International Telecommunication Union
Standardization Sector

Recommendation

ITU-T L.1070 (11/2023)

SERIES L: Environment and ICTs, climate change, e-waste, energy efficiency; construction, installation and protection of cables and other elements of outside plant

E-waste and circular economy

Global digital sustainable product passport opportunities to achieve a circular economy

ITU-T L-SERIES RECOMMENDATIONS

Environment and ICTs, climate change, e-waste, energy efficiency; construction, installation and protection of cables and other elements of outside plant

OPTICAL FIBRE CABLES	L.100-L.199
Cable structure and characteristics	L.100-L.124
Cable evaluation	L.125-L.149
Guidance and installation technique	L.150-L.199
OPTICAL INFRASTRUCTURES	L.200-L.299
Infrastructure including node elements (except cables)	L.200-L.249
General aspects and network design	L.250-L.299
MAINTENANCE AND OPERATION	L.300-L.399
Optical fibre cable maintenance	L.300-L.329
Infrastructure maintenance	L.330-L.349
Operation support and infrastructure management	L.350-L.379
Disaster management	L.380-L.399
PASSIVE OPTICAL DEVICES	L.400-L.429
MARINIZED TERRESTRIAL CABLES	L.430-L.449
E-WASTE AND CIRCULAR ECONOMY	**L.1000-L.1199**
POWER FEEDING AND ENERGY STORAGE	L.1200-L.1299
ENERGY EFFICIENCY, SMART ENERGY AND GREEN DATA CENTRES	L.1300-L.1399
ASSESSMENT METHODOLOGIES OF ICTS AND CO2 TRAJECTORIES	L.1400-L.1499
ADAPTATION TO CLIMATE CHANGE	L.1500-L.1599
CIRCULAR AND SUSTAINABLE CITIES AND COMMUNITIES	L.1600-L.1699
LOW COST SUSTAINABLE INFRASTRUCTURE	L.1700-L.1799

For further details, please refer to the list of ITU-T Recommendations.

Recommendation ITU-T L.1070

Global digital sustainable product passport opportunities to achieve a circular economy

Summary

Recommendation ITU-T L.1070 provides an overview of global and common opportunities to represent sustainability, mainly environmental related (including human health), details about digital technology products, either collective information and communication technology (ICT) product models, batches or individual product items. These product details are intended for representation in digital format instead of on paper. The details can represent design-related information, products at the time of manufacturing, including relevant information for product transparency and a potential for a circular lifecycle, such as details related to the origin of materials composition, design, manufacturing, energy consumption, maintenance, repair, preparation for reuse, final recycling and may include links to related documentation. Product details can include or relate to information that changes over the lifespan of a product as a result of reconfiguration events, including repair, upgrade, usage, sale and final recycling. The details should exclude any personal or business-sensitive information.

Recommendation ITU-T L.1070 provides an overview of sustainability opportunities, environmental related, about product-related digital information common to all ICT products, with global scope for harmonization, i.e., relevant to any region, that can support the development of the circular economy of ICT products. Product-related digital information can be represented under digital technology, such as product identifiers, data formats, linked data and system architectures. It relates to and can complement regional and global standards.

History*

Edition	Recommendation	Approval	Study Group	Unique ID
1.0	ITU-T L.1070	2023-11-06	5	11.1002/1000/15598

Keywords

Digital, digital product passport, environmental sustainability, ICT, product details.

* To access the Recommendation, type the URL https://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID.

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications, information and communication technologies (ICTs). The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

Compliance with this Recommendation is voluntary. However, the Recommendation may contain certain mandatory provisions (to ensure, e.g., interoperability or applicability) and compliance with the Recommendation is achieved when all of these mandatory provisions are met. The words "shall" or some other obligatory language such as "must" and the negative equivalents are used to express requirements. The use of such words does not suggest that compliance with the Recommendation is required of any party.

INTELLECTUAL PROPERTY RIGHTS

ITU draws attention to the possibility that the practice or implementation of this Recommendation may involve the use of a claimed Intellectual Property Right. ITU takes no position concerning the evidence, validity or applicability of claimed Intellectual Property Rights, whether asserted by ITU members or others outside of the Recommendation development process.

As of the date of approval of this Recommendation, ITU had not received notice of intellectual property, protected by patents/software copyrights, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the appropriate ITU-T databases available via the ITU-T website at http://www.itu.int/ITU-T/ipr/.

Table of Contents

Introduction

The 2005 World Summit on Social Development [b-UN 2005] identified sustainable development goals (SDGs) with three pillars: economic development; social development; and environmental protection. The economic pillar has to do with trade. The social pillar has to do with people: workers; users; and other people and collectives affected. The environmental pillar has to do with the challenges of consuming materials to produce products and energy to power them, their use, the production of electrical and electronic waste (e-waste), and any indicators related to positive and negative effects on people and nature.

In the context of sustainability, Agenda 2030 [b-UN 2015] establishes a shared blueprint for peace and prosperity for people and the planet, now and into the future. It specifies SDGs for social, economic, and ecologically sustainable development [b-UN 2021].

There are well-defined targets for the climate crisis. The Intergovernmental Panel on Climate Change (IPCC) specifies the different trajectories, specifically compliance with the 1.5°C objectives described by the IPCC Special Report on 1.5°C [b-IPCC 2018]. To meet this goal, the world should cut emissions to net zero by 2050.

ITU defined the Connect 2030 Agenda with Goal 3 on Sustainability, where ITU recognizes the need to manage emerging risks, challenges and opportunities from the rapid growth of information and communication technology (ICT). There are several initiatives to speed up reductions in environmental impact like SDG 2030 (United Nations Environment Programme (UNEP)), Race to Zero (26th UN Climate Change Conference of the Parties (COP26)), NetZero, and science-based targets. Data is needed to implement these initiatives.

The Aarhus convention [b-UNECE Aarhus] and the related Escazu agreement [b-UNECLAC Escazu] recognize environmental rights related to access to environmental information and the need for mechanisms to render these rights effective.

ICT products (electrical and electronic equipment such as routers, switches; consumer products like smartphones) have environmental, social and economic impacts at each stage in their lifecycle, starting from the supply chain, including the reverse supply chain, ending as e-waste at end-of-life. It has to do with energy, natural resource consumption and emissions of various kinds, to name a few.

Currently, more than 6 billion new ICT products are sold annually worldwide. There are estimates of 1.5 billion smartphones [b-Statista] in 2021, 126 million desktop computers, 659 million laptops, and 513 million wireless fidelity routers produced every year (2021). These numbers are expected to grow over the next 5–10 years with new "smart" technologies [b-ITU-T L.1024].

As a result of growing production and sales, e-waste is one of the fastest growing waste stream, most of it discarded in the municipal waste stream, leading to a loss of secondary resources [b-UNU] valued at US$57 billion in 2019 (more than the gross domestic product of many countries) Additionally, e-waste is often shipped illegally to developing countries [b-UN 2010].

The contribution of ICT in terms of electricity use is a significant factor: by 2030, ICTs may use a larger share of global electricity and globally released greenhouse gas (GHG) emissions [b-Andrae 2020a]. Clean sources of energy and locality can nevertheless help reduce GHG emissions [b-Amponsah].

However, for some ICT products, upstream activities of raw material acquisition, transport and production contribute most to the environmental impact [b-Andrae 2016].

In contrast, ICTs can enable vast efficiencies in social and economic life through digital solutions that can improve energy efficiency, inventory management, and reduction of travel and transportation impacts (e.g., telework and videoconferencing, substituting physical products with digital information). This capacity is referred to as second-order or enablement effects.

[b-ITU-T L.1470] defines GHG emissions trajectories for the ICT sector as compatible with the United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement**.** Therefore, the digital world is part of the problem and may be part of the solution.

The circular economy (CE), and the term circularity, is about "designing out waste and pollution, keeping products and materials in use, and regenerating natural systems" [b-EMF-B]. In the context of ICT products, circularity aims to achieve the best use of ICT products with maximal lifespan, which helps decarbonize the environment. A circular approach in the electronics industry is widely accepted as the required transformation to move away from a linear "take-make-waste" model of production and consumption [b-EMF-A].

With a focus on environmental sustainability and circularity in the DPP for ICT products, this Recommendation presents:

- the description of the scope of the digital product passport (DPP) in clause 6;
- the description of DPP opportunities;
- the definition of the required ICT product types to consider in DPPs;
- the definition of required principles and properties of digital product information in DPPs, all in clause 7;
- the feasibility of implementing these opportunities in a global DPP system is discussed in clause 8.

This Recommendation provides a basis for other DPP standards about detailed information models for ICT products, specific ICT product categories, as well as regional and global DPP standards.

This Recommendation was developed jointly by the European Telecommunications Standards Institute Technical Committee Environmental Engineering (ETSI TC EE) and ITU-T Study Group 5. It is published as Recommendation ITU-T L.1070 and [b-ETSI TS 103 881], which are technically equivalent, by ITU and ETSI, respectively.

Recommendation ITU-T L.1070

Global digital sustainable product passport opportunities to achieve a circular economy

1 Scope

This Recommendation specifies a digital product passport (DPP) for information and communication technology (ICT) products to be represented in digital format, including an overview of the opportunities and benefits to include information relevant to sustainability, mainly environmental related, focusing on circularity and transparency.

This Recommendation does not define which items should be filled out for all or different product families in their DPP nor the targets, limits or specific requirements a product has to meet.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T L.1023] Recommendation ITU-T L.1023 (2023), *Assessment method for circularity performance scoring*.

[ITU-T L.1034] Recommendation ITU-T L.1034 (2022), *Adequate assessment and sensitization on counterfeit information and communication technology products and their environmental impact*.

[ITU-T L.1102] Recommendation ITU-T L.1102 (2016), *Use of printed labels for communicating information on rare metals in information and communication technology goods*.

[ITU-T L.1410] Recommendation ITU-T L.1410 (2014), *Methodology for environmental life cycle assessments of information and communication technology goods, networks and services*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 authenticity [b-ISO/IEC 27000]: Property that an entity is what it claims to be.

3.1.2 batch [b-EC 2023]: A subset of a specific model composed of all products produced in a specific manufacturing plant at a specific moment in time.

3.1.3 circular economy [b-ITU-T L.1604]: An economy closing the loop between different life cycles through design and corporate actions/practices that enable recycling and reuse in order to use raw materials, goods and waste in a more efficient way.

NOTE 1 – The circular economy concept distinguishes between technical and biological cycles, the circular economy is a continuous, positive development cycle. It preserves and enhances natural capital, optimizes resource yields, and minimizes system risks by managing finite stocks and renewable flows, while reducing waste streams.

NOTE 2 – Definition adapted from [b-ITU-T L.1022] and [b-ITU-T L.1020].

3.1.4 circularity: Designing out waste and pollution, keeping products and materials in use, and regenerating natural systems.

NOTE – The definition is based on [b-EMF-B].

3.1.5 component [b-ETSI EN 303 808]: Hardware constituent of a product that cannot be taken apart without destruction or impairment of its intended use.

NOTE – A populated printed circuit board may be considered a component and/or a part from the perspective of this Recommendation.

3.1.6 digitalization [b-OECD]: Use of digital technologies and data as well as interconnection that results in new or changes to existing activities.

3.1.7 e-waste; WEEE [b-ITU-T L.1031]: Electrical or electronic equipment that is waste, including all components, sub-assemblies and consumables that are part of the equipment at the time the equipment becomes waste.

NOTE – The terms e-waste and waste electrical and electronic equipment (WEEE) are used interchangeably.

3.1.8 extended producer responsibility (EPR) [b-ITU-T L.1021]: A policy principle to promote total life cycle environmental improvements of product systems by extending the responsibility of the manufacturers of the product to various parts of the entire life cycle of the product, and especially to the take-back, recycling and final disposal of the product.

3.1.9 ICT goods [ITU-T L.1410] or [b-ETSI ES 203 199]: Tangible goods deriving from or making use of technologies devoted to or concerned with: the acquisition, storage, manipulation (including transformation), management, movement, control, display, switching, interchange, transmission or reception of a diversity of data; the development and use of the hardware, software, and procedures associated with this delivery; and the representation, transfer, interpretation, and processing of data among persons, places, and machines, noting that the meaning assigned to the data is preserved during these operations.

NOTE – [b-ETSI ES 103 199] uses the word "equipment" instead of "goods".

3.1.10 ID tag [b-ITU-T Y.2213]: A physical object which stores one or more identifiers and optionally application data such as name, title, price, address, etc.

3.1.11 integrity [b-Wikipedia]: The maintenance of, and the assurance of, data accuracy and consistency.

3.1.12 intermediate product [b-EC 2022]: A product that requires further manufacturing or transformation such as mixing, coating or assembling to make it suitable for end-users.

3.1.13 item [b-EC 2023]: A single unit of a model.

3.1.14 model [b-EC 2023]: A version of a product of which all units share the same technical characteristics and the same model identifier.

3.1.15 product [b-EC 2022]: Any physical good that is placed on the market or put into service.

NOTE – ICT goods are ICT products.

3.1.16 refurbishment [ITU-T L.1023]: Industrial process which produces a product from used products without any changes influencing safety, original performance, purpose or type of the product.

NOTE – New and/or used parts can be used during refurbishment. The definition is based on [b-ETSI EN 303 808].

3.1.17 remanufacturing [ITU-T L.1023]: Industrial process which produces a product from used products or used parts where at least one change is made which influences the safety, original performance, purpose or type of the product.

NOTE – The product created by the remanufacturing process may be considered a new product when placing on the market. The definition is based on [b-ETSI EN 303 808].

3.1.18 repair [b-ITU-T L.1022]: Process of returning a faulty product to a condition where it can fulfil its intended use.

3.1.19 risk [b-EC 2020]: The combination of the probability of occurrence of harm and the severity of that harm limited to human health or safety of persons, to property or to the environment.

3.1.20 servitization [b-ITU-T L.1024]: The process of creating value by adding services to products. In more detail 'the offering in terms of "goods or services" through "goods and services" to the marketing of bundles of "goods + services + support + knowledge + self-service".

NOTE – See [b-Kowalkowski] for a definition as "The transformational processes whereby a company shifts from a product-centric to a service-centric business model and logic".

3.2.21 supply chain due diligence [b-ITU-T L.1061]: The obligations of the economic operator which places a product on the market, in relation to its management system, risk management, third party verifications by notified bodies and disclosure of information with a view to identifying and addressing actual and potential risks linked to the sourcing, processing and trading of the raw materials required for product manufacturing.

3.1.22 sustainable development [b-UN 1987]: Development that meets the needs of the present without compromising the ability of future generations to meet their needs.

3.1.23 tag-based identification [b-ITU-T Y.2213]: The process of specifically identifying a physical or logical object from other physical or logical objects by using identifiers stored on an ID tag.

3.1.24 traceability [b-ISO 9000]: Ability to trace the history, application or location of an object.

3.1.25 tracing [b-van Dorp]: The ability to follow the supply chain upward and determine the source of a product.

3.1.26 tracking [b-van Dorp]: The ability of keeping track of the flows of products transporting from upstream to downstream in a supply chain.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 authenticity: Ability of proving an assertion, such as the identity of a computer system user.

3.2.2 accountability: Equivalent to answerability, liability and the expectation of account reporting, with the obligation to inform about (past or future) actions and decisions, to justify them.

NOTE – Adapted from [b-Dykstra] [b-Schedler].

3.2.3 centralization: Data, function, process, system where a single entity or a small group, has exclusive control or responsibility for it.

3.2.4 collective product: A product batch or product model with common characteristics for multiple product items.

3.2.5 decentralization: Property of data, function, process or system that is not centralized or controlled by a single or few entities.

3.2.6 digital product passport: A structured collection of product-specific data conveyed through a unique identifier.

NOTE – Definition based on European Commission document [b-EC 2022].

3.2.7 digital product passport provision: Process and responsibility of collecting, creating, maintaining, validating, supplementing, storing and delivering data from source(s) to targets, which includes the provision of a service and managing the data related to it.

3.2.8 digital product passport supplier: Any product operator responsible for provisioning (supplying) the associated data that is included in or linked to a digital product passport.

NOTE – Product operator can be a manufacturer, refurbishment service provider or importer who introduces the product to market, whereas an external third party digital product passport (DPP) service provider is not considered as a DPP supplier as they are not primarily responsible for the product details contained in the DPP.

3.2.9 economic operator: Include the manufacturer, authorized representative, importer, distributor, fulfilment service provider, or any legal person with legal responsibility concerning manufacture.

NOTE – Adapted from [b-EC 2020].

3.2.10 global digital sustainable product passport: The subset of a digital product passport, global in regional scope, focused on environmental sustainability aspects.

3.2.11 identity: A unique indication of a person or thing, verified by authentication.

3.2.12 individual product: A product item.

3.2.13 information accessibility: Ability to access and benefit from information to the widest range of actors and situations.

3.2.14 information composability: Ability to combine and assemble self-contained and stateless information components, as with structured linked data.

3.2.15 information confidentiality: A set of rules or a promise to limit access or place restrictions on certain types of information.

3.2.16 information privacy: The relationship between the collection and dissemination of data.

3.2.17 information transparency: Clarity about relevant details, needed for a decision or an assessment.

3.2.18 information verifiability: The ability to review, inspect, audit, test to establish, document and confirm the veracity of an assertion.

3.2.19 linear economy: Cradle-to-grave; the 'take-make-waste' model; i.e., extracting, manufacturing, using and wasting.

NOTE – Paraphrased from [b-ITU-T L.1022].

3.2.20 modular product: A product that, in a container, includes module(s) (component product(s)) that can easily be replaced or added.

3.2.21 product operator: Any actor that can transform and supply modified products and therefore can supply the information a digital product passport conveys about them, as a result of manufacture or other operations.

NOTE – These other operations could be: packaging, configuration, maintenance, repair, upgrade, refurbishment, remanufacturing or recycling.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

ADR International Carriage of Dangerous Goods by Road

CE Circular Economy

CRT Cathode Ray Tube

DGR	Dangerous Goods Regulations
DPP	Digital Product Passport
EPR	Extended Producer Responsibility
EPREL	European Product Registry for Energy Labelling
e-waste	electrical and electronic waste
FAIR	Findable, Accessible, Interoperable and Reusable
GHG	Greenhouse Gas
GHS	Globally Harmonized System
HMIS	Hazardous Materials Identification System
HS	Harmonized System
ICT	Information and Communication Technology
ID	Identifier
LCA	Lifecycle Assessment
PCDS	Product Circularity Data Sheet
PIC	Prior Informed Consent
RID	Regulations Concerning the International Carriage of Dangerous Goods by Rail
SCIP	Substances of Concern In articles as such or in complex objects (Products)
SDG	Sustainable Development Goal
SDS	Safety Data Sheet
TPS	Transactions Per Second
URL	Uniform Resource Locator
WEEE	Waste Electrical and Electronic Equipment

5 Conventions

Generally, ITU-T Recommendations use the term "ICT goods" instead of "ICT products", However, considering this Recommendation is about the DPP, both terms are used interchangeably. Hence the term "product" should be considered synonymous with the term "goods" in this Recommendation.

6 Description and scope of the digital product passport

For ICT products, access to digital information about a product, a DPP, enables or facilitates the activities of product operators, such as manufacturers, buyers, owners, repairers, refurbishers, recyclers, market surveillance authorities, environmental and sustainability auditors, and customs authorities.

A DPP may provide access to digital data, such as linked data, with access to lists, datasheets, manuals and guides, that contain reliable environmental sustainability data. For instance, it can facilitate circulation (maintenance, repair, reuse, recycling tasks) by providing support information for tasks that contribute to extended use.

Access to digital data about products can help diverse organizations exchange and aggregate data records about models and individual products to produce factual or empirical statistics about the durability of products, among other qualities and make recycling and electrical and electronic waste (e-waste) management more accountable and verifiable. The demand for public digital data can result in manufacturers, governments and users implementing voluntary or mandatory reporting and monitoring mechanisms to assess these qualities and become an incentive to design and use more circular ICT products and processes.

Relevant digital information can be anything useful to a product operator, user, member of the general public or researcher into materials, design, usage, maintenance, repair, spare parts, and ways to recover and dismantle components and recycle them. That can be extended to specifications, programming, firmware and software to allow maintenance and usage, even when manufacturers stop maintenance to allow third parties to do so.

Raw materials (including scarce critical raw materials, secondary materials) and the adverse social and environmental risks from the presence of hazardous substances, deserve special attention and require environmental responsibility from product manufacturers to monitor and inform about the social and environmental implications of their supply chain in design and manufacturing, facilitate due diligence by public procurement, as well as regarding the reverse supply chain when products may be reused or are no longer used and should be recycled and materials recovered.

Having all this information related to sustainability and specifically about circularity in digital and standardized format can bring qualities, facilitate and improve many processes, and help citizens, organizations, and governments to assess their environmental footprints and other statistics about the digital and ICT sector. This is a central topic of the idea behind the so-called product information sheets or DPP as part of a sustainable digital transformation of society [b-ITU SDTD] [b-EC 2021]. The global harmonization of sustainability requirements can facilitate regional regulation to all stakeholders to promote circular and sustainable ICT products.

This structured collection of product-related information, represented as digital data, can facilitate and bring transparency about design, manufacturing, use, reuse and recycling processes, such as facilitating impact assessment on the environment. A product passport can help integrate existing and new data, facilitate interoperability across different actors involved, and bring in quality properties such as transparency, traceability, verifiability, and accountability of digital products, infrastructures, and services that lead to sustainable digitalization.

There are related initiatives and standards regarding which product information is relevant from an environmental perspective from several standards' development organizations. These are described in Appendix I.

Different sources and viewpoints influence the design and implementation of DPP systems:

- global environmental sustainability and circular economy (CE) opportunities raised in this Recommendation;
- regional requirements resulting from policy and regulatory choices by governmental actors in different regions;
- the self-regulation choices among the involved actors in the supply and demand of DPPs;
- results from the experience and the evolution of DPP implementations.

A phased introduction of a DPP, driven by regional legislation or regulation by public authorities or multi-stakeholder self-regulation agreements, would enable an early introduction of core product digital information and evolution towards comprehensive information details to promote the most environmentally sustainable products.

7 Circular digital products

The scope of products in this Recommendation is digital technology products (ICT products and their components, electrical and electronic equipment, and e-waste), focusing on circular and sustainable products.

This clause describes stages, challenges and digitalization considerations at different stages and for different actors in the CE, desirable properties of DPP data and the specification of what constitutes a product for the purposes of a DPP in terms of sustainability information.

7.1 Objectives for a circular economy

Three main objectives are recognized for the CE for electronics in [b-WEF PACE]:

1) new products use more recycled and recyclable content;
2) products and their components are used for longer;
3) after the end of the use stage, products are collected and recycled to a high standard.

These objectives translate into eco-design, circular business and ownership models, and more circular e-waste management.

The following list gives some examples of aspects that can support taking CE into use:

- product durability and reliability;
- product reusability;
- product upgradability, reparability, maintenance and refurbishment;
- the presence of substances of concern in products;
- product energy and resource efficiency;
- recycled content in products;
- product remanufacturing and recycling;
- carbon and environmental footprints of products;
- expected generation of waste materials from products.

7.2 Lifecycle stages

Circular digital products undergo several lifecycle stages, specified in [ITU-T L.1410] or the technically aligned [b-ETSI ES 203 199], and face challenges that the digitalization of the lifecycle information supported by a DPP can help with.

The lifecycle stages of ICT products are grouped as goods raw material acquisition, production, use and end-of-life. They can benefit from circularity in diverse ways as follows.

- **Raw material acquisition**: Raw material acquisition starts with extracting natural resources (e.g., iron ore, crude oil, etc.). It ends with transporting raw materials from raw materials processing to part or component production facilities [ITU-T L.1410] or the technically aligned [b-ETSI ES 203 199].
- **Production**: Production or manufacturing starts with parts production, followed by assembly and ends with the transportation of ICT products and support products to use [ITU-T L.1410] or the technically aligned [b-ETSI ES 203 199].
- Design and manufacturing decisions determine the use of primary materials extracted from nature and secondary materials captured from e-waste.
- **Use**: The use stage includes ICT products procurement, sale, use, reuse, repair, modification and other support activities [ITU-T L.1410] or the technically aligned [b-ETSI ES 203 199].
- In the use stage, products can be used and transferred for reuse until they are no longer valid for that purpose. During use, products consume energy, parts can be added or replaced, and suffer from wear and tear and change during an expected long lifespan. The product warranty period, access to product repair, availability of security and software updates, access to repair instructions, repair tools and services, spare parts, consumables, the ability to detect

counterfeit products and parts, and the ability to reuse or single-use nature make a difference in durability and quality of service.

- **End-of-life treatment**: Such treatment starts with the collection and transport of de-installed ICT products or support products to storage, disassembly, parts reuse, dismantling and shredding facilities, and ends with the recycling of raw materials, recovery of secondary materials and final disposal of treated waste ICT and support products [ITU-T L.1410] or the technically aligned [b-ETSI ES 203 199].

7.3 Challenges in the electronics lifecycles

Despite the push towards a CE, with an impetus to systemic improvement and awareness-raising, on-ground implementation challenges hold back more efficient and circular electronics lifecycles. These are, according to [b-ITU 2021], as follows.

- **Insufficient and unreliable data on e-waste flows**: Such as for the determination of fair and effective regulation and policies, realistic collection targets and tailored e-waste management programmes. The Global E-waste Statistics Partnership [b-ITU GESP] helps countries compile data and statistics on e-waste flows using an internationally harmonized measurement framework.
- **Information asymmetry and limited trust**: Such as between suppliers of components, producers and recyclers on product composition, or repairers and recyclers on product components, due to concerns from producers on the confidentiality of their product information, often without mechanisms to verify the data by external parties to limit the risk of fraud.
- **Informal and unreported e-waste**: Such as when the informal sector primarily manages e-waste; regulatory obligations of the ICT products sector, especially under EPR policy schemes, require producers to have visibility over and report the sources of their raw materials and where products end up. The Basel Convention [b-UNEP Basel 1989] requires that hazardous and other wastes in its scope move transboundary by the prior informed consent (PIC) procedure, whereby every shipment should travel with a movement document and the consent of all states concerned in transboundary movement.
- **Insufficient consumer participation and appropriate end-of-life channels**: Such as returning a product to the producer or disposing of it in a municipal e-waste bin. Low worldwide collection and standard recycling rates indicate that a barrier exists.
- **Inefficient e-waste management processes**: Such as those that are costly and complicated as more ICT products are introduced to the market.
- **Insufficient cooperation between stakeholders throughout lifecycles**: E.g., installers change the original hardware configuration of the equipment during installation, users change or upgrade a product with new or altered components, repairers modify a defective product and hence change the composition of a product in use.

7.4 Digitalizing information about ICT product lifecycles

The application of digital technologies, specifically a DPP, can support the transition to a circular electronics industry, helping to address the challenges just introduced and to optimize existing solutions with digitalization, as well as enabling new transformation methods. Such application implies satisfying the needs of all stakeholders. Each actor that creates and modifies products has its own responsibility in contributing to the corresponding product information.

A DPP enables transparency and facilitates traceability implementation in the supply chain across all actors. For instance, digital certification of legitimate parts and components, materials, actors and product tracking, can be used to create a digital chain of custody throughout the lifespan, ranging from primary or secondary materials to e-waste and prevention of the introduction of counterfeit elements with environmental risks [ITU-T L.1034].

These properties are described in more detail in clause 7.5. In terms of the lifecycle stages described previously, the benefits can be as follows.

Raw material acquisition

The raw material acquisition stage can provide transparency and traceability by reporting details of the supply chain in terms of actors involved in material extraction or secondary (recycled) material recovery, processing and tracking, particularly the presence of critical raw materials or hazardous substances and manufacturing waste. For instance, [ITU-T L.1102] allows the communication of information about rare metals.

Production

The production (manufacturing**)** stage can support transparency and traceability by reporting information coming from supply chain actors (e.g., designer, tier 2, tier 1, manufacturer) involved in parts production and assembly. In the design phase, circular design can contribute useful digital data about designed energy efficiency, durability, repairability, reusability, and recyclability. Readily accessible digital information in a DPP for that product can facilitate and even automate processes along the supply chain and product lifecycle, proving compliance with legislation, facilitating market surveillance by public authorities and customs, and supporting sustainability claims. This information will help identify and buy sustainable products.

Use

A DPP can facilitate public procurement by providing standardized informative details, document links, verification details, ecolabels, environmental scorings and energy efficiency labels, to guide due diligence, selection and purchase, and give valuable data to keep track of products in an inventory to manage preventive maintenance and repair.

Precise, detailed and updated product information can facilitate decisions towards increased durability through the use, upgrade, repair and reuse of parts, components or the product, provide information to enable public policies that may restrict single use or prevent the destruction of unsold products, detect premature obsolescence and incentivize servitization.

Regarding the reuse of refurbished and remanufactured products, a DPP can help reduce uncertainty when procuring pre-owned ICT products.

It can facilitate repair, upgrade or refurbishment (repair manuals, spare parts for users or professionals), which helps prevent unnecessary replacement. It can facilitate the collection of empirical repairability metrics, as well as the collection of actual energy consumption measurements in the use stage.

Products with a DPP for collective products, a product model or product batch, can become unique individual product items in the use stage. Circularity and a long lifespan imply processes that modify products that make them unique. They may require product operators to produce an individual DPP that reflects these unique characteristics and changes in a unique product item over the initial model-specific DPP.

ICT products change during the use stage due to usage, reconfiguration of modular products, repair and reconfiguration, and wear and tear that therefore lead to the possibility of dynamic data addition or item level updates for their corresponding individual DPPs. That can increase the divergence and mismatch between the DPP at the production stage and after modifications during the use stage, particularly when these changes affect the environmental performance and composition of a product.

All these processes contribute to product life extension, combined with more circular business models, such as leasing rather than product ownership, product as a service and asset sharing, increasing the longevity of ICT products as they pass through several users before their end of life is reached.

End-of-life treatment

In end-of-life treatment, the collection of products can be improved by providing information to assist in the correct return or disposal of products. Improved recycling can be achieved by having accurate information about materials and other product characteristics that can facilitate or automate triage and prevent environmental risks. Such information includes details of the selection of components to reuse or product remanufacturing, improvements in sorting and pre-treatment of waste to extract secondary materials, treatment and prevention of harm to people and nature from the presence of hazardous substances.

Digitalization supports transition of informal sector workers to the formal system by building capacity and introducing more transparency and accountability with business opportunities that enable social innovation. Specifically, precise and reliable data can help optimize and automate e-waste sorting, dismantling and recycling.

Digital data can facilitate the creation of marketplaces for e-waste, materials and pre-owned products throughout the product life: with platforms for traceable and transparent transactions for e-waste and secondary resources, enabling informal sector integration and mainstreaming. This transparency can inform and facilitate the implementation of public policies to prevent the destruction of unsold or still usable (and reusable) consumer products, or transborder movements of e-waste, which are environmental problems.

Convenient, incentivized, and optimized e-waste collection and takeback help transfer incentives to consumers to dispose of waste responsibly in return for digital rewards. EPR schemes can involve manufacturers in a more efficient, informed and accountable way.

Market surveillance

Authorities in charge of market surveillance or customs authorities should get precise digital information about source attribution for all DPP-covered products in a market: unique product identifiers (IDs; what), unique operator IDs (who), unique facility IDs (where), and additional information, such as information about and verification of regulatory compliance, when relevant and according to regional laws and regulations. Authorities need to interact with the DPP system that represents the market, to verify correctness of product information.

On collecting and maintaining product information

Digital standardized and linked information allows and provides the details required to assess the sustainability impact of ICT products and their supply chain. Specifically, it can bring several benefits as follows.

- **Facilitation of knowledge generation throughout the product life**: Feeding databases and datasets for data integration and analysis, and compliance with national or regional regulations about the right to reuse and repair.
- **Reduced paperwork and administrative burden**: Digitalization can help streamline administrative aspects of the electronics lifecycle in addition to the direct benefits, such as reducing paperwork, record-keeping effort and human error, as well as provision of digitized ways to report product conformity, digitization efforts in the e-waste management sector will improve the accessibility of practical information in that field.
- **The digitalization of information**: Necessary to comply with the PIC procedure for transboundary movements of e-waste under the Basel Convention. In its 2022-2023 Workplan, the Basel Convention Parties established a working group to explore electronic approaches to notification and movement documents [b-UNEP Basel 2021].

- **Creating a digital chain of e-waste custody**: Integration of multiple layers of logistics, administration and approval processes to go into an efficient and effective e-waste management system; digitalization and automation of operations to provide a credible chain of custody, manage inventories, issue recycling certificates, financial calculations, settlements and report creation for compliance purposes.
- **Making monitoring and enforcement more efficient**: Virtual monitoring and auditing processes. Audits, previously carried out in person, are now conducted virtually. Sustainable Electronics Recycling International (SERI) provides advisories for the necessary checks and balances to conduct remote audits [b-SERI]. These digital audits are also helping auditors overcome the stress of continuous physical audits [b-Leif].
- **Building capacity and creating awareness**: Provision of information to inculcate a positive attitude towards circularity.
- **Promotion of the reduction of carbon and environmental footprints**: By providing impact-related information and linking incentives to sustainability performance levels.
- These improvements rely on agreements to identify relevant data and access to it.

This information should protect personal data privacy and business data confidentiality, as well as ensuring credibility and usefulness. These desirable data quality properties are described in clause 7.5.

7.5 Desirable properties of product information

In the context of access to environmental information, following what the Aarhus convention [b-UNECE Aarhus], the Escazu agreement [b-UNECLAC Escazu] or EU directive 2003/4/EC [b-EU 2003] recognize, the quality properties described as follows render environmental and sustainability-related information useful and reliable at the product level and in aggregate terms for statistical purposes.

Among the desirable principles, product information shall implement measures to apply the following.

- **Digitalization**: Beyond creating a digital representation, this refers to the enabled changes, usually optimization and improvement activities.
- **Data findability, accessibility, interoperability and reusability**: Are commonly referred to as findable, accessible, interoperable and reusable (FAIR) principles. [b-Wilkinson]
- **Usefulness**: Fit for purpose, avoiding unneeded information.
- **Accuracy**: Correct, precise, according to fact; bringing clarity, avoiding vague and confusing information.
- **Inclusivity**: Limited or progressive complexity and cost to prevent excluding small economic actors.
- **Transparency**: Clarity is a need to trust and scale up circular processes.
- **Accountability**: A key to answerability, liability, and the expectation of account reporting, and linked to past and future actions.
- **Standardization**: This can help to maximize compatibility, interoperability, quality, repeatability or quality. Harmonization can facilitate standardization of customs processes across national or regional boundaries.
- **Information privacy**: This is the relationship between the collection and dissemination of data, and privacy protection of the subjects involved.
- **Information protection**: Respect and protection of intellectual property and business confidentiality.

Among the data quality properties, provision of guarantees to ensure that bad things do not happen shall implement measures to apply the following.

- **Accessibility**: Although the ability to facilitate access and benefit from information on a need basis to a broad range of actors and situations may be helpful, some information may require or benefit from restricted access (e.g., industrial and trade secrets, personal privacy, business confidentiality) according to the needs and profiles of the actors involved, or appear in summarized information (e.g., yes/no answers to questions as on a product circularity data sheet (PCDS)).
- **Free access to relevant information**: In the DPP of a product is needed by consumers (i.e., anyone in the general public) for informed purchases and use. This also raises the need to present information consumers can understand, which can be met by appropriate presentation (e.g., user friendly, in the local language).
- **Persistency**: Accessibility in terms of the longevity of accessibility to information, related to the expected longevity of products (durability).
- **Authenticity**: The ability to prove an assertion and the identity and authentication of actors involved helps ensure digital information has an accurate and representative value.
- **Identifiability**: Authenticity as it applies to prove the matching to the corresponding product.
- **Composability**: Linked data is vital for products composed of components and materials in products that are transformed and reconfigured during their lifespan.
- **Integrity**: Maintaining data accuracy and consistency over the entire lifecycle of a product is vital for a CE. Data carriers can reduce manual data entry errors, and internal software in ICT products can report internal data directly to the DPP (i.e., digital twin) to ensure information integrity.
- **Verifiability**: Allows a way to confirm the veracity of assertions about sustainability and circularity. This can be implemented through third-party verification schemes, digital signatures (it identifies information sources, and non-repudiation, and can determine integrity or alteration) and (links to) documents.
- **Traceability (of products)**: Tracking and tracing are essential for a responsible CE, following individual product items and flows along supply chains. Digital linked data and IDs for products and actors can facilitate traceability throughout the lifecycle.

Digitalized information enables accessibility, contributing to the clarity (transparency) of the electronics or ICT sector and its users and monitors. That clarity relies on accuracy and maintenance to assure information integrity. Information should have the property of being accurate and valid. Confidence in the validity of information leads to the quality of being verifiable, supported by documented facts. Verifiability enables accountability, the ability to answer, an enabling attribute to support access to environmental information in line with what international agreements recognize about environmental information quality. In fact, verifiability and accountability enable the prevention of greenwashing, the avoidance of vague, unfounded, unsubstantiated claims, and are dependent on clarity and accuracy.

DPPs are enablers to the ability to track and trace product flows (e.g., products, components, materials, e-waste) after the product has been placed on the market. Tracing allows for verification of the aftermarket history of an item, status, location or components using documented recorded identification, determination of the origin, composition, and actors involved and deducting from that repair or end-of-life handling possibilities. Tracking reveals what happened to a product after it was placed on the market and in the future, which is helpful for impact assessment and reporting. Since aftermarket repair and enhancement of products rely on components and materials that can change over the lifespan of products and components, these relationships lead to the requirement for data composability, as linked data that can change by linking as the related material element changes over its circular life.

Complete traceability information is unfeasible as it encodes digital data and every detail of every input. Details are relevant according to the system's objectives. There are differences to consider in the breadth, depth, and precision of traceability systems [b-Golan]. [b-KEEP] adds access and latency (speed), both applicable to DPP and traceability applications as follows.

- **Breadth** (level of detail) describes the amount of information the digital system records. Breadth can range from high (many) to low (few, including product ID).
- **Depth** of the system is how far back or forward in time the system tracks. Depth can range from high (e.g., from raw materials acquisition) to lower (e.g., from production).
- **Precision** (granularity) reflects the degree of assurance that a system can pinpoint a particular product or those with common characteristics. Precision can range from high (individual product items, components or parts) to low (batches or models).
- **Access** refers to the number of different parties with full or partial access to product and process data. Access can range from high (economic and product operators such as suppliers, customers, users, regulators or legislators) to low (owners only).
- **Latency** (change) is the length of time it takes between parties to share and update product information. It can range from instantly, the moment it happens, to slow (eventually) to out of date (already changed again).

In summary, standardized ways should be provided to share linked data about all related participants and items (traceable) related to specifications (design), materials, parts, products, flows (as business processes), decisions with outcomes (e.g., production, sale or purchase, transfer, disposition). This data should be in digital form, accessible and transparent (transparency) to the relevant actors, trustworthy (integrity, verifiability) and detailed (composable, traceable) to facilitate informed and efficient decision-making, action, scaling up to the global market and the assessment of impacts.

Regarding accuracy, while some environmental information in ICT products would remain static (unchanged), other information changes during a lifespan as the product changes to keep it precise and up-to-date (latency). The two categories of attributes have the following issues to consider.

- Static attributes are product information required at the moment of placement on the market, remaining stable over the product lifetime. Static attributes can be applied at the model level and are the manufacturer's responsibility. They serve mainly for purchasing decisions, not CE activities.

  Examples of static attributes include the model ID, the reparability score, dismantling information, estimated energy consumption and environmental footprint information, including when new spare parts are integrated.
- Dynamic attributes are modifiable product details that remanufacturers, refurbishers and repairers can change as they perform CE activities.

  Examples of these attributes are changes in critical raw material information or updates to the percentage of recycled content resulting from integrating spare parts with differing specifications from the original part.

For the dynamic attributes to remain correct during the entire lifecycle of a product, DPPs should cope with the following issues.

- CE actors have to ensure accurate DPP updates when there are changes in a product.
- It is very burdensome for CE actors and consumers to host DPP records and assume product liability for information requirements.
- Market surveillance authorities need to expand their capabilities to enforce and verify compliance with timely updates of the dynamic attributes by independent repairers.
- There may be a large energy usage implication from a jump in data storage needs in cases when model- or batch-based DPPs are replaced by individual DPPs.

- Economic and product operators, the market, need a learning period to fully understand and build on the DPP potential.

Regarding accessibility and longevity (persistence), information can be encoded as data placed by the following methods.

- **In a data carrier on the product**: Very accessible but limited data storage space depending on the different label method types (e.g., one and two-dimensional codes), with priority for product and actor identification, and for risks (e.g., presence of substances of concern) and value (e.g., presence of rare metals [ITU-T L.1102], digital or uniform resource locator (URL) link to retrieve further information). Longevity, as long as it is readable, equal to the product, but updates typically require data carrier replacement.
- **Inside the product or packaging**: In a non-volatile medium inside (internal storage) or outside the product (external storage such as a pen drive). Longevity, as long as it is readable, updates require local data file updates, as long as the medium allows.
- **Online**: Through a web link (e.g., GS1 digital link [b-GS1DL]) obtained from a data carrier. Longevity, as long as it is provided with updates by the data provider.

The choices depend on the technical limitations of the different storage options, the dimensions and capabilities of physical products in their ability to incorporate a data carrier, legislation in different regions, as well as self-regulation and preferences of manufacturers. However, online information needs to be accessible (a URL that resolves into the data required) for a period that matches the expected durability of the product (considering a circular lifespan with reuse).

7.6 Definition of the product

What the product is in the context of electronics and ICT products has to do with the required or recommended level of detail in terms of breadth, precision or granularity of identification. A DPP shall refer to the following non-exhaustive list of product types.

- **Individual ICT product**: Such as a serialized or customized individual ICT product item.
- **Collective ICT product**: An ICT product batch or model with common characteristics for multiple product items.
- **Modular ICT product**: An ICT product that combines a container product (e.g., rack, chassis) with included modules (ICT products) that can easily be replaced or added.
- **Replaceable parts (products)**: Such as batteries, display modules, or consumables like print cartridges.
- **Accessory products**: Such as cables and keyboards.

Choices on breadth, precision or granularity depend on product characteristics and agreements across actors about the level of detail to report in a DPP.

The product scope of DPP has considerable implications for the DPP architecture and implementation. Alternatives are discussed and compared in clause 8.

7.6.1 Classes of products (verticals)

Some characteristics are specific to ICT product classes (verticals) with specific environmental requirements for function or form (components). Some examples of product categories follow.

- **Electric and autonomous vehicles**: Have large batteries and many critical ICT elements (products), with specific environmental and personal safety requirements.
- **Smartphones**: With mobility requirements and smaller batteries and electromagnetic emissions.
- **Computers**: With diverse characteristics and product ranges.

- **Displays**: With the potential presence of lead in cathode ray tube monitors [b-Macauley] or mercury in liquid crystal displays [b-Elo], among others.
- **Office equipment**: Including fax machines, laser printers, ink-jet printers, scanners and photocopying machines), with serious potential environmental risks to human health from the concentration of volatile organic compounds, ozone and respirable particles (PM_{10}) [b-Lee].
- **Network products**: With diverse characteristics and product ranges.

These verticals are not covered in the specific details in this Recommendation.

7.6.2 Customization and change

While new or remanufactured consumer or industrial ICT products are produced in large quantities with identical features, therefore represented by a DPP in common, customized (modified) products (as a result of reconfiguration, repair, refurbishment, incorporating new, modified or second-hand pieces) tend to acquire unique environmental characteristics and may require individual DPPs to accurately reflect them.

The details about the sustainability of products in a DPP can be fixed at different times as follows.

– A model passport may be fixed at design time (at product launch).

– A product batch passport may be fixed at manufacturing time.

– Changes during the lifespan affect one or a few product item units, not all. Environmentally sensitive changes may require individualized DPPs that extend or replace the DPP for the product model or batch (as a supplement, complement or specific variant of the previous or collective DPP).

NOTE – Changes are linked to the previous DPP for traceability. The degree of change is related to latency as described in clause 7.5.

A decentralized approach would allow a new passport or supplement to be created and linked to its predecessor every time the information changes due to modifications made by the product operator that has specific information to report, and attached to a data carrier in the product or registered in a decentralized search or lookup service for serialized or unique products.

7.6.3 Relevant details to sustainability

Consideration of a circular lifespan of products results in the need to report information related to or resulting from processes, ranging from raw material acquisition, manufacturing, usage, servitization, transfer, maintenance, repair, refurbishing, remanufacturing, disassembly, recycling and recovery (related to [b-ITU-T L-Suppl.28]). Such consideration results in a collection of relevant information, affected and extended by these processes, with details in Appendix I as far as sustainability-related standards and databases are concerned. However, design decisions result in many relevant informative details as introduced by clause 7.1 of this Recommendation, in line with the details described in [ITU-T L.1023].

8 Guidance for implementation

This Recommendation, which is global and broad (generic), presents an overview from an environmental perspective (sustainability) of the digitalization of product-related information integrated and harmonized under a DPP representation.

DPPs are expected to incorporate data in response to demand from ICT service providers, product operators, consumers and sector regulatory authorities. DPPs can be linked and provide information about compliance with regulations and standards: such as requirements, responsibility, support, verifiability, audit, traceability and transparency, that can be checked digitally. That arrangement should benefit all stakeholders and reduce the burden of taking informed decisions to optimize and assess the sustainability of ICT products.

Specific product categories, regions, governments, industries and citizens (stakeholder groups) may raise additional requirements from sustainability and other perspectives, so DPPs are expected to evolve in terms of refinement and harmonization, similarly to the way other global public information systems have evolved. Discussion, consensus, standardization and legislative processes on these can enable agreements to develop concrete and specific DPP specifications, including required and voluntary (recommended or optional) values, static and dynamic. This can be achieved according to existing standards, public regulations and industrial self-regulation, to deliver all digital data that can help achieve more sustainable ICT products due to the efficiencies and savings from digitalization of product information.

However, there are two aspects of DPP from a circularity perspective as follows.

- **Collective: product model or batch**. Manufacturers and importers, as economic operators introducing industrial, professional or consumer products to the market, are the informed and responsible actors to produce DPPs for new or remanufactured ICT products in volume, which can be found from a data carrier in the product itself. All product items in a given batch or model usually share the same reported characteristics and can therefore share the same DPP. The economic operator introducing a product to the market can publish and even update that DPP information (versioning) in their website to allow anyone to read the data carrier on the product, find and access that DPP document, with informative details and links to the latest related informative and verification details, and with content that can be customized to the needs and profile or credentials of the visitor.

  These DPPs can be updated to reflect improved or localized information (specific details or in local languages of a region), the effect of software updates and adaptation to comply with changing or different regulations for products already on the market.

- **Individual**: **product item**. Product operators in the CE can modify individual product items and, therefore, their environmental information. Product items get modified through repair, reconfiguration, refurbishment and recycling. Given their knowledge about the details of product item modifications, they can issue a new DPP for that modified product item that refines, updates or complements the original collective (e.g., model based) DPP. A DPP for a new product item should relate to the previous or initial (model or batch, collective) DPP. The new DPP may be found by either attaching a new data carrier to the product item or by a model+serial unique number lookup in a public searchable DPP repository.

  These individual DPPs, precise to the environmental characteristics and performance of the product item, with verifiable information linked to public databases and digital ledgers, precisely identifying the economic and product operators and third parties involved, increase trust in the DPP information by users of modified (repaired, reconfigured or refurbished) second-hand products and helps the final recycler to manage e-waste according to the latest product item characteristics at end of life, which may differ significantly from those just after manufacture. Reliable and accurate DPPs are key to facilitating the development of a CE of long-lasting ICT products and increasing the circularity supported by safe (precise, reliable, etc.) environmental sustainability information while reducing processing costs, and increasing scale and quality or accuracy in product processing.

Therefore, DPP information can be corrected, and extended by responsible actors that can provide information meeting the desirable quality properties in clause 7.5. However, product information changes for an unmodified material product (versioning) differ from those for product modification or customization, usually done for individual items, which can require an individual DPP issued by the product operator that modified the product, with its corresponding data carrier attached to the product.

DPPs should be available on a product item or the Internet for a long enough period (retention period), at least covering the time a product can be on the market and reach recyclers. This means content should not be hosted on the economic or website of the product operator alone.

In addition to providing informative product details, specifically about environmental sustainability, a DPP can also include details of the quality of information to validate claims made by diverse product operators in the CE market.

8.1 DPP architecture considerations

The product-level scope of DPP has considerable implications for the DPP architecture and implementation. Alternatives are compared in Table 1.

Table 1 – Impact of the product-level scope of DPP architecture

	Product-level scope of DPP			
Comparison item	Brand	Product model (collective)	Product batch (collective)	Individual product item
Creator or maintainer of DPP and the data, see Note 1	Manufacturer	Manufacturer	Manufacturer	Manufacturer or third party
Third party horizontal infrastructure to maintain DPPs, see Note 2	–	–	–	Infrastructure capability rollout needed, see Note 3
Basis of DPP identity	Brand ID	Model ID	Batch ID	Serial number
Track passport versions forwards or backwards, see Note 4	–	OK	OK	Implementation open, see Note 5
DPP data and data transaction volume, see Note 6	Lowest	Low	Low or medium	High

NOTE 1 – 'Maintain' refers to either DPP editing capability or the capability to create an updated version or a DPP supplement. It can also refer to maintaining a DPP data delivery service.

NOTE 2 – If the manufacturer creates a DPP, it can be read-only for other actors, who can start using it at will. This differs from a large-scale horizontal or product-item DPP with maintenance, updating or editing capability for relevant actors.

NOTE 3 – This involves the formulation of several implementation and data security-related questions, see discussion in Notes 5 and 6.

NOTE 4 – This row assumes that model- or batch-based product passports are maintained by the manufacturer, as it might be somewhat difficult to justify other approaches. When manufacturers maintain the data, the solution architecture is still distributed since each manufacturer maintains their own data. In that case, it is also easy to arrange the linking of different passport versions, both backwards and forwards.

NOTE 5 – If each individual product item has its own passport so that third party upgrade or repair services need to produce a new revised passport, they have to have either editing rights to the manufacturer's data (which can be problematic in many ways), or to establish their own data. In the latter case, the passport history of a product can be obtained by searching all passport versions on a web service having inks to information about the product ID and economic or product operator placing the product on the market. If the manufacturer desires to analyse the events in the life of a product, then forward tracking of passport versions may be very difficult in this type of scenario.

NOTE 6 – Volume has an implied impact on data storage, data processing and energy consumption. In the worst case, this may even compromise getting any net benefits from DPP (See Appendix II).

Appendix I

Related work, standards and data sources concerning environmental sustainability

(This appendix does not form an integral part of this Recommendation.)

I.1 Related work

A DPP relates to existing available data formats, linked data, wire and storage data formats and system architectures, as well as being complementary to upcoming initiatives that are regional (e.g., European DPP) and global (ISO PCDS [b-ISO 59040], [b-IEC 82474-1]) specifications and standards. Integration and standardization with a global scope aiming at reducing the burden of already providing partial information through multiple specific and regional standards.

This Recommendation considers ICT products classified according to [ITU-T L.1023] on an assessment method for circular scoring by facilitating data collection that can show the effect of a design decision in practice. It can help collect details as data records along the lifespan of ICT products to assess and report impacts of circular business models as in [b-ITU-T L.1024], about servitization: selling services instead of equipment. It can facilitate the calculation of lifecycle environmental impacts of different ICT products according to the ITU-T L.1400 to [b-ITU-T 1451] and mobile phones according to [b-ITU-T L.1015]. These and more are listed in more detail in clause I.2.

I.2 Standards and data sources related to sustainability

International standards provide guidance and the framework to implement circularity across the electronics lifecycle. The aim is to collect opportunities from existing standards about valuable details represented in a DPP.

Table I.1 presents ITU-T recommendations according to the main stages of a circular lifecycle, introduced in clause 7.2.

Table I.1 – ITU-T Recommendations according to lifecycle stages

Raw material acquisition and production	**Use**	**End-of-life treatment**	**Other sustainability – related Recommendations**
Green batteries for hand-held devices [b-ITU-T L.1010]	Servitization [b-ITU-T L.1024]	Sustainable e-waste management [b-ITU-T L.1021]	ID tag requirements [b-ITU-T L.361]
Assessment of circular scoring [ITU-T L.1023]	Circular public procurement [b-ITU-T L.1061]	E-waste management for countries [b-ITU-T L.1030]	Criteria evaluation environmental impact of mobiles [ITU-T L.1015]
Methodology to identify key equipment for environmental impact and e- waste generation assessment of network architectures [b-ITU.T L.1050]		Certification of e-waste recyclers [b-ITU-T L.1032]	Material efficiency and circular economy definition [b-ITU-T L.1022]

Table I.1 – ITU-T Recommendations according to lifecycle stages

Raw material acquisition and production	Use	End-of-life treatment	Other sustainability – related Recommendations
Printed labels for communicating information on rare metals in ICT goods [ITU-T L.1102]		Recycling rare metals [b-ITU-T L.1100]	Environmental impact assessment [b-ITU-T L.1400]
		E-waste reduction targets [b-ITU-T L.1031]	
Methodology for environmental life cycle assessments (LCAs) [ITU-T L.1410]	Methodology for environmental LCAs [ITU-T L.1410]	Methodology for environmental LCAs [ITU-T L.1410]	

[ITU-T L.1410] or the technically aligned [b-ETSI ES 203 199] provides a methodology for environmental LCAs of ICT goods, networks and services, for the environmental assessment of the lifecycle impact of ICT goods, networks and services. Data should be collected for all mandatory processes. The collected data, whether measured, calculated or estimated, are utilized to quantify the inputs and outputs.

[ITU-T L.1023] outlines the circularity aspects and indicators for circular product design of relevance for circular ICT.

The ITU-T L.1023 methodology translates into guidance for the identification of the margin of improvement level for each indicator. The detailed table brings specific digitalized details required for scoring (yes/no questions in the style of a PCDS) and supporting information.

The PCDS [b-PCDS 2020][b-PCDS 2023][b-ISO 59040] is an initiative that provides a public specification for suppliers of materials and semi-finished products to provide verifiable information about the circularity properties of their materials. It is inspired by the (material) safety data sheet [b-UNECE SDS], which chemicals suppliers use to provide safety information about their substances and mixtures. The PCDS offers a standardized format with trustful data without scoring or ranking these aspects. There is a third-party verification process to validate the content (audit) and a data exchange protocol to be specified separately. It has three objectives: to provide basic data on materials circularity; improve the sharing efficiency of circularity data; and encourage the circularity performance of products. A new PCDS can be created at each stage of the material transformation process. The material supplier passes their PCDS one step up the supply chain to allow for its integration into the material transformation process of the next tier. Each material manufacturer is responsible for storing the information related to PCDS statements and making such information accessible to other stakeholders upon request. A PCDS is designed to be integrated through the supply chain. Given its aim, PCDS constitutes a good generic circularity information source for a DPP.

There are information and data sources (databases, lists, registries, codes) agreed in the scope of regional and global conventions that provide details about agreements on substances, materials, labelling and identification of national, regional or global scope, that can be referenced in a DPP as follows.

– The globally harmonized system [b-UNECE GHS] for classification and labelling: categories, symbols and risk phrases for hazardous substances.

  NOTE – GHS can be used to determine the relative hazardousness of substances and compounds [b-Andrae 2020b].

– UN Numbers for hazardous substances [b-UN 2019].

– Hazardous substances and materials SDSs [b-UNECE SDS].

– Harmonized systems codes for trade categories of products and e-waste, issued by the World Customs Organization [b-WCO HS].

– Basel Convention codes [b-UN Basel 2023].

– Transport codes ([b-UNECE ADR], International Civil Aviation Organization (ICAO) etc.).

– Schemes for classification and labelling of raw and secondary materials.

– product conformity database [b-ITU PCD].

– Traceability registries.

Table I.2 – Information and data sources on regional and global environmental agreements

Description	Full name	Region	Description
Globally harmonized system (GHS)	Globally harmonized system of classification and labelling of chemicals international [b-UNECE GHS]	Global	The GHS includes the following elements: a) harmonized criteria for classifying substances and mixtures according to their health, environmental and physical hazards; and b) harmonized hazard communication elements, including requirements for labelling and safety data sheets.
Harmonized system (HS) codes	Harmonized commodity description and coding systems [b-WCO HS]	Global	The harmonized system (HS) is an international nomenclature for the classification of products. It allows participating countries to classify traded products on a common basis for customs purposes. At the international level, the HS for classifying products is a six-digit code system.

Table I.2 – Information and data sources on regional and global environmental agreements

Description	Full name	Region	Description
UN Numbers	UN numbers are assigned by the United Nations Committee of Experts on the Transport of Dangerous Goods.	Global	UN numbers or UN IDs are four-digit numbers that identify dangerous products, hazardous substances and articles (such as explosives, flammable liquids, toxic substances, etc.) in the framework of international transport.
Transport codes and requirements (ADR), RID and International Civil Aviation Organization/ International Air Transport Association (ICAO/IATA) delivery and global solutions)	Agreement concerning the international carriage of dangerous goods by road [b-UNECE ADR]: Regulations concerning the international carriage of dangerous goods by rail [b-OTIF RID]: Dangerous goods regulations [b-ICAO/IATA DGR]:	UNECE region and global	Regulations including transport codes, hazard classification symbols, packaging instructions and safety data sheets for the different means of transport (road, train and air).
SDS	Safety data sheet [b-UNECE SDS]	Global	
ITU PCD	Product conformity database [b-ITU PCD]	Global	Result of the ITU programme to enhance conformity and interoperability of ICT products implementing ITU Recommendations or part thereof.
SCIP	Database for information on substances of concern in articles as such or in complex objects (products) [b-ECHA SCIP]	EU	
ECHA-Candidate list	Candidate list of substances of very high concern for authorization [b-ECHA SVHC]	European Union	
ECHA-Authorization list	Authorization list [b-ECHA AL]	European Union	
EPREL	*European product registry for energy labelling* [b-EC EPREL]	European Union	
HMIS	*Hazardous materials identification system* [b-ACA HMIS]	USA	
WHMIS	*Workplace hazardous materials information system* [b-CA WHMIS]	Canada	
Directive 67/548/EEC and the related amendment	European hazard symbols from Dangerous Substances [b-EU 2008]	European Union	

Appendix II

A simple estimate of the volume of data and transactions

(This appendix does not form an integral part of this Recommendation.)

ITU estimates [b-ITU 2023] that in 2023, 67% of the global population, or 5.4 billion people, are using the Internet. In Europe, this percentage goes up to 90.5%, which means 621 million people.

Regarding ICT products, [b-GSMA 2023] has global estimates of 5.2 billion active individual products in 2020, with a forecasted 5.7 billion in 2025. That translates for Europe to 472 million in 2020, with a forecast of 480 million in 2025. Forecast of shipments of ICT products [b-Andrae 2020a] estimates more than 100 million desktops, 350 million laptops, and 780 million customer routers in the coming years, representing 1.23 billion individual products. Regarding the yearly sale of smartphones, [b-Statista] estimates 1.5 billion sold globally. [b-Cordella] reports a durability range of 3-5 years for these smartphones, with typically one battery change (i.e., battery issues after use periods of 2-3 years).

Regarding relevant details about a digital product that might be reflected in a DPP, a proposal from the Luxembourg government [b-PCDS 2023] considers hundreds of statements (data items). Some of these items may require references to external data, like documentation, certificates, and databases such as those about hazardous substances. A rough working assumption about the volume of data per item is around 1 kB.

Regarding relevant events along with lifespan, these relate to processes, design decisions, and the supply chain, which in manufacturing typically includes tier 2, tier 1, and production/assembly steps, then distribution, sale and use by a customer, and final recycling, considering a circular lifespan [b-APC]. The manufacturing phase can produce secondary materials (industrial mining). The use phase can be further detailed, including update, repair, upgrade, end-of-use, refurbishment, product reuse, reuse of their parts, recycling, and secondary material extraction (urban mining). All that translates into about 17 different processes that may affect a product and its related digital data.

Products are in different phases of their lifespan, with a rate of change probably significant during the manufacturing phase and the recycling phase and then slowly changing over years (e.g., one or two changes of battery during an extended lifespan, one repair, one or two cycles of reuse, until final recycling). A rough estimate of the change volume is around one event per each process during lifespan.

The volume of direct data that may represent a DPP may be estimated considering all the products available in different stages of their lifespan in a year, in the range of 1.5 billion smartphones + 1.23 billion computer and networking products sold every year, multiplied by 4 years of average durability, multiplied by 1 kB. That results in roughly 11 TB of data if every single product in the world adopts a DPP.

Looking at the number of transactions associated with any relevant event or changes to the record. That can be estimated to be equivalent to 2.73 billion products sold yearly multiplied by 17 events over their total lifespan (assuming the imprecise simplification that these events are spread uniformly). That results in roughly 46 billion transactions per year or 1 471 transactions per second (TPS) if every product item (individual) in the world adopts a DPP to record changes in every step of its extended lifespan.

However, if the number of transactions per item (e.g., serial number) is reduced to the minimum of manufacturing and recycling of each item, the rate reduces to 167 TPS. If the transactions only occur per batch or model, that reduces the rate to a negligible TPS value.

Bibliography

[b-ITU-T L.361] Recommendation ITU-T L.361/L.64 (2012), *ID tag requirements for infrastructure and network elements management.*

[b-ITU-T L.1010] Recommendation ITU-T L.1010 (2014), *Green battery solutions for mobile phones and other hand-held information and communication technology devices*.

[b-ITU-T L.1015] Recommendation ITU-T L.1015 (2019), *Criteria for evaluation of the environmental impact of mobile phones*.

[b-ITU-T L.1020] Recommendation ITU-T L.1020 (2018), *Circular economy: Guide for operators and suppliers on approaches to migrate towards circular ICT goods and networks*.

[b-ITU-T L.1021] Recommendation ITU-T L.1021 (2018), *Extended producer responsibility – Guidelines for sustainable e-waste management*.

[b-ITU-T L.1022] Recommendation ITU-T L.1022 (2019), *Circular economy: Definitions and concepts for material efficiency for information and communication technology*.

[b-ITU-T L.1024] Recommendation ITU-T L.1024 (2021), *The potential impact of selling services instead of equipment on waste creation and the environment – Effects on global information and communication technology*.

[b-ITU-T L.1030] Recommendation ITU-T L.1030 (2018), *E-waste management framework for countries*.

[b-ITU-T L.1031] Recommendation ITU-T L.1031 (2020), *Guideline for achieving the e-waste targets of the Connect 2020 Agenda*.

[b-ITU-T L.1032] Recommendation ITU-T L.1032 (2019), *Guidelines and certification schemes for e-waste recyclers*.

[b-ITU-T L.1050] Recommendation ITU-T L.1050 (2022), *Methodology to identify key equipment for environmental impact and e-waste generation assessment of network architectures*.

[b-ITU-T L.1061] Recommendation ITU-T L.1061 (2023), *Circular public procurement of information and communication technologies*.

[b-ITU-T L.1100] Recommendation ITU-T L.1100 (2012), *Procedure for recycling rare metals in information and communication technology goods*.

[b-ITU-T L.1400] Recommendation ITU-T L.1400 (2023), *Overview and general principles of methodologies for assessing the environmental impact of information and communication technologies*.

[b-ITU-T L.1451] Recommendation ITU-T L.1451 (2019), *Methodology for assessing the aggregated positive sector-level impacts of ICT in other sectors*.

[b-ITU-T L.1470] Recommendation ITU-T L.1470 (2020), *Greenhouse gas emissions trajectories for the information and communication technology sector compatible with the UNFCCC Paris Agreement*.

[b-ITU-T L.1604] Recommendation ITU-T L.1604 (2022), *Development framework for bioeconomy in cities and communities.*

[b-ITU-T Y.2213] Recommendation ITU-T Y.4108/Y.2213 (2008), *NGN service requirements and capabilities for network aspects of applications and services using tag-based identification*.

[b-ITU-T L-Suppl.28] ITU-T L-series Recommendations – Supplement 28 (2016), *Circular economy in information and communication technology; definition of approaches, concepts and metrics*.

[b-ITU 2021] ITU, GSMA, Sofies, WEEE Forum (2023). *Digital solutions for a circular electronics value chain: A thought paper for International E-Waste Day 2021*. Geneva: International Telecommunication Union. Available [viewed 2023-12-14] at: Thought Paper 2021.pdf (itu.int)

[b-ITU 2023] ITU (2023). *Statistics*. Geneva: International Telecommunication Union. Available [viewed 2023-12-15] at: https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx

[b-ITU GESP 2023] Global E-waste Statistics Partnership (2023). *Consultation on the methodology for measunring the global progress of e-waste legislation*. Geneva: International Telecommunication Union; United Nations Institute for Training and Research. Available [viewed 2023-12-20] at: https://globalewaste.org/

[b-ITU PCD] ITU (Internet). *Product conformity database.* Geneva: International Telecommunication Union. Available [viewed 2023-12-12] at: https://www.itu.int/net/itu-t/cdb/ConformityDB.aspx

[b-ITU SDTD] ITU (2023). *Sustainable digital transformation dialogues*. Geneva: International Telecommunication Union. Available [viewed 2023-12-13] at:https://www.itu.int/en/ITU-T/Workshops-and-Seminars/sg05rg/sdtd/Pages/default.aspx

[b-ISO 9000] International Standard ISO 9000:2015, *Quality management systems – Fundamentals and vocabulary*.

[b-ISO/IEC 27000] International Standard ISO/IEC 27000 :2018, *Information technology – Security techniques – Information security management systems.*

[b-ISO 59040] ISO/DIS 59040,[1] *Circular economy – Product circularity data sheet*.

[b-IEC 82474-1] IEC/DIS 82474-1,[1] *Material declaration – Part 1: General requirements*.

[b-ETSI TS 103 881] Technical Specification ETSI TS 103 881[1] (2023), Environmental Engineering (EE); *Global digital sustainable product passport opportunities to achieve a circular economy*.

[b-ETSI ES 203 199] ETSI Standard ETSI ES 203 199 V1.3.1 (2015), *Environmental engineering (EE); Methodology for environmental life cycle assessment (LCA) of information and communication technology (ICT) goods, networks and services*.

[b-ETSI EN 303 808] European Standard ETSI EN 303 808 V1.1.1 (2023), *Environmental engineering (EE); Applicability of EN 45552 to EN 45559 methods for assessment of material efficiency aspects of ICT network infrastructure goods in the context of circular economy*.

[b-GS1DL] GS1 (Internet). *GS1 digital link.* Brussels: GS1. Available at: https://www.gs1.org/standards/gs1-digital-link

---

[1] At the stage of draft at the time of publication.

[b-GSMA 2023] GSMA (2023). *The mobile economy 2023.* London: GSMA. 52 pp. Available [viewed 2023-12-15] at: https://www.gsma.com/mobileeconomy/wp-content/uploads/2023/03/270223-The-Mobile-Economy-2023.pdf

[b-ICAO/IATA DGR] International Civil Aviation Organization/ International Air Transport Association (2023). *Dangerous goods regulations (DGR).* Available [viewed 2023-12-12] from: https://www.iata.org/en/publications/dgr/

[b-IPCC 2018] IPCC (2018). *Global warming of 1.5°C*, Technical Report. Geneva: Intergovernmental Panel on Climate Change. 616 pp. Available [viewed 2023-12-09] from: https://www.ipcc.ch/sr15/

[b-OECD] OECD (2019). *Going digital: Shaping policies, improving lives*. Paris: OECD Publishing. 168 pp. Available [viewed 2023-12-11] from: https://www.oecd.org/publications/going-digital-shaping-policies-improving-lives-9789264312012-en.htm

[b-OTIF RID] OTIF (2023). *Convention Concerning International Carriage by Rail (COTIF): Appendix C – Regulations concerning the international carriage of dangerous goods by rail (RID)*. Gümligen: Intergovernmental Organisation for International Carriage by Rail. 1099 pp, Available [viewed 2023-12-13] at: RID_2023_e_30_June_2023.pdf (otif.org)

[b-SERI] SERI COP. (2022). *Advisory No. 24: R2v3 Remote transition audits* Available [viewed 2023-12-20] at: https://sustainableelectronics.org/wp-content/uploads/Advisory-24-Remote-Transition-Audit-Rev.-1.1.pdf

[b-UN 1987] UN: Secretary-General; World Commission on Environment and Development (1987). *Report of the World Commission on Environment and Development: Our common future.* New York, NY: United Nations. 374 pp. Available [viewed 2023-12-08] from: https://digitallibrary.un.org/record/139811

[b-UN 2005] United Nations General Assembly (2005). *2005 World Summit outcome*, Resolution A/60/1, adopted 2005-09-15. New York, NY: United Nations. 38 pp. Available [viewed 2023-12-08] at: https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_RES_60_1.pdf

[b-UN 2010] United Nations – Department of Economic and Social Affairs –Sustainable Development (2010).*Trends in sustainable development – Chemicals, mining, transport, waste management 2010–2011*. New York, NY: United Nations. 41 pp. Available [viewed 2023-12-09] from: https://sdgs.un.org/publications/trends-sustainable-development-chemicals-mining-transport-waste-management-2010-2011

[b-UN 2015] United Nations General Assembly (2015). *Transforming our world: The 2030 Agenda for Sustainable Development,* Resolution A/70/1, adopted 2015-09-25. New York, NY: United Nations . 35 pp. Available [viewed 2023-12-08] at: https://undocs.org/en/A/RES/70/1

[b-UN 2019] United Nations (2019). *Recommendations on the transport of dangerous goods, model regulations,* 21st revised edition. New York, NY: United Nations. 470 pp. Available at: https://unece.org/fileadmin/DAM/trans/danger/publi/unrec/rev21/ST-SG-AC10-1r21e_Vol1_WEB.pdf

[b-UN 2021] United Nations – Department of Economic and Social Affairs – Sustainable Development (Internet). *The 17 goals*. Available [viewed 2023-12-08] at:: https://sdgs.un.org/goals [b-UNECE Aarhus] UNECE (1998). *Convention on access to information, public participation in decision-making and access to justice in environmental matters*, Aarhus, 1998-06-25, UN Doc. ECE/CEP/43, 38 I.L.M. 517 [Aarhus Convention]. Geneva: United Nations Economic Commission for Europe. 25 pp. Available [viewed 2023-12-09] at: cep43e.pdf (unece.org)

[b-UNECE ADR] ADR 2023. *Agreement concerning the international carriage of dangerous goods by road*. Geneva: United Nations Economic Commission for Europe. 2 vols. Available [viewed 2023-12-12] at: https://unece.org/transport/standards/transport/dangerous-goods/adr-2023-agreement-concerning-international-carriage[b-UNECE GHS] GHS 2021. *Globally harmonized system of classification and labelling of chemicals*, Rev. 9. Geneva: United Nations Economic Commission for Europe. 556 pp. Available [viewed 2023-12-12] at: GHS_Rev9E_0.pdf (unece.org)

[b-UNECE SDS] UNECE (2007). *Annex 4: Guidance on the preparation of safety data sheets (SDS)* Geneva: United Nations Economic Commission for Europe. 20 pp. Available [viewed 2023-12-12] at: https://unece.org/DAM/trans/danger/publi/ghs/ghs_rev02/English/08e_annex4.pdf

[b-UNECLAC Escazu] ECLAC (2023). *Regional agreement on access to information, public participation and justice in environmental matters in Latin America and the Caribbean*. Santiago: United Nations Economic Commission for Latin America and the Caribbean. 38 pp. Available [viewed 2023-12-09] from: https://www.cepal.org/en/escazuagreement

[b-UNEP Basel 2021] UNEP, Basel Convention (2021). *Fifteenth Meeting of the Conference of the Parties to the Basel Convention – Matters related to the implementation of the Convention: work programme of the Open-ended Working Group for the period 2022-2023*, UN/CHW.15/19. Geneva: United Nations Environment Programme. 5 pp. Available [viewed 2023-12-14] at: UNEP-CHW.15-19.English.pdf

[b-UNEP Basel 1989] UNEP, Basel Convention (1989). *Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal – Protocol on liability and compensation for damage resulting from transboundary movements of hazardous wastes and their disposal – Text and annexes*. Geneva: United Nations Environment Programme. 126 pp. Available [viewed 2023-12-09] at: Basel Convention on the Control of Transboundary Movements of Hazardous Wastes -20113644.pdf (unep.org)

[b-UNEP Basel 2023] UNEP, Basel Convention (2023). *Decisions*. Geneva: United Nations Environment Programme. Available [viewed 2023-12-20] at: https://www.basel.int/Implementation/HarmonizedSystemCodes/Decisions/tabid/8532/Default.aspx

[b-UNU] Forti, V., Baldé, C.P., Kuehr, R., Bel, G. (2020). *The global e-waste monitor 2020*. United Nations University (UNU)/United Nations Institute for Training and Research (UNITAR) – co-hosted SCYCLE Programme, International Telecommunication Union (ITU) and International Solid Waste Association (ISWA), Bonn/Geneva/Rotterdam. 119 pp. Available [viewed 2023-12-09] at: https://www.itu.int/en/ITU-D/Environment/Documents/Toolbox/GEM_2020_def.pdf

[b-WCO HS] World Customs Organization (2022). *Harmonized system*. Brussels: World Customs Organization. Available [viewed 2023-12-12] at: Harmonized System | WCO Trade Tools

[b-WEF PACE] Platform for Accelerating the Circular Economy (2019). *A new circular vision for electronics – Time for a global reboot*. Geneva: World Economic Forum. 24 pp. Available [viewed 2023-12-13] at: https://www3.weforum.org/docs/WEF_A_New_Circular_Vision_for_Electronics.pdf [b-EC 2020] Directorate General for Environment (2020). *Proposal for a Regulation of the European Parliament and of the Council concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) No 2019/1020*, COM/2020/798. Brussels: European Commission. Available [viewed 2023-12-11] from: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020PC0798

[b-EC 2021] European Commission (2021). *EU countries commit to leading the green digital transformation*. Brussels: European Commission. Available [viewed 2023-12-13] at: https://digital-strategy.ec.europa.eu/en/news/eu-countries-commit-leading-green-digital-transformation

[b-EC 2022] Directorate General for Environment (2022). *Proposal for ecodesign for sustainable products regulation.* Brussels: European Commission. Available [viewed 2023-12-11] at: https://ec.europa.eu/environment/publications/proposal-ecodesign-sustainable-products-regulation_en

[b-EC 2023] GROW.H.3 (2023). *Draft standardisation request as regards digital product passports*. Brussels. European Commission. 23 pp.. Available [viewed 2023-12-11] from: https://ec.europa.eu/docsroom/documents/56175?locale=en

[b-EC EPREL] European Commission (2023). *European Product Registry for Energy Labelling.* Brussels: European Commission. Available [viewed 2023-12-12] at: https://eprel.ec.europa.eu/screen/home

[b-ECHA AL] European Chemicals Agency (Internet). *Authorisation list*. Helsinki: European Chemicals Agency. Available [viewed 2023-12-15] at: https://echa.europa.eu/authorisation-list

[b-ECHA SCIP] European Chemicals Agency (Internet). *WFD – Waste Framework Directive: SCIP database*. Helsinki: European Chemicals Agency. Available [viewed 2023-12-12] at: https://echa.europa.eu/scip-database

[b-ECHA SVHC] European Chemicals Agency (Internet). *Candidate list of substances of very high concern for authorisation*. Helsinki: European Chemicals Agency. Available [viewed 2023-12-13] at: https://echa.europa.eu/candidate-list-table

[b-EU 2003] European Union (2003). Directive 2003/4/EC of the European Parliament and of the Council of 28 January 2003 on public access to environmental information and repealing Council Directive 90/313/EEC. *Off. J. Eur. Union*, **L41**, pp. 26-32. Available [viewed 2023-12-14] from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32003L0004

[b-EU 2008] European Union (2008). Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006 (Text with EEA relevance). *Off. J. Eur. Union* **L353**, pp. 1-1355. Available [viewed 2023-12-15] at: CL2008R1272EN0250010.0001_cp 1..2 (europa.eu)

[b-ACA HMIS] American Coatings Association (2023). *US hazardous materials identification system*. Washington, DC: American Coatings Association. Available [viewed 2023-12-12] from: HMIS® — American Coatings Association (paint.org)

[b-Amponsah] Amponsah, N.Y., Troldborg, M., Kington, B., Aalders, I., Hough, R.L. (2014). Greenhouse gas emissions from renewable energy sources: A review of lifecycle considerations. *Renew. Sustain, Energ. Rev.* **39**, pp. 461-475. Available [viewed 2023-12-09] at: https://doi.org/10.1016/j.rser.2014.07.087

[b-Andrae 2016] Andrae, A.S.G. (2016). Life-cycle assessment of consumer electronics: A review of methodological approaches. *IEEE Consum. Electron. Mag.* **5**(1), pp. 51-60. Available [viewed 2023-12-09] at: https://ieeexplore.ieee.org/document/7353286

[b-Andrae 2020a] Andrae, A.S.G. (2020). New perspectives on internet electricity use in 2030. *Eng. Appl. Sci. Lett.* **3**(2), pp. 19-31. Available [viewed 2023-12-09] at: https://pisrt.org/psr-press/journals/easl-vol-3-issue-2-2020/new-perspectives-on-internet-electricity-use-in-2030/

[b-Andrae 2020b] Andrae, A.S.G., Vaija, M.S. (2020b). Cost effective method for determining the relative hazardousness of substances and compounds. *Int. J. Adv. Res. Eng. Manag*. **6**, pp. 16-28.

[b-APC] Navarro, L., Kazi, S., Finnegan, S. (Internet). *A guide to the circular economy of digital devices*. Melville: Association for Progressive Communications. Available [viewed 2023-12-15] at: https://circulartech.apc.org/books/a-guide-to-the-circular-economy-of-digital-devices

[b-CA WHMIS] Health Canada (2023). *Workplace hazardous materials information system.* Ottawa, ON: Government of Canada. Available [viewed 2023-12-15] at: https://www.canada.ca/en/health-canada/services/environmental-workplace-health/occupational-health-safety/workplace-hazardous-materials-information-system.html

[b-Cordella] Cordella, M., Alfieri, F., Clemm, C., Berwald, A. (2021). Durability of smartphones: A technical analysis of reliability and repairability aspects. *J. Cleaner Production*. **286**, 125388. https://doi.org/10.1016/j.jclepro.2020.125388

[b-Dykstra] Dykstra, C. A. (1939), The quest for responsibility, *Am. Political Sci. Rev*. **33**(1), pp. 1-25. doi:10.2307/1949761.

[b-Elo] Elo, K., Sundin, E. (2014). Automatic dismantling challenges in the structural design of LCD TVs. *Procedia CIRP*, **15**, pp. 251-6. https://doi.org/10.1016/j.procir.2014.06.058

[b-Golan] Golan, E., Krissoff, B., Kuchler, F., Calvin, L., Nelson, K., Price, G. (2004). *Traceability in the US food supply: Economic theory and industry studies*, Agricultural Economic Report No. (AER-830). Washington, DC: United States Department of Agriculture. 56 pp. https://www.ers.usda.gov/publications/pub-details/?pubid=41632

[b-EMF-A] Ellen MacArthur Foundation. (Internet). *Circular consumer electronics: An initial exploration*. Available [viewed 2023-12-20] at: https://www.ellenmacarthurfoundation.org/circular-consumer-electronics-an-initial-exploration

[b-EMF-B] Ellen McArthur Foundation (Internet). *What is the circular economy?* Cowes: Ellen McArthur Foundation. Available [viewed 2023-12-09] at: https://www.ellenmacarthurfoundation.org/circular-economy/what-is-the-circular-economy

[b-KEEP] Liljestrand, K., Wehner, J., Björkman, M. (2021). *KEEP: Keeping electrical and electronic products*. Gothenburg: Chalmers Industriteknik. 26 pp. Available [viewed 2023-12-09] from: https://keepelectronics.com/#/

[b-Kowalkowski] Kowalkowski, C., Gebauer, H., Kamp, B., Parry, G. (2017). Servitization and deservitization: Overview, concepts, and definitions. *Indust. Market. Manag.* **60**, pp. 4-10. DOI: 10.1016/j.indmarman.2016.12.007

[b-Lee] Lee, S.C., Lam, S., Fai, H.K. (2001). Characterization of VOCs, ozone, and PM_{10} emissions from office equipment in an environmental chamber. *Build. Environ*. **36**(7), pp. 837-42. https://doi.org/10.1016/S0360-1323(01)00009-9

[b-Leif] Leif, D. (2020). Pandemic upends certification audit sector. *E-Scrap News*. Available [viewed 2023-12-09] at: https://resource-recycling.com/e-scrap/2020/07/30/pandemic-upends-certification-audit-sector/

[b-Macauley] Macauley, M., Palmer, K., Shih. J.-S. (2003). Dealing with electronic waste: Modeling the costs and environmental benefits of computer monitor disposal. *J. Environ. Manag.* **68**(1), pp. 13-22. https://doi.org/10.1016/S0301-4797(02)00228-1

[b-PCDS 2020] Product circularity data sheet – Luxembourg (2020). *Circularity showcase: The product circularity data sheet (PCDS) – 8th December 2020 – Questions and answers*. Luxembourg: Ministry of the Economy. 4 pp. Available [viewed 2023-12-15] at: https://pcds.lu/wp-content/uploads/2020/11/20201218_WebinarPCDS_QA.pdf

[b-PCDS 2023] Product circularity data sheet – Luxembourg (2023). *What is the PCDS exactly? – The product circularity data sheet decoded*. Luxembourg: Ministry of the Economy. Available [viewed 2023-12-15] at: https://pcds.lu

[b-Schedler] Schedler, A. (1999), Conceptualizing accountability, In: Schedler, A., Diamond, L., Plattner, M.F., editors.. *The self-restraining state: Power and accountability in new democracies*, pp. 13-28. Boulder, CO: Lynne Rienner Publishers.

[b-Statista] Statista (Internet). *Number of smartphones sold to end users worldwide from 2007 to 2022*. Hamburg: Statista. Available [viewed 2023-12-09] at: https://www.statista.com/statistics/263437/global-smartphone-sales-to-end-users-since-2007/

[b-van Dorp] van Dorp, K. (2002). Tracking and tracing: A structure for development and contemporary practices. *Logist. Inform. Manag*. **15**(1), pp. 24-33. https://doi.org/10.1108/09576050210412648

[b-Wikipedia] Wikipedia (2023). *Data integrity*. St Petersburg, FL: Wikipedia Foundation. Available [viewed 2023-12-20] at: https://en.wikipedia.org/wiki/Data_integrity

[b-Wilkinson] Wilkinson, M.D., Dumontier, M., Aalbersberg, U.J. et al. (2016). The FAIR guiding principles for scientific data management and stewardship. *Sci. Data*. **3**, 160018. http://dx.doi.org/10.1038/sdata.2016.18

SERIES OF ITU-T RECOMMENDATIONS

Series A	Organization of the work of ITU-T
Series D	Tariff and accounting principles and international telecommunication/ICT economic and policy issues
Series E	Overall network operation, telephone service, service operation and human factors
Series F	Non-telephone telecommunication services
Series G	Transmission systems and media, digital systems and networks
Series H	Audiovisual and multimedia systems
Series I	Integrated services digital network
Series J	Cable networks and transmission of television, sound programme and other multimedia signals
Series K	Protection against interference
Series L	**Environment and ICTs, climate change, e-waste, energy efficiency; construction, installation and protection of cables and other elements of outside plant**
Series M	Telecommunication management, including TMN and network maintenance
Series N	Maintenance: international sound programme and television transmission circuits
Series O	Specifications of measuring equipment
Series P	Telephone transmission quality, telephone installations, local line networks
Series Q	Switching and signalling, and associated measurements and tests
Series R	Telegraph transmission
Series S	Telegraph services terminal equipment
Series T	Terminals for telematic services
Series U	Telegraph switching
Series V	Data communication over the telephone network
Series X	Data networks, open system communications and security
Series Y	Global information infrastructure, Internet protocol aspects, next-generation networks, Internet of Things and smart cities
Series Z	Languages and general software aspects for telecommunication systems

Published in Switzerland
Geneva, 2023