	3	3	9	
Ethical Standards Adherence	3	3	3	9	
Ethical Oversight	3	3	3	9	
Impact Assessment	2	3	3	8	
Ethical Training and Awareness	2	2	2	6	removed
Continuous Reflection	3	3	3	9	
Feedback Integration	3	3	3	9	
Transparency and Communication	3	3	3	9	
Collaboration Accessibility	3	3	3	9	
Diversity and Representation	3	3	3	9	
Collaborative Support	3	3	3	9	
Co-creation Opportunities	3	3	3	9	
Outcome Sharing	2	2	2	6	removed
Grassroots Engagement	3	3	3	9	

Table D1 (cont. 2)

Indicators	01. Accuracy	02. Directness	03. Specificity	Relevance score	Status
Community-led Solutions	3	3	3	9	
Local Knowledge Utilization	3	3	3	9	
Capacity Building	3	3	3	9	
Impact Assessment	3	3	3	9	
Inclusive Decision-making	3	3	3	9	
Representation	1	2	3	6	removed
Transparency	3	3	3	9	
Accountability	3	1	1	5	removed
Training Availability	3	3	3	9	
Training Relevance	3	3	3	9	
Training Affordability	3	3	3	9	
Training Support	2	3	2	7	
Training Assessment and Feedback	3	3	3	9	
Community Engagement	3	3	3	9	
Resource Availability	3	3	3	9	
Inclusive Policies	3	3	2	8	
Feedback Mechanisms	3	3	3	9	
Collaboration Platforms	3	2	2	7	
Documentation and Guidance	3	3	3	9	
Community Support	3	3	3	9	
Gender disparity	3	3	3	9	
Inclusivity in Content and Design	3	3	3	9	
Gender Equality and Empowerment	3	3	3	9	
Algorithmic Fairness	3	3	3	9	
Cultural and Contextual Relevance	3	3	3	9	
Data Representation Equity	3	3	3	9	
Bias Monitoring and Adaptation	3	3	3	9	

APPENDIX E: PHASE 4 - CATEGORIZATION OF STATEMENTS

Table E1. Extended statements per expertise domain

Indicators	Expertise domain	Indicators	Expertise domain	Indicators	Expertise domain
2.3 Infrastructure Readiness	IT	1.12 Maintainability	Economics	3.9 Continuous Reflection	DI Expert
2.4 Integration with Existing Systems	IT	1.13 Scalability	Economics	3.10 Feedback Integration	DI Expert
2.6 Resilience and Security	IT	1.14 Economic Sustainability	Economics	6.2 Diversity and Representation	GESI
2.14 Adaptation to local context	Country Expert	3.1 Data Privacy	IT	6.6 Community-led Solutions	GESI
1.3 Problem-Solution Fit	Country Expert	3.3 Data Accuracy	IT	7.2 Training Relevance	GESI
1.4 Adaptive Capability	Country Expert	3.4 Data Portability	IT	7.6 Training Assessment and Feedback	GESI
1.5 Problem Identification Accuracy	Country Expert	3.5 Transparency of Data Practices	IT	4.4 Algorithmic Fairness	Data
1.8 Engagement in Problem Definition	GESI	3.6 Ethical Standards Adherence	IT/Ethics	4.6 Data Representation Equity	Data
1.9 Local Contextual Understanding	Country Expert	3.7 Ethical Oversight	IT/Ethics	4.7 Bias Monitoring and Adaptation	Data
1.11 Long-term Viability	Economics	3.8 Impact Assessment	IT/Ethics		

APPENDIX F. PHASE 5 - AHP PAIRWISE COMPARISON RESULTS

Table F1. Results of AHP pairwise comparison analysis for MDII indicators

Indicator	Data Availability	Ease of Data Collection	Unique-ness	Total Weight
Solution Performance	75%	75%	50%	64%
Functionality	25%	25%	50%	36%
Relevance to Target Group	25%	33%	67%	44%
Severity Assessment	75%	67%	33%	56%
Digital Gap Reduction	100%	100%	100%	100%
Community Impact	23%	28%	13%	19%
Individual Empowerment	23%	33%	17%	21%
Social Equity	20%	13%	22%	20%
Cultural Sensitivity	17%	14%	26%	21%
Social Capital Building	17%	13%	22%	19%
Digital Availability	33%	69%	40%	39%
Quality and Functionality	33%	15%	20%	26%
Cost of Access	33%	16%	40%	35%
Affordability	26%	29%	29%	27%
Cost Transparency	28%	16%	19%	23%
Subsidy Availability	26%	34%	22%	25%
Cost of Transition	9%	12%	13%	11%
Cost Predictability	12%	9%	17%	14%
Ease of Adoption	50%	50%	25%	39%
Accessibility Features	50%	50%	75%	61%
Data Accessibility	100%	100%	100%	100%
Transparency and Communication	100%	100%	100%	100%
Gender disparity	40%	14%	33%	35%
Inclusivity in Content and Design	40%	43%	33%	37%
Gender Equality and Empowerment	20%	43%	33%	27%
Documentation and Guidance	67%	67%	33%	52%
Community Support	33%	33%	67%	48%

Table F1 (cont.)

Indicator	Data Availability	Ease of Data Collection	Unique-ness	Total Weight
Cultural and Contextual Relevance	100%	100%	100%	100%
Skill Acquisition	100%	100%	100%	100%
Appeal and Engagement	25%	29%	21%	23%
Perceived Value	25%	29%	25%	25%
User Satisfaction	25%	29%	25%	25%
Innovation Relevance	25%	14%	30%	26%
Ease of Use	33%	40%	47%	40%
Error Management	33%	40%	10%	23%
Performance Efficiency	33%	20%	43%	37%
Collaboration Accessibility	24%	40%	25%	25%
Collaborative Support	63%	40%	25%	44%
Co-creation Opportunities	14%	20%	50%	30%
Grassroots Engagement	13%	40%	36%	25%
Local Knowledge Utilization	26%	11%	15%	20%
Capacity Building	48%	37%	33%	40%
Impact Assessment	14%	12%	16%	15%
Inclusive Decision-making	50%	75%	67%	59%
Transparency	50%	25%	33%	41%
Training Availability	29%	40%	24%	27%
Performance Monitoring and Feedback	25%	20%	40%	31%
Training Affordability	29%	20%	20%	24%
Training Support	18%	20%	17%	17%
Community Engagement	25%	20%	25%	25%
Resource Availability	25%	35%	25%	25%
Feedback Mechanisms	25%	20%	30%	27%
Collaboration Platforms	25%	25%	21%	23%