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6G4SOCIETY

KVIs For Sustainability

GUIDANCE DOCUMENT

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A working proposal to prompt strategic discussion and inform next steps

SHIFTING FROM ASSESSING VALUE TO SUSTAINABILITY

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Research and Innovation projects aiming for sustainability must look beyond immediate efficiencies to address enduring, systemic change.

This framework proposes a shift in impact measurement from capturing value in the moment (KVIs) to a dynamic assessment of long-term sustainability (KSIs). KSIs embed time, interdependence, and systemic alignment, adding a forward-looking layer that asks: "Are we on the right path for the long run?" Short-term indicators alone cannot reveal whether immediate wins are building the foundations needed for enduring impact, or whether the solutions developed will enable flourishing within the societal, environmental, and economic systems where they must operate. The framework aims to support projects in selecting and configuring KVIs based on specific features that strengthen their connection to sustainability.

KSIs are not a new type of indicator; they are KVIs configured to assess sustainability. They extend the impact snapshot that KVIs provide by adding temporal and systemic dimensions, tracking whether the values we aim to create persist, diffuse, and remain equitable over time.

Tracking Trajectory, Not Just Snapshots

While KVIs typically ask: "How are we doing now?" and focus on immediate value creation, KSIs embed time, interdependence, and systemic alignment. They add a forward-looking layer that asks: "Are we on the right path for the long run?" Short-term indicators alone cannot reveal whether immediate wins are building the foundations needed for enduring impact, or whether the solutions developed will enable flourishing within the societal, environmental, and economic systems where they must ultimately operate.

5 Principles for sustainability-oriented indicators

To guide this strategic shift, a sustainability-oriented framework for indicators must be built upon five core principles. These principles ensure that assessments are comprehensive, forward-looking, and grounded in the systemic realities of societal, environmental, and economic systems.

- **Assess holistically across pillars:** Assess impact simultaneously across societal, environmental, and economic dimensions of sustainability. Integrate complementary methods, disciplines, perspectives, especially those that mix top-down and bottom-up, to capture sustainability's complexity [1] [2] [3] [4] [5] [6] [7] [8] [9] [10].
- **Map interdependencies and trade-offs:** Evaluate how actions in one area create consequences in others, and how they raise challenges around trade-offs [11] [12] [13] [14] [15].
- **Orient towards the future:** Track both immediate results and signals that solutions will persist, diffuse, and remain effective over time. Look for signals of adaptive capacity and resilience [16] [17].
- **Ground decisions in stakeholder engagement and a theoretical framework:** Co-define what sustainability means by engaging diverse stakeholders, especially those most affected in the context being explored. Ground the decisions (about values and indicators) in a theoretical framework that clarifies the purpose of the assessment [18] [19].
- **Identify the contextual boundaries within which solutions must operate**: be transparent about both the ecological limits and equitable distributions that ensure legitimacy and justice across who benefits and who bears costs. Clearly articulate progress towards what and for who, ensuring the means do not become the end of the analysis, and helping to identify realistic leverage points [10] [20].

Overall, addressing KVIs for sustainability (KSIs) requires adopting a holistic, multi-level framework that aligns strategies across individual, organizational, and policy levels. This includes addressing immediate downstream needs (e.g., providing devices or training) while

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simultaneously tackling upstream structural barriers (e.g., funding broadband expansion or reforming policy) to achieve lasting change.

These principles provide the strategic foundation for engaging KVIs to support sustainability assessment. This requires actions on two fronts:

- Projects should be responsible for providing early proof of directionality (securing the KSI signals), often grounded in a theoretical framework.
- Institutional/funding bodies should be responsible for long-term follow-up and scaling, often grounded in governance and strategic policy.

Operationalising The Shift from Value to Sustainability

This section offers a proposal for how to operationalise the KSI principles into practice, by working through a scenario based on equitable access to/from 6G and presenting examples of how each of the principles can be enacted in indicator planning. The goal is to set a high bar for sustainability proof without making the process so demanding that it becomes impossible to meet. It also tries to translate the principles into something actionable.

The following steps outline how project teams can begin generating early evidence of sustainability directionality:

1. **Frame your sustainability ambition and boundaries:** What change are you pursuing and over what timeframe? What are the non-negotiable success conditions?
2. **Scope relevant sustainability elements:** Map which values and related socio-technical enablers (equity and justice, ecological limits and regeneration, circularity, decent work and inclusion, etc.) your work directly or indirectly affects.
3. **Assess interdependencies and trade-offs**: Plan how you'll interpret indicators in relation to each other, how do improvements in one area create consequences in others?
4. **Design a future-oriented indicator set**: Select indicators that cover multiple sustainability dimensions (societal, ecological, economic) and multiple time horizons (immediate outcomes + signals of durability, diffusion, and long-term viability).
5. **Integrate complementary assessment methods**: Integrate diverse approaches (quantitative metrics, qualitative assessment, stakeholder engagement) to capture sustainability's complexity.
6. **Establish governance for ongoing learning**: Create mechanisms for regular review: who assesses progress, when, and how do findings influence project decisions and direction?

Further Articulation with Examples

Step 1: Frame Your Sustainability Ambition and Boundaries

Before selecting indicators, clarify what sustainability means in your project's specific context: what type of change you aim to influence, over what timeframe, and why these elements are priorities. This initial framing establishes both a compass for interpreting future impact and a foundation ensuring indicator selection is driven by a clear, realistic, and legitimate vision of change.

- **Type of sustainability change:** Articulate whether your project is optimizing within current systems (e.g., improving efficiency), reforming governance (e.g., changing how decisions are made), or contributing to a transformation (e.g., enabling fundamentally different relationships between technology, society, and the environment).

- **Sustainability timeframe and pathway:** Define the immediate outputs you expect within the project period and the longer-term changes your work might enable through specific mechanisms.
- **Grounding Priorities for Legitimacy:** Discuss your framing with key stakeholders, especially those most affected by the sustainability challenges you address, to ensure your definition of "better" or "success" aligns with their priorities. Ground these insights in a theoretical framework that offers a systemic view.

Example Step 1

Type of sustainability change: A project developing energy-efficient network protocols is primarily optimizing within current sustainability constraints (reducing energy per data unit). However, it could contribute to sustainability transformation if the protocols enable fundamentally different network architectures, such as low-power designs that make connectivity viable in resource-constrained settings, expanding equitable access.

Sustainability timeframe and pathway: Immediate outcomes might include X% energy reduction per gigabyte transmitted (measurable within 3 years). Longer-term sustainability changes could include deployment in underserved regions where lower energy requirements reduce infrastructure costs and enable connectivity for currently excluded communities, adoption by diverse types of network operators (not just major telecom companies), or rebound effect mitigation that ensures efficiency gains lead to reduced total consumption rather than increased use. These do not have to be outcomes you can achieve within the project, but they define where you are trying to contribute.

Grounding Priorities for Legitimacy: Engaging with network operators, communities facing digital exclusion, and environmental groups might reveal different priorities. If community stakeholders emphasize that access barriers are more urgent than incremental efficiency gains in already-connected areas, this suggests you need indicators tracking deployment feasibility and actual access in underserved regions, not just peak performance metrics. If environmental stakeholders demonstrate that rebound effects are the critical concern, this suggests you need indicators measuring total system energy consumption and usage patterns, not just per-unit efficiency. These stakeholder insights should directly shape which indicators you select and prioritize.

Why not just use SDGs or EU 2050 targets directly? While high-level frameworks like the Sustainable Development Goals (SDGs) provide essential guidance, they operate at a national and global scale. Simply mapping your work to "SDG Goal X" fails to explain the specific mechanism linking a technical improvement to a sustainability outcome. You must articulate how your technical achievement is supposed to create sustainability change in order to select the right evidence and indicators.

A project could claim to address SDG 9 (Industry, Innovation and Infrastructure) by developing more efficient network protocols. But there is a critical step between the technical achievement and the sustainability contribution: how does this efficiency actually change systems in sustainable directions? You need to articulate the mechanism: Does the efficiency enable network deployment in areas where energy costs previously made it unviable, expanding access? Does it enable edge computing architectures that reduce reliance on energy-intensive centralized data centers? Without specifying this mechanism, "how" it contributes, it is not possible to determine what evidence (e.g. indicators) are needed. The indicators needed to track whether efficiency is enabling connectivity in underserved areas are completely different from indicators tracking total system energy use or architectural shifts.

Step 2. Scope Relevant Sustainability Elements

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It is next important to connect a project's ambition to concrete aspects of sustainability across the societal, environmental, and economic pillars. This will involve mapping which sustainability elements the work directly or indirectly affects each dimension. This helps determine which impacts are central and which are peripheral, guiding focused indicator development. For each relevant element, clarify the key questions your indicators need to help answer. The framework uses the Triple Bottom Line as a foundation but requires identifying specific elements within each dimension and articulating what you need to assess.

A note: This activity is grounded in systems thinking, which can be complex. However, such an approach is valuable to frame and understand the sustainability challenge at hand. Once established, it is possible to argue for which reductionist approaches, focusing on simpler and narrow issues, are more appropriate to act on [79]. Only then can the narrower actions be justified and legitimised. While balanced assessment across dimensions is ideal, focus on elements your project meaningfully affects. It is better to deeply assess 2-3 relevant elements, with a strong grounding as to why those two are priority (rather than convenient) than superficially check boxes across all three dimensions.

How this could be done:

- **Impact pathway mapping:** Work backward from your intended change to the current state to identify which elements are preconditions for the outcomes. For example, energy efficiency only improves access if affordability is the primary barrier.
- **Documenting reasoning:** Create a sustainability scope document explaining why you selected certain elements and excluded others, ensuring transparency.
- **Checking for systemic connections:** Use frameworks like the SDGs as prompts to identify interdependencies. If you address one goal, which others does it connect to? Ground these connections in existing research.

Example Step 2 (not a full scoping document, preliminary entry points only)

Sustainability Pillar	***Key Elements to Map (Examples)***	***Questions (Examples)***
Societal	e.g. Equity and Justice, Access and Inclusion, Wellbeing, Capacity Building, Decent Work.	Who benefits and who bears costs? Does the work reduce or reinforce inequalities? Are marginalized groups included? Does it build local capacity or create dependencies?
Environmental	e.g. Ecological Limits and Regeneration, Circularity, Resource (including energy) Efficiency, Life Cycle Impacts, Biodiversity	Are there rebound effects that increase total consumption? Does the code require frequent hardware upgrades (driving e-waste)? Can it run on existing/older hardware (extending device lifespans)? Does it enable or hinder device repair and reuse?
Economic	e.g., Economic Viability, Market Diffusion, Decent Livelihoods.	Is the solution economically sustainable beyond project funding? Does it create quality economic opportunities? Can it diffuse to those who need it most? Does it build or extract value?

Preconditions: marginalised groups are included in the design decisions, network demands are addressed so that rural areas have equal service as urban areas, e-waste is reduced so people can keep their devices, device compatibility with new services, reliable power structure, affordable data plans, digital literacy and cultural relevance, trust in the technology and service providers.

Step 3: Assess Interdependencies and Trade-Offs of the sustainability Elements

Sustainability is systemic, and progress in one area often comes with consequences (positive and negative) elsewhere. Sustainability cannot be understood by looking at dimensions in isolation. Trade-offs between different sustainability elements, or between a sustainability element and a performance or market driver, are always difficult decisions. Assessing interdependencies and trade-offs helps reveal where progress in one area may create challenges or opportunities in another, and where leverage points exist for systemic benefits or risk harms. It also helps clarify priority and success models. Every action has impacts and consequences elsewhere in the system that need to be acknowledged to really propel a benefit forwards.

Example Step 3

Value	Connection to Inclusivity and 6G
Digital Literacy & Skills	Exclusion deepens if skills do not match the tech, and communities either cannot use what is provided or can't maintain it
Energy Consumption & Efficiency	Expanding access (societal) must not lead to unmanageable energy demand or emissions increases
Resource Conservation	Low-income users often rely on older, less-efficient devices, creating a cycle of digital and material waste exclusion.
Affordability & Cost	Inclusivity is impossible if the technology is too expensive for marginalized groups.
Economic Growth	Inclusivity requires that the economic benefits are accessible to SMEs and rural areas.

Example Trade-Offs relevant to these interconnections:

- **Energy efficiency vs. hardware requirements:** If achieving efficiency gains requires newer hardware with specialized chips, you may reduce per-unit energy but increase e-waste and deployment costs, undermining both ecological circularity and economic accessibility goals. Monitor: Do efficiency improvements correlate with hardware upgrade requirements?
- **Deployment in underserved areas vs. total energy use:** If protocols successfully enable connectivity in new regions, total system energy consumption will increase even if per-unit efficiency improves. This could be acceptable if it advances equity goals, but monitor: Is the energy increase proportional to new access gained, or are rebound effects occurring in already connected areas?

To move beyond immediate social value, assess impacts across all dimensions of sustainability; recognise their interconnections and select based on this. It is important to focus on both the positive (handprint) and negative (footprint) impacts as part of this.

How this could be done:

- **Work through pre-existing literature:** Research how the areas you aim to improve relate to other sustainability dimensions to understand the holistic conditions needed for impact.
- **Create a Trade-Off Matrix:** Early in the project, document the potential positive and negative impacts for every major intended gain. For example, an energy-saving

innovation may have consequences for social equity or create new capacity-building risks. Pre-agree on the acceptable bounds for any negative trade-offs.

Step 4. Design a Future Oriented Indicator Set

Indicators turn intentions into evidence. Designing a multi-dimensional indicator set ensures you are tracking immediate outcomes and early signals of long-term sustainability capturing not just efficiency gains but also the durability and systemic effects of your work.

With interdependencies understood, now select indicators that reflect sustainability across multiple dimensions and time horizons. This ensures your measurement system captures both immediate outcomes and signals of long-term viability. Sustainability assessment requires a framework that considers how present needs are met without compromising the ability of future generations to meet theirs. The key challenge is finding early evidence a project can provide that shows it actually bends the curve on a sustainability problem. While measures within a project cannot provide evidence of actual outcomes after deployment (e.g. it is not possible to measure lives saved or livelihoods improved), there can be proxy indications of future sustainability. Design a set that covers multiple time horizons and tracks both direct project outputs and indicators of macro-level change.

Example Step 4

Pillar	KVs	**Immediate outcomes** (within project period)	**Longer-term signals** (measurable within project, indicative of future sustainability)
Social	Access and inclusion	KVI: Number and diversity of operators participating in pilot deployments (adoption breadth signal)	KSI: Interest and capacity assessment from community/small operators: Are they engaged in pilots and do they have pathways to adoption post-project? (proxy for future equitable diffusion) KSI: Documented barriers to access in target communities: are these being addressed or remain unchanged? (proxy for if access can lead to inclusion)
Economic	Economic viability in low-resource settings	KVI: Deployment cost per user in low-resource settings compared to conventional protocols (viability indicator)	KSI: Presence of sustainable business models: have any pilot operators identified viable economic pathways beyond project funding? (proxy for durability) KSI: Engagement from diverse operator types: are major telecoms AND community networks involved, or just one type? (proxy for market concentration vs. distribution)
Environmental	Energy efficiency and life-cycle impacts	KVI: Energy consumption per gigabyte transmitted in test deployments (technical efficiency baseline)	KSI: Hardware compatibility: can protocols run on existing infrastructure versions, or do they require upgrades? (proxy for resource conservation) KSI: Stakeholder assessment of rebound risk: do operators/users anticipate efficiency enabling increased consumption or reduced total use? (indicates circularity potential and deployment barriers)

Start from existing, established indicators, when possible. Which indicator sets already capture elements relevant to sustainability? Which need to be extended or reconfigured to reflect durability, diffusion, or systemic alignment? Which can be translated to the 6G ecosystem?

Step 5: Design Indicators that require Complementary Assessment Methods

No single metric can capture sustainability. Combining quantitative, qualitative, and participatory approaches provides a richer, more credible picture of progress, helping projects understand both what is changing and why it matters, which help to identify what to focus on.

Sustainability's complexity requires integrating different types of evidence and perspectives that reveal different dimensions of change. Combining different methods ensures that the full picture of change is captured, e.g., what happens, how it happens, and for whom. This can draw upon, among others: quantitative metrics, qualitative assessments, participatory evaluation, systems mapping, comparative analysis, life-cycle assessments, societal readiness assessments, social return on investment, as many more.

Why multiple methods matter:

- Quantitative metrics show *what* and *how much*
- Qualitative methods reveal *why*, *how*, and *for whom*
- Participatory approaches ensure *relevance* and *legitimacy*
- Systems perspectives uncover *structural factors* that enable or constrain change

How this could be done:

Example Step 5

Combining methods: Track energy consumption and deployment costs quantitatively while conducting qualitative interviews with diverse operators, especially smaller, rural, or community-based providers, about real-world barriers to adoption. Use participatory workshops with underserved community stakeholders to interpret what viable deployment and accessible connectivity actually mean in their contexts. Numbers alone will not reveal whether cost reductions translate to equitable access given local economic conditions, infrastructure gaps, or capacity constraints.

Tracking patterns over time: Do not just measure whether you achieved X% energy reduction or cost savings; track whether these gains enable broader adoption across different operator types and geographies. Monitor whether smaller operators show growing interest and capability to deploy, or whether barriers persist despite technical improvements. Assess whether efficiency gains remain stable as protocols scale to diverse environments, including resource-constrained settings.

Integrating perspectives: If quantitative data shows deployment costs decreasing but qualitative feedback reveals that technical complexity, training and literacy requirements, or maintenance burdens remain prohibitive for community networks or rural operators, this integration exposes that cost reduction alone will not achieve equitable access. You may need to prioritize simplified architectures, better documentation, local capacity building, or different deployment models over further technical optimization to ensure 6G reaches underserved populations.

- **Combine measurement approaches:** Use quantitative metrics for tracking performance and scale (energy use, costs, adoption rates), qualitative assessment for understanding context and mechanisms (stakeholder interviews, case studies), and participatory methods for co-defining success and interpreting findings with those most affected.
- **Track patterns, not just points:** Do not just measure whether a target is hit; track the rate of change and stability. Does progress plateau quickly or show sustained momentum? Can gains be maintained under changing conditions? Patterns over time reveal more about sustainability potential than single measurements.
- **Integrate perspectives systematically:** Plan how different methods inform each other. For example, if quantitative data shows deployment costs decreasing, qualitative interviews can reveal whether this makes adoption more likely or whether other barriers remain dominant.

Step 6: Establish Governance for Ongoing Learning

Sustainability is a continuous process of learning and adjustment. Embedding governance and review mechanisms ensures sustainability indicators guide real decisions, shaping the project's direction rather than serving only as post-hoc reporting tools. This principle becomes actions that are not just for projects but for the support structures around them, from funding bodies to expert advisory groups.

To ensure sustainability remains central throughout the project lifecycle, governance structures must turn measurement into learning and course correction. This step embeds review, reflection, and decision-making mechanisms that keep sustainability visible and actionable, not just reported, to ensure continuous learning and accountability for the long-term KSIs.

Some examples of how this could work:

Regular sustainability review cycles: Quarterly team meetings specifically examining sustainability indicators (not just technical milestones). Review all three dimensions together to spot trade-offs early. Standing agenda item should be to ask: "What are we learning about our pathway to equitable access?"

Stakeholder advisory panel: Semi-annual meetings with representatives from community networks, digital inclusion organizations, and environmental groups identified in the stakeholder mapping activities. They review indicator data, provide context on what is changing in their domains, and advise on whether the project remains on a credible sustainability pathway or needs course correction.

Decision triggers: Pre-define what findings would prompt project changes. For example: "If hardware compatibility drops below X%, we revisit protocol design to reduce upgrade requirements," or "If operator diversity decreases, we prioritize simplification and documentation over performance optimization."

Documentation and transparency: Maintain a sustainability assessment log tracking:

- what is being learned,
- trade-offs encountered, and
- decisions made with indicator results.

Share this with funders and broader research community, contributing to collective learning about how R&I projects can pursue sustainability transformation, not just technical innovation.

Integration with technical governance: Ensure sustainability indicators inform technical decisions, not just exist in parallel. When technical teams propose protocol modifications, standard review includes: "How does this affect our sustainability pathway? What do our indicators suggest about this direction?"

Example Step 6

TABLE 1 Example of governance needs

Governance Mechanism	Action	Application Level
Phased Funding	Mandate that second-phase funding requires documented commitment and budget allocation by *two* non-profit partners for deploying the platform in low-income or rural areas.	Project Level
Institutionalized Rolling Follow-Up	A subsequent R&I project receives a small budget to survey the original platform's users 5 years later, measuring long-term gains and *dependency* on external.	Ecosystem Level
Procurement Alignment	Future institutional procurement for 6G technology must use an Equity Check Indicator as a mandatory, weighted criterion.	Policy/National Level

AN INTERCONNECTION EXAMPLE

This section demonstrates how KSIs in the development of 6G are not isolated metrics but are deeply interconnected assessments across social, economic, and environmental dimensions. By using digital inclusivity as an exemplar, we can map how a single policy goal, such as bridging the digital divide, triggers a cascade of effects. This approach shifts the focus from siloed technical performance observations to a holistic value-web, where progress in one pillar (e.g., social sustainability) must be balanced against potential tensions in others (e.g., environmental and economic sustainability).

The Foundation of Digital Inclusivity

Digital inclusivity is no longer defined solely by physical access to a network. Theoretical frameworks, such as the Three-Level Digital Divide, emphasize that inequality persists across three intertwined levels: the first-level (physical and financial access), the second-level (skills and meaningful usage patterns), and the third-level (the ability to derive tangible socio-economic benefits) [21]. Four critical dimensions for vulnerable groups need to be considered: availability, affordability, digital literacy, and content sensitivity [22]. In 6G, this intertwines the need for universal access, strategic infrastructure investment, affordability of services and devices. Digital Inclusivity promises socio-economic benefits, such as economic growth, job opportunities, etc. But it also requires financial investment to support the growth in infrastructures and devices needed to make services accessible. This new infrastructure also could increase the environmental footprint and the potential to generate more e-waste as people upgrade their equipment and devices. In addition, without digital literacy, the capability to navigate advanced 6G interfaces, access remains hollow, failing to translate into the economic growth or social mobility promised by next-generation connectivity. A lack of digital skills acts as a barrier to innovation and security, effectively excluding populations from the societal benefits of ICT, including 6G. Instead of bridging current digital disparities, 6G and related technologies risk reproducing such patterns unless there is inclusive planning [23].

This suggests that the ability to derive tangible benefits for 6G will only widen if the underlying access, literacy, affordability, and resource gaps are not addressed before these new frontiers become mainstream.

Intertwined Features

Based on the above review, operationalising digital inclusivity with a focus on equitable access for 6G, must include indicators from the Social, Economic, and Environmental pillars. The following table illustrates how specific features are fundamentally linked.

Pillar	Feature/Indicator	Connection to Literature & Interdependency
Social	*Skills, literacy, access, availability* KSI combination: - 6G network coverage by income or geographic region - Affordability burden, predicted % of income spent on 6G services - Digital literacy for 6G applications, based on task completion success ratio - % of documented barriers to access in target communities that are being addressed, per external audit	Without high success ratios in literacy, users cannot reach the “Third-Level” of tangible outcomes, regardless of network speed [21].
Economic	Financial *access, affordability* KSI combination: - Cost per gigabit for different user segments - SME access to 6G-enabled services - Ratio of pilot operators identified viable economic pathways beyond project funding	Despite 5G expanding four times faster than its predecessor, infrastructure density has struggled to maintain pace with this growth. This is evidenced by inconsistent coverage and around 20% speed gaps between rural and urban areas in France, Spain, Germany, and even more in the UK, and large 5G availability gaps remain [24]. In Greece, there is a 40% gap [25]. In addition to service barriers, affordability remains key to people getting access to mobile broadband services [76]. But this comes with fears that affordability stands in tension with return on investment for those providing the infrastructure [26].
Environmental	*Energy, resources* KSI combination: - Energy consumption per bit - Predicted E-waste generation from device upgrade cycles - Carbon intensity of networks, via models - Proportion of polled energy policy experts assessing rebound risk as acceptable via Delphi methodology	Universal access requires investment in infrastructure [27]. Expanding digital access grows our ecological footprint by requiring more infrastructure. From base stations to data centres, the entire lifecycle of this hardware (including manufacturing and operation) demands significant energy and raw materials [26] [28].

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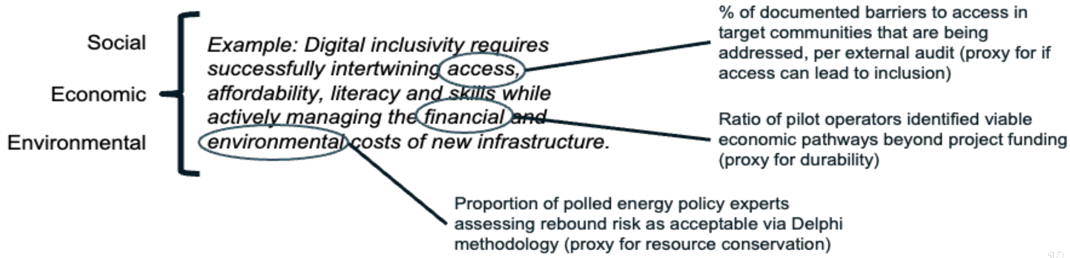
Below is a short summary of the intertwined digital inclusivity issues, both handprint and footprint, that need to be considered. For each of the three pillars, an example social enabler indicator is provided. For equitable access, pair immediate technical indicators with assessments of how design choices address existing barriers. Coverage expansion should be paired with evidence that deployment strategies actively consider and mitigate barriers facing underserved communities. Reduced service costs should be paired with identified economic pathways demonstrating how affordability translates beyond project funding into sustainable access. Decreased energy per bit should be paired with expert assessment of rebound effect risks that could undermine efficiency gains. This approach combines indicators of present capabilities with proxies for future equitable outcomes, ensuring technical progress creates genuine conditions for access rather than theoretical possibility.



References

[1] F. Rohde *et al.*, 'Broadening the perspective for sustainable artificial intelligence: sustainability criteria and indicators for Artificial Intelligence systems', *Curr. Opin. Environ. Sustain.*, vol. 66, p. 101411, Feb. 2024, doi: 10.1016/j.cosust.2023.101411.

[2] D. Podger, E. Hoover, G. Burford, T. Hak, and M. K. Harder, 'Revealing values in a complex environmental program: a scaling up of values-based indicators', *J. Clean. Prod.*, vol. 134, pp. 225–238, Oct. 2016, doi: 10.1016/j.jclepro.2015.08.034.

[3] T. B. Ramos, 'Sustainability Assessment: Exploring the Frontiers and Paradigms of Indicator Approaches', *Sustainability*, vol. 11, no. 3, p. 824, Feb. 2019, doi: 10.3390/su11030824.

[4] M. Oliveira *et al.*, 'Circular Economy and the Transition to a Sustainable Society: Integrated Assessment Methods for a New Paradigm', *Circ. Econ. Sustain.*, vol. 1, no. 1, pp. 99–113, Jun. 2021, doi: 10.1007/s43615-021-00019-y.

[5] B. Gutiérrez-Nieto, J. Camón-Cala, B. Cuéllar-Fernández, and Y. Fuertes-Callén, 'A bibliometric analysis of the social return on investment', *Humanit. Soc. Sci. Commun.*, vol. 12, no. 1, p. 1189, Jul. 2025, doi: 10.1057/s41599-025-05529-w.

[6] T. Calzolari, A. Genovese, and A. Brint, 'Circular Economy indicators for supply chains: A systematic literature review', *Environ. Sustain. Indic.*, vol. 13, p. 100160, Feb. 2022, doi: 10.1016/j.indic.2021.100160.

[7] Social Value International and EY, 'Sustainable Development Goals reporting and the Social Value International framework', 2019. [Online]. Available: https://static1.squarespace.com/static/60dc51e3c58aef413ae5c975/t/60f8030e1ea6a807ba854462/1626866448576/EY-and-SVI-SDGs-UPDATED_11112019.pdf

[8] Social Value International, 'The Relationship between Social Value Principles and the Natural Capital Protocol', 2017. [Online]. Available: https://static1.squarespace.com/static/60dc51e3c58aef413ae5c975/t/60f80344f02e4006ea738677/1626866512352/Discussion_Paper_on_SVP_NCP-FINAL-VERSION-2-1.pdf

[9] L. Drees, R. Luetkemeier, and H. Kerber, 'Necessary or oversimplification? On the strengths and limitations of current assessments to integrate social dimensions in planetary boundaries', *Ecol. Indic.*, vol. 129, p. 108009, Oct. 2021, doi: 10.1016/j.ecolind.2021.108009.

[10] B. Baue, 'Compared to What? A Three-Tiered Typology of Sustainable Development Performance Indicators.', UNRISD Working Paper 2019-5, 2019. [Online]. Available: https://sdpi.unrisd.org/wp-content/uploads/2022/12/Three-Tiered-Typology-for-SDPi.pdf

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[11] B. Purvis and A. Genovese, ‘Better or different? A reflection on the suitability of indicator methods for a just transition to a circular economy’, *Ecol. Econ.*, vol. 212, p. 107938, Oct. 2023, doi: 10.1016/j.ecolecon.2023.107938.

[12] G. A. Aguilar-Hernandez, ‘A Novel Framework to Measure Circularity Trade-offs and Synergies in the Global Context’, *J. Circ. Econ.*, vol. 3, no. 1, Jun. 2025, doi: 10.55845/YTGD9041.

[13] OECD, ‘Better criteria for better evaluation: Revised evaluation criteria definitions and principles for use.’ Dec. 2019. [Online]. Available: https://www.oecd.org/content/dam/oecd/en/publications/reports/2019/12/better-criteria-for-better-evaluation_f7a307eb/15a9c26b-en.pdf

[14] United Nations Environment Programme, ‘Understanding and Managing Interlinkages. Supporting document to the UNEP FI Interlinkages Mapping’. Dec. 2024. https://www.unepfi.org/wordpress/wp-content/uploads/2024/12/Understanding-and-Managing-Interlinkages.pdf

[15] S. Campbell and M. Zellner, ‘Wicked Problems, Foolish Decisions: Promoting Sustainability through Urban Governance in a Complex World Symposium: Governing Wicked Problems’, *Vanderbilt Law Rev.*, vol. 73, no. 6, p. 1643, Dec. 2020, [Online]. Available: https://scholarship.law.vanderbilt.edu/vlr/vol73/iss6/3

[16] European Commission, Directorate-General for Financial Stability, Financial Services and Capital Markets Union, ‘Commission Delegated Regulation (EU) 2023/2772 of 31 July 2023 supplementing Directive 2013/34/EU of the European Parliament and of the Council as regards sustainability reporting standards’. 2023. [Online]. Available: https://eur-lex.europa.eu/eli/reg_del/2023/2772/oj/eng

[17] A. Halsband, ‘Sustainable AI and Intergenerational Justice’, *Sustainability*, vol. 14, no. 7, p. 3922, Mar. 2022, doi: 10.3390/su14073922.

[18] J. Knox-Hayes, S. Chandra, and J. Chun, ‘The role of values in shaping sustainable development perspectives and outcomes: A case study of Iceland’, *Sustain. Dev.*, vol. 29, no. 2, pp. 363–377, Mar. 2021, doi: 10.1002/sd.2152.

[19] M. S. Reed, A. J. Dougill, and T. R. Baker, ‘PARTICIPATORY INDICATOR DEVELOPMENT: WHAT CAN ECOLOGISTS AND LOCAL COMMUNITIES LEARN FROM EACH OTHER’, *Ecol. Appl.*, vol. 18, no. 5, pp. 1253–1269, Jul. 2008, doi: 10.1890/07-0519.1.

[20] IPCC, *Global Warming of 1.5°C: IPCC Special Report on Impacts of Global Warming of 1.5°C above Pre-industrial Levels in Context of Strengthening Response to Climate Change, Sustainable Development, and Efforts to Eradicate Poverty*, 1st edn. Cambridge University Press, 2022. doi: 10.1017/9781009157940.

[21] A. J. Van Deursen and J. A. Van Dijk, ‘The first-level digital divide shifts from inequalities in physical access to inequalities in material access’, *New Media Soc.*, vol. 21, no. 2, pp. 354–375, Feb. 2019, doi: 10.1177/1461444818797082.

[22] M. M. H. Raihan, S. Subroto, N. Chowdhury, K. Koch, E. Ruttan, and T. C. Turin, ‘Dimensions and barriers for digital (in)equity and digital divide: a systematic integrative review’, *Digit. Transform. Soc.*, vol. 4, no. 2, pp. 111–127, May 2025, doi: 10.1108/DTS-04-2024-0054.

[23] WSIS Forum, ‘Inclusive and Ethical ICT Policies for a Sustainable and Equitable Digital Future. Session Outcome Document’, 2025. Available: https://www.itu.int/net4/wsis/forum/2025/Files/View/DOC/b6c0322b5862f01188b8005056a84dbd/outcomedocument_session_413_isu_cub.pdf

[24] Khatri, Hardik, ‘France’s urban-rural mobile experience gap has narrowed with 5G’, Open Signal, May 2024. [Online]. Available: https://insights.opensignal.com/2024/05/07/frances-urban-rural-mobile-experience-gap-has-narrowed-with-5g

[25] OECD, *Closing Broadband Connectivity Divides for All: From Evidence to Practice*. OECD Publishing, 2025. doi: 10.1787/d5ea99b2-en.

[26] Federal Communications Commission, ‘FCC Technology Advisory Council 6G Working Group Report August 5, 2025’, 2025. [Online]. Available: https://www.fcc.gov/sites/default/files/FCC-TAC-6G-Working-Group-Report-2025-Final.pdf

[27] Deloitte and ISPI, ‘The Digital Divide: A Barrier to Social, Economic and Political Equity’. 2025. https://www.ispionline.it/wp-content/uploads/2025/04/Background_Material_Digital-Transition_vShared.pdf

[28] NGMN Alliance, ‘6G Requirements & Design Considerations’, 2023. https://www.ngmn.org/wp-content/uploads/NGMN_6G_Requirements_and_Design_Considerations.pdf