Overview of ICT sustainability standard landscape

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Abstract: This report gives an overview of standards, certification schemes, and governance frameworks that address the environmental impact of internet infrastructure and digital services. It describes the landscape across four layers of the technology stack: hardware, network infrastructure, software and applications, and organizational reporting. It then draws on the wider literature on sustainability certification to identify recurring themes and open research gaps, including weak verification of claims, inconsistent terminology, and limited coverage of the software layer. The report closes with directions for further work on this topic.

Keywords: ICT sustainability, green software, sustainability standards, certification schemes, environmental impact assessment

1 Introduction

Standards and norms that address the environmental impact of the internet apply at different points in the technology stack. This report describes that landscape across four layers: hardware, network infrastructure, application and software, and organizational reporting. Each layer has developed its own instruments, largely independent of the others, which results in a landscape that is broad but not well integrated.

The review draws on standardization body publications (ITU-T, ISO/IEC, ETSI), industry consortium output (Green Software Foundation), and academic literature on sustainability certification more broadly. The aim is to identify recurring themes and open research gaps that can guide further work on ICT sustainability standards.

2 The Standards Landscape by Layer

2.1 Hardware Layer

The hardware layer covers the environmental impact of end-user devices and their manufacturing, use, and disposal. Standards here are the most mature, since they build on decades of product-level environmental labeling outside ICT, such as the Energy Star program that began in the United States in 1992 [Un24]. Devices carrying labels such as EPEAT, TCO Certified, or Blue Angel go through a defined assessment process before manufacturers can apply the mark to a product [IE09; RA24; TC24]. These schemes cover criteria such

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as energy consumption during use, material composition, and end-of-life recyclability. Underlying assessment methods draw on ISO 14040 and 14044, the life cycle assessment standards, which give a general method for calculating a product's environmental footprint from production to disposal [In06a; In06b].

Because hardware labeling follows an established product certification model, it is the layer with the clearest assessment process. An independent body tests the product against fixed criteria before the label is granted. This makes hardware standards comparatively easy to verify against their own stated procedures, though the criteria themselves vary between schemes and are not harmonized.

2.2 Network Infrastructure Layer

The network and facility layer addresses the energy used to run data centers, telecommunications networks, and the broader physical infrastructure that carries internet traffic. The main metric here is Power Usage Effectiveness (PUE), which compares total facility energy use to the energy used by computing equipment alone [CE19; In16]. PUE is referenced by frameworks such as the EU Code of Conduct for Data Centre Energy Efficiency, a voluntary scheme that sets efficiency targets for data center operators in Europe [Eu24a].

The International Telecommunication Union's Study Group 5 (ITU-T SG5) develops Recommendations for this layer, including methodologies for assessing the environmental impact of ICT at city and organizational scale [In14; In23a]. ETSI runs a parallel effort through its Industry Specification Group on Operational Energy Efficiency for Users (ISG OEU), which brings together ICT users across sectors to define key performance indicators and reference specifications for infrastructure efficiency [ET11; ET24]. Unlike hardware labels, these instruments are mostly voluntary and not tied to a product certification process, so adoption depends on operators choosing to report against them rather than a mandatory audit.

2.3 Application and Software Layer

The application and software layer is the newest and least established. Unlike hardware or facilities, software has no physical form to send to a testing lab, which made it difficult for a long time to define a comparable measurement approach. The Software Carbon Intensity (SCI) specification, developed by the Green Software Foundation and now published as ISO/IEC 21031:2024, addresses this gap [Gr24b; In24]. SCI expresses a software system's carbon emissions as a rate per functional unit, for example per user or per transaction, rather than as a total figure. The calculation combines energy consumption, the carbon intensity of the energy source, and embodied emissions from the hardware the software runs on [Gr24b].

Because SCI is a calculation method rather than a certification, it does not by itself verify compliance with any criteria. Organizations calculate their own score and can choose whether and how to disclose it. Other software-layer standards, such as the GHG Protocol's own guidance and emerging work like the Software Water Intensity project, are at an earlier stage of adoption [Gr24a; Wo04]. This intersects with the network layer: a software system's carbon intensity depends in part on the PUE and grid intensity of the infrastructure it runs on and the network activity it causes, which links the two layers conceptually.

2.4 Organizational and Governance Layer

The organizational layer covers how companies and public bodies report and manage their overall ICT-related environmental impact, and how regulation shapes that reporting. ISO 14064 provides a general method for quantifying and verifying greenhouse gas emissions at the organizational level, which ICT companies can apply alongside sector-specific guidance [In18; In19]. ITU-T Recommendation L.1471 gives guidance for ICT organizations setting net-zero targets [In23b], and L.1470 defines emissions trajectories for the sector consistent with the Paris Agreement [In20].

Regulation interacts with this layer. The EU's Corporate Sustainability Reporting Directive (CSRD) creates mandatory reporting obligations that apply to digital infrastructure and services among other business activities [Eu22]. The EU AI Act requires providers of general-purpose AI systems to report energy consumption, though it does not currently mandate a standardized method for calculating that figure or require public disclosure [Eu24b]. This creates space for voluntary standards such as SCI to serve as a measurement method that organizations can use to meet a reporting requirement that the regulation itself leaves open.

2.5 Normative References Between Standards

A standard's text often points to another standard for its assessment method, its criteria, or its reporting basis. Such a pointer is a normative reference: to apply the standard, an organization must also apply the standard it references, not merely read it for background.

Based on the assumption that these normative references give a good impression of how standards interact, we extracted the normative references from available ISO 14000 and ITU-T L.1400 series standards and constructed graphs with standards as nodes and normative references as directed edges.

This examination started from the twenty ITU-T Recommendations in the L.1400 series and the forty-eight standards of the ISO 14000 family. Ten of the ITU-T Recommendations are guidance documents rather than a Recommendation or Methodology, and were excluded, since they carry no normative references of their own and are not built on the same assessment-method basis as the rest of the series. Among the remaining standards, some were dropped because no local file or public preview reached their normative references clause, so their references could not be confirmed against primary text. Others were dropped because they carry no normative references of their own and are also never cited by any other standard in the set, leaving them disconnected from the network entirely.

Figure 1 shows the normative reference network among the retained ISO 14000 standards on their own. Figure 2 shows the retained ITU-T L.1400 Recommendations together with the ISO standards they cite directly. These connections are via ISO 1440, 14044 and 140641–2. These standards contain the foundations of eco-balancing (ISO 14040), requirements and guidelines (ISO 14044), and principles and requirements on how to quantify and report GHG emissions on an organizational (ISO 14064-1) and project level (ISO 14064-2). This shows the common methodological and conceptional foundation. of the two series.

3 Certification, Labeling, and Policy Context

A separate body of standards translates measurement into consumer- or procurement-facing claims: eco-labels, audits, and certification marks. These schemes aim to make sustainability claims comparable and verifiable, similar to energy labels for household appliances. The literature on certification schemes in general, not limited to ICT, treats these instruments as tools for reducing uncertainty for buyers and signaling compliance to regulators [Tu26].

Standards increasingly sit inside a regulatory context. The EU AI Act and the CSRD, described above, illustrate how voluntary technical standards interact with binding legal requirements, and how organizations use standards to demonstrate compliance [Eu22; Eu24b].

Literature on certification schemes across sectors, not specific to ICT, describes a fragmented landscape: many overlapping standards, limited alignment with international benchmarks such as the ISO 14000 series, and slow movement toward harmonization rather than full convergence [CPD24]. This pattern appears in ICT sustainability as well, where organizations face a wide range of standards, labels, and reporting frameworks with no single authoritative reference point.

4 Research Gaps

- **Verification and transparency.** Sustainability claims in ICT, particularly around software and services, are difficult to verify independently. Assessment procedures and underlying data are often not disclosed, which limits the ability of researchers or practitioners to check claims against a standard's own criteria [Tu26].
- **Underrepresentation of certification research.** Systematic reviews of sustainability certification research, across sectors, find that certification and standards

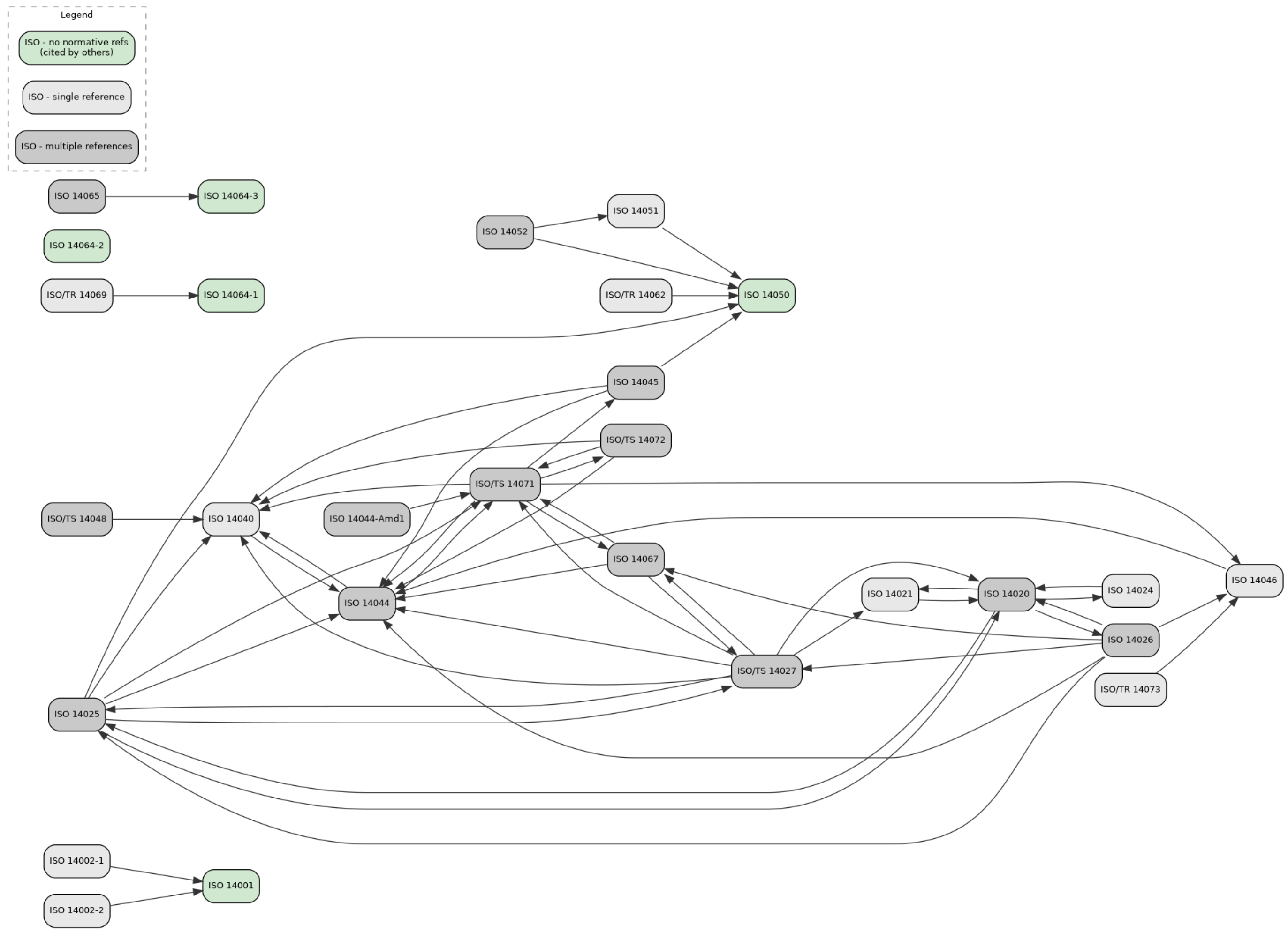

Fig. 1: Normative references of ISO 14000 family standards

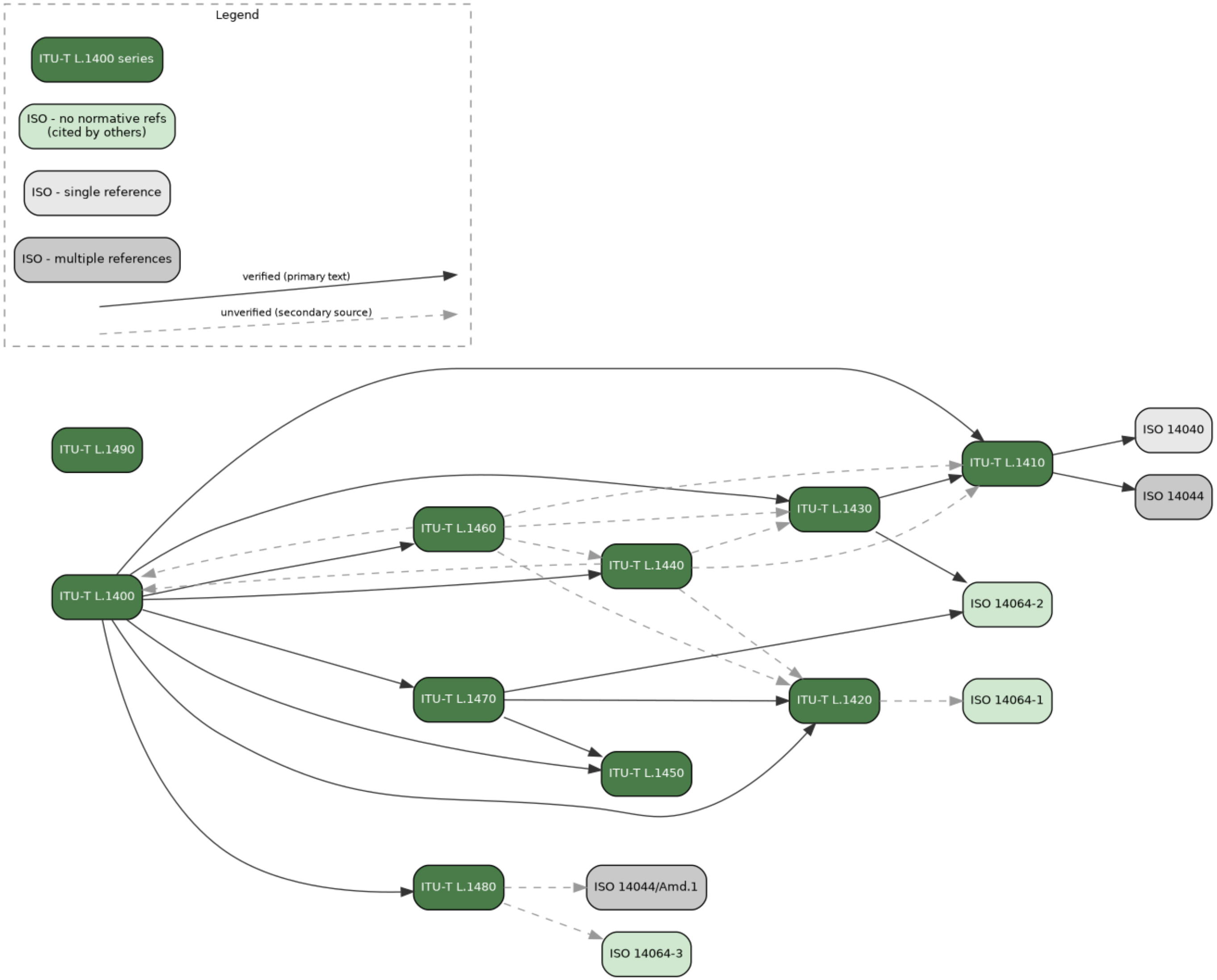

Fig. 2: Normative references of ITU-T L.1400 series and ISO 14000 standards

remain a smaller research area compared to related themes such as corporate social responsibility or sustainable innovation, despite growing practical relevance [CPD24].

- **Software and network layer coverage.** Most mature, widely adopted standards address hardware, facilities, or organizational reporting. Standards that address the software and application layer directly, such as SCI [Gr24b; In24], are newer and less established. This leaves a gap in the literature around how software-level standards interact with the infrastructure-level standards that came before them.
- **Practitioner validation.** Standards and taxonomies developed through desk research or expert consultation are often validated through peer review and conference presentation, but rarely through structured engagement with practitioners who would apply them. This limits evidence on real-world usability of the standards [PPI26].

5 Key Findings

- Standards for greening the internet operate at multiple, only loosely connected layers: hardware and device, data center and network infrastructure, software and applications, and organizational reporting. No single standard spans all four layers.
- ITU-T is the main source of formal international standards for ICT environmental impact, but adoption and enforcement vary because most ITU-T Recommendations are non-binding.
- The move toward software-specific carbon accounting (SCI, ISO/IEC 21031) is recent, reflecting a shift from a focus on hardware efficiency toward the emissions caused by how software is written and run [Gr24b; In24].
- Across sustainability certification research generally, fragmentation and lack of harmonization are recurring, well-documented problems, not unique to the ICT sector [CPD24; PPI26].
- Transparency of assessment procedures and underlying data is repeatedly identified as a limiting factor for the credibility of sustainability claims, both in ICT-specific work and in certification research more broadly [Tu26].

6 Directions for Further Work

Further work on this topic should first define scope: which layer or layers of internet infrastructure it addresses (hardware, network, software, or organizational level). It should then position its contribution against the gaps listed in Section 4, for example verification, software-layer standards, or practitioner validation, and justify that gap with the certification and digital sustainability literature cited here, which shows these are recognized, ongoing problems rather than isolated observations.

7 Conclusion

The standards landscape for ICT sustainability is broad but fragmented. Hardware standards are the most mature and the easiest to verify. Network, software, and organizational standards are newer, increasingly shaped by regulation, and rely more heavily on self-reported data. Closing the verification gap and connecting the four layers into a more coherent system remain open problems for both standardization bodies and researchers.

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