autorité de régulation des communications électroniques, des postes et de la distribution de la presse

ADEME
AGENCE DE LA TRANSITION ÉCOLOGIQUE

ASSESSMENT OF THE ENVIRONMENTAL IMPACT OF THE ICT SECTOR: METHODOLOGICAL GAP ANALYSIS

Technical Experts Committee

April 2023

ISSN n°2258-3106

FOREWORD

The technical experts committee on measuring the environmental impact of digital technologies was set jointly by Arcep and ADEME on December 2020. It aims at fostering a mutual understanding between telecom/ICT players and environmental players. Made up of technical experts working on a long-term horizon, the Committee may provide an independent technical recommendation/insight enabling to share views and to build up consensus on any technical topic/issue relating to the measurement of the environmental impact of ICT.

Chaired by Catherine Mancini (Leader Project Management at Nokia) also chairing the Fiber Optics Expert Committee and the Mobile Expert Committee set up by Arcep, the Committee includes experts from the following entities: Altice (SFR), Akamai, Amazon Web Service (AWS), Apple, APL, Bouygues Telecom, Cisco, DDemain, Eco-info (CNRS), Ericsson, GreenIT, Google, Huawei, Institut Mines Telecom, Institut Numérique Responsable (INR), Intel, Iliad (Free), LCIE Bureau Veritas, Microsoft, Meta, Netflix, Nokia, OVH Cloud, Orange, Qualcomm, Samsung and The Shift Project.

Committee program management officer: Arcep (Ahmed Haddad), ADEME (Erwann Fangeat)

NOTE

This report reflects the outcome of the Committee's validation. The Committee is thankful to the following invited experts for their review and contributions: Jens Malmodin, Gauthier Roussilhe.

This report is categorized within the following focus areas of the Technical Experts Committee:

- METHODOLOGIES FOR MEASUREMENT AND IMPACT ASSESSMENT
- KEY PERFORMANCE INDICATORS
- DATA

ASSESSMENT OF THE ENVIRONMENTAL IMPACT OF THE ICT SECTOR: METHODOLOGICAL GAP ANALYSIS

Summary

The International Telecommunication Union (ITU) has developed in 2018 an international standard that defines the Information and Communication Technology (ICT) sector boundaries and its carbon footprint (life cycle emissions of goods, networks and services) known as the ITU-T L.1450 recommendation. However, the multiplicity of published studies on the assessment of the carbon footprint of the ICT sector highlights more or less critical discrepancies leading to different evaluation results. Actually, the sources of variability in these estimates are due to the use of different data sources, variations in the timeliness of the data used and different approaches to boundaries of the analysis (the scope of ICT). From a methodological perspective, although methodologies promoted by ITU (and here specifically the ITU-T L.1450 recommendation) are considered as well anchored within the ITU experts' community, they are not sufficiently well diffused within published studies.

The Technical Expert Committee initiated a work item to approach the issue of ICT sector environmental impact assessment through the question of measurement methodology (including scope, indicators, reference standards etc.) while acknowledging other associated issues (in particular those relating to availability of data). The work item aims at highlighting the methodological gaps between ICT sector impact assessment studies, testing the implementation of L.1450 and recommending whenever possible on areas of improvement.

The work item was carried out in three steps:

- First, the Committee derived an analysis matrix. The matrix synthesizes the methodological requirements/specifications as promoted by L.1450 agreed by the Committee to be considered as a baseline for the methodological coverage/gap analysis;
- Then, the coverage/gap analysis matrix was applied on a sample of three published studies dealing with the environmental impact assessment of the ICT sector. The studies are selected to cover a wide range of views and reflect different flavors (ICT industry research institute, an environmental think-tank and a consultancy study commissioned by a public entity). Authors of the selected studies are affiliated to entities which are members of the Committee: Ericsson for Malmodin and Lundèn's study (2018), The Shift Project for its study on the environmental impact of ICT (2021) and Negaoctet consortium for the ARCEP/ADEME's study on the environmental impact of Digital in France (2022);
- Finally, based on the analysis of the three selected studies and their alignment towards L.1450, including but not limited to the boundary differences outlined in the second step, several improvement areas were identified for L.1450 and for future standardization.

The different methodological gaps pointed out and possible enhancements deal with:

- The workability and applicability of L.1450
- Modulating L.1450 with respect to the assessment level of the study
- ICT & IoT, including industrial IoT
- ICT & Blockchain, cryptocurrencies and artificial intelligence
- ICT & Satellites and airborne systems

- Environmental impact categories beyond Climate Change; such as Biodiversity and other Planetary Boundaries
- Support goods, rollout activities and support/maintenance activities
- Datacenter facilities rollout
- Telecommunication Datacenters
- ICT service development and operation support
- Private Internet for specific purposes
- Blurring boundaries between ICT and E&M sectors
- Environmental Extended Input Output (EEIO) approach
- Calibrating the assessment with estimates of the ICT sector footprint from the organizational perspective
- Guidance for a dataset user on the criteria to support the selection and collection of suitable impact and activity data
- Guidance for a dataset provider on the best practices for the creation and maintenance of suitable impact and activity data

The outcome of the work item at its different steps is reflected in this report.

Any comment or suggestion for improvement are welcome and should be addressed to: ComiteExpertsMesure@arcep.fr

History

Edition	Approval	Title
1.0	2023-03-06	Assessment of the environmental impact of the ICT sector: Methodological gap analysis

Keywords

Environmental lifecycle assessment (LCA), ICT sector, ITU-T L.1450, methodological gap analysis.

Report Citation

Arcep/ADEME Technical experts committee on measuring the environmental impact of digital technologies (2023). *Assessment of the environmental impacts of the ICT sector: Methodological gap analysis.*

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1. Objective and scope of the document

1.1. Objective of the workflow

The ITU has developed an international standard that defines the ICT sector boundaries and its carbon footprint (life cycle emissions of goods, networks and services) [ITU-T L.1450]. Despite this, the multiplicity of published studies on the assessment of the carbon footprint of the ICT sector highlight more or less critical discrepancies leading to different evaluation results. Some publications (e.g. [Freitag – 2020]) have attempted to highlight and analyze the main differences between a selection of peer-reviewed studies which estimate ICT's current and projected share of global Greenhouse Gaz (GHG) emissions; they identify sources of variability in these estimates due to the use of different data sources, variations in the timeliness of the data used, different approaches to boundaries of the analysis (the scope of ICT).

The Committee aims to approach the issue of ICT sector environmental impact assessment through the question of measurement methodology[1] in a first stage (including scope, KPIs, reference standards…) while acknowledging other associated issues (in particular those relating to availability of data) that could be addressed in a second stage.

In particular, addressing the methodological issue calls for identifying, understanding and potentially solving the discrepancies / limitations observed between the various impact assessment methodologies known to the Committee.

One may categorize these limitations into 3 types including:

- Misalignments between methodologies;
- Gaps left by a methodology;
- Weakly specified fields/relaxed aspects of a methodology which may favor arbitrariness or personalization.

These limitations could at different degrees explain the gap between results.

From the methodological perspective, regarding the environmental impact assessment of the ICT sector, although methodological recommendations promoted by ITU (mainly the ITU-T L.1450 recommendation) are considered as well anchored within the ITU experts' community, they are not sufficiently well diffused within published studies.

[1] In this document, the term "methodology" is used to describe each of the technical documents published by different organizations (ITU/ETSI, WRI/WBSCD etc.) either being a standard, technical report, recommendation or guidelines to support a practitioner in the footprint assessment of ICT.

1.2. Scope of the workflow

The workflow is scoped considering the following assumptions:

- Focusing first on the ICT sector before extending to related sectors (especially E&M);
- Focusing on direct effects (footprint) before extending thereafter to induced / indirect effects of ICT;
- A multi-criteria analysis is preferred, a mono-criteria based on GHG impact is also accepted as an input wherever a multi-criteria analysis is not possible;
- Addressing the work at a global level and considering restricting the geographical scope of the analysis to the perimeter of France. In case of country level assessment, the service being considered consists of ICT service used by French users: this includes the impact of ICT usage in France even when being provisioned by ICT assets located abroad and excluding the impact of ICT assets in France intended to serve foreign usage. This is in line with tier-2 assessment at city level as defined in ITU L.1440 recommendation;
- Addressing the impacts categorized under the whole life cycle (i.e. the raw materials acquisition, production, the distribution/transport, the usage and the end-of-life treatment) of ICT assets covering the three categories including terminal/devices, networks and DC;
- The methodological analysis will first address a high-level scope, i.e. the overall footprint of digital technologies including ICT (as defined by ITU L.1450), Entertainment and media (E&M) and some emerging technologies; while suggested possible refinement may be envisaged for future works;
- Focusing on the current footprint of the ICT sector as defined by ITU L.1450 recommendation (present snapshot assessment) before expanding to future trajectories (prospective assessment).
- ICT sector definition follows OECD definition[2] which refers to ICT products and has the following guiding principle: "ICT products must primarily be intended to fulfill or enable the function of information processing and communication by electronic means, including transmission and display".

1.3. Supporting references

- **[ITU L.1450]** ITU L.1450 (2018): Methodologies for the assessment of the environmental impact of the information and the communication technology sector.
  https://www.itu.int/rec/T-REC-L.1450
- **[ITU L.1410]** ITU L.1410 (2014): Methodology for environmental impact assessment of ICT goods, networks and services.
- https://www.itu.int/rec/T-REC-L.1410
- **[ITU L.1440]** ITU L.1440 (2015): Methodology for environmental impact assessment of information and communication technologies at city level.
  https://www.itu.int/rec/T-REC-L.1440

[2] Organization for Economic Co-operation and Development (OECD), "Information Economy Product Definitions Based on the Central Product Classification (version 2)," in OECD Digital Economy Papers, No. 158, 2000.

http://www.oecd-ilibrary.org/science-and-technology/information-economy-product-definitions-based-on-the-central-product-classification-version-2_222222056845

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

  https://www.itu.int/rec/T-REC-L.1470
- **[Malmodin & Lundén – 2018]** Malmodin & Lundén, "The energy and Carbon footprint of the Global ICT and E&M sectors 2010-2015" (2018)

  https://www.mdpi.com/2071-1050/10/9/3027
- **[The Shift Project – 2021]** The Shift Project, « Note d'analyse – Impact environnemental du numérique : tendance à 5 ans et gouvernance de la 5G » (2021)

  https://theshiftproject.org/wp-content/uploads/2021/03/Note-danalyse_Numerique-et-5G_30-mars-2021.pdf
- **[ADEME/ARCEP – 2022]** Lees Perasso Etienne, Vateau Caroline, Domon Firmin, ADEME, Arcep, BUREAU VERITAS, A. Theobald, « Evaluation de l'impact environnemental du numérique en France et analyse prospective. Evaluation environnementale des équipements et infrastructures numériques en France (Rapport 2/3) » (2022)

  https://librairie.ademe.fr/consommer-autrement/5226-evaluation-de-l-impact-environnemental-du-numerique-en-france-et-analyse-prospective.html
- **[EC DG Connect – 2013]** European Commission, Directorate-General for the Information Society and Media, ICT footprint: pilot testing on methodologies for energy consumption and carbon footprint of the ICT-sector, Publications Office, 2013

  https://data.europa.eu/doi/10.2759/94701
- **[EC DG Connect-JRC – 2011**] "Analysis of Existing Environmental Footprint Methodologies for Products and Organizations: Recommendations, Rationale and Alignment", Deliverable 1 to the Administrative Arrangement between DG Environment and Joint Research Center No. N 070307/2009/552517, including Amendment No 1 from December 2010 (2011)

  https://ec.europa.eu/environment/eussd/pdf/Deliverable.pdf
- **[Freitag – 2020]** C. Freitag, M. Berners-Lee, K. Widdicks, B. Knowles, G. Blair and A. Friday, "The climate impact of ICT: a review of estimates, trends and regulations", February 2021 https://api.semanticscholar.org/CorpusID:231802073
- **[GHGP- ICT Guidance – 2017]** ICT Sector Guidance built on the GHG Protocol Product Lifecycle Accounting and Reporting Standard, Carbon Trust, GeSI (2017)

  https://www.gesi.org/research/ict-sector-guidance-built-on-the-ghg-protocol-product-life-cycle-accounting-and-reporting-standard

1.4. Terms and definitions

This document uses the following terms:

- **Allocation [or Partitioning]:** Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems or between different parts of the studied product system (definition based on ISO 14044:2006).

- **Embodied emissions:** All the emissions other than those from the use stage (definition based on [GHGP- ICT Guidance – 2017]).

- **Environmentally Extended Input Output (EEIO):** Models that estimate GHG emissions for different product sectors, by allocating national GHG emissions to groups of products based on economic flows (definition based on [GHGP- ICT Guidance – 2017]).

- **Enterprise network:** An internal network of an enterprise that connects computers and related devices across departments and workgroups to each other and to the Internet (definition based on [ITU L.1470]).
NOTE: Enterprise network designates Intranets within organizations including private connectivity links connecting organizations' distributed sites, routers, work/office user terminals (laptops, desktops, tablets etc.), small cells and distributed antenna systems installed within organization's geographic footprint or WLAN network equipment. An organization refers to a "Company, corporation, firm, enterprise, authority or institution, or part or combination thereof, whether incorporated or not, public or private, that has its own functions and administration." (definition based on ISO 14064-1).

- **Hybrid LCA:** Method that combines the approach of process-sum and economic input-output LCAs. Different models exist, prioritizing data from either process-sum or input-output data (definition based on [ITU L.1410]).

- **Hotspot:** Processes and activities that have a large contribution to the total environmental impact.

- **ICT-specific secondary data:** Secondary data emerging from ICT-specific applications and processes (definition inspired from [ITU L.1410]).

- **ICT network:** Set of nodes and links that provide physical or over the air information and communication connections between two or more defined points (definition based on [ITU L.1410]).

- **ICT end-user goods:** Any device that can connect to CPE or networks (definition based on [ITU L.1410]).

- **ICT service (application):** Use of ICT goods and/or networks to provide value to one or more users (definition based on [ITU L.1410]).

- **Lifecycle stage:** One of several consecutive and interlinked stages of a product system (definition based on [ITU L.1410]).
NOTE: The GHG protocol ([GHGP- ICT Guidance – 2017]) defines five lifecycle stages including: Material acquisition and preprocessing, Production, Product distribution and storage, Use and End-of-life; additionally, ICT service may include a stage for installation or service deployment and build which refers to preparing the ICT service prior to use. The installation stage for ICT services may be accounted separately or may be included in the stage of distribution and storage. Note that the stages defined in the GHG Protocol differ from the standards of ETSI and ITU ([ITU L.1410]), where lifecycle stages of an ICT product system include Good raw material acquisition, Production (this includes the distribution of the final product and its storage), Use and Good end-of-life treatment; transport/travel is considered as a generic process that reoccur several times during these lifecycle stages. Different categorizations of the lifecycle could be envisaged as long as they are transparently defined.

- **Primary data:** Quantified value of a unit process or an activity obtained from a direct measurement or a calculation based on direct measurements at its original source (definition based on ISO 14046:2014)

- **Proxy data:** Data from a similar activity that is used as a stand-in for the given activity. Proxy data can be extrapolated, scaled up, or customized to represent the given activity (definition based on [GHGP- ICT Guidance – 2017]).

Shall, **should** and **may**: This Guidance uses precise terminology and distinguishes between requirements and recommendations, (i.e., between the words 'shall', 'should' and 'may'). Terminology is based on ISO/TS 14072 and ISO 14044/ISO 14040, in that order. 'Shall' is only used when this strength of obligation is also required in the aforementioned document, while 'should' is used to identify recommended elements that can be disregarded with proper justification. Finally, 'may' is used for other allowed elements or alternatives.

2. A sequential approach for the workflow

The workflow is carried out in three steps:

- **Step 1:** Deriving an analysis matrix which synthesizes the methodological requirements/ specifications as promoted by a relevant ITU recommendation taken as a baseline for the methodological coverage/gap analysis (cf. Section 3.1 and Annex A);
- **Step 2:** Applying the coverage/gap analysis matrix on a sample of three published studies ("control studies") dealing with the environmental impact assessment of the ICT sector (cf. Section 3.2 and Appendix I);
- **Step 3**: Highlighting the main lessons and formulating relevant recommendations for methodology development based on the outcome of the analysis in Step 2 (cf. Section 4).

The approach for the workflow is illustrated in the figure below:

Figure 1 - Illustration of the steps of the workflow

3. Methodological coverage/gap analysis

3.1. Criteria for the analysis (step 1)

Methodological coverages/gaps are identified and analyzed with respect to a set of key methodological considerations (criteria) derived from a common reference standard agreed to be considered as a baseline for the analysis. Based on the scoping (cf. Scope of the workflow), the Committee agreed that the recommendation ITU-T L.1450 (hereafter referred as "The Recommendation") - as the leading international standard for deriving ICT sector carbon footprints – would be considered as the baseline methodology.

Part I of the Recommendation specifies how to define GHG emissions in the ICT sector for a past, current or future situation, considering the full lifecycle of ICT goods and services. The Recommendation covers only the footprint of the sector (i.e. the life cycle GHG emissions of the sector).

An analysis matrix outlining the specifications of the L.1450 methodology is derived and agreed by the Committee. The structure of the matrix follows the 5-phased assessment procedure described in the Recommendation including, (i) Definition of the goal and scope, (ii) Data collection and analysis, (iii) ICT sector footprint calculation, (iv) Interpretation of results and (v) Reporting. The analysis is composed of a study-wide part complemented with Product category specific part (by ICT category including: ICT end-user goods, ICT Network goods and Data centers).

All items of the matrix have been cross-referenced to the applicable clause of L.1450 and in some cases to L.1410 when needed.

Refer to Table A.1 in Annex A for the template of the analysis matrix.

3.2. Implementation through three sample studies (step 2)

Three sample studies dealing with the environmental impact assessment of the ICT sector are "tested" against the analysis matrix. The studies are selected to cover a wide range of views and reflect different flavors (ICT industry research institute, an environmental think-tank and a consultancy study commissioned by a public entity). Authors of the selected studies are affiliated to entities which are members of the Committee: Ericsson for Malmodin and Lundèn's study (2018) [Malmodin & Lundén - 2018], The Shift Project for its 2021 study on the environmental impact of ICT [The Shift Project - 2021] and APL/LCIE for the ARCEP/ADEME's study (2022) [ADEME/ARCEP - 2022].

3.2.1. Short description of the studies

Study 1 **[Malmodin & Lundén – 2018]**: "The energy and Carbon footprint of the Global ICT and E&M sectors 2010-2015" by Malmodin and Lundén, Sustainability (2018)

This peer-reviewed study presents estimations of the energy and carbon footprint of ICT and E&M sectors globally for 2010–2015 including a forecast to 2020. It builds on three previous global studies (2007, 2011, and 2018) and a Swedish study (2015) by the same authors. The study is based on an extensive dataset which combines primary and secondary data for operational (use stage) energy consumption and life cycle greenhouse gas emissions for the included sub-sectors, including energy and carbon footprint data from about 100 of the major global manufacturers, operators, and ICT and

E&M service providers. The data set also includes sales statistics and forecasts for equipment to estimate product volumes in addition to published LCA studies and primary manufacturing data to estimate the embodied carbon footprint of products. The paper is based on and contains a high-level analysis regarding its alignment with ITU-T L.1450.

Study 2 **[The Shift Project – 2021]**: "Environmental Impact of ICT: trends for 5 years and governance of 5G" by The Shift Project (2021)

The purpose of the study was to strengthen the quantification work of the global environmental footprint of the digital sector which was initiated with the study "Lean ICT – Pour une sobriété numérique" in 2018 (The Shift Project). It was made possible by updating scenarios of their 2018 study. The study estimates the footprint of the ICT sector from 2013 to the latest year for which data are available at the time of publication (2019) and projects its future development until 2025. The geographic scope is global, although some details are presented at a finer scope (European or French scope) when primary data are available.

Study 3 **[ADEME/ARCEP – 2022]**: "Assessment of the environmental impact of ICT in France and prospective analysis" by Lees Perasso et al. (APL/LCIE) for ARCEP/ADEME (2022)

The report is part of an analysis process, but also of a prospection process related to digital technologies future. The study covers the whole digital perimeter, from the network installations to terminals and considering the network, equipment and datacenters impacts. Specifically, the study consists in an evaluation of France digital technologies impacts with the Life Cycle Assessment (LCA) methodology. It covers the three categories of digital technologies: user terminals, networks and datacenters, and calculates a panel of 12 impact indicators, including climate change, natural resource consumption or particulate matter. Results are presented at the France-wide scale, per inhabitant, and are detailed under several levels of analysis in order to get a more acute interpretation, and a better comprehension of direct environmental stakes related to digital technologies in France. Finally, typical companies and household digital technologies-related impacts are calculated.

3.2.2. Boundary alignment analysis

Each of the three selected studies is screened and analyzed in detail with respect to the criteria outlined in an analysis matrix (cf. Annex A) regarding the alignment with the Recommendation. The alignment with each criterion is qualified according to the level of compliance with the related provisions described in the Recommendation.

Following the Conventions of the Recommendation:

i. *Full compliance* refers to the situation where a requirement has been strictly followed and for which no deviation was identified;

ii. *Partially compliant* refers to the situation where the study complied with the majority of the required provisions attached to the criterion, but not all (due to data gaps, a lack of transparency in databases, and so forth.);

iii. *Non-complian*t refers to a situation where the study was unable to fulfill the required provisions attached to the criterion.

The outcome of the alignment analysis for each control study is detailed in Appendix I.

The life cycle stages of the equipment covered by the three control studies as well as the scope and assumptions applied are summarized in Table 1 and in the following text. In relation to the criteria listed in Annex A this refers to a subset of the analysis criteria related mainly to the study boundaries. However, other criteria that could explain difference in results between the studies, such as assumptions regarding life time, emissions factors, data age, data quality and modelling of energy consumption are not described or analysed in this chapter.

NOTE: The list items does not say anything about the importance of individual items which could be major or minor contributors to the overall result.

Table 1 - Summary of the scope, the stages covered and assumptions for the 3 control studies

ICT Component	**[Malmodin & Lundén - 2018]**	**[The Shift Project - 2021]**	**[ADEME/ARCEP - 2022]**	**Within ICT according to ITU L. 1450**
END USER DEVICE				
Smartphones	Yes	Yes	Yes	Yes
Feature phones	Yes	Yes	Yes	Yes
Fixed phones	Yes	Yes	Yes	Yes
Tablets	Yes	Yes	Yes	Yes
Laptops/notebooks	Yes	Yes	Yes	Yes
Desktops PCs	Yes	Yes	Yes	Yes
Displays	Yes	Yes	Yes	Yes
Computer peripherals	Yes	Yes	Yes	Yes
Projectors	Yes(1)	No	Yes	No(1)
Cameras	Yes(1)	Yes	No	No(2)
Home media players/ audio-systems/ traditional speakers	Yes(1)	No	No	No(1)
Portable media players e.g. iPods	Yes(1)	No	No	No(1)
Smart speakers	Yes	Yes	Yes	Yes
Smartwatches/fitness trackers	Yes(1)	Yes	Yes	Yes
Headphone/earphone	Yes(1)	No	No	No(1)
Game consoles	Yes(1)	Yes	Yes	No(1)
Arcade game machines	Yes(1)	Yes	No	No(1)
NETWORKS				
Customer premise equipment (routers, modems)	Yes	Yes(3)	Yes	Yes
Enterprise networks	Yes	Yes	No	Yes(4)
Lower power, lower bandwidth CPEs for IoT	Yes	No	No	Yes
Fixed telephony PSTN	Yes	No	No	Yes
Mobile networks	Yes	Yes	Yes	Yes
Fixed access wired networks	Yes	Yes	Yes	Yes
Network operator activities such as offices, travel, maintenance of equipment, etc.	Yes	Yes	No	Yes
DATA CENTERS				

Servers and switchs	Yes	Yes	Yes	Yes(5)
Building	Yes, dedicated buildings	No	Yes, dedicated buildings	Not specified
Cooling	Yes	Yes	Yes	Yes(5)
Backup power supplies	Yes	Yes	Yes	Yes(5)
Data center operator activities such as offices, travel, maintenance of equipment, etc.	Yes	Yes	Yes	Yes(5)
TVs, TV peripherals and networks for E&M				
TVs	Yes(1)	Yes	Yes	No(1)
Radios	Yes(1)	No	No	No(1)
Cable TV and broadcast networks including satellite, DTT, aerial amplifiers	Partly (1) (10)	No	No	No(6)
Satellite dishes	Yes (1)	No	No	No(1)
Paper media	Yes(1)	No	No	No(1)
Printers, copy machines and scanners	Yes(1)	No	Yes	No(1)
User devices used for E&M including Gaming consoles, DVD players etc.	Yes(1)	Yes	Yes(9)	No(1)
Magnetic and optical storage media	Yes(1)	No	No	No(1)
Content production	Yes(1)	No	No	No(1)
Concerts, festivals and events	Yes(1)	No	No	No(1)
Other digital technologies or trends				
Cryptocurrencies and blockchains	No	Yes	No	Not specified
AI/ML	Yes	Yes	No	Yes(8)
IoT	Restrictive scope(11)	Expansive scope(12)	Expansive scope(13)	Restrictive scope(7)
Telecommunication satellite	No	No	No	Yes
Private Internet e.g. for military purposes	Partly	No	No	Not specified
Key assumptions				
Geographic scope	Global	Global	Country level (France)	Country, group of countries or global
Use phase included	Yes	Yes	Yes	Yes
Embodied included	Yes	Yes	Yes	Yes
Embodied based on LCAs	End user devices, networks and data centers included but with varying depth in estimates	Partially (end-user devices)	Partially (end user devices, networks and DC)	Yes
End of life included	Yes, scenario based	No	Yes, scenario based	Yes

Critical review	Verification made through a scientific peer review process organized according to the state-of-the-art	Verification made through internal review	Critical review by a third party in accordance with ISO 14044 requirements	Verification either by third party in accordance with ISO 14064-3 or through peer review process
Sensitivity	No	No	Yes	Yes
Uncertainty	Sources identified	Sources identified	Sources identified	Yes(14)

(1) Items belonging to E&M sector
(2) Camera devices belong to E&M sector while surveillance cameras are part of the ICT sector (IoT devices)
(3) Set Top Box (STB) was allocated to End-user device category
(4) Enterprise networks are allocated to DC category
(5) Except telecommunication DC (e.g. core nodes) which are allocated to ICT Networks category.
(6) Cable TV network services provided by the operator should be allocated to ICT network goods (ICT sector) if the organization is not structured in a way that enables them to be separated – if this is the case, they should be regarded as part of the E&M sector and not allocated to the ICT sector.
(7) Consumer electronics primarily intended for communication purposes. As a first step to categorize IoT device data based on data availability, the following categories may be included: public displays, surveillance cameras, payment terminals, smart meter communication modules and wearables.
(8) Considered from a perspective of an ICT service, i.e. part of ICT services category (considering that the use of ICT network goods, ICT end user goods and data-centers by ICT services are allocated to these categories and not to the ICT service category).
(9) Game consoles are considered; DVD players are excluded.
(10) According to J. Malmodin, the so-called "Aerial amplifiers" that amplify the TV-signal from a rooftop antenna to a TV or TV STB have not been considered. Often, they are mounted close to the antenna or in attics and are not so visible and therefore easy to forget. As they are always on, these equipment have a fairly high annual energy consumption. J. Malmodin indicated that they are now included in their new studies.
(11) It includes: For ICT: Smart meters, wearables, payment terminals, surveillance cameras; for E&M: Headphones and other audio devices, vehicle infotainment displays.
(12) It includes: Security video IP cameras for home, Security video IP cameras for Public/Business, Security control smart locks, Automation water heaters, Automation street lights, Automation space conditioning smart thermostats, Automation space conditioning air conditioners, Automation lightings – smart light Wifi, Automation lightings – smart light LPWAN, Automation cooking (oven + Cooktop) and Range Hood, Automation audio (VA speakers), Automation appliances (refrigerators, freezers, washing machines, clothes dryers, dishwashers, small appliances), Smart Meters, Sensors for residential LPWAN, Sensors for residential Wifi, Sensors industry LPWAN, Sensors health LPWAN, Gateways for business, Gateways LPWAN to Wifi, Communication Building Control, Blinds + Windows.
(13) It includes: connection modules embedded into an object (smart bulb, stove for instance) or a device (refrigerator, oven for instance). The list is similar to IoT devices in [ADEME/ARCEP – 2022] study.
(14) The different sources of uncertainty shall be identified and their impact shall be qualitatively considered.

Key takeaways of the alignment analysis are summarized below:

- **Compliance with the Recommendation:** The alignment analysis shows different compliance levels regarding some critical provisions of the Recommendation (e.g., provisions related to the calculation of embodied emissions). Areas of non-compliance are mainly due to difficulties regarding access to primary data, collecting data sets with the right granularity, availability of product level high-quality LCA data[3] and allocation rules.
- **ICT sector boundaries and IoT:** The alignment analysis shows varying approaches adopted by the control studies to ICT sector boundaries particularly regarding IoT.

  Unlike [The Shift Project – 2021] and the [ADEME/ARCEP – 2022] which consider a wider approach regarding the scope of IoT, [Malmodin & Lundén – 2018] considers a conservative approach[4] encompassing IoT/M2M for which the authors had been able to get good data about. [Malmodin

[3] Data to be considered as high-quality shall fulfill the following criteria: timeliness, accuracy and accessibility [ITU L.1450]

[4] According to a comment from J. Malmodin, their list of IoT/M2M items includes: For ICT: Smart meters, wearables, payment terminals, surveillance cameras; for E&M: Headphones and other audio devices, vehicle infotainment displays.

& Lundén – 2018] did not include other common IoTs like connected devices from other sectors such as those embedded in vehicles, buildings or IoT used for military, medical, security and industrial purposes although the study expects that they would add to GHG emissions in the future. According to Malmodin, these devices only constitute a minor part of the IoT/M2M. This is based on a "future IoT/M2M scenario" investigated in the study. The applied scenario included 1 Billion new ICT access points (e.g., small-cell wireless base stations, 28 Billions ICT communication modules built into non-ICT equipment and devices representing the connectivity of the electronic equipment and devices of other sectors, as well as 500 Billions sensors and tags modelled based on the existing technology

Specifically, [The Shift project – 2021] points out the rise of IoT communicating objects (embedded connectivity in machines, sensors, actuators, RFID tags …) they form the foundation of industry 4.0 and robotics in a manufacturing environment. In [Malmodin & Lundén – 2018] study only the electronic hardware of the IoT devices are included; according to authors, one may also claim that an IoT device which is primarily intended for communication purposes should be allocated to ICT, while one for which connectivity is a feature should be allocated according to its primary purpose (another sector).

- **Telecommunication satellites:** None of the three studies include satellite due to unavailability of data ([The Shift project – 2021] [ADEME/ARCEP – 2022]), while [ADEME/ARCEP – 2022] has addressed it through sensitivity analysis to justify the cutoff. Recommendation L. 1450 categorizes satellite telecommunications as part of ICT (ICT network goods) and satellite-based broadcast networks as part of E&M. With the proliferation of satellite constellations and the acceleration pace of their renewal (Geostationary satellite may last over 15-20 years, while Low Earth Orbit satellite are characterized by their short lifecycle (typically 5 years)), it is nowadays hardly reasonable to cutoff this item and the lack of data for a reliable modelling shall be addressed.
- **Impact categories:** Most studies focus on Climate Change but they lack to address other environmental impact categories (resources/material use, water, toxicity etc.).

  While multi-criteria environmental impact assessment brings a valuable information to prevent a transfer of environmental damage from one category to another, the different environmental categories have not the same level of reliability (LCIA methods have not the same level of consensus and data is scarcer) considering the influence of normalization and weighting approaches to highlight some impact categories at the detriment of others.
- **ICT vs E&M:** [Malmodin & Lundén – 2018] established a clear distinction between ICT and E&M sectors in the assessment and the delimitation choice in boundary setting is almost well-aligned with the Recommendation. [The Shift Project – 2021] and [ADEME/ARCEP – 2022] included some end-users devices categorized as E&M equipment according to the Recommendation such as: Game consoles, TV, printers/scanners.
- **Datacenter (DC) facilities:** Among the three control studies, only [ADEME/ARCEP – 2022] study explicitly accounts for the impact of DC facilities: DC building construction and maintenance while assuming a generic architectural layout applied to all types of DCs considered in the study (public cloud/colocation DC, private DC, HPC etc.). Moreover, [Malmodin & Lundén – 2018] has confirmed that buildings and smaller housings´ embodied emissions are included for datacenters and network sites. According to [ADEME/ARCEP – 2022] estimations, the impact of DC facilities rollout is not the most significant part of the total impact of DC (by far when taking into account the servers' impact). However, within the DC perimeter but when excluding servers, this contribution is still not that neglectable (up to 25% of DCs total impact depending on the considered impact category).
- **ICT services:** ICT service comprises software development and update, ICT or IT consultants. Although "ICT service" is highlighted as a separate category belonging to the ICT sector boundaries (cf. Annex A of the Recommendation [ITU L.1450]), none of the three studies reported it as an

identifiable separate item highlighting the high level of uncertainty in addressing this category. [ADEME/ARCEP -2022] and the [The Shift Project – 2021] study didn't consider this item due to lack of data, whereas for [Malmodin & Lundén – 2018] estimates of this category include software development, IT services and E&M content production. However, they consider the accuracy of this part substantially lower than for other parts due to boundary setting challenges.

- **Private/Enterprise networks including ICT networks for military organizations:** Unlike [Malmodin & Lundén – 2018], [ADEME/ARCEP -2022] and [The Shift Project – 2021] studies do not consider Private and Enterprise Networks due to lack of data, however, none of the three studies include ICT infrastructure and networks used by military organizations due to lack of data.
- **Support goods, rollout activities and support/maintenance activities:** A lack of accuracy and completeness is noticed regarding the approach of addressing support goods, network infrastructure rollout activities, and maintenance activities within the three studies at different extent. Particularly, allocation of operators and providers´ support activities to specific products is challenging as networks are constantly evolving while organizations are working on many parallel updates.
- **Cryptocurrencies:** Similar to L.1450, [Malmodin & Lundén – 2018] does not include cryptocurrencies with the rationale that mining cryptocurrencies required specific hardware not regular servers. Another rationale behind this is that estimates for 2015 are very small, meanwhile their impact is included if they run their operations on standard ICT server/PC Hardware. According to [Freitag – 2020] this is challenged by Belkhir considering mining computers and servers use GPUs which are found in gaming and therefore within the scope of ICT. [The Shift Project – 2021] includes the impact of crypto-currencies such as Bitcoins as a future driver of ICT energy consumption and GHG emissions with the rationale that this topic is supported by IT equipment (e.g. servers).

4. Methodological gap identification and recommendations

Based on the analysis of the three selected studies and their alignment towards L.1450, including but not limited to the boundary differences outlined in Chapter 3, several improvement areas were identified for the Recommendation and for future standardization.

This analysis is based on the boundary discussion in Chapter 3 and also on the broader analysis of the three studies.

4.1. General considerations

4.1.1. Workability and applicability of the Recommendation

a) Gap description:

Estimating how well a study is aligned with the Recommendation may be a challenging task with a risk of the reviewer's subjectivity. To get a robust and reliable compliance analysis, one may check the different items of the study - i.e. general items, specific items at a product/category level (e.g. assumptions, collected data, calculation approach) – with respect to the provisions of the Recommendation (while considering the requirement level of each provision: mandatory, recommended, optional).

b) Recommendation/guidance:

The analysis matrix derived by the Experts' Committee (cf. Annex A) could be published as a template, which could be supplemented with examples to illustrate the task. As such, it would facilitate the implementation of the Recommendation (especially by non-experts) and help to easily identify any weak spots and ways of improvement of a study as well as to increase the transparency of reporting. When it comes to comparing the alignment of two or more studies towards the Recommendation, it is recommended that the comparison should be undertaken by the same reviewer.

4.1.2. Modulating the Recommendation's provisions with respect to the assessment level of the study

a) Gap description:

While the different studies show different ambition levels, for instance regarding the objective (high level screening assessment to inform on hotspots *vs* deep dive detailed granular assessment) and the target audience (general public *vs* experts), together with different constraints (the availability of primary data, the ability to invest on sufficient resources for data collection and assessment etc.), some provisions of the Recommendation could be relaxed or modulated to cope with the ambition level *vs* the constraints of the study.

b) Recommendation/guidance:

Acknowledging that a full alignment of an ICT sector assessment with the Recommendation may be very challenging, the Recommendation could be modulated to cope with the ambition level of the study *vs* its constraints and the purpose of the assessment. To achieve such a tradeoff, 3 levels of assessment could be identified for estimation and monitoring purposes:

- **Tier-1 assessment:** Detailed assessment that relies on primary data[5], while ICT-specific secondary data[6] are used at a last resort complement or for calibration/check purpose. Specifications of Tier 1 assessment are aligned with the Recommendation with some refinement in specific provisions.
- **Tier-2 assessment:** Simplified assessment that relies on a mix between primary and ICT-specific secondary/proxy data[7]. Primary data should be privileged as much as possible as secondary data would be used to fulfill data gaps or for calibration purpose.
- **Tier-3 assessment:** Screening assessment aiming at accounting for the significant and relevant sources of emissions and providing coarse estimate. Screening is a "quick/overview" assessment using mainly secondary/proxy data (readily available data); it may group similar elements using the most common element as a proxy to focus on the footprint hotspots.

  NOTE: It is important to privilege the use of the most up-to-date data as possible, as ICT sector performances evolve rapidly over time.

[5] Quantified value of a unit process or an activity obtained from a direct measurement or a calculation based on direct measurements at its original source (ISO 14046:2014, clause 3.6.1)

[6] Secondary Data are data obtained from sources other than a direct measurement or a calculation based on direct measurements at the original source (ISO 14046:2014, clause 3.6.1)

[7] Proxy Data are data from a similar activity that is used as a stand-in for the given activity. Proxy data can be extrapolated, scaled up, or customized to represent the given activity (GHG Protocol – Product Life Cycle Accounting and Reporting Standard)

Due to its averaging and high-level approach, Tier-3 assessment should not be used to report the footprint of a specific fine-grained item as such a granularity may require specific allocations:

- Example 1: Reporting the footprint of ICT networks disaggregated as fixed networks *vs* mobile networks *vs* Wifi networks or by wireless technology (2G *vs* 3G *vs* 4G etc.);
- Example 2: Reporting the footprint of ICT disaggregated according to the type of use (professional *vs* personal).

NOTE: Due to its screening approach, Tier 3 assessment shall not be used to monitor the evolution of the sector's emissions, nor to define a baseline of the ICT sector GHG emissions when deriving a GHG emissions budget for the sector considering a 2°C or lower trajectory. Part II of the Recommendation provides guidance for defining an ICT sector trajectory compatible with a 2°C or lower scenario, based on the overall global carbon budget and different future emissions scenarios.

Further guidance on the specifications of each type of assessment is provided in Appendix II.

The practitioner shall identify the most suitable level of assessment for each (sub-)category of the ICT sector in line with the scope, the purpose of the assessment, the ambition level of the study and the constraints (cost and timeline, resources/staff involved etc.).

Tier-3 and Tier-2 assessments may be adopted as a starting point before escalating towards a more in-depth and committed analysis using Tier-1 assessment; in this case it is recommended to prepare a plan to go all the way to Tier-1. In addition, depending on data availability, studies may use different assessment tiers for different subcategories of the ICT sector.

When repeating the assessment (for instance in case of a multi-phased study or a recurring study), it is recommended that the practitioner, at each occurrence of the assessment and providing a given level of assessment, targets to appreciate the progress done in the extent of alignment with the provisions in Appendix II and to privilege whenever possible to escalate for more ambitious tier of assessment.

4.2. Specific considerations

4.2.1. ICT & IoT, including Industrial IoT

At this stage, IoT would not represent a major share of ICT emission. For future estimate and considering their exponential growth rate, IoT devices are expected to represent a significant share of the connectivity inventory and thus may constitute a major contributor to the ICT sector footprint; but this needs additional consideration to define the boundary, to avoid double counting of devices with other sectors (e.g. the appliance sector) and to take into consideration the impact of hardware profile of an IoT device (e.g. main-powered vs battery-powered IoT may exhibit a significant difference in terms of their impact assessment, what allocation principles when determining the relevant share of the footprint of an IoT device etc.).

NOTE: Appendix III provides an example of a first screening approach regarding the inclusion of a list of IoT/M2M items prone to communicate through wireless networks.

In addition, with the increasing amount of IoT devices, subscriptions generally used as a prime contextual data, may be less correlated with users and other contextual parameters may become more important and relevant to consider. The connectivity of IoT devices may not be subscription-based, but served through IP or narrow-band solutions that might not form part of the statistics, such a situation may likely bias the estimates. This would need consideration when establishing guidelines for calculating subscription intensities.

The Committee may conduct further work to refine its knowledge and come up with recommendations for methodology development or guidance regarding: the scope of IoT (including for example Unmanned Aerial Vehicle (UAV)/drones) in relation to ICT and other sectors, the boundaries of the assessment of IoT devices and the complexity of the subscription concept with regards to IoT.

4.2.2. ICT & Blockchain/ Cryptocurrencies and Artificial Intelligence

According to IEA[8], cryptocurrency mining seems to have a non-neglectable electricity consumption (100-140TWh in 2021) compared to global Data center electricity use (220-320TWh in 2021). IEA analysis points out that Crypto mining energy use increased at rate of +2300%[9] between 2015 and 2021 largely higher than Datacenter energy use (excluding crypto) It worth mentioning the lower lifetime of hardware used for crypto-mining (GPU and ASICs) and the lack of manufacturing data.

According to Malmodin, 2020 estimate for all additional electricity not counted already for in the study's ICT estimates is around +75 TWh, mainly from Bitcoin "mining machines", but also from additional use of standard ICT Hardware (e.g. GPUs). According to Malmodin, it's important to consider crypto as a specific subsector and shouldn't be added to e.g. datacenters and the ICT sector.

According to The Shift Project, cryptocurrency mining is one of the drivers of the growth of data centers' energy consumption (420TWh in 2019, growth rate of 6-10% a year) and is also a prominent example of the lack of awareness of the energy intensiveness of digital technology.

With regards to current trends and the growing perspective of the use of crypto-mining and blockchain, this needs additional consideration to define the boundary and to avoid double counting perspective this includes for instance understanding the potential specificities of hardware and infrastructure being used to implement and run blockchain technology and the protocol of consensus used compared with conventional ICT infrastructure/hardware[10]. In addition to cryptocurrencies, Blockchain applications include NFT.

The same challenge in terms of the need to define the boundary is also exposed for the case of AI/ML as AI computing resources ("stacks of hardware and software used to support specialized AI workloads and applications in an efficient manner"[11]) may differ from general purpose compute resources.

There is a need for a specific standard on cryptocurrencies and AI/ML or for a more inclusive version of the Recommendation handling the ICT sector (as addressed with the current version of the Recommendation) with associated emerging technologies like Blockchains and AI/ML).

NOTE: A substantial part of the cryptocurrency footprint run within Datacenters is already accounted through Datacenter footprint.

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[8] https://www.iea.org/reports/data-centres-and-data-transmission-networks

[9] The growth from 2015 to 2021 starts from a very low adaptation rate however substantial growth has been maintained over the last few years.

[10] ITU-T Technical Specification, FG-AI4EE D.WG2-05, « Guidelines on energy efficient blockchain systems », 03/2021

[11] OCDE (2022), "Measuring the environmental impacts of artificial intelligence compute and applications : The AI footprint", *Documents de travail de l'OCDE sur l'économie numérique*, n° 341, Éditions OCDE, Paris

https://doi.org/10.1787/7babf571-en

4.2.3. ICT & Satellites and airborne systems

According to Malmodin, the last decades (1990-2020), number of launches have been lower than 100 and the direct GHG emissions from a launch is in the order of 1000 ton CO2e and consequently lower than 0.1 MT CO2e globally. Even if all embodied CO2e and other GHG emissions and effects are included (e.g. from launch site, satellite assembly, etc.), the total might likely be lower than 1 MT CO2e. Moreover, satellites related to ICT may likely takes a share lower than 50% of all, while mentioning that rocket launches also include astronauts and supply going to the space station. However, the upcoming of multiple LEO-satellite mega-constellations for global coverage gives this topic a whole new importance as thousands of new satellites will be required and launches will increase accordingly.

Supplement 26[12] to ITU L.1410 Recommendation provides a case study on the assessment of GHG emissions of a hybrid satellite broadband system over its lifecycle. Published in 2016, the case study in the Supplement considers a geostationary satellite to provision ICT services. ITU may further refine this research area by addressing the case of LEO satellite constellations (which have a shorter lifetime compared to other GEO satellites) and develop specific methodologies in this area which is expected to grow in importance. This would leverage on existing guidelines such as the set of Guidelines for Space System Life Cycle Assessment released in 2016 and the space specific LCA datasets compiled in an ESA LCA Database[13]. When quantifying the impact of Satellite from an ICT sector footprint perspective, the assessment shall also include all the different segments and activities of the space mission associated with the whole lifecycle of the satellite including:

- Launch segment encompassing materials and propellants production, assembly, launch event and end of life of the launcher (with possible refinement like modelling expendable *vs* reusable launchers given the launch rate, the use of micro launchers etc.).
- Space segment encompassing materials and propellants production, assembly, operation of the satellite, and disposal of the satellite (including space debris scenario management)
- Ground segment and support activities including infrastructures, facilities and supporting activities of the ground system.

Factoring such calculation into “pluggable” metrics (expressed through an appropriate functional unit like “Kg to Orbit”) by distinguishing LEO vs GEO satellites could be a useful input for the assessment.

NOTE: Space LCA is gaining a growing interest in the LCA research community. Space systems engage a strong particularity that makes the use of LCA more challenging: space missions are the only human activity that crosses all the stages of the atmosphere and stays “out” of the natural environment and ecosystems. LCA methodology has been developed to quantify environmental impacts on the earth eco-sphere. In addition to the current gaps, which include the resource depletion and the lack of circular approaches and recovery of materials, there is also the question of space debris (and the impact in terms of light pollution[14]) and the characterization of how the burden shifts between the Earth and the orbital environment, in the LCIA framework; all these gaps must be addressed to cover the full scope of space activities.

Similarly, to Telecommunication Satellites, the impact of airborne telecommunication systems called also High-Altitude Platform Systems (HAPS) or Space-born Datacenters should be addressed although these solutions are not currently widely used.

Methodological guidance would be required for the assessment of the impact of Telecommunication satellites/airborne telecommunication systems in the case of country-based studies or studies

[12] https://www.itu.int/ITU-T/recommendations/rec.aspx?id=12894&lang=en

[13] https://blogs.esa.int/cleanspace/2020/11/19/environmental-lca-database/

[14] L. Miraux, “Environmental limits to the space sector’s growth” Science of The Total Environment, Vol. 806, 2022 https://www.sciencedirect.com/science/article/abs/pii/S0048969721059404

performed for a group of countries. Further considerations regarding the assessment boundaries for Telecommunication Satellites are provided in Appendix IV.

4.2.4. Environmental impact categories beyond Climate Change; such as Biodiversity and other Planetary Boundaries

The Recommendation L.1450 does not provide any guidance for assessing other impact categories at the sector level although ITU-T L.1410 Recommendation is not specific to Climate Change. Considering the need for multi criteria assessment and associated challenges (data availability, LCIA methods confidence level, the choice of normalization and weighting factors which are optional elements according to ISO but based on value choices), the Recommendation could be improved by providing methodological guidance for more a comprehensive environmental impact assessment encompassing the mid-point impact categories recommended by ILCD[15].

In particular, methodological enhancement area include:

- Providing methodological guidance to assess a set of privileged and relevant impact categories for the ICT sector beyond Climate Change including: Natural resources (fossil, mineral and metal) depletion, impact categories considered relevant for the case of the EEE sector[16] or other identified relevant categories in multi-criteria ICT footprint assessment studies[17] including categories that maybe relevant because of other activities included within the assessment scope (e.g. ozone depletion for the case of rocket launch)
- Providing methodological guidance for assessing supplementary specific categories that maybe relevant to capture the specificities of the country (e.g. energy mix of the country) in case of sub global level assessment. In addition, the following flow indicators should be assessed and provided as a supplement: raw material (MIPS indicator), primary energy consumption and waste production. Other flow indicators could be envisaged to spotlight the focus of specific issues and thus provide complementary information for more concrete and operational improvement actions. Such flow indicators may include: Gross water consumption, bespoke indicators for space debris (such as mass reentering the atmosphere, mass disposed in the ocean, mass left in space).

The topic of biodiversity is gaining a growing interest in the ICT sustainability community; however, little methodological guidance is available on how to integrate biodiversity in the ICT sectoral level impact assessment, due to the challenging task for assessing biodiversity alteration and the difficulties to proceed with allocations. Ongoing work within ITU aims at approaching Biodiversity at an organizational level (i.e. biodiversity footprint of an ICT organization) through the lens of the 3 scopes.

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[15] https://eplca.jrc.ec.europa.eu/uploads/ILCD-Handbook-LCIA-Background-analysis-online-12March2010.pdf

[16] For example, by applying normalization and weighting factors recommended by the PEF Guide (PEF 3.0), PEFCR IT equipment/storage subsystems, published in 2020 identifies Climate Change, fossils resource use, minerals and metals resource use and particulate matter as the most relevant impact categories for IT equipment/storage system product group. **NOTE:** As this version of the PEFCR document was expired since 31/12/2021, this is only cited for informative purpose.

https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_ITequipment_Feb2020_2.pdf

[17] Based on normalization and weighting factors recommended by the PEF Guide (PEF 3.0), the [ADEME/ARCEP – 2020] study identified Ionizing radiations, Fossils resource use, Minerals and metals resources use, Climate Change and Particulate matter as the relevant impact categories for an assessment of the footprint of digital technologies in France.

Other initiatives such as SBTN[18] and TNFD[19] aim at helping organizations/cities calculate their biodiversity footprint and set associated targets.

One way forward would be to extend this work, once matured, at a sectoral level (through for instance a consolidation/aggregation of individual biodiversity of ICT organizations).

Another topic of interest concerns the integration of the Planetary Boundaries (PB) Framework in the assessment of the environmental impact of the ICT sector. The challenge raised here is how to translate the Control Variables, used to be performed at a global scale, into a sectorial approach. The case may even be harder if the assessment is carried at narrower geographical scale (country, group of countries etc.). Although this topic is still at a research stage, possible approaches for integrating the PB Framework might be to consider the application of PB in the context of assessing and reporting the impact of ICT organizations and then proceed with aggregation to achieve an estimate at a sectoral level (organizational approach), this approach is considered as the appropriate way to proceed and more in line with current initiatives (SBTN, TNFD); another approach would consider PB in the context of LCA of ICTs (i.e. keeping with the perspective of the ICT sector deliverables, i.e. goods, networks and services)[20].

It should also be noted that Biodiversity is captured within the Planetary Boundaries Framework through Biosphere Integrity (including genetic diversity and functional diversity) earth system process. Overall the extension of impact categories for sector level assessment is considered important but challenging due to data constraints (few input studies available) and lack of consensus around recalculation of life cycle inventory data to impacts in the life cycle impact assessment step.

4.2.5. Support goods, rollout activities and support/maintenance activities

According to the Recommendation, Network infrastructure rollout and maintenance are categorized within “support activities”, it includes the following assets/activities/process:

(i) Goods installed on site or at facilities for the grid and the non-grid power supply of ICT networks and for cooling purposes;

(ii) Support activities including deployment activities (such as: trenching and digging for network rollout, infrastructure reinforcement etc.) and support activities for the maintenance and supervision (fault recovery, assets renewals etc.).

The current version of the Recommendation lacks specifications to support better characterization of these items. Possible BU modelling-based options to address these gaps may include:

(i) Goods installed at sites/facilities for cooling/power supply purposes: Energy consumption of these goods could be derived by considering assumptions on PUE of a site/facility (DC facility, network site).

(ii) Support activities, including:

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[18] Science Based Targets Network targets freshwater, land, ocean and biodiversity: https://sciencebasedtargetsnetwork.org/

[19] Task-force on Nature-related Financial Disclosures (TNFD) Framework: https://tnfd.global/

[20] Bergmark, P., Zachrisson, G., (2022) “Towards considering Planetary Boundaries in Life Cycle Assessments of ICT”. International Conference on ICT for Sustainability (ICT4S), 2022, pp. 128-139 https://doi.org/10.1109/ICT4S55073.2022.00024

Erlandsson, Bergmark and Höjer (2022) “Establishing the planetary boundaries framework in the sustainability reporting of ICT companies – A proposal for proxy indicators” https://www.sciencedirect.com/science/article/pii/S0301479722026056?via%3Dihub

- Deployment activities: The opportunity to reuse secondary data based on LCA studies where relevant functional units expressing the impact in unitary terms spread of the whole lifetime of the asset (e.g. impact of fiber construction per Km per year, impact of construction per tower per year) is more relevant as these data may hardly evolve over time (construction and trenching processes are less likely to vary over a significant timeframe). Further refinement could be envisaged for higher accuracy, for instance by modulating the functional unit aforementioned with the geotype (e.g. green space in rural areas, asphalt surfaces in urban areas), the type of fiber deployment (e.g. aerial vs buried), the fiber network construction method (e.g. conventional excavation, micro-trenching, narrow trenching …).
- Support activities for maintenance and supervision: statistical reporting leveraging relevant KPIs (such as Mean Time To Failure (MTTF), Mean Time Between Failures (MTBF), number of intervention per site) for the ICT facility/infrastructure coupled with assumptions on a typical maintenance journey.

An alternative option based on TD operator's' reporting would limit any bias of BU modelling by reflecting the actual performance, however one may acknowledge the challenges to perform robust allocations if the practitioner intends to isolate these items.

4.2.6. Datacenter facilities rollout

a) Gap description:

The Recommendation does specify the rules of inclusion of DC facilities (building and container) including DC facilities construction and maintenance or whether they are considered part of the construction/building sector. In some cases, a DC may be housed within a commercial building.

Depending on the building structure, DC facilities may last between 5 (for container) to 20 years (for building).

b) Recommendation/guidance:

The activities included under building construction and maintenance may be more specified in the Recommendation to include building rehabilitation and restoring.

When a DC is deployed in modular fashion (i.e. within containers), the impact of the container shall be included within the assessment as a container would be considered as a site. The same situation applies for a container used for networks.

For building, it is not often usual to include building in LCA of ICT products[21], however, for an assessment at the sectoral level it shall be included when the building is specific to ICT (for example, DC buildings, wafer factories or display fabs are attributable to ICT sector). For the case where the building is not specific to ICT (e.g. offices, stores) the inclusion is optional, and if included an allocation should be performed considering the lifetime and percentage of a building used. While these are not currently expected to significantly change the footprint at a sectoral level, the possible development of buildings within which a mini-DC coexist with other non-ICT activities (offices, tertiary services,

[21] Buildings treated as Capital goods and thus there are considered as non-attributable processes, according to the GHG Protocol – ICT Guidance (Chapter 1, Introduction and General Principles) [GHGP- ICT Guidance – 2017]

residential etc.) for supporting the deployment of Edge Computing would worth further attention regarding allocation.

A general principle can be that if a building cannot easily and fast be reused for other purposes, it shall be considered as a specific building.

4.2.7. Telecommunication Datacenters

a) Gap description:

The Recommendation specifies that an ICT network operator´s telecommunication DC shall be allocated to ICT network, while other ICT network operator DC shall be allocated to data centers (cf. Annex A of [ITU L.1450])

b) Recommendation/guidance:

Telecommunication DC refers to DC hosting ICT network equipment (telecommunication core network nodes, metro/Edge/IP core data transmission network nodes). Other ICT network operator DC refers generally to DC hosting Business Support Systems (BSS) and other supporting IT systems of a telco.

With the increasing virtualization and cloudification of network functions, more and more network equipment are being shift into virtual appliances and to be run on the same DCs where regular IT cloud workload are executed. With cloudification of network functions, the allocation of these network functions between networks and DC need further consideration and guidance. Due to the difficulty to distinguish between IT *vs* network related workloads when they are supported by the same cloud platform, an allocation to DC may be an easy way forward as other allocation principles may be too complicated.

4.2.8. ICT service development and operation support

a) Gap description:

ICT service comprises: software development and update, ICT or IT consultants. The use of ICT services in terms of ICT goods/networks/DC energy consumption is already included in the footprint of the use stage of these goods/networks/DC. By including network and data center operators support activities also their services are covered. The challenge lies in the accounting for the remaining part of the footprint due to other service providers than operators (e.g. over-the-top services providers) which is related to the embodied and operational footprint in terms of offices, shops, transport and travel performed by the developer of the services as well as operation support and maintenance. To estimate this is considered challenging as there is no reliable global statistics on how many people are employed in the ICT service sub-sector.

b) Recommendation/guidance:

The Recommendation acknowledges that data uncertainties can be larger for this part of the footprint. For this reason, it can be convenient to present the results with and without ICT services included.

The use of ICT services is already counted as part of the footprint of the ICT goods, networks and data center and thus shall be reported accordingly and not within the ICT service category to avoid double counting/reporting.

ICT service reporting thus includes only the attributable share for the use of offices, transport, travel of ICT service developers/consultants (within the assessed geographic boundaries of the study) and ICT program/software development (the so called “Build phase”) for those services which are not already accounted for in the network and data center categories.

For major service providers, the following approach may be applied: In the case of GHG emissions for instance, ICT service development and operation support can be derived from GHG reporting of all ICT companies encompassing scope 1, scope 2 and some categories of scope 3 GHG emissions (including at least Business Travel and Employee Commuting categories). This calculation approach assumes two approximations:

- All ICT organizations are addressed equivalently irrespective of their sectorial positioning (i.e. an organization operating 100% within the ICT sector is handled similarly as a cross-sector ICT organization with activities, for instance, spanning across ICT and E&M).
- It includes all employees of the ICT organization.

While acknowledging that might be differences between ICT organizations, the proposed approach would provide a reasonable estimation (with no need of complex apportionment) of the ICT service development and operation support subcategory when undertaking the assessment at the global level.

For an assessment at a sub-global level (i.e. for country or a group of countries), one may derive from the above calculations GHG emission per employee and combine it with the number of employees involved in providing ICT services within the geographic boundaries of the study. However, such an approach may disregard potentially impacting parameters including: the level of contracting, the localization of the typical client being served by the ICT organization and the localization of the service provided (for instance, for an assessment in France, how to consider the service being run in France but for which the Build phase is undertaken abroad).

For other parts of ICT services, the number of employees in the ICT sector could be estimated by excluding those in manufacturing (OEM) and networks operator’s activities, which is used together with estimates of the environmental impact of an average ICT office worker.

4.2.9. Private Internet for specific purposes

a) Gap description:

Private Internet refers to ICT goods, networks and services deployed and used for specific purposes and are generally associated with stringent requirements (quality of service, security, isolation …). This may span over a range of different purposes including: ICT for military purpose, ICT for Mission Critical, ICT for Public Protection and Disaster Relief (PPDR) or for any vertical with very specific constraints or needs (deployed as standalone dedicated networks).

b) Recommendation/guidance:

At the time being, private Internet (for military purpose) may not be considered due to confidentiality reasons.

However, private Internet should be considered as part of the assessment as with regards to the ISIC definition of the ICT sector[22], the legal or institutional status is not, in itself, the determining factor for

[22] https://unstats.un.org/unsd/classifications/Econ/Download/In%20Text/ISIC_Rev_4_publication_English.pdf

an activity to belong in a given ISIC division. Networks for special usage and associated with stringent requirement such as Public Protection and Disaster Relief networks are part of the ICT sector.

4.2.10. Blurring boundaries between ICT and E&M sectors

With the increase of digitalization, the frontier between E&M and ICT sectors becomes challenging to set up. The distinction between both sectors according to the Recommendation were originally established according to OEDC definition of these sectors which are in turn based on the latest revision of ISIC[23] classification of economic activities.

The ability to connect to a network, to communicate and exchange information is being embedded into an increasing number of new devices and equipment used by other sectors making the frontier between ICT and E&M increasingly blurring, the same challenge would also apply when comparing the scope of ICT with other sectors.

When looking at the frontier between ICT and E&M sectors, the rationale of the categorization may be to focus on the main usage, which is still subject to subjective choices especially for future devices (AR/VR devices)/applications (metaverse). Several arguments may motivate such a boundary setting, while being challenged particularly for prospective assessment:

- One may argue that this boundary setting aims at reflecting the uses for which a given product category was originally designed (for instance the case of Broadcast, TV and Radio assigned to E&M). However, this argument does not consider whether and how the product usage (and so its design) might have changed over time. Such examples include the case of Cable-TV (CATV) networks considered as E&M, which have been modernized and evolved to also include broadband communication services.
- Some activities like cinemas, theaters, festivals and other entertainment events require almost physical human presence and reflect more the original motivation (entertainment rather than the communication purpose). With the generalization of virtual cultural event and the advent of metaverse, digitalization of cultural events may challenge this argument.
- Embedding communication features or capabilities into an equipment/device does not entail systematically to integrate it within the ICT sector, otherwise the sector definition would become meaningless. However, Connected TV is an example of a device which its inclusion within E&M is still questionable as the connected part becomes more and more prominent. At the same time, one may argue that TVs main function is to entertain, then this information could come from a specific network or over internet. This is in line with a connected fridge with a main function to keep food cold. A TV which is not connected over internet (or at all) may still function. From this perspective a connected TV may just be another IoT device. From a conceptual point of view, investigating the main function of the device might be the guiding principle for categorization, while this raises the question of the opportunity to keep with the current sector division or to enlarge the current definition of the ICT sector.

The Committee may conduct further work to refine its knowledge and come up with recommendations for methodology development or guidance regarding the boundaries between ICT and E&M sectors.

[23] https://unstats.un.org/unsd/classifications/Econ/Download/In%20Text/ISIC_Rev_4_publication_English.pdf

4.2.11. Need for further methodological guidance on other considerations

In addition to the aforementioned identified areas of methodological improvement, the gap analysis of the 3 studies had highlighted the need for developing further guidance to address other considerations:

a) Environmental Extended Input Output Analysis (EEIOA) approach:

There is a need to develop specific provisions to ensure rigorous application of EEIOA when assessing the impact of the ICT sector, this would confer more robustness to Tier-3 and Tier-2 assessment studies using EEIO approach, and potentially used to cover data gaps for Tier-1 assessment.

b) Calibrating the assessment with estimates of the ICT sector footprint from the organizational perspective:

The Recommendation mainly aims at considering the ICT sector footprint from the perspective of its deliverables (ICT goods, networks and services). As a complement, the Recommendation has included some guidance on the way to derive the footprint of the sector from an organizational perspective, while outlining its shortcomings.

As ICT organizations are increasingly enticed to report their GHG footprint and to constantly enhance their reporting, the organizational approach is gaining maturity. If an organizational approach would be used as supplement to calibrate the assessment result of the ICT sector footprint from the perspective of its deliverables, further technical guidance would be needed to support an alignment of the two approaches.

c) Guidance for a dataset user on the criteria to support the collection of suitable impact and activity data:

Practitioner shall evaluate different data sources to create the best possible estimate of the footprint of the ICT sector, while respecting the principles of the Recommendation (Relevance, Completeness, Consistency, Accuracy and Transparency). Referring to these principles, the practitioner shall use a combination of the most recognized, representative and high-quality data available[24] considering their timeliness, their accuracy and their accessibility.

Availability of representative and high-quality data is a corner stone requirement to ensure a reliable assessment and reduce bias/uncertainties. Several Datasets have been developed the last several years (manufacturers' CFP-based dataset, datasets from academia/research centers/environmental think tanks, datasets from private industrial/environmental consortia, datasets from institutional entities …) and many others are expected to come, **further guidance may be needed to support a practitioner with relevant criteria that could form a basis for a scoring approach for selecting and collecting the most suitable impact data depending on the assessment ambition level.**

[24] Data availability does not prejudge about the condition of access to data (free access *vs* subscription based)

d) Guidance for a dataset provider on the best practices for the creation and maintenance of suitable impact and activity data:

Developing high-quality datasets to enable robust estimate of the ICT sector footprint at global/local level may be challenging and resources consuming, this would also impose requirements regarding the update of the dataset to reflect as closely as possible the fast dynamics of the ICT sector development. Further guidance may be required for a practitioner on the best practices/compliance rules for the creation and maintenance of impact/activity dataset.

By levering on existing works (ILCD Entry level from JRC[25] etc.) and considering the specificities of approaching the ICT sector assessment, **best practices/compliance rules could be envisaged for data creation and maintenance at different levels of dataset**: data at a component level, data at an equipment/device level, data at a system-wide level (networks, datacenter etc.), data at a service/project level. The uncertainty analysis shall ensure that the sensitivity of results to significant inputs, outputs and methodological choices, and defined use scenarios could be understood.

NOTE: Depending on the targeted level of a dataset, the complexity and the efficiency of the uncertainty analysis should be balanced (refer to Appendix VIII of ITU L.1410 for more information).

[25] For instance, ILCD Handbook recommends the use of five criteria (Overall data quality including Technological representativeness, Geographical representativeness, Time-related representativeness, Completeness, Precision/uncertainty, Methodological appropriateness and consistency; Method (LCI modelling framework applied); Nomenclature; Review and Documentation) to classify data sets in a harmonized and comparable way.

Refer to ILCD Handbook – General Guide on LCA- Detailed guidance – Annex A (Data quality concepts and approach) (2010) https://eplca.jrc.ec.europa.eu/ilcd.html

Annex A Analysis matrix for alignment control with ITU L.1450 recommendation

(This Annex is related to Section 3.1)

Table A.1 - Template of the analysis matrix according to ITU L.1450 Recommendation

#	Criteria	Description of the attached provision	L.1450 reference	Notes
Study-wide part				
1	**General principles & background**		**8.2. a**	ITU-T L.1450 step 1 (see Fig 1)
1.1	Normative standards and frameworks	ITU-T L.1450 (part I), ITU-T L.1410, ISO 14040/44		L.1450 refers to overall sector, L.1410 refers to individual ICT products, networks and services; ISO 14040/44 refers to generic products and services
1.2	Principles	Has the study strived to apply the principles of Relevance; Completeness; Consistency; Accuracy; Transparency	6	
2	**Definition of the goal and scope**		**8.2. a**	ITU-T L.1450 step 1 (see Fig 1)
2.1	Goal of the study	Define the overall goal of the study with regards to ICT sector coverage, time horizon and geographical coverage	8.2.a.1, 8.3.1	Example from L.1450: *"The study covers the footprint of the ICT sector, as specified by the boundaries, for country A. Results are specified in terms of absolute first order GHG emissions for each year from 20xx to 20yy".*
2.2	Absolue vs relative footprint	Define whether the study assesses only an absolute ICT sector footprint or whether it also targets a relative ICT sector footprint.	8.2.a.2, 8.3.1, 8.3.4	L.1450 mainly refers to an approach based on the deliverables of the sector. For organizational approach refer to L.1450 Appendix III
2.3	Reference unit	Define the reference unit/functional unit	8.2.a.3, 8.3.2	L.1450 use the term "reference unit" and defines it as : *The reference unit shall be defined as:* *1) the overall life cycle GHG emissions generated by the ICT sector as specified by the boundaries and for the specified geographical coverage over 1 year.* It also sees GHG emission per subscription and GHG emissions per data as optional additional reference flows. (An alternative term is "functional unit")
2.4	Study-wide boundaries	Define the ICT sector boundary (refer to Annex A of L.1450)	2, 8.3.3.1, Annex A	Outcome is to list any deviation (add-on or removal) with L.1450 Annex A
2.5	Study-wide boundaries	Define the geographic boundaries (representing ICT used within a country, group of countries, global etc.)	8.2.a.4, 8.3.3.2	
2.6	Study-wide boundaries	Define the time horizon (historic, current or future footprint)	8.2.a.4, 8.3.3.3	Define the ICT sector boundary (refer to Annex A of L.1450)

3a	**Data Collection and analysis (study wide)**		**8.2.b**	ITU-T L.1450 step 2 (see Fig 1)
3.3	Reference for relative emissions		8.2.b.3, 8.3.4, 8.5, 8.5.8	Including data source
4	**ICT sector footprint calculation**		8.2.c, 8.6-8.7	ITU-T L.1450 step 3 (see Fig 1)
4.1	ICT equipment calculation		8.2.c.1, 8.6	For each category of equipment specify any deviation from the guidance of 8.6
4.2	ICT sector calculation		8.2.c.2, 8.7	specify any deviation from the guidance of 8.7
4.3	Future extrapolation		8.7.2	Specifically describe how any extrapolation to the future was made and any deviations from 8.7.2
5	**Interpretation of results**		8.2.d, 8.8	ITU-T L.1450 step 4 (see Fig 1)
5.1	Principles		8.2.d.1, 6, 8.8	
5.2	Sensitivity analysis		8.8.2	
5.3	Data coverage (overall)		8.8.2	
5.4	Data quality (overall)		8.8.2	
5.5	Trend analysis		8.8.3	
5.6	Comparison		8.2.d.2, 8.8.3	
5.7	Intensities (optional)		8.2. d.3	# users and #data traffic need to be independently collected
6	**Reporting**		8.9	ITU-T L.1450 step 5 (see Fig 1)
	Reporting		8.9	State any deviation from 8.9
7	**Critical review**		8.10	ITU-T L.1450 step 5 (see Fig 1)
	Critical review		8.10	State any deviation from 8.10
Product category specific part				
3b	**Data Collection and analysis (product category specific)**		**8.2. b**	ITU-T L.1450 step 2 (see Fig 1)
3.1	Data collection and modelling per equipment type/category of goods		8.2. b.1	when possible based on L.1410
3.1.1	Equipment data	Sales volumes	8.2.b.1, 8.5, 8.5.1	
3.1.2	Equipment data	Installed base	8.2.b.1, 8.5, 8.5.1	
3.1.3	Equipment data	Operating lifetime	8.2.b.1, 8.5, 8.5.2	
3.1.4	Equipment data	GHG emission per category of goods: use stage GHG emissions	8.2.b.1, 8.5, 8.5.3-6	
3.1.5	Equipment data	GHG emission per category of goods: embodied GHG emissions	8.2.b.1, 8.5, 8.5.3-6	
3.1.6	Equipment data	GHG emission factors applied	8.2.b.1, 8.5, 8.5.7	including data sources
3.1.7	Equipment data	Contextual data	8.2.b.1, 8.5, 8.5.9	Data to be used for interpretation of results such as #subscribers, #data traffic etc.
3.2	Collection of meta-data per equipment type/category of goods			
3.2.1	Meta-data	Material & process-sum LCA, environmentally extended Input-Output or hybrid		L.1410 recommends the process-sum approach

3.2.2	Meta-data	Assumptions undertaken for the data collection per equipment (including usage profiles)	8.2. b.4	
3.2.3	Meta-data	Data sources detailed per equipment and data	8.2.b.4, 8.4.2	Including references and quality (peer-review, 3rd-party review…)
3.2.4	Meta-data	Data age (product info, processes etc. separated)		
3.2.5	Meta-data	Reference flow	8.2. b.4	
3.2.6	Meta-data	Any allocations performed within or between life-cycles (including handling of end-of-life treatment)	8.2. b.4	Refer to L.1410 for allocation rules
3.2.7	Meta-data	Cut-offs, extrapolations and use of proxy data	8.2.b.4, 8.4.3	
3.2.8	Meta-data	LCA tool & database	8.2. b.4	LCA tool and database used (per equipment)
3.2.9	Meta-data	Data quality (timeliness, accuracy, accessibility)	8.2.b.4, 8.4.1	
3.2.10	Meta-data	Primary or secondary data	8.2. b.4	
3.2.11	Meta-data	LCIA method		Based on L.1410, PEF or equivalent

Annex B Summary of the methodological gaps in Recommendation L.1450

(This Annex is related to Section 4)

This Annex (Table B.1) summarizes all methodological gaps and proposed enhancements in Recommendation L.1450 presented in the main body of this document and related clause(s) in the document. In addition, this document (including its Appendices) contains several recommendations which also need consideration.

Table B.1 – Summary of the methodological gaps described in this document

Methodological gap	Type	Related clause
Workability and applicability of the Recommendation	General. Methodological approach	4.1.1 Annex A Appendix I
Modulating the Recommendation with respect to the assessment level of the study	General. Methodological approach	4.1.2 Appendix II
ICT & IoT, including IIoT	Specific. ICT and emerging technologies	4.2.1 Appendix III
ICT & Blockchain/Cryptocurrencies and Artificial Intelligence	Specific. ICT and emerging technologies	4.2.2
ICT & Satellites/airborne systems	Specific. ICT and emerging technologies	4.2.3 Appendix IV
Environmental impact categories beyond GHG; such as Biodiversity and other Planetary Boundaries	General. Impact assessment	4.2.4
Support goods, rollout activities and support/maintenance activities	Specific. Scope	4.2.5
Datacenter facilities rollout	Specific. Datacenter	4.2.6
Telecommunication Datacenters	Specific. Datacenter	4.2.7
ICT service development and operation support	Specific. ICT service	4.2.8
Private Internet for specific purposes	Specific. ICT networks	4.2.9
Blurring boundaries between ICT and E&M sectors	Specific. Scope	4.2.10
EEIOA approach	General. Methodological approach	4.2.11
Calibrating the assessment with estimates of the ICT sector footprint from the organizational perspective	General. Methodological approach	4.2.11
Guidance for a dataset user on the criteria to support the selection and collection of suitable impact and activity data	General. Data Collection & modelling	4.2.11
Guidance for a dataset provider on the best practices for the creation and maintenance of suitable impact and activity data	General. Data Collection & modelling	4.2.11

Appendix I Details of the alignment analysis for the 3 control studies

(This Appendix is related to Section 3.2)

Detailed alignment analysis of the 3 control studies are included as Supplementary Materials in the form of a tabular matrix. They can be provided at request.

Appendix II Further guidance on the specifications of the proposed tiers of assessment

(This Appendix is related to Section 4.1)

This appendix provides further guidance on the methodological specifications of the proposed three tiers of assessment.

Whatever the Tier of assessment selected for the study, the practitioner shall target to follow the principles of Relevance, Completeness, Consistency, Accuracy and Transparency when undertaking the assessment. Referring to these principles regarding data collection, the practitioner shall evaluate different data sources to come up with the best possible estimate.

II.1 Tier-1 assessment

Specifications of this type of assessment are aligned with the Recommendation. Further specifications include:

- Embodied emissions: Process-sum-based LCA could be combined with EEIO estimates (calibration) to come up with a hybrid LCA able to compensate for any potential truncation errors due to process-sum LCA.
- A gravity analysis[26] as well as a quantitative uncertainty analysis should be addressed through its 3 categories (parameter, scenario and model uncertainty) and by characterizing the important sources of uncertainties in line with L.1410 Recommendation[27]. Uncertainty can be quantified through sensitivity analysis (in line with requirements on sensitivity analysis as defined in ISO 14044 standard) and testing alternative scenarios. Parameter uncertainty includes the assessment of the propagated uncertainty of the input data to the overall results. For this, uncertainty parameters on the raw data (input parameters) need to be defined; the uncertainty of the environmental impact indicators (output parameters) could then calculated with a Monte Carlo simulation if appropriate. The Recommendation could be enhanced by recommending on a set of relevant input parameters for each lifecycle stage and corresponding statistic law (e.g. log-normal) and variance to achieve a given confidence interval[28].
- Sensitivity analysis shall be carried out.
- Reporting and presentation of results: In addition to presenting the total ICT sector footprint, main results shall present the footprint per at least the following ICT sub-categories: end-user goods excluding IoT, IoT devices, fixed networks, mobile networks, Enterprise networks, Datacenters and ICT services development and operation support. Results shall be disaggregated by lifecycle stages.

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[26] Gravity analysis (e.g. Pareto analysis) is a statistical procedure that identifies those data having the greatest contribution to the indicator result. These items may then be investigated with increased priority to ensure that sound decisions are made. (refer to ISO 14044)

[27] The practitioner shall refer to Appendix VIII of L. 1410 for further details.

[28] The GHG Protocol provides guidance on approaches of quantifying parameter uncertainty https://ghgprotocol.org/sites/default/files/Quantitative%20Uncertainty%20Guidance.pdf

Any refinement in the reporting granularity to support insightful interpretation is encouraged while keeping compliance with the Recommendation's requirements[29], this may include for instance: highlighting specific focus (satellite telecommunication/HAPS, enterprise networks etc.) or specific applications (blockchain, AI/ML etc.), Fixed networks vs WiFi networks vs cellular mobile networks, networks per access technology, Traditional Datacenter vs Cloud Datacenters vs Edge Computing Datacenter etc.

- Compliance self-check with the Recommendation shall be carried out (Annex A can be used as a template for alignment analysis).
- Critical Review: Verification shall be made by an independent third party. In this case, the name and coordinates of this third party must be given. Moreover, this third-party verification must be managed in accordance with ISO 14064-3, which specifies the requirements for the selection of GHG validators or verifiers, the establishment of the assurance level, objectives, criteria and scope, the determination of the validation or verification method, evaluation of data, information, information systems and GHG controls, assessment of GHG declarations and development of validation or verification opinions, as well as in accordance with ISO 14044. Furthermore, a review statement shall be provided.

II.2 Tier-2 assessment

- Assessment scope: The assessment shall cover the full different lifecycle stages.
- Embodied carbon emissions shall be based on Simplified LCAs[30] with an age of up to 3 years for hotspot equipment. For equipment with a low impact, alternative methods include PCF based on component characterization and Hardware parametrization[31] (e.g. Boavizta model, iNEMI LCA Eco-impact Estimator tool[32]).
- EoL phase shall be assessed considering the relevant metrics (weight, proportion of constituent materials receiving EoL treatment etc.) and EoL management options (complete recycling, incineration/energy recovery, landfill disposal with/without gas recovery etc.). EoL scenario-based modelling could be used. Further guidance on allocation among lifecycle stages for recycling and modelling EoL activities are provided by L.1410 and EF methodology for instance.
- For the case of a country/a group of countries-wide level assessment:
    - Considering the case of internationally used Datacenter and referring to the Recommendation and the example of allocation described in Appendix VII of L. 1440, it is advisable to allocate the impacts from Datacenters serving users inside and outside the country/group of countries boundaries, either located within the countries or abroad, according to the traffic.
    - Considering the case of a Telecommunication satellite, it is advisable to proceed with allocations throughout all activities of the value chain of the satellite (launch phase, operation and support activities).
    - Other internationally-used ICT goods/networks such as submarine communication cable systems and internet backbone should be handled with allocations.

[29] In case of non-compliance with the standard set of Tier-1 while aiming at a more granular reporting, the practitioner should consider the opportunity to fallback to Tier-2 type assessment.

[30] A new Work Item is currently being launched within ITU-T considering the development of a guidance on how to perform simplified LCA assessment with examples for goods. Once released and implemented by ICT equipment manufacturers, the new Recommendation would foster a streamline production of Simplified LCAs of ICT end-user devices.

[31] More detailed can be found on the GHG Protocol ICT Guidance [GHGP-ICT Guidance – 2017]

[32] https://www.inemi.org/

- Allocation of emissions among independent products that share the same process/asset: L.1450 and L.1410 recommendations allocation rules apply, the method chosen should most closely reflect the underlying use of the shared asset based on the most limiting or constraining factor. Whenever several allocation rules seem applicable, the variation of the result with the allocation rule shall be tested (this can be part of the sensitivity analysis).
- Reporting of results: results should be disaggregated by lifecycle stages; results shall be presented for the four main ICT categories (ICT end-user devices including IoT, networks, Datacenters and ICT services development and operation support).
- Sensitivity analysis shall be carried out. Uncertainty analysis should be qualified through its 3 categories (parameter, scenario and model uncertainty) by identifying the important sources of uncertainties[33]
- Compliance self-check with the Recommendation is highly recommended (Annex A can be used as a template for alignment analysis).
- Critical review:
    - This verification can be made by an independent third party. In this case, the name and coordinates of this third party must be given. Moreover, this third-party verification must be managed in accordance with ISO 14064-3, which specifies the requirements for the selection of GHG validators or verifiers, the establishment of the assurance level, objectives, criteria and scope, the determination of the validation or verification method, evaluation of data, information, information systems and GHG controls, assessment of GHG declarations and development of validation or verification opinions, as well as in accordance with ISO 14044. Furthermore, a review statement shall be provided.
    - This verification can also be made through a scientific peer review process organized according to the state-of-the-art.

II.3 Tier-3 assessment

Potential requirements of the Recommendation that could be relaxed include:

- Assessment scope: The assessment may focus on all lifecycle stages except End-of-life stage. End of life stage could be either cutoff or embarked within “Embodied emissions[34]”.

- For end-user devices:
    - The assessment may focus on hotspot end-user device categories currently including: Screens (incl. TV, computer screens etc.), laptop/ computers and smartphone.
      NOTE: As the ICT sector evolves over time, end-user device categories qualified as hotspots for a given timeframe might not be still considered as hotspots for a prospective time frame. Any choice of specific items shall be transparently reported and duly justified. This needs to consider product sales volumes as well as the impact per product.

    - Where up-to-date LCAs for the relevant devices are not available, embodied carbon emissions should be based on LCAs with an age of up to 5 years while considering their representativeness. Where available LCAs might be outdated (5+ years), such LCAs could be reused after applying appropriate adjustment factors

[33] Appendix VIII of [ITU L.1410] provides further details on handling uncertainties of LCAs for ICT and examples of important uncertainty sources at each lifecycle stage.

[34] According to [GHGP-ICT Guidance – 2017] embodied emissions refer to all the emissions other than those from the use stage.

to extrapolate their evolution. Several data sources for end-user devices embodied emissions are available, some of them are public/free of charge databases like include: ADEME Base Empreinte Database[35], Boavizta DB[36], published PCF from manufacturers; others such as PAIA Project Database[37], NegaOctet Database[38] are subject to access fees …

NOTE: When different data sources are available, the practitioner should privilege the selection of a data source with a publicly described methodology.

- o In case of lack of data, the practitioner may consider a Top-Down approach by calculating the overall embodied emissions of the end-user goods ICT industry without allocating it to specific product categories based on companies scope 1, 2 and 3 reporting. Where it is not possible to be exhaustive, published primary data reporting for major ICT companies could be used and scaled (for instance according to economic parameters such as revenue or physical parameters such as shipment volume) to the targeted scope[39].
- o Economic input/output assessment could be used as an alternative Top-Down approach given economic data (e.g. financial data), available multi-regional Environmentally-Extended Input Output Analysis (EEIOA). However, it should be acknowledged that EEIOA data sets may not exist for all countries and that EEIOA categories are broad and that cost not always correlate well with environmental impacts. Still, EEIOA data may help cover data gaps. Tables and appropriate mapping of the assessed equipment with the entries of EEIOA tables[40]. Examples of EEIOA data such as E3IOT are provided by the GHG Protocol website[41].

- For Networks and Data-centers:

[35] Base Empreinte® is the new impact database from ADEME resulting from the merge of the Base Carbone® and Base IMPACTS® databases.

https://base-impacts.ademe.fr/

[36] Boavizta makes available an open Database (data repository) of carbon footprint (use phase and embodied carbon emissions) of different equipment subcategories (laptop, screen, smartphone, desktop, server, tablet, printer) and from different manufacturers.

https://dataviz.boavizta.org/

[37] PAIA (Product Attribute to Impact Algorithm) is a streamlined LCA tool developed by MIT in concert with Arizona State University and University of California. PAIA provides cost-effective estimates of the carbon footprint of a product class including notebooks, desktops, LCD monitors, servers, network switches and storage. The PAIA tool conforms with IEC 62921 requirements and uses data from participating companies and secondary emission factors from third party sources (such as Ecoinvent).

https://quantis.com/who-we-guide/our-impact/sustainability-initiatives/paia/

[38] According to NegaOctet website, NegaOctet Database contains 1,500 components and equipment classified according to four levels of granularity (digital components, Equipment, Systems and Digital services). Each piece of equipment is associated with up to 30 impact factors.

https://negaoctet.org/en/home/

[39] Actually, this approach would go beyond the embodied emissions of equipment unless performing allocations to exclude specific Scope 3 categories if they are well-reported.

[40] EEIO data are non-process based secondary data derived from EEIO analysis. EEIO data is often comprehensive, however, a drawback of using EEIO data for Hardware embodied emissions is that ICT advancements occur rapidly with the onset innovations, but lag in being included in EEIO databases (updated generally each 5 years) [GHGP-ICT Guidance – 2017]. Unlike process-based LCAs which may lead to underestimated results due to truncation errors, EEIO-bases estimates have the advantage of taking account of emissions from all supply chain pathways. On the other hand, EEIOA data include economic measures that may not scale entirely with the emissions and they may also give disproportionate estimates for high-end part (such as ICT) of the broad categories established.

[41] https://ghgprotocol.org/life-cycle-databases

- Embodied carbon emissions could be calculated by means of a lifecycle stage ratio profiling (in this case as a ratio of the operational emissions) if the assessment targets a country/group of country with a relatively high carbon intensity electricity grid or for an assessment at a worldwide level, although this method is more relevant for products/systems with a long operating time. Example of embodied stage ratios can be found in the literature[42]. For countries with a relatively low carbon intensity electricity grid, embodied carbon emissions could be based on secondary data derived through ready-to-use Bottom Up modelling of relevant (i.e. qualify as hotspot) network/DC goods (e.g. Boavizta model), scientific literature or the use of LCAs with a timeliness of up to 5 years. As an example, relevant goods for Networks (respectively for DC) include Radio Base Stations for mobile networks (respectively IT Servers and storage). If applying lifecycle stage ratio profiling, it is important to consider that data can only be reused if reflecting the same energy mix as the one applicable within the studied boundaries.

  Other Top-Down approaches such as Economic input/output assessment and network/DC goods ICT industry organizational footprint reporting[39] could be used as an alternative method as well. See above.
- Operational carbon emissions: In the absence of measured data of energy consumption during ICT network/DC operation, energy consumption could be calculated by means of intensity metrics (e.g. through the use of available data on network/DC intensity factor multiplied by an appropriate activity data such as network/DC subscriptions etc.) with an age of up to 3 years.

  NOTE: Particular care should be attached to the physical scope of intensity metrics used for the assessment; any metric used shall be transparently defined.

  Alternative methods include the use of data on energy consumption as reported in ESR reports (Scope 1, scope 2 and specific categories of scope 3[43]) and eventually after applying appropriate apportionment (through economic allocation for instance) to target the specific scope of the study[44].

- [GHGP- ICT Guidance – 2017] provides several examples for Tier-3 type assessment.

- For the case of a country/a group of countries-wide level assessment:
  - The allocation of the internationally used ICT goods and networks (e.g. Datacenters, submarine cable networks, Internet Backbone networks etc.) could follow the principles outlined in L.1440 recommendation (i.e. the impact from ICT goods/networks located within the country/group of countries and used inside and outside its boundaries should be fully allocated to the country/group of countries; whereas impacts from ICT goods/networks located abroad but used by

[42] Appendix 5.2 of the ICT Sector Guidance – Chapter 5 Hardware provides examples of ratio figures [GHGP-ICT Guidance – 2017]. Note that a precautionary approach is required when using lifecycle stage ratio profiling as ratio figures were generally developed based on historical lifecycle assessments for ICT equipment and thus these ratios may be sensitive to equipment type, their age, the usage profile (for instance the activation of power-saving features) and the country/region of usage.

[43] Including Fuel & Energy related Emissions from Scope 3 (category 3) to consider from well to tank and Transmission & Distribution losses when “readjusting” the emission factors.

[44] Availability of up-to-date data for a global scale assessment would be fostered by the ongoing work for setting up a new ITU-T Recommendation aiming at providing guidance to support the creation of an ITU database on GHG emissions of the ICT sector at word-wide level.

the country/group of countries may not be allocated to the country/group of countries).

  - For the case of Telecommunication satellites, and by applying the same approach, one may consider to discard the impact of activities of the launch segment and the ground segment (i.e. support activities (e.g. operation control centers) or facilities (e.g. Ground stations)), if they had occurred/are located outside the geographical boundaries of the study while applying relevant allocations (for instance, by scaling with parameters such as use time or amount of data) to get the share of the impacts of activities of the Space segment (i.e. the satellite).

- Reporting of results: results are reported for embodied emissions and operational emissions (use stage) or can be reported for only highly significant lifecycle stages. Reporting can be done for the 3 main ICT categories (ICT end-user devices, networks and Datacenters).
- Sensitivity analysis shall be carried out. Where a high uncertainty is identified, conservative assumptions are privileged.
- While, a compliance self-check with the Recommendation may be done (Annex A can be used as a template for alignment analysis), the principle of Transparency regarding methodological assumptions and data used shall prevail. Moreover, results should be presented together with a disclaimer regarding their limitations.

Table II.1 provides overview of provisions of the three types of assessment.

Table II.1 - Overview of the three types of assessment

Methodological aspect	Tier 1	Tier 2	Tier 3
Type	Detailed assessment aligned with the Recommendation, with add-on specifications	Simplified assessment mostly aligned with the Recommendation with relaxed provisions	Screening, averaged assessment
Data types	Primary data complemented by/calibrated with ICT specific secondary data	Primary data are privileged Complemented by ICT specific secondary data/proxy data	Mainly secondary/proxy data
Lifecycle stages	Full life cycle	Full life cycle	Full life cycle except EoL
Assessment granularity	Fine-grained assessment, medium to high level of details	Fine-grained assessment, medium to high level of details	Coarse-grained assessment (hotspots), low level of details
The use of allocations	Allowed	Allowed	Not recommended
Embodied emissions	Up-to-date detailed LCA Hybrid LCA: Process-sum-based calibrated with EEIO	3 y. old simplified LCA for hotspots Process-sum	5 y. old simplified LCA ICT industry reporting EEIOA-based estimates
Operational emissions for DC/networks	Measured data	Measured data	Modelling using intensity metrics
End-of-life modelling	Required	Required	Could be discarded (cutoff)
Testing	Gravity analysis recommended Quantitative uncertainty recommended Sensitivity analysis required	Qualitative uncertainty recommended Sensitivity analysis required	Sensitivity analysis required

Reporting granularity	Per lifecycle stages Per ICT subcategories	Per lifecycle stages Per main ICT categories	Embodied vs Operational or Highly significant lifecycle stages Per main ICT categories
Reporting requirements	Compliance self-check Critical review required	Compliance self-check Critical review recommended	Compliance self-check Disclaimer is recommended Transparency prevails
Restrictions	Could be used for ICT footprint monitoring and baseline for future trajectories	Could be used for ICT footprint monitoring and baseline for future trajectories	Could not be used for ICT footprint monitoring and baseline for future trajectories

Appendix III An example on categorizing IoT devices with regards to the ICT sector

(This Appendix is related to Section 4.2)

This appendix (Table III.1) provides an example of categorizing (i.e. including or excluding) a set of IoT/M2M devices with respect to the ICT sector. The table below is part of a reply of the Expert Committee (issued 05/2022) to a request from the Mobile Expert Committee (submitted 03/2022) regarding the scope of IoT with respect to ICT.

Criteria for inclusion of connected devices within the boundaries of ICT/IoT, should be developed to decide whether a device is included fully or based on its connectivity part or not at all. This categorization is considered as a first proposal of the Committee, a refinement may be needed in a future work.

Table III.1 – Example of categorizing IoT/M2M devices within the scope of ICT

IoT/M2M device	Within ICT scope – current[45]	Within ICT scope – future[46]
Remote alarm for industrial facilities (business market)	No	Not expected at this stage
Logistics and telematics: Positioning system for assets tracking including equipment, truck, bicycle, city scooter …	Yes, optional, detailed guidance not yet provided	To be discussed
Payment terminals	Yes, optional, detailed guidance not yet provided	To be discussed
Car embedded connectivity system (e-Call, telemetry, telematics, SOFA/FOTA, infotainment/Wifi onboard…) provided by the car maker	No	Not expected at this stage
Car embedded connectivity system (e-Call, telemetry, telematics, SOFA/FOTA, infotainment/Wifi onboard …) provided by the car reseller	No	Not expected at this stage
Telemetry system used for utility networks located either at end-user premises (smart meter) or within the utility network (ex. Electricity switchyard substations etc.)	Yes, optional, detailed guidance not yet provided	To be discussed
Dispenser machine (for beverage, food etc.)	No	Not expected at this stage
Train/transport maintenance supporting equipment	No	Not expected at this stage
Lifts	No	Not expected at this stage
Interphone/Intercom	Yes, optional, detailed guidance not yet provided	To be discussed
Radar Speed Control systems	No	Not expected at this stage
(Construction) Site crane	No	Not expected at this stage
Electric vehicule charging station	No	To be discussed
Parking station (smart) meter/assistant	Yes, optional, detailed guidance not yet provided	To be discussed
Wearable (consumer market)	Yes, optional, detailed guidance not yet provided	To be discussed

[45] According to ITU L.1450 - Annex A: current version in force

[46] According to ITU L.1450 - Annex A: work in progress/future study item within ITU-T

Household products: Remote alarm system (consumer market)	No	Not expected at this stage
Household products: Voice assistant, Remote assistant device for the elderly/disabled …	No	To be discussed
Household products: connected refrigerators	No	Not expected at this stage
Household products: washing machines	No	Not expected at this stage
Household products: security cameras	Yes, optional, detailed guidance not yet provided	To be discussed
Household products: door bells/door locks	No	Not expected at this stage
Household products: Light bulbs	No	Not expected at this stage
Household products: Thermostats	No	Not expected at this stage
Household products: another connected appliance	No	To be discussed

Appendix IV Considerations on the assessment boundaries of telecommunication satellites

(This Appendix is related to Section 4.2)

As very few space missions serve an identical purpose or function (Earth observation, telecommunications, science), obtaining a relevant functional unit which enables the comparison based on the 'function' of a satellite or that could be easily reused by a practitioner for an ICT footprint assessment study is challenging. For example, for a telecommunications space mission, two examples of possible functional units could be envisaged:

(i) "One space mission in fulfilment of its requirements"
(ii) "Provisioning MB of data transferred over a distance of *x* km".

While the first option enables to reflect well the specificity of a space mission, this functional unit may be subject to debate due to the difficulty to compare between space missions. In contrast, the second option would enable direct plugging-in and ready-to-use results as well as comparison between missions serving the same purpose and requirements, however, the practitioner may generally need to address with care some considerations (scope of the assessment, allocation rules, scaling to fit the need the study) prior to reusing the results.

Whatever the selected functional unit and following ESA LCA Guidelines, a complete space mission system assessment shall cover the space segment, the launch segment and the ground segment; the breakdown of all phases (A to F) of the space mission is illustrated in Figure IV.1.

Considering the contribution of a telecommunications satellite in the ICT sector footprint requires considering its impact through a whole lifecycle perspective and applying a relevant share to some related activities within the space mission. This is why, it is recommended to consider a space mission perspective in line with ESA Guidelines[47] (level 1 LCA in the space sector) and then to implement adequate allocations on some activities/process/assets to align with the scope (telecommunication satellite services) and boundaries (temporal and geographical boundaries) of the assessment. By doing so, this appendix advocates for an assessment boundary at mid-way between a space segment LCA[48] and a space mission LCA. In particular, setting assessment boundaries of telecommunication satellites from an ICT perspective should be undertaken on light of the following considerations:

- Excluded unit process from a space mission scope may be excluded from the assessment boundaries of telecommunication satellites
- Included unit process in a space segment scope shall be included within the assessment boundaries of telecommunication satellites. Any excluded unit process shall be justified.
- When calculating the impact of telecommunications satellites, some of the activities of the space mission are considered as foreground activities while other as background, as identified in Table IV.1.

[47] Space System Life Cycle Assessment (LCA) guidelines, ESA (2016). https://blogs.esa.int/cleanspace/2020/11/19/environmental-lca-database/

[48] Space segment LCA aims at assessing the environmental impacts related to a specific spacecraft over its entire life-cycle, from R&D phase to the disposal of stages (cradle-to-grave) without considering impacts from its launch segment or ground segment activities.

Table IV.1 - Activities of the space mission and Telecommunication satellite assessment boundaries

Segment [Phase]	Activity/process	Type	Boundary settings guidance from an ICT perspective
Space segment [A+B][(1)]	Office work and people traveling. Testing	Background	May be excluded[(6)]. If included, consider only energy consumption for the operation of the design facilities and staff traveling, both directly related to the mission.
Space segment [C+D][(2)]	Resource extraction, manufacturing of spacecraft/satellite components	Foreground	Shall be included. "Cradle-to-Gate" LCA of all material/equipment (platform components) and instruments (payload components) included in the spacecraft. Production and EoL of packaging for spacecraft elements are discarded (assumed to be negligible).
Space segment [C+D][(2)]	Resource extraction, production of propellants for spacecraft/satellite	Foreground	Shall be included
Space segment [C+D][(2)]	Assembly, Integration and Testing (AIT)	Foreground	Shall be included. All AIT levels (instrument/payload, platform and satellite levels). Power consumption of major impacting testing activities including power consumption for heating, ventilation and air conditioning of AIT facilities and cleaning of clean room coats. Embodied emissions of AIT facilities and AIT related R&D and overhead activities may be excluded[(6)].
Space segment [C+D][(2)]	Transport of spacecraft/satellite components and assembly	Foreground	Shall be included
Space segment [C+D][(2)]	Office work and people traveling	Foreground	Should be included, only energy consumption for the operation of the design facilities and staff traveling, both directly related to the mission[(6)].
Launch segment [C+D][(2)]	Office work and people traveling	Background	May be excluded
Launch segment [C+D][(2)]	Production of launcher components and propellants for launcher	Background	Production of a launcher may be excluded. Upstream emissions caused by extraction and production of Propellants should be included
Launch segment [C+D][(2)]	Launcher stage assembly	Background	May be excluded
Space segment [E1a][(3)]	Transport of spacecraft/satellite to launch site	Foreground	Shall be included. Embodied emissions of the container are included (allocation to the number of uses if it is reused for several missions[49])
Space & Ground segment [E1a][(3)]	Launch campaign	Foreground	Shall be included. Only the usage phase (Ground Station operation and Control Center operation) corresponding to the preparation of the spacecraft.
Launch segment [E1b][(3)]	Production & assembly, launch campaign	Background	May be excluded
Launch segment [E1b][(3)]	Launch event	Background	Should be included
Ground segment [E2][(4)]	Use of flight operations control centers over the mission lifetime	Foreground	Should be included Including communication between stations in the Ground segment
Ground segment [E2][(4)]	Use of ground stations over the mission lifetime	Foreground	Should be included Including communication between stations in the Ground segment
Ground segment [E2][(4)]	Use of payload data handling station over the mission lifetime	Foreground	Should be included Including communication between stations in the Ground segment

[49] For instance, 20 times for telecommunications satellites (default assumption according to ESA LCA Handbook)

Ground segment [E2](4)	Use of payload data control center(s) over the mission lifetime	Foreground	Should be included Including communication between stations in the Ground segment
Space segment [F](5)	Spacecraft/satellite end of life	Foreground	Shall be included. Further guidance needed[50]
Ground segment [F](5)	Ground operation for EoL of the spacecraft/satellite	Foreground	May be discarded (assumed to be negligible)
Infrastructure	Construction and EoL of design, production and testing facilities	Background	May be excluded(6) Embodied emissions of ICT goods used in these facilities may be excluded
Infrastructure	Construction and EoL of launch facilities	Background	May be excluded(6) Embodied emissions of ICT goods used in these facilities may be excluded
Infrastructure	Construction and EoL of Mission control and operation centers	Background	Should be included(6) Embodied emissions of ICT goods used in these facilities may be excluded
Infrastructure	Construction and EoL of Ground stations	Background	Should be included(6) Embodied emissions of ICT goods used in these facilities may be excluded
Infrastructure	Construction and EoL of Payload data ground segment	Foreground	Should be included(6) Embodied emissions of ICT goods used in these facilities may be excluded

(1) A+B Phase: Feasibility + Preliminary definition
(2) C+D Phase: Detailed definition + Qualification and production
(3) E1 Phase: Launch and commissioning; E1a sub-phase: Spacecraft related activities; E1b sub-phase: Launcher-related activities
(4) E2 Phase: Utilization phase
(5) F Phase: Disposal: This phase covers the activities linked to the EoL of the spacecraft/satellite, passivation or either re-entry of the spacecraft/satellite in the atmosphere or its placement into a graveyard orbit and the associated ground segment operations.
(6) In general, infrastructure investment (design, production and testing facilities, launch facilities, mission control and operation centers, ground stations and Payload data handling stations and control centers) are assessed separately due to data availability and could be included considering specific allocation assumptions to reflect the share of the mission; however, in case where some of these facilities might be easily reconfigured to serve other purposes (e.g. design and manufacturing of earth observation satellites) beyond the scope of the ICT sector, thus they could be excluded from the assessment.

According to pilot screening studies commissioned by ESA, [C+D] phase, [E1] phase and ultimately [E2] phase are found to be the hotspots of an environmental impact of a Telecommunication Space mission[51]. Hotspots refer to several impact categories.

Once a complete space mission system assessment is secured, further methodological guidance would be required to address the following issues:

- Allocation rules to address the case of multi-purpose space missions: According to ESA LCA Guidelines, the mass criterion is recommended as a general rule to solve multi-functionality (ex. allocating the impact of the launcher in case of dual launch).
- Allocation rules to address the case of country level ICT assessment studies.

[50] Currently, as there are specific LCA guidelines available to characterize the environmental impacts of re-rentry and/or placement into a graveyard orbit; only flow indicators (e.g. dry mass left in the space and mass reentered atmosphere) could be considered.

[51][C+D] and [E1] phases are hotspots considering a single score multi-criteria assessment (PEF normalization and weighting approach); [C+D], [E1] and [E2] phases are hotspots if we focus on Climate Change.

Augustin Chanoine (Deloitte), Environmental Impacts of Launchers and space missions – Clean Space Industrials Days, 2017

https://indico.esa.int/event/181/contributions/1443/attachments/1336/1561/2017_CSID_Chanoine_LCA_launcher_space_missions_FV.PDF

- Allocation rules to solve potential overlap between the ICT sector and other sectors (e.g. launching of satellites /space vehicles, space freight and transportation support activities *à priori* classified under the Transportation and Storage sector[52]).

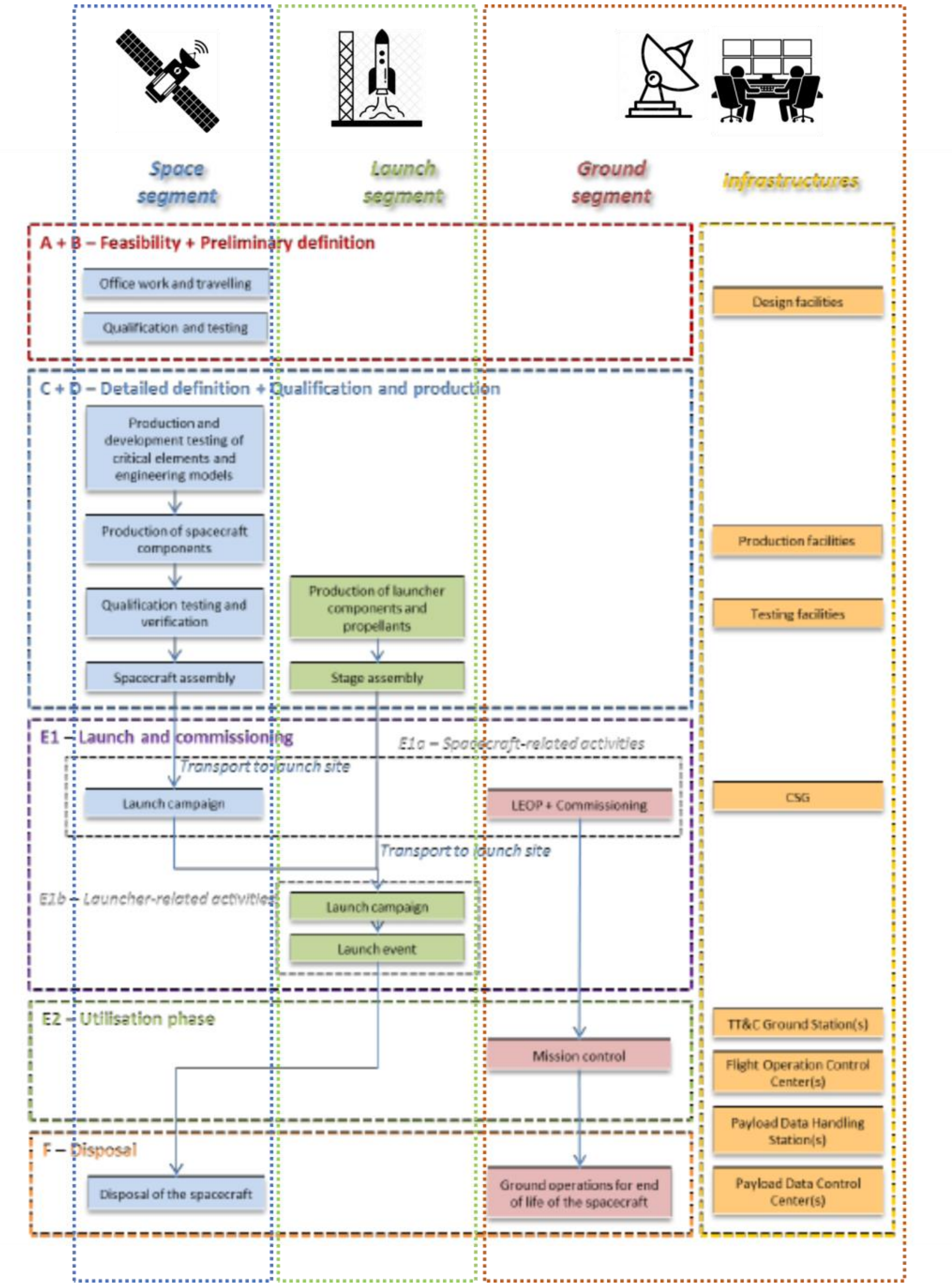

Figure IV.1 - System Boundaries of the space mission and activities/phases involved in the different segments (source: ESA Space LCA Handbook)

52 According to International Standard Industrial Classification of all Economic Activities (ISIC), Rev.4 (2008).

autorité de régulation
des communications électroniques,
des postes et de la distribution de la presse

Arcep at a glance

The Regulatory Authority for Electronic Communications, Postal Affairs and Print Media Distribution (Arcep), a neutral and expert arbitrator with the status of independent administrative authority (IAA), is the architect and guardian of internet, fixed and mobile telecoms and postal networks in France.

ADEME at a glance

At ADEME – France's National Agency for the Ecological Transition – we are firmly committed to fighting global warming and resource depletion. ADEME is a public establishment, under the joint authority of the Ministry for the Ecological Transition and the Ministry for Higher Education, Research and Innovation.

ISSN n°2258-3106