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Environmental Engineering (EE); Guidance on simplified Life Cycle Assessments (LCA) of Information and Communication Technologies (ICT)

Reference

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Foreword

This final draft ETSI Standard (ES) has been produced by ETSI Technical Committee Environmental Engineering (EE), and is now submitted for the ETSI Vote phase of the ETSI Membership Approval Procedure (MAP).

Modal verbs terminology

In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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Executive summary

The present document provides guidance on how to perform, use and report simplified LCAs.

Moreover, it gives guidance on when the use of simplified approaches is relevant and recommended.

Introduction

A Life Cycle Assessment (LCA) is a systematic methodology which gives an understanding of the relative importance of the different life cycle stages/activities. LCAs assist companies in determining where to put their efforts to improve life cycle environmental performance and also to monitor how this performance changes over time. However, it is important to keep in mind that the results of an LCA are always model-based representations of real environmental impact, and the absolute impact of a certain product, network, service or organization is beyond reach. This is true for all kinds of product systems, but especially so for the complex product systems of the ICT sector.

An LCA addresses potential environmental impact; an LCA does not predict absolute or precise environmental impact due to the relative expression of potential impacts to a reference unit, the integration of environmental data over space and time, the inherent uncertainty in modelling environmental impact, and the fact that some possible environmental impacts are clearly future impacts (ISO 14040 [3], clause 4.3).

In practice, it is virtually impossible to collect enough data for an assessment to give the absolute performance of a product system. Even then, the results would still have model and scenario uncertainty.

Consequently, any LCA result is only valid under the assumptions of the study and is still associated with substantial uncertainty, which needs to be considered so the outcome of the assessment is interpreted in a correct way. This goes for detailed LCA assessment approaches described in Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2], and even more so if further simplifications are needed.

Yet, simplified approaches are needed in different situation to give an approximation of the environmental impacts of products. The present document will outline when such approaches are relevant and how they could be performed, used and reported.

Providing a LCA fully respecting Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2] is a very complex and time-consuming task. Not all companies and organizations have the financial and human resources to meet the requirements demanded. Hence, to onboard a large community across the industry and monitor the achievements of environmental targets it seems useful to provide relevant parties (operators, OEMs, integrators, service providers and software developer) with simplified approaches to assess environmental impacts of ICT goods and services. This can be viewed as a "Minimal Viable" approach that encourage parties to deliver life cycle impact estimates with limited investment, time and costs.

As for detailed LCA in line with Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2], techniques such as uncertainty analysis and sensitivity analysis are important to understand the results of a study and what conclusions can be made.

Quantitative results of detailed LCA's by different LCA practitioners cannot be compared without considerations of assumptions, limitations in data, differences in data sets and scenarios as described in Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2]. This is even more true for simplified approaches which are to a larger extent based on generic data, simplifying assumptions etc. To allow for comparability of results, whether based on detailed or simplified approaches, product category rules would need to be developed at product category level that allows for developing common detailed scenarios and assumptions. Results based on such Product Category Rules would be comparable but at the expense of being less representative to the actual conditions of the individual product.

1 Scope

The present document provides guidance on how to perform, use and report simplified LCAs for ICT products and services.

Moreover, it gives guidance on when the use of simplified approaches is applicable and what are the limitations.

2 References

2.1 Normative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found in the ETSI docbox.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long-term validity.

The following referenced documents are necessary for the application of the present document.

[1] Recommendation ITU-T L.1410 (11/24): "Methodology for environmental life cycle assessments of information and communication technology goods, networks and services".

[2] ETSI ES 203 199 (V1.4.1): "Environmental Engineering (EE); Methodology for environmental Life Cycle Assessment (LCA) of Information and Communication Technology (ICT) goods, networks and services".

NOTE: References [1] and [2] are technically equivalent.

[3] ISO 14040:2006: "Environmental management — Life cycle assessment — Principles and framework".

[4] ISO 14044:2006: "Environmental management — Life cycle assessment — Requirements and guidelines".

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long-term validity.

The following referenced documents may be useful in implementing an ETSI deliverable or add to the reader's understanding, but are not required for conformance to the present document.

[i.1] Recommendation ITU-T L.1420 (2012): "Methodology for energy consumption and greenhouse gas emissions impact assessment of information and communication technologies in organizations".

[i.2] Void.

[i.3] Recommendation ITU-T L.1451 (2019): "Methodology for assessing the aggregated positive sector-level impacts of ICT in other sectors".

[i.4] Void.

[i.5] Recommendation ITU-T L.1450 (2018): "Methodologies for the assessment of the environmental impact of the information and communication technology sector".

[i.6] Supplement ITU-T L. Suppl. 57 (2023) - Recommendation ITU-T L.1420: "Scope 3 guidance for telecommunication operators".

[i.7] J. Malmodin, N. Lövehagen (2024): "A methodology for simplified LCAs of electronic products". In proceedings of Electronics Goes Green, Berlin, 18-20 June 2024. DOI: 10.23919/EGG62010.2024.10631258.

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[i.11] GSMA™: "Scope 3 Guidance for Telecommunication Operators".

[i.12] M. Ercan, J. Malmodin, P. Bergmark, E. Kimfalk, E. Nilsson: "Life cycle assessment of a smartphone". In: Proceedings of the ICT for sustainability (ICT4S), 2016. Amsterdam, The Netherlands.

[i.13] ETSI TS 104 134 (V1.1.1): "Environmental Engineering (EE); Simplified Method for including Uncertainty and Sensitivity Aspects in Calculations of the Avoided Environmental Impact of Information and Communication Technology Solutions".

[i.14] A.S.G. Andrae: "Year 2025 global average midpoint proxy intensities for GWP100, ADP (minerals), Ecotoxicity (CTUe) and water scarcity (m 3) for use in simplified LCA of ICT products", 2025. DOI: 10.13140/RG.2.2.10765.45288.

[i.15] Andrae A.S.G. and Vaija M. S. (2017): "Precision of a Streamlined Life Cycle Assessment Approach Used in Eco-Rating of Mobile Phones".

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[i.19] Suer J., Traverso M. & Jäger N. (2022): "Review of Life Cycle Assessments for Steel and Environmental Analysis of Future Steel Production Scenarios". Sustainability 2022, 14, 14131.

[i.20] Andrae A. S. G, & Vaija M. S. (2014): "To Which Degree Does Sector Specific Standardization Make Life Cycle Assessments Comparable?—The Case of Global Warming Potential of Smartphones". Challenges, 5(2), pp. 409-429.

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[i.28] Andrae, A. S. G. (2020): "Hypotheses for primary energy use, electricity use and CO_2 emissions of global computing and its shares of the total between 2020 and 2030". WSEAS Transactions on Power Systems, 15(50-59), 4.

[i.29] Kristanto G. A. & Koven W. (2019): "Estimating greenhouse gas emissions from municipal solid waste management in Depok, Indonesia". City and environment interactions, 4, 100027.

[i.30] INEMI: "Eco-Impact Estimator, Phase 3".

[i.31] Carbon Trust/GESI: "ICT Sector Guidance built on the GHG Protocol Product Life Cycle Accounting and Reporting Standard", July 2017.

[i.32] Y. Yang, Y. Park, T. M. Smith, T. Kim, H.-S. Park: "High-Resolution Environmentally Extended Input-Output Model to Assess the Greenhouse Gas Impact of Electronics in South Korea".

[i.33] Greenhouse Gas Protocol: "Corporate Value Chain (Scope 3) Standard".

[i.34] Greenhouse Gas Protocol: "Corporate Standard".

[i.35] ETSI EN 303 808: "Environmental Engineering (EE); Applicability of EN 45552 to EN 45559 methods for assessment of material efficiency aspects of ICT network infrastructure goods in the context of circular economy".

[i.36] CLC/TR 45550:2020: "Definitions related to material efficiency", (produced by CEN).

[i.37] ISO 14046:2014: "Environmental management — Water footprint — Principles, requirements and guidelines".

[i.38] ETSI ES 202 336-1: "Environmental Engineering (EE); Monitoring and Control Interface for Infrastructure Equipment (Power, Cooling and Building Environment Systems used in Telecommunication Networks) Part 1: Generic Interface".

[i.39] Greenhouse Gas Protocol: "Product Life Cycle Accounting and Reporting Standard".

3 Definition of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the following terms apply:

activity data: quantitative measure of a level of activity that results in GHG emissions

NOTE: See Corporate Value Chain (Scope 3) Standard [i.33], clause 7.2.

black box module: device, system or object which can be viewed solely in terms of its input, output and transfer characteristics without any knowledge of its internal workings

NOTE 1: In this context the black box module may consist of several part categories such as integrated circuits, mechanics, cables, etc., e.g. a power module on a PCBA.

NOTE 2: See ETSI ES 203 199 [2], clause 3.1.

CO2 equivalent (CO2 e): universal unit of measurement to indicate the Global Warming Potential (GWP) of each of the seven greenhouse gases, expressed in terms of the GWP of one unit of carbon dioxide

NOTE 1: It can be used to evaluate releasing (or avoiding releasing) different greenhouse gases against a common basis.

NOTE 2: See Corporate Standard [i.34], glossary.

commercial lifetime: length of time that a good is owned for before a new one is bought to replace it

NOTE 1: This term may be used to estimate the lifetime of consumer products.

NOTE 2: See ETSI ES 203 199 [2], clause 3.1.

comparative analysis: analysis aiming to compare two different product systems based on the same functional unit

NOTE: This definition comes from ETSI ES 203 199 [2].

cradle-to-gate: partial life cycle of ICT goods or parts, from material acquisition through to when they leave the factory gate (e.g. immediately following the production)

NOTE 1: See ETSI ES 203 199 [2], clause 3.1. This definition has been amended from GHG Protocol Product Standard [i.39].

NOTE 2: E.g. ICT goods ready to be put on the market/sales with no need for further processing.

cut-off: amount of energy or material flow, or the level of environmental significance associated with unit processes or product systems excluded from the study

NOTE: Unit processes excluded from the studied product system in an LCA.

data gap: LCI flows excluded from a unit process within the studied product system

NOTE: See ETSI ES 203 199 [2], clause 3.1.

depreciation time: time during which a (new) revenue-generating asset reaches its residual economic value

NOTE: The depreciation time is sometimes referred to as the legal lifetime.

Economic Input-Output approach (EIO): method using tables, called Input-Output (IO) tables, that describe financial transactions between economic sectors in a national economy, to approximate environmental impacts

embodied emissions: life cycle(s) emissions from the following life cycle stages:

- raw material acquisition;
- production; and
- end-of-life treatment.

EXAMPLE: All life cycle stages other than the use stage.

NOTE 1: See ETSI ES 203 199 [2], clause 3.1.

NOTE 2: Each life cycle includes transportation as generic process as described in ETSI ES 203 199 [2].

embodied environmental impact: life cycle(s) environmental impact from the following life cycle stages:

- raw material acquisition;
- production; and
- end-of-life treatment.

EXAMPLE: All life cycle stages other than the use stage.

NOTE 1: See ETSI ES 203 199 [2], clause 3.1.

NOTE 2: Each life cycle includes transportation as generic process as described in ETSI ES 203 199 [2].

emission factor: factor allowing GHG emissions to be estimated from a unit of available activity data (e.g. tonnes of fuel consumed, tonnes of product produced) and absolute GHG emissions

NOTE 1: See Corporate Standard [i.34], glossary and Recommendation ITU-T L.1451 [i.3].

NOTE 2: Another example is: kgCO_2e/kWh electricity, kgCO_2e/(tonne × km).

environmental impact: impact including positive and negative aspects on the environment

NOTE: See ETSI ES 203 199 [2], clause 3.1.

extended operating lifetime: aggregated duration of the actual use periods of the first user and consecutive use periods associated with reuse

NOTE 1: The user in different life cycles can be the same or different user.

NOTE 2: Reuse and refurbishment, enable several use periods and consecutive life cycles.

NOTE 3: ETSI EN 303 808 [i.35] definition is aligned with TR 45550:2020 [i.36].

NOTE 4: See ETSI ES 203 199 [2], clause 3.1.

functional unit: See ISO 14040 [3], clause 3.20.

GHG emission intensity: numerical value of Greenhouse Gas (GHG) emissions per unit

Global Warming Potential (GWP): ratio of the warming of the atmosphere caused by one greenhouse gas to that caused by a similar mass of carbon dioxide

NOTE 1: GWP is calculated over a specific time frame generally 100 years.

NOTE 2: See ETSI ES 203 199 [2], clause 3.1.

ICT goods: tangible goods deriving from or making use of technologies devoted to or concerned with:

- the acquisition, storage, manipulation (including transformation), management, movement, control, display, switching, interchange, transmission or reception of a diversity of data;
- the development and use of the hardware, software, and procedures associated with this delivery; and
- the representation, transfer, interpretation, and processing of data among persons, places, and machines, noting that the meaning assigned to the data is preserved during these operations.

NOTE: See ETSI ES 203 199 [2], clause 3.1.

ICT network: set of nodes and links that provide physical or over the air information and communication connections between two or more defined points

EXAMPLE: Wireless network, fixed network, Local Area Network (LAN), home network and server network, access networks, core networks, cloud computing networks.

NOTE: See ETSI ES 203 199 [2], clause 3.1.

ICT service (application): use of ICT goods and/or networks to provide value to one or more users

EXAMPLE: Teleconferencing, teleworking, e-ticketing, e-learning, e-healthcare, smart transport and logistics, procurement systems, supply chain management systems, music/film distribution over the Internet or voice over IP, machine-to-machine systems.

NOTE: See ETSI ES 203 199 [2], clause 3.1.

ICT-specific EoLT: any disassembly/dismantling/shredding/recycling process which needs special adaptation for handling of ICT goods

NOTE: See ETSI ES 203 199 [2], clause 3.1.

ICT-specific infrastructure: basic structures needed for the operation of the goods, network or service

EXAMPLE: Antenna towers, cabling systems.

infrastructure: basic structures needed for the operation of the society

EXAMPLE: Transportation systems, buildings and power plants.

NOTE: See ETSI ES 203 199 [2], clause 3.1.

LCA practitioner: person(s) or organization(s) performing an LCA

NOTE: See ETSI ES 203 199 [2], clause 3.1.

life cycle: See ISO 14040 [3], clause 3.1.

life cycle stage: one of several consecutive and interlinked stages of a product system

NOTE: See ETSI ES 203 199 [2], clause 3.1.

lifetime: duration which may correspond to commercial lifetime, operating lifetime, extended operating lifetime or depreciation lifetime

NOTE: See ETSI ES 203 199 [2], clause 3.1.

location-based data: average grid emission factor data for the given locality or region

NOTE: Description is from Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2] main text.

market-based data: emissions from electricity that a company have purposefully chosen, e.g. derived from contractual instruments

NOTE: Description is from Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2] main text.

modelled data: assumption-driven estimates, such as estimates resulting from scenarios, which are forward looking or scaled up from smaller pilot studies

NOTE: See ETSI ES 203 199 [2], clause 3.1.

natural resource: material source, such as wood, water, or a mineral deposit, that occurs in a natural state

NOTE: See ETSI ES 203 199 [2], clause 3.1.

node: point in a network topology at which lines intersect or branch

NOTE: See ETSI ES 203 199 [2], clause 3.1.

operating lifetime: duration of the actual use period (consisting of both active and non-active periods) for the first user

NOTE 1: Storage time is not included in operating lifetime.

NOTE 2: See ETSI ES 203 199 [2], clause 3.1.

operator: organization operating networks and services

NOTE: See ETSI ES 203 199 [2], clause 3.1.

other EoLT: any disassembly/dismantling/shredding/recycling process which does not need special adaptation for handling of ICT goods but could be used for any kind of good

NOTE: See ETSI ES 203 199 [2], clause 3.1.

part: constituent of ICT goods and support goods

EXAMPLE: Cable.

NOTE: See ETSI ES 203 199 [2], clause 3.1.

part category: classification of a part e.g. by its type

EXAMPLE: Fibre cable.

NOTE: See ETSI ES 203 199 [2], clause 3.1.

primary data: See ISO 14046 [i.37], clause 3.6.1.

primary energy: energy content of natural resources which can be used for energy production

NOTE: See ETSI ES 203 199 [2], clause 3.1.

primary raw material: material which originates from natural resources

NOTE: See ETSI ES 203 199 [2], clause 3.1.

process category: classification of a process type

EXAMPLE: Landfill, air, ship and train.

NOTE: See ETSI ES 203 199 [2], clause 3.1.

product system: See ISO 14040 [3], clause 3.28.

public data: data which is available to the public without access being restricted by requirements on membership, none-disclosure agreements, or similar restrictions

NOTE: See ETSI ES 203 199 [2], clause 3.1.

raw material: See ISO 14040 [3], clause 3.15.

raw material extraction: production of extracted raw materials used in raw material processing

NOTE: See ETSI ES 203 199 [2], clause 3.1.

raw material processing: production of processed raw materials used in in Part production

NOTE: See ETSI ES 203 199 [2], clause 3.1.

raw material recycling: production of raw materials from recycled products

NOTE: See ETSI ES 203 199 [2], clause 3.1.

recycling rate of disposed raw material: rate at which disposed goods end up in a recycling process is part of the scope of the LCA

NOTE: See ETSI ES 203 199 [2], clause 3.1.

reference product system: system (basically non-ICT but can also be ICT) which is replaced by ICT

EXAMPLE: Traditional service which is replaced by an ICT service.

NOTE: See ETSI ES 203 199 [2], clause 3.1.

re-use: process by which a product or its parts, having reached the end of their first use, are used for the same purpose for which they were conceived

NOTE 1: Reuse after second or subsequent usage is also considered as reuse, but normal, regular or sporadic use is not considered as reuse (TR 45550:2020 [i.36] and ETSI EN 303 808 [i.35]).

NOTE 2: ICT goods usage by a new user or in a new context is considered to be reuse.

NOTE 3: Definition amended from ETSI EN 303 808 [i.35] with additional note 2.

NOTE 4: See ETSI ES 203 199 [2], clause 3.1.

scope 3 emissions: scope 3 emissions are a consequence of the activities of the company, but occur from sources not owned or controlled by the company

NOTE 1: Some examples of scope 3 activities are extraction and production of purchased materials; transportation of purchased fuels; and use of sold products and services.

NOTE 2: Relevant Scope 3 categories for ICT companies are listed in Recommendation ITU-T L.1420 [i.1].

NOTE 3: See Corporate Standard [i.34].

secondary data: See ISO 14046 [i.37], clause 3.6.2.

secondary raw material: material which origins from recycled primary raw materials

NOTE: See ETSI ES 203 199 [2], clause 3.1.

service provider: organization operating a service (could be the same organization as the operator)

NOTE: See ETSI ES 203 199 [2], clause 3.1.

simplified Life Cycle Assessment: methodology to assess the environmental impact of a product or service with a more streamlined evaluation approach compared to a LCA following Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2]

NOTE: It aims to provide a fast and cost-effective overview of the environmental performance of a product or service, enabling informed decision-making for product design and manufacturing.

storage time: length of time for which the goods are stored, including for both before and after its use stage

NOTE: See ETSI ES 203 199 [2], clause 3.1.

support activity: activities supporting unit processes associated with the function of the good, network or service

NOTE 1: Examples of support activities are activities directly associated with the product system, such as marketing, development and sales and also more general activities of the organization, such as data support, communication, and financial support.

NOTE 2: See ETSI ES 203 199 [2], clause 3.1.

support goods: device, system or object needed to realize the function of supporting the use of ICT goods

EXAMPLE: Goods for power supply and temperature regulation.

NOTE 1: See ETSI ES 202 336-1 [i.38] for an explanation which defines support goods for networks as infrastructure goods.

NOTE 2: See ETSI ES 203 199 [2], clause 3.1.

the 50/50 method: allocation method that allocates the credits equally to the life cycle using and the one supplying recycled material

NOTE 1: In reuse/refurbishment scenarios, the LCA practitioner needs to clearly declare how the allocation of raw materials has been handled in the assessment.

NOTE 2: See ETSI ES 203 199 [2], clause 3.1.

unit process: smallest element considered in the life cycle inventory analysis for which input and output data are quantified

NOTE 1: See also ISO 14040 [3] and ISO 14044 [4].

EXAMPLE: Part unit process such as IC Encapsulation and Display module assembly.

NOTE 2: See ETSI ES 203 199 [2], clause 3.1.

waste: See ISO 14040 [3], clause 3.35.

3.2 Symbols

Void.

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AEC	Annual Electricity Consumption
ALY	Active Lifetime Years
CTU	Comparative Toxic Unit
EEF	Electricity Emission Factor
EEIO	Environmentally Extended Input Output analysis
EF	Emission Factor
EoLT	End of Life Treatment
GHG	Greenhouse Gas
GHGP	Greenhouse Gas Protocol
GWP	Global Warming Potential
ICT	Information and Communication Technology
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCSRP	Life Cycle Stage Ratio Profiling
PCR	Product Category Rules
PP	Product Parameter
PPCA	Parametrized Product Characteristics Approach
PSR	Product Specific Rules
PWB	Printed Wiring Board

4 Introduction to simplified LCA approaches

4.1 General

Life Cycle Assessment (LCA) is an established methodology to assess environmental impact of goods and services using life cycle perspective including raw material acquisition, production, use and end of the life stages. ISO 14040 [3] and ISO 14044 [4] were the first international standards on LCA and based on that there are other LCA standards that have been developed for different purposes. For ICT sectorial use, Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2] provides the detailed methodology for LCA of ICT goods, networks and services. While LCA is a valuable tool, an LCA study in line with Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2] can be complex and resource intensive task which require significant time, data and expertise, therefore simplified approaches are required to address these challenges.

For any LCA assessment, it is important to define the product system to be assessed, goal and scope of the study, inventory analysis, impact assessment and interpretation of results. As described in Recommendation ITU-T L.1410 [1], on the higher level the following four lifecycle stages shall apply to ICT goods:

1) Goods raw material acquisition

2) Production

3) Use

4) End of Life Treatment (EoLT)

Any LCA, including simplified ones should follow the structure of Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2]. Consequently, they need to consider the following aspects:

1) General requirements: including life cycle stages, definition of the product system to be assessed, operating lifetime, etc.

2) Goal and scope definition, including also the functional unit, system boundaries, cut-off rules, data quality and requirements

3) Life Cycle Inventory (LCI): data collection, data calculation, allocation procedure

4) Life Cycle Impact Assessment (LCIA): impact categories

5) Life cycle interpretation including uncertainty analysis and sensitivity analysis

6) Reporting

The goal of the LCA study states the intended application and the reasons for carrying out the study, information about the intended audience, i.e. those to whom the results of the study are intended to be communicated, and whether the results are intended to be used in comparative assertions intended to be disclosed to the public.

The LCI consists of data collection, calculation, and allocation. When applicable, data quality requirements from section 6.2.5 of Recommendation ITU-T L.1410 [1] and ISO 14044 [4] clause 4.2.3.6 should be followed. LCA practitioners are encouraged to collect primary activity data on the use stage of the product under analysis. When primary data are not available, secondary data for the product category can be used.

The LCIA aims to evaluate the significance of potential environmental impacts using the LCI results. In general, this process involves associating inventory data with specific environmental impact categories and category indicators, thereby targeting to understand these impacts. Recommendation ITU-T L.1410 [1] provides the list of environmental impact categories (see Recommendation ITU-T L.1410 [1], section 7.1, Table 5). However, due to historical data availability, climate change impact (Global Warming Potential) is the most common impact category that is usually used for the impact assessment with this methodology.

In the life cycle interpretation, the results of the LCA are evaluated to answer questions raised in the goal definition. This phase should also provide information on conclusion, limitations, and recommendations. The sources of uncertainty and methodological choices made shall be assessed and disclosed. The interpretation shall include a sensitivity check of the significant inputs and outputs. For detailed information see ISO 14044 [4] and Recommendation ITU-T L.1410 [1].

4.2 Simplified approaches

Simplified LCAs are useful to assess the different life cycle stages/activities in a scalable way for complex products. Most electronic products consist of thousands of components from hundreds of suppliers. An LCA, in line with Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2], requires all flows within product full life cycle to be included in the assessment, which makes this time consuming and requires lots of work. Huge amounts of data are needed for complex goods, networks and services.

The main goal of a simplified LCA approach is to limit the time and resources spent without sacrificing the result quality too much. Also simplified LCA allows to analyse results of different goods/services, avoiding focusing on one single LCA, which may lead to suboptimizations.

There are different simplified LCA approaches and which one to use will depend on its purpose and data availability as well as resource and time.

Simplified approaches described further in the present document are:

- Product Parameter (PP) method which uses modularity and commonality among the ICT hardware to estimate the impact. A product environmental impact assessment is simplified by using a limited list of product parameters, at least 10, and use a process sum approach. This method is described in more detail in clause 5.2.

NOTE: A previous LCA study is not required, and this simplified LCA approach can be seen as an LCA study of its own.

- Life Cycle Stage Ratio Profiling (LCSRP) method which uses the commonality among the ICT goods and their associated life cycle stage ratio profiles to estimate the environmental impact. It relies on the existence of a previously performed LCA of a similar product. This method is described in more detail in clause 5.3.

- One parameter LCA (1PLCA) method uses an existing LCA of a similar product to estimate the environmental impact of an ICT good based on one or a few parameters such as weight or size. This method is described in more detail in clause 5.4.

- Environmentally Extended Input Output analysis (EEIO) method which is based on the material and energy flow of upstream supply chain activities. The environmental impact is estimated linking acquired material and products with respective environmental impact (e.g. via financial data). This method is described in more detail in clause 5.5.

A simplified LCA method shall explicitly show how it simplifies the requirements of Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2] for LCA of ICT goods. A simplified LCA method shall use the same terminology and nomenclature as Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2].

A simplified LCA method's life cycle stages shall have the same start and end as outlined in Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2].

4.3 Applicability of LCAs and simplified LCA

LCAs should primarily be used for the following purposes:

- identification of hotspots and opportunities to improve the environmental performance of goods, networks, services and organizations;
- information to decision-makers in industry, government or non-government organizations about typical environmental performance of a product system/organization to assist their policy choices;
- selection of relevant indicators of environmental performance for monitoring;
- understanding of the potential impact of new services and solutions;
- understanding of improvements between generations.

Contrarily, an LCA (without detailed specification of conditions in a Product Category Rule) is less suitable for:

- benchmarking or absolute comparison of LCA results between studies from different sources;
- product system performance legislation (measurable parameters more appropriate, e.g. if use is found to be the hotspot, average use power or electricity consumption is more suited to be used instead of the use carbon footprint); and
- labelling of ICT goods, networks and services based on LCA results.

An LCA in line with Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2] gives the most accurate result when enough data is accessible. However, such an LCA is a complex and resource intensive task that works best in a research or study context, not as a tool for streamlined exchange of information regarding individual products. For such exchanges, simplified approaches work as a complement and gives sufficient accuracy.

Simplified approaches could be relevant in different application areas, such as:

- Approximation of environmental footprint: Input to studies of ICT services where the footprint or the embodied emissions of the product is less significant and/or studies where an average market estimate is sufficient. This may be an intermediate step, for example giving input to other studies.
- Input to sectoral footprint reporting: Providing input to studies on ICT sector footprint in combination with other data sets on large scale i.e. country, regional or global level and where an average market estimate is sufficient. L.1410-based LCA results may not be available for all ICT goods or services when the purpose is to understand ICT sectoral footprint, therefore simpler methods are likely required. See also Recommendation ITU-T L.1450 [i.5].
- Input to customer scope 3 reporting: LCA goods user/owner may want to have an understanding of their scope 3 emissions. LCA results are useful for facilitating collaborations and exchanges between parties in value chain on their decarbonation efforts. See also Supplement ITU-T L. Suppl. 57 [i.6].
- Selection of relevant environmental impact categories: Simplified LCA can be a useful tool for a screening study, where the main purpose is to understand the most significant environmental impacts categories.
- Hotspot analysis: Hotspot analysis gives high-level understanding in which part of the product life cycle the biggest environmental impacts appear, thus guiding actions to reduce those.

- Comparative analysis: The aim of a comparative analysis is to compare the environmental impacts of two different solutions. The practitioner shall set the analysis boundaries and other assumptions to be suitable for comparative analysis. Recommendation ITU-T L.1410 [1] gives guidance in Part II for conducting comparative analysis. Comparative analysis can also be used to analyse the impact of improvement actions.

- LCA results intended for public disclosure: The credibility of LCA results improves with usage of high quality LCA input data, usage of more detailed assessment methodology and when multiple flows are included in the study. Therefore, LCA according to Recommendation ITU-T L.1410 [1] and simplified LCA with PP method provide the best basis for this.

As listed above, studies with simplified LCA approaches can be used for various purposes. A guidance to choose an appropriate approach is provided in clause 4.4. Depending on the required accuracy of the LCA result and data availability, it can also be used to develop product environmental footprint or product carbon footprint information

A screening analysis is a simplified preliminary LCA study for getting high level overview and identifying the processes or stages with most significant environmental impacts, which helps to focus on most critical areas for improvement without conducting or before conducting an LCA in line with Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2]. Simplified LCA assessment can be done with readily available data or proxy data or secondary data to make a quick approximation. It provides insights about the main factors and drivers of environmental impact and to identify the opportunities for improvement. These results are typically used for internal communications to share information with suppliers and partners for communicating the environmental impact and improvement opportunities.

Comparisons of LCA results (absolute and relative values) are not suitable regardless of using detailed and/or simplified methods. This is beyond the scope of the present document as such comparisons would require that the assumptions, including goal and scope of the study, system boundaries, functional unit, cut-off criteria, allocation rules, method used, and other assumptions, and context of each LCA study are equivalent, which typically only are achieved if performed by the same LCA practitioner and organization and at the same time period.

4.4 Decision tree for choosing approach

4.4.0 Determining possible approaches

When considering which LCA method is the most appropriate one for the purpose of the LCA study, based on the purpose of the study, the following decision trees in Figures 1 to 3 give guidance to the LCA practitioner. For approximation of environmental footprint or input to sectoral footprint reporting, see Figure 1. For customer scope 3 reporting or selection of relevant environmental impact categories, carbon footprint and impact other than GHG emissions, see Figure 2. For hotspot analysis or comparative assessment as in Recommendation ITU-T L.1410 [1] Part II, LCA results intended for public disclosures, see Figure 3.

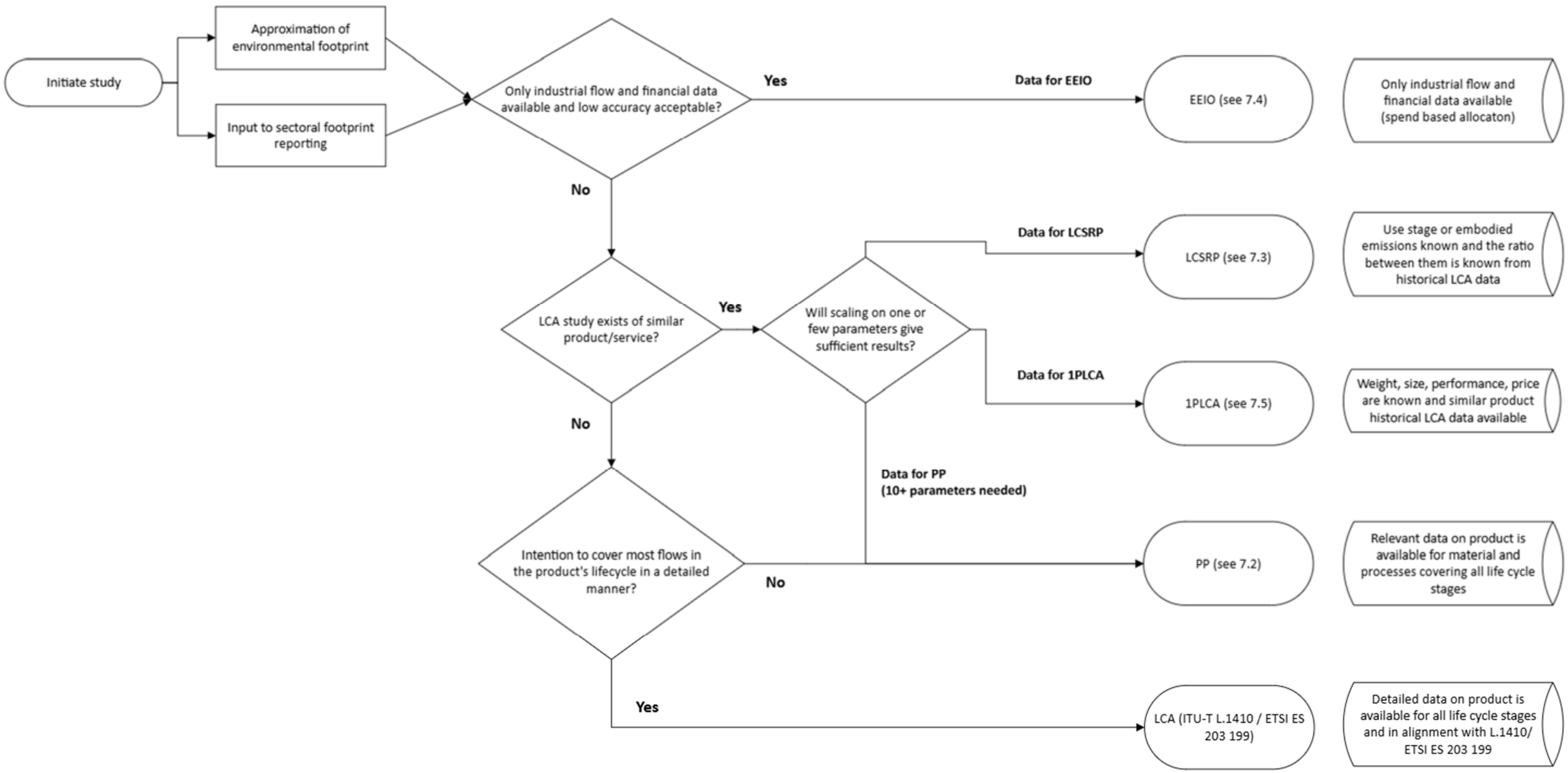


Figure 1: LCA or simplified LCA alternatives for approximation of environmental footprint or input for sectoral footprint reporting

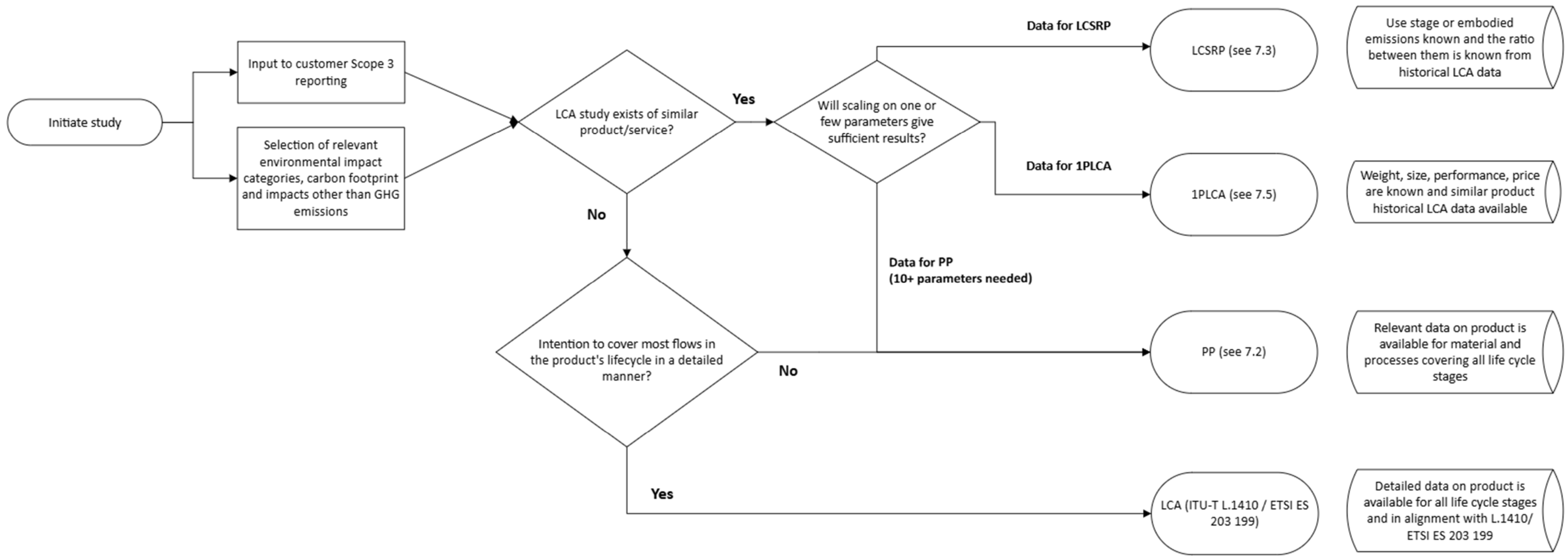


Figure 2: LCA or simplified LCA alternatives for obtaining input to customer scope 3 reporting or for selection of environmental impact categories

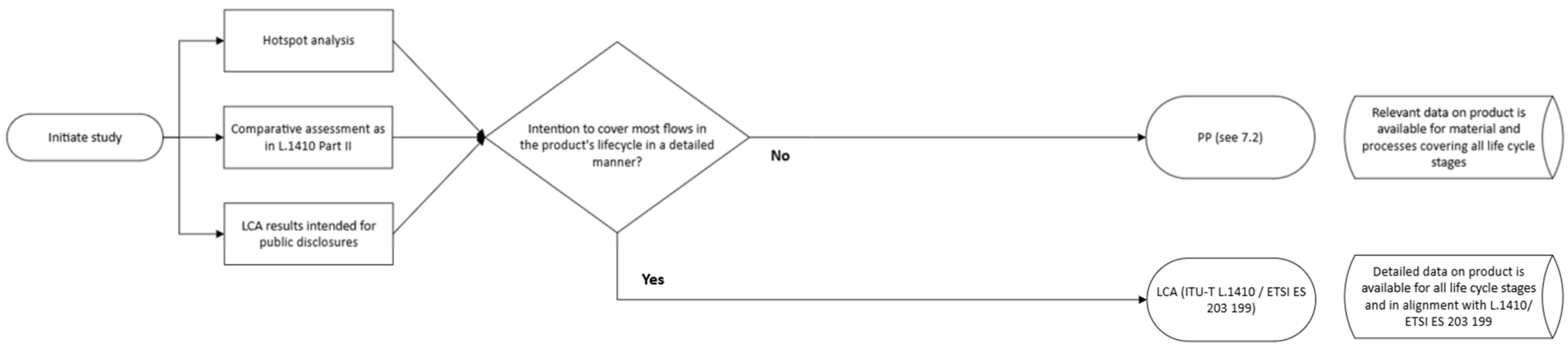


Figure 3: LCA or Simplified LCA alternatives for hotspot analysis, comparative assessments or public disclosures

4.4.1 Data availability

After setting the goal and scope of a study, the data available will constrain the LCA approach options.

If no LCA study of the product/service exists or no existing LCA meets the requirements for a sufficiently similar product/service (see clause 4.4.2), a new LCA study is needed. There are two options for this:

a) An LCA study according to Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2] can be performed.

b) A simplified LCA approach using a limited number of Product Parameters and applying Emission Factors from various data sources including supplier data - the PP method.

All LCA methods may reuse intermediate or final results of existing LCA studies. Studies based on Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2] or PP-method may additionally reuse the inputs of existing LCA studies.

If an LCA study result exists of a similar product (can be an internally performed LCA or from an external source) a simplified LCA approach using a more limited number of product parameters (typically 1-5) can be used. This recommendation describes the 1PLCA and the LCSRP approach.

LCA studies according to Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2] and a simplified LCA approach using the PP method can be used as input for simplified LCA approaches using an existing LCA study. The effort required by different LCA methods varies between the methods and it should be noted that compared to Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2], simplified LCA methods allow higher number of assessments and/or more complex assessments for given effort.

Note that even if a suitable LCA exist, a company/organization may still want to do a more detailed LCA to increase their understanding of different LCA methodologies and gather more knowledge for future purposes.

The accuracy of the results of any LCA will depend on the input data. When working on an LCA study, the following aspects should be considered:

- Up-to-date primary data from suppliers are preferred.
- To cover improvements in the supply chain, new data need to be collected regardless of approach.
- Reusing previous data can mask trend shifts in the results that would be visible with more current or specific data.
- The practitioner should be aware of the data age and conditions upon which the data was developed.

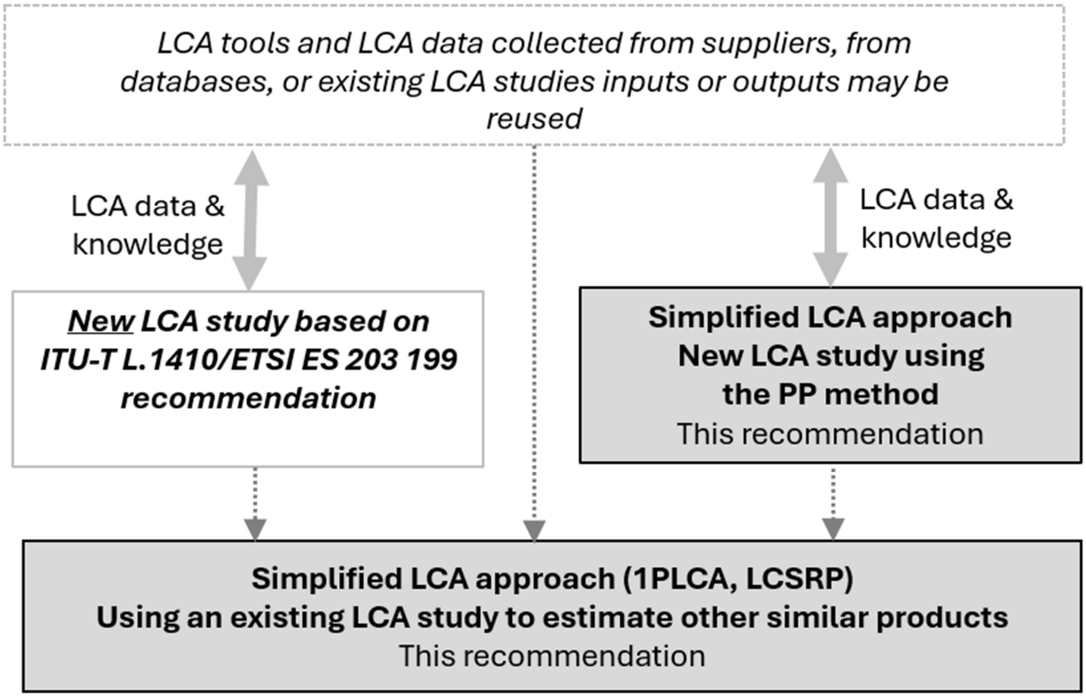


Figure 4: The relationship between the main simplified LCA approaches described in the present document and the relation to Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2] The results from all LCA methods may cover products, product systems or services

A more detailed guide that lists the benefits and drawbacks of the various LCA approaches including time and resources needed and how the results can be used can be found in Annex A.

4.4.2 Reusing data for similar products

Some simplified methods are based on reusing information from existing LCA studies. The LCA practitioner shall ensure that the existing LCA studies are representative for the case at hand, including technically similar representativeness of the products/services.

Existing LCA studies are best reusable when they have been developed for the same purpose, for a similar type of product or service, with system boundaries that can be applied to the new study, etc. These conditions are easier to judge if the existing study and the new study are performed by the same organization or department.

When an existing LCA is used to estimate e.g. the embodied carbon footprint of another product, that product needs to be sufficiently similar to the product for which an LCA exists. A few key aspects need to be considered:

- Time difference (less than 5-year recommended)
- Technology (e.g. type of display technology)
- Product type or building practice (e.g. type of server)
- Special case: Regionalization (especially electricity mix / electricity EFs)
- Product key parameters, do they scale as assumed? (e.g. display area)

To avoid an unacceptable level of uncertainty, it is recommended that the technology and product type or building practice is similar, and that the time difference between the products is limited to about 5 years. The exact timeframe varies with products and its related technologies and building practices.

Note that even if the existing LCA is new, the data used in the LCA may be older.

Geographical location, in which country or region in the world the product is produced, impacts the LCA result to a large degree, especially for electronic products as the share of electricity of total energy is typically high and the use of renewable energy sources varies greatly with geographical location. It is recommended to use LCA data based on the global market if the new product estimate is also for a global market. To be able to adjust for the difference between regions, data is needed about various electricity mixes, emission factors and electricity consumption in production stage.

What is considered to be sufficiently similar depends on the purpose of the study. For a high-level estimate, the requirements on similarity may be lower than e.g. providing data on embodied emissions for a certain product to a customer.

4.5 Overview of different approaches

The previous clauses describe the application areas of different LCA approaches. When evaluating which method would be most suitable for a study, also the limitations of different methods need to be considered. All methods are subject to the following limitations:

- Emission factors need updating when technology advances.
- Obsolete emission factors or reuse or previous data may hide trend shifts in environmental impacts.
- Improvements in real supply chain may not be visible if emission factors are generic estimations.
- Ensuring that the input data and parameters are up-to-date requires initial effort investment.
- High quality of an LCA result depends on multiple factors including (but not limited to) selection of the LCA method, appropriately setting the goal & scope of the study, setting assessment boundaries and cut-off limits properly, quality of input data, applying allocations in a well-justified manner, using a representative functional unit (when applicable), etc.

Table 1 describes different methods briefly at high-level and gives the main limitations that may be specific to them.

Table 1: Descriptions and limitations of different approaches

	Description	Main limitations
LCA in line with Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2]	Detailed assessment with high accuracy, covering the entire life cycle of a product.	High amount of time and work effort needed. Full data set needed for all material and energy flows.
Simplified LCA with Product Parametrization method (PP method)	Simplified approach which uses modularity and commonality among components to estimate impact. Can offer sufficient accuracy for streamlined exchange of information regarding individual products.	Product data on materials and processes needed together with applicable emission factors.
Simplified approach using existing LCA (LCSRP, 1PLCA)	Quick approach to estimate the environmental impact when LCA results of a similar product are already in place and no new information is needed in understanding hotspots.	A previous LCA needed of a similar product. Practitioner needs to pay attention to uncertainty and sensitivity issues and to the conditions and assumptions which were used when developing the initial data.
EEIO	EEIO uses financial and GHG emission input-output data for an industry sector which results in an average emission factor per monetary unit. Such a factor can be used to calculate the embodied emissions of a product or part of a product for e.g. one supplier.	Accuracy of results may be low. EEIO tables may be specific to certain regions and / or industrial sectors. May include infrastructure investment without considering its lifetime. EEIO is subject to variation in currency exchange rates and prices.

5 Detailed guidance for simplified LCA approach

5.1 General

5.1.0 Introduction

This clause gives more detailed information per each simplified method by describing requirements, goal & scope of the study, inventory analysis, impact assessment and interpretation of the results. Topics that are common to different simplified methods are presented in clauses 5.1.1 to 5.1.5.

5.1.1 Embodied environmental impacts in a simplified LCA

It is typically the embodied environmental impacts that are the most complex part of a simplified LCA. Simplified approaches for calculating the embodied environmental impacts can be based on the parametrized data (based on materials and processes included, components) (e.g. PP method in clause 5.2) and each multiplied by a corresponding Emission Factor (EF) or based on a previous LCA of similar product making an estimation based on lifecycle stage ratio profiling (e.g. LCSRP in clause 5.3) or using the material flow and factors weight, size, quantity, performance, share of total and price (e.g. 1PLCA in clause 5.4), or using economic flows (e.g. EEIO in clause 5.5).

The cradle-to-gate environmental impacts, excluding the final transport to the customer and the end-of-life stage, is recommended to report separately from the embodied environmental impacts to facilitate the reuse of the LCA results, as the final transport and EoLT is individual to a customer. Both final transports and EoLT also happens in the future from the perspective of the supplier/vendor and are therefore subject to higher uncertainties compared to the cradle-to-gate impacts. The final transport to the customer and the EoLT stage are typically not significant in the total life cycle of electronic products, but it should be described if and how they have been included as they are often cut off.

5.1.2 Use stage environmental impacts in a simplified LCA

The use stage calculations in a simplified LCA is typically a simple straight-forward result of a few parameters that describe the use stage like average annual electricity consumption, active lifetime years, and an average electricity emission factor.

Exemplifying this for Global Warming Potential (GWP), the Use stage Carbon Footprint (UCF) for products that operate using only electricity is typically calculated using two product parameters, the Annual Electricity Consumption (AEC) and the Active Lifetime Years (ALY), and an Electricity Emission Factor (EEF) which will depend on the energy source of the electricity in the geographical context chosen:

$$UCF = AEC \times ALY \times EEF \quad (1)$$

The global average electricity emission factor may be used for products with a global market, while country-specific or other geographical electricity emission factor might be used when applicable.

The use stage is typically significant in LCA studies for ICT equipment and it is recommended that the electricity consumption is measured if feasible. However, it is practically impossible to measure over a product's entire lifetime, so estimates are also needed, e.g. average lifetime and average power consumption per unit of time.

The use stage can include more details and parameters, as described further in clause 5.2.3.3.

5.1.3 Data quality

When available and feasible LCA practitioners are encouraged to use primary data and data from their own supply chain. The use of primary data and data from own supply chain makes the LCA result more accurate and representative, and it helps to better capture the actual supply chain improvements. If primary data or supply chain data are not available, then data from trusted third-party databases or other secondary data can be used. High-quality data should always be prioritized, although the purpose of the study and data availability may lead to usage of secondary, modelled or aggregated data.

The present document also provides examples for emissions factors which can be used when primary data or data from own supply chain is not available. The example emission factor values are available in Annex B. In coming years, update on those emission factors is needed. LCA practitioners shall provide justification and reasoning for the data choices made during the LCA calculation, especially when using the data sourced from non-public sources and third-party database or other secondary data.

The data quality requirements also depend on intended use of the LCA result, especially in case of simplified LCA as can be seen from the decision tree in clause 4.4 and overview in clause 4.5. It is LCA practitioners' responsibility to fulfil the data quality requirements for the LCA study based on the available data and intended use of the LCA results.

5.1.4 Energy mix

Emission factors of electricity production between regions can vary significantly and therefore determining the emission factor properly is essential in terms of getting a representative result. Emission factors between energy suppliers may also vary depending on the energy production method used. General recommendation is to use as accurate emission factors as possible.

When available, usage of market-based electricity emission factors is preferred for Production stage. Location-based data can be used when market-based data is not available.

Manufacturers can do Use stage assessment by using different scenarios with different location-based or market-based electricity emission factors appropriate for the region. ICT goods users may wish to do more specific assessment for a specific use case - in such cases the evaluation of Use stage impacts can be done using the most accurate emission factors available.

Practitioner needs to indicate whether location or market-based data has been used in the assessment.

5.1.5 Cut-off

Using cut-off in Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2] requires an estimate of the impact level of different activities and simplified LCA methods can be useful for this purpose. Care needs to be taken when use of cut-off is considered in a simplified LCA assessment, since it is not necessarily clear what could be the 'simplified version of a simplified LCA' for doing rough estimation about the order of magnitude of inventory items or impact category results.

If simplified LCA study is re-using the results from an existing LCA study done according to Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2], then cut-off on top of previously done cut-off should be avoided - this could potentially result in excessive usage of cumulative cut-offs.

Considering that in simplified LCA the list of flows and activities may already be reduced, the use of cut-off in simplified LCA shall be avoided as far as possible.

If cut-off is used, then cut-off criteria from Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2] shall be followed.

5.2 Product Parameter (PP) method

5.2.1 General introduction to PP method

The most important step in simplified LCA, is to aggregate similar materials and components to create a description of the product using a limited set of Product Parameters (PP). This is the rationale behind the proposed PP method in the present clause.

The PP method is especially developed for companies/organizations to be able to do simplified LCAs for many more of its individual products/services compared to doing detailed LCA studies. The PP method can especially be used for:

- Development of Product Carbon Footprint (PCF), or Product Environmental Footprint, or other more specific data, e.g. Embodied Carbon Footprint (ECF) data, for products and services.

- Facilitating collaborations and exchanges of Product Environmental Footprint, PCF, or other specific data, e.g. ECF data, between suppliers, vendors/manufacturers, and customers belonging to the same product/service eco-system. This helps all involved parties to focus efforts on the key parts of the supply chain to e.g. reduce GHG emissions.

The accuracy of the LCA results will depend on the data availability. As it is time and resource demanding to collect supplier data, general generic and average data will be used to cover the data gaps. However, primary data are preferred if available and can be used for the PP method. Advantages of expanding the number of parameters in the PP method are presented in Annex C.

The PP method can be described in a few steps leading to general simplifications made compared to a Life Cycle Assessment (LCA) according to Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2]:

1) Identify the raw materials and processes contributing significantly to the total environmental impact. This can be done based on research works and expertise.

2) Aggregate similar materials and components to create a description of the product using a limited set of PPs. For example, all semiconductors can be grouped into one parameter.

3) Collect Emission Factors (EFs) for the aggregated materials, components and processes. Based on the PPs, most environmental (potential) impact indicators, e.g. the GWP, can be calculated using EFs already available from existing LCA studies and LCA databases.

4) Calculate the environmental impact by combining the PPs and the EFs for raw materials and processes.

5) The use stage impact is calculated by using the life cycle electricity consumption with appropriate electricity grid EFs.

6) To further improve the result of the cradle-to-gate impact, the EF data for key raw materials and processes can be collected from suppliers for the assessed product.

To put it short: it is recommended to focus on a limited amount of data covering the most impacting raw materials/processes, use existing data on EFs and then improve the accuracy of the results by collecting EFs from suppliers for the analysed product. Increasing the number of parameters used in the analysis is also recommended when higher precision is needed. A comparison between the unit processes in Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2] and the PP method is made in Annex E.

The generic way to calculate the impact of a contributing material/process/activity will use three elements i.e. PP, adjust factor (*f*) and EF of the PP, as presented in equation 2.

$$Impact = \sum_n (PP_n \times f_n \times EF_n) \quad (2)$$

Each identified material/process/activity is described by a PP and its unit. The unit is often weight but quantity, area, and volume, are also common units. The factor (f) can be used for yield or any other adjustment and is often set to one (1) except for raw materials where it typically describes the material losses during production (a ratio between the material content in the final product and the material input).

The PP simplified LCA method described in this clause focuses on the total lifecycle GWP calculated based on Greenhouse Gas (GHG) emissions and effects related to a product's total lifecycle. The examples are limited to GWP. The method can be used to calculate any other environmental impact categories if accurate EFs are available.

When using the PP method for comparative purposes, the LCA practitioner will most probably use the same chosen product parameters and improvements are then reflected by the changes in PP value and/or EFs and factors used for yield or any other adjustment. The PP method may also be used for comparative analysis as defined in Recommendation ITU-T L.1410 [1] principles Part II, hence both comparing to non-ICT-based and ICT-based solutions. Resulting year to year values from the same manufacturer of the same/similar products can be compared as they are assessed using the same functional unit and equivalent methodological considerations, such as performance, system boundary, data quality, allocation procedures and cut-off rules. Comparative analysis with the PP method has not been further described within the present document.

5.2.2 Goal and Scope definition of PP method

The goal and scope of a simplified LCA using the PP method should be clearly stated by the LCA practitioner. This includes choosing parameters (materials, processes, activities) to include, see clause 5.2.5 (Figure 7) for recommended parts. The impact category/categories to investigate are also decided in the goal and scope.

5.2.3 Life Cycle Inventory (LCI) of PP method

5.2.3.0 Introduction to PP method inventory creation

The life cycle inventory for the PP method includes grouping parameters (materials, processes, activities) for the assessed product, listing applicable factors (when needed) and collecting corresponding EFs for the impact categories investigated. The factor (f) can be used for yield or any other adjustment as described in clause 5.2.1. Thereafter the impact is calculated for each parameter, as shown in equation 3. A template of proposed EFs is provided in Annex F. The clauses are covering the lifecycle stages raw material including packaging, production covering all manufacturing processes, assembly and support activities as well as outbound transport, use and EoL.

$$Parameter\ impact = PP \times f \times EF \qquad (3)$$

5.2.3.1 Raw Materials stage

The raw material emission factors in the PP method should cover all activities, including transportation, from the cradle (e.g. the mine), to the transport of the raw material in a basic product form (e.g. ingot, slab, sheet, rod, wire for metals), to part production facilities. Preferably, the transportation of the basic product to the production/manufacturing facility is collected separately and can then be included in the raw material stage. If a non-specific transport is included in the material EF or if it is included in the production stage it can be estimated if no further details are available to the LCA practitioner.

Note that further material production/manufacturing processing are not part of the raw material stage. It is seen as part of the production / manufacturing processes for a part/component (as described in clause 5.2.3.2).

It is natural to simply divide raw materials into metal and metal alloys, plastics and other materials (e.g. ceramics/glass) included in the product, and packaging and documentation materials that are not part of the product, but should be included for completeness.

Raw materials contributing significantly to the total investigated environmental impact of the product shall be included. This can be done based on research works and expertise. The provided examples and EF template (Annexes D, F, G, H) can give guidance on which raw materials to include. The remaining weight of the total product still needs to be considered in the assessment. It is recommended that the remaining weight, made up by the weight of the materials not included specifically in the short list of raw materials, can be treated similarly to a specific raw material by creating a "miscellaneous/other material" category, for which an average EF is used. It is not recommended to report a material aggregated if its share of the cradle-to-gate impact versus the total impact is significant. In the smartphone example in Annex D, all basic raw materials are aggregated together as their total cradle-to-gate GHG emissions is < 5 % of the total GHG emissions. The list of raw materials in a smartphone is very long but no material represents a large share, so it makes little sense to list any material individually. A resulting EF for aggregated materials should be listed.

If raw materials are included in one or a few "black box" manufacturing/process models (see next clause), then at least the total weight of all these materials should be listed and commented with for example "all raw materials included in supply chain models". No factor or EF can/need to be listed then.

Raw materials are the most investigated stage in an LCA and there are numerous existing LCA data in databases and in literature.

Note that transportation activities, especially between different life cycle stages may be included differently in EFs, depending on the source. Therefore, the practitioner needs to carefully investigate what an EF covers, both to avoid double counting but also to avoid missing important impacts from transportation.

The present document does not go into how EFs for raw materials should be established. A list of proposed EFs to include is provided in Annex F.

Different types of the same basic raw material (e.g. the basic metal and its alloys) may be calculated and reported individually or together. Different uses have different losses. In the example below, copper with different losses due to use in PCB and cable manufacturing processes are calculated individually but can be reported together with a resulting loss factor.

Copper (in PCB), PP = 0,5 kg, f = 1,4, EF = 6,4 kg CO_2e/kg, GHG impact = 4,5 kg CO_2e
Copper (in cables), PP = 1 kg, f = 1,1, EF = 6,4 kg, GHG impact = 7,0 kg CO_2e
is combined to
Copper (total), PP = 1,5 kg, f = 1,2 (aggregated factor for different processes), EF = 6,4 kg, GHG impact = 11,5 kg CO_2e

NOTE 1: The copper (in PCB) above is used to form copper foil, Copper Clad Laminate (CCL), and used in various surface finishing processes that is seen as part of the overall PCB production/manufacturing process.

A raw material EF may be for Primary material production and based on production from ore or other natural resources, or it can be for Secondary material production including also recycled content. These EFs include transportation used in the raw material production/manufacturing. EFs for primary and secondary material production can also be combined into one EF for a specific supplier or supply chain. This is a simple way of including recycling or the use of recycled material in the production stage. Given that EoLT often happens in the future compared to when a LCA is performed, it can be motivated that this is the known impact cradle-to-gate, that happens before the customer get the product. Any EoLT and recycling needs to be addressed by the customer that scraps the product. The EoLT stage and recycling is described in clause 5.2.3.4.

NOTE 2: Primary material production based on raw materials from ore etc. and secondary material production based on recycled material should not be mixed up with primary and secondary data which relates to the data source as described in clause 5.1.3.

5.2.3.2 Production stage

5.2.3.2.0 Types of processes in production stage

The production stage for the PP method may be divided into three main types of manufacturing processes when describing EF: Mechanics, Electro-Mechanics, cables and batteries, and Electronics supply chain processes. It also includes all manufacturer assembly and support activities as well as outbound transport. For refurbished ICT goods the environmental impact associated with the refurbishment process need to also be considered in the assessment, in Production stage.

5.2.3.2.1 Mechanics, Electro-Mechanics, cables and batteries processes

Mechanics typically include the frame parts of the product, such as the racks and cabinets and any mounting kits needed including all nuts, bolts and screws. A production process typically starts with raw materials supplied in a basic product form, proceeds through mechanical processing, and ends in surface finishing. Mechanical processing may include steps where materials are melted or semi-melted like casting for metals and injection moulding for plastics.

Electro-Mechanics include connectors, and various power components, as well as simple active components like electric motors and fans up to more complex climate modules. Electronics included in these electro-mechanical components should be treated separately from its host, but this should be done by the supplier, and no details need to be reported. Cables and batteries are not electro-mechanics but is in the PP method treated the same way. Apart from potentially included electronics, these components are produced in quite simple mainly mechanical processes like mechanics, but they are generally more complex and operate on electricity and/or are needed for the electrical/electronic function of the main electronic host product.

Even a "simple" part can be quite complex with many process steps involving more suppliers than the key supplier. Figure 5 shows how a complex part can be handled by the key supplier. Complex part can be split in a few key process steps resulting in a robust total EF for the final part. The key supplier may have gotten data from other 3rd party suppliers. The manufacturer may only see the total EF for the total part.

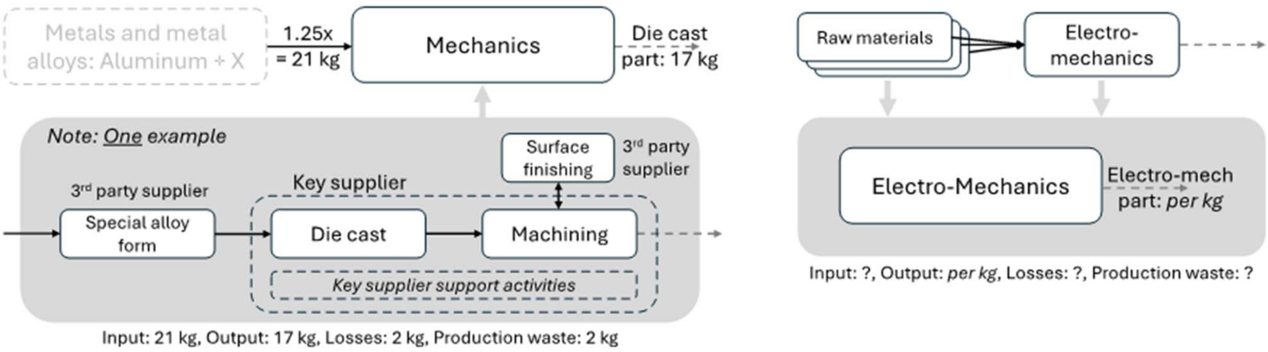


Figure 5: Handling of more complex mechanical and electro-mechanical parts

The left part of Figure 5 shows how a complex part can be split in a few key process steps involving several suppliers. The right part of Figure 5 shows how, e.g. data of an electro-mechanical part may be aggregated. It must be possible to combine the production stage with the raw material stage without requiring detailed information for certain components that are handled as "black boxes", e.g. a battery. That the EFs include the entire lifecycle, from cradle-to-gate, must be clearly stated.

NOTE: The raw material input and how much is lost and recycled in the production stage are key data that is essential in any LCA. Figure 5 shows examples of this key data. There are no requirements to report this internal data, but this data is key to be able to accurately calculate the impact of recycling in/out of the studied products lifecycle.

The "Key supplier support activities" in Figure 5 (left) is activities like research and development, market and sales, and other corporate activities and is related to warehouses, offices, travel, commuting, and other non-production activities. They should ideally be included in an LCA but is often not significant in the raw materials and mechanics / electro-mechanics stage and are therefore optional to include.

5.2.3.2.2 Electronics supply chain processes

Three key electronic component production processes typically make up a majority share of the total energy and GHG emissions for electronics (in this order): ICs, Displays, and PCBs. This stage is largely based on [i.7] that in turn is based on [i.8], which describes this further.

ICs, displays and PCBs are aggregated into specific PPs. For example, all semiconductors die area is aggregated into only one PP, or a few PPs depending on semiconductor types i.e. memories, ASICs CPUs, etc. The level of simplification and modelling approach is up to the LCA practitioner.

NOTE: For ICs the die areas within are occasionally not available and then mass-based approaches outlined in Annex E of Recommendation ITU-T L.1410 [1] are suitable for a convenient implementation. Links between chip capacity metrics and die area are also useful, e.g. for memories [i.9].

The principles described in clause 5.2.3.2.1 also apply to electronic parts/components with two main differences. First, the electronic parts/component suppliers support activities should be included just like for manufacturers. Second, for displays, PCBs, and semiconductors, also the infrastructure, the machinery and production site itself should be included as described in [i.8]. The reason is that these parts/stages have proven to be significant in the LCA results of these key electronic components. Figure 6 summarizes the scope of the key electronic components production.

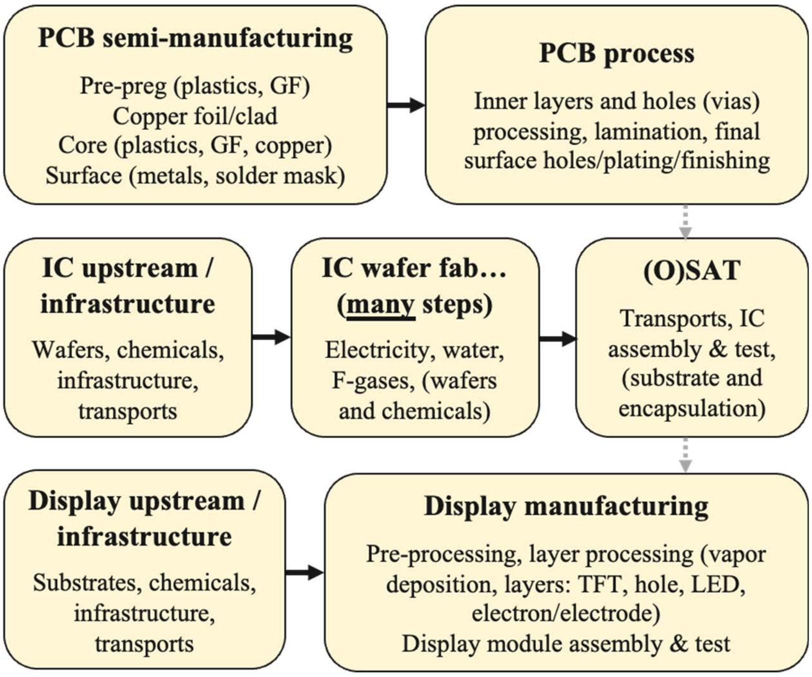


Figure 6: Scope for the key electronic components production (PCBs, ICs, displays)

Standard components mean components with no or little semiconductors, like basic types of resistors, capacitors, inductors, simple diodes and transistors. There is a longer list of more special component types that can be grouped into power, opto, radio or microwave components. All these components typically do not make up a large part of the total cost or weight of an electronic product. Many process steps for standard components have a lot in common with PCB and display surface chemistry processing but are simpler. The standard components are treated with a common emission factor per weight. Larger specific components can be treated separately when needed, e.g. the special components in a smartphone: camera(s), microphone, speaker, and vibrator. Examples of GHG EFs for average IC, PCB, display and standard components are provided in Annex B.

5.2.3.2.3 Manufacturer activities

This activity includes the assembly of all parts/components into final products and getting them ready to be delivered to customers, hence it includes testing, packaging and storing. The assembly and test may also be done by third-party suppliers (Electronic Manufacturing Services, EMS), and an average EF for all assembly and test sites may be used for the whole market.

The manufacturer's own support activities need to be included, as they often have a larger impact on the results than the assembly & test activities. The support activities cover all offices and other non-production sites like internal data centres, all employee business travel and commuting. Furthermore, all R&D including SW support and development, market & sales, and other corporate activities should be included. Related third-party activities should also be included, just like EMS.

NOTE: The manufacturing activities are complex but most large manufacturers have a developed energy and GHG reporting system in place with third-party review and certification that can be used as the main data source for this stage.

All outbound transports to the customers gate(s) are included in the production stage.

Inbound transport to the manufacturer of the final product, assembly & test (including EMS), and other manufacturer support activities (also including third-party activities) can be reported aggregated, but shall clearly indicate what is included and other information needed to understand the background of the figures, especially if something is excluded.

The outbound transport may be calculated as an average for the (global) market the product is aimed for, e.g. based on last year's market average and it is recommended to report it separately so any customer can replace it with their specific transport data.

5.2.3.3 Use stage

5.2.3.3.0 Introduction

The use stage lifetime environmental impact is a straight-forward multiplication of Annual Electricity Consumption (AEC), Active Lifetime Years (ALY), and an Electricity Emission Factor (EEF) as presented in equation 2. The AEC may be modelled based on various operation modes and their respective share of time. Measurements of the product in real operation is of course the best alternative.

For a product in use 24/365 the AEC is the average power (watt) times 8 766 hours (24 h × 365,25 days).
For example, a mobile network radio consuming 150 W on average resulting in 150 W × 8 766 = 1 315 kWh/year, an 8-year lifetime would result in 10,5 MWh.

For a product with two or more specific operation modes, e.g. a TV the calculation needs to be divided.
"Off": 20 h/day × "Off" Power, e.g. 0,3 W for a TV, resulting in 2,2 kWh/year
"On": 4 h/day × "On" Power, e.g. 100 W for a TV, resulting in 146 kWh/year
AEC = 0,3 W × 20 h × 365,25 days + 100 W × 4 h × 365,25 days = 148 kWh/year

As the use stage of a product often happens in the future compared to when the simplified LCA is performed the annual electricity consumption and the active lifetime years are unknown. Therefore, these are often based on similar products on the market. However, there are many different products and only few measurements available. Furthermore, there are other aspects to consider like early product failures, and some products act as spare parts, or the product is non-active at times for other reasons. The non-active lifetime between the final shut-off and EoLT do also not count, as it can be many non-active years without any electricity consumption.

As the use stage can happen in any country, it is also suggested that a few different key countries with different electricity EFs are used to show the large variations in the results depending on where the product is used, hence the electricity mix. A manufacturer may also calculate and add an average electricity EF that represents their specific market average. For products with a global market, a global electricity EF is appropriate to use. Both Annexes H and D show the different in use case GHG emissions depending on country/region for a mobile radio network and a smartphone.

5.2.3.3.1 Additional impacts in use stage

Additional impacts related to the use stage can be identified for electronic products, but to include any additional use stage data is optional as it can be viewed as out of scope. These impacts are often irregular or non-frequent, and typically out of control for the manufacturer. They may also be viewed as part of another products lifecycle and should therefore not be included.

The first type of additional use stage impact is *support goods use*, which is related to the operation which may require extra power conversions / losses and/or extra climate/cooling. The extra electricity may be included in the form of a factor. For telecom sites the term "site-factor" that include both power and climate/cooling equipment used may be utilized. For data center equipment, the PUE-factor can be used as site-factor. The embodied impact of this extra site equipment may also be included. The operation electricity can also come from off-grid sources like batteries, diesel generators and solar panels, also in combination, and these extra electricity sources may also be accounted for in a LCA study.

The second type of additional impact is related to *operator support activities* for operation and maintenance of the product e.g. service vehicles used by telecom operators.

Activities extending the operating lifetime of the product hence relating to spare parts and repair may also be included in the LCA study. These can be quite straight-forward to include for a manufacturer in control of those activities and use the same general formula in equation 3 including the parameter, a factor and an EF.

5.2.3.4 EoLT

The EoLT stage in an LCA is made up of two activities, the waste collection (transportation) and mechanical processing, and the recycling of materials and/or the treatment of residual waste. Possible energy recovery is not covered in the present document. If a product will be refurbished, the lifetime extension decision is done in EoLT while the actual refurbishment activities are part of Production stage [1].

A global average EF does not exist for the EoLT stage like for the use stage (a global average electricity EF). However, the collection and mechanical processing of waste typically has low GHG EFs, in the order of 0,1 to 1 kg CO_2e per kg electronic waste collected and processed. For instance, 0,2 kg CO_2e per kg for larger equipment and 0,5 kg CO_2e per kg for smaller user devices have been used in [i.7].

Recycling of the metal content in the product has a much greater importance than the EoLT stage itself.

Further details on EoLT, metal recycling and 50/50 method are presented in Annex I.

5.2.4 Life Cycle Impact Assessment (LCIA) of PP method

In the LCIA the total embodied environmental impact is calculated using equation 2 summarizing the parameter impact based on the product parameter (PP_n, from 1 to n), multiplied with their corresponding factor (f_n) and emission factor (EF_n).

The use stage impact is in its simplest form calculated from electricity consumption and active lifetime, as presented in equation 1 and clause 5.2.3.3. However, it should include additional impacts in use stage (clause 5.2.3.3.1); these are treated with parameters and appropriate EFs. The total use stage impact is the sum of these.

The total environmental impact is the sum of the embodied impact and the use stage impact.

$$Embodied\ impact = \sum_n (PP_n \times f_n \times EF_n)$$

$$Use\ stage\ impact = AEC \times ALY + \sum_i (PP_i \times EF_i)$$

$$Total\ impact = embodied\ impact + use\ stage\ impact$$

In many cases, figures per year are a more useful measure compared to total lifetime impact. This is calculated by first determining the total lifetime impact and then simply dividing it with the same Active Lifetime Years (ALY) as was used in the (equation 2).

Fully including the EoLT stage and recycling of materials is complex. As the EoLT stage happens in the future, compared to when the LCA is performed, it may not be controlled by the manufacturer. There are however simple ways of handling it by combining recycling ratios in/out of the product's lifecycle, combining primary and secondary material production EFs (new metal from ore / recycled metal), and by creating an EoLT future scenario.

5.2.5 Life cycle interpretation of PP method

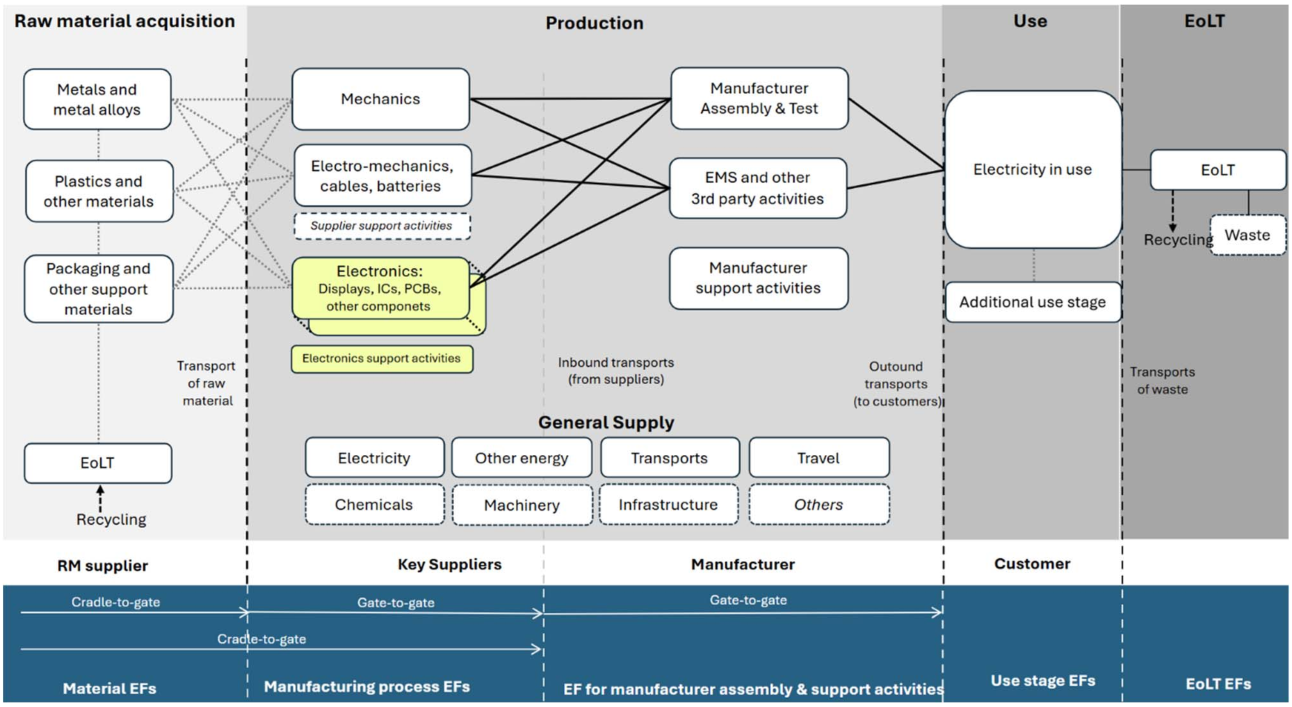
A calculation for a simplified LCA typically becomes one calculation table where each row contains the data (PP, f, EF), calculation, and result per raw material/process/use/EoLT, see examples in Annexes H and D. The individual results should be summed per product stage following tree structure described below:

- Raw materials stage (including transportation):
  - Metals and metal alloys (may include recycled content)
  - Plastics and other materials (e.g. glass fibre, ceramics)
  - Packaging and documentation
- Production stage:
  - Manufacturing processes (including transportation):
    - Mechanics (e.g. frames, fronts, screws)
    - Electro-mechanics (e.g. batteries, cables/connectors)
    - Electronics:
      - Displays
      - Printed Circuit Boards (PCBs)
      - Semiconductors / Integrated Circuits (ICs)

        - Standard components
    - Manufacturer assembly & support activities:
        - Transports in (from suppliers)
        - Manufacturer sites (e.g. offices, stores, warehouses and internal data centres)
        - Employee related activities (e.g. travel, commuting)
        - Assembly & Test (including also Electronic Manufacturing Services (EMS))
        - Outbound transports (to customers)
        - Other related third-party activities
- Use stage:
    - Operation (electricity consumption) of the product itself
    - Additional use stage:
        - Off-grid operation and/or additional electricity for power losses and cooling
        - Maintenance and repair
- EoLT stage:
    - EoLT collection, processing (and residual waste)
    - Metal and metal alloys recycling (can be connected to the input of raw materials)
    - Other materials recycling or energy recovery

EoLT stage should include both collection and processing of the scrap, as well as recycling of metals.

Figure 7 shows the list above in an LCA flowchart with boxes and key inputs/outputs.



NOTE: Dotted boxes under the dotted line indicate parts that are optional or/and are hard to fully include.

Figure 7: Parts covered in a simplified LCA using the PP method

The assessment report shall state whether the activities presented in dotted lines are within the system boundary or not. It is common practice to exclude e.g. road infrastructure, vehicle production and the construction of office buildings.

Recommendation ITU-T L.1410 [1] specifies that transport from raw material supplier to the part production facilities belongs to the RMA life cycle stage. However, sometimes suppliers may include the impacts of inbound transport to the parts production in the EF of the manufacturing process. This situation can be handled in one of the following ways, depending on what type of reporting is expected and what data can be made available:

1) by reporting the impacts of RMA and Production stages together, without separating them; or

2) by adding corrective entries to the inventory:

   - by subtracting RMA outbound transport impacts from Production; and

   - by adding the same impacts to RMA stage inventory.

This requires an estimate of the magnitude of the transport impact in question.

For the final assembly both the inbound transports from key suppliers and outbound transports to customers are treated as part of manufacturer activities that typically perform the simplified LCA study.

NOTE: There is a need to understand what is covered in the material and manufacturing process EFs, so that the transportation is included, but not double counted.

Manufacturer support activities shall be included also in a simplified LCA. The assessment report shall state whether suppliers' support activities are within the system boundaries or not.

5.2.6 Reporting and review

Reporting of a simplified LCA using the PP method shall be made in alignment with clause 6.

Further recommendation for the PP method:

- Transparently report which materials/processes/activities that have been included.
- Preferably the EFs used are provided together with the result, or at least sources of the EFs used.
- The potential environmental impact results do not need to be presented per included material/process/activity but can be grouped together and presented for parts of the different life cycle stages. Preferably results for the raw materials, production without the outbound transport, outbound transport, use and EoL are presented separately.
- Non key raw materials should be included, but they can be grouped and treated as one parameter in the list of PPs and EFs used.
- The use of primary and secondary raw materials input needs to be presented and any future recycling (e.g. use of the 50/50 allocation method) in EoL needs to be transparently explained.
- Manufacturer support activities can be reported aggregated but needs to specify what is included (e.g. inbound transport, assembly & test (including EMS), offices, business travel, and other support activities.
- Explanation of how the annual electricity consumption has been estimated or measured.

5.2.7 Implementation examples of PP method

Annex G presents the Parametrized Product Characteristics Approach for simplified LCA, which is a detailed application of the PP method for ICT network product example and applies it on a fictive ICT consumer good for several impact categories.

Annex J presents component characterization as an implementation of PP method focusing on key parameters of ICT components that has significant environmental impact based on past LCA data and showing an example calculation of a printed wiring board.

5.3 Life Cycle Stage Ratio Profiling (LCSRP)

5.3.1 General introduction to LCSRP

The Life Cycle Stage Ratio Profiling (LCSRP) methodology is a way to estimate the environmental impact of ICT goods by using the common characteristics and the associated life cycle stage ratio profiles. This approach provides high level estimation of the environmental impact of specific types of ICT goods focusing on environmental impact that constitute of a substantial proportion of the total life cycle impacts. Usually, these ratio values are derived from the historical life cycle assessment data of different ICT goods with specific usage profiles.

The life cycle stage and the associated impacts are usually available as percentage or ratio, which is then used to calculate the impact associated to the respective lifecycle stage and eventually estimate the total environmental impact of the product. It is important that the LCA practitioner understands the equipment categories and the conditions under which the ratio data was derived and the potential impact from the age or date of the historical data. Following clause provides more description of this methodology.

An example calculation using LCSRP method is described in Annex K.

5.3.2 General requirement for LCSRP

In case of LCSRP methodology, it is common to combine life cycle stages other than use stage as embodied environmental impact of the ICT goods. The ratio between the use stage impact and embodied environmental impact helps to do simple approximation of the allocation of environmental impact when the actual impact of either of these two is known (i.e. use stage or embodied impact).

When the product system under study consists of products or modules for which LCA results are already available, then the study may be conducted with more than one input parameter. Care needs to be taken with system boundaries and other assumptions being applicable between different input parameters.

5.3.3 Goal and Scope definition of LCSRP

For LCSRP methodology, quite often the goal is to perform a screening assessment, product environmental footprint, or embodied emission estimation to provide input to the scope 3 assessment or other studies. LCSRP is not suitable for external communication and comparative assertions intended to be disclosed to the public. The data quality for those purposes is not sufficient in LCSRP methodology.

5.3.4 Life Cycle Inventory (LCI) of LCSRP

For LCSRP methodology, the data is collected from the life cycle stages where the data is most easily available, for example, use stage energy consumption, and based on that data, the environmental impact of other stages is calculated. Typical example of allocation used for the LCSRP methodology is allocation ratio of use and embodied emissions.

5.3.5 Life Cycle Impact Assessment (LCIA) of LCSRP

Life cycle impact assessment is done in alignment with Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2].

5.3.6 Life cycle interpretation of LCSRP

In the life cycle interpretation, the results of the LCA are evaluated in order to answer questions raised in the goal definition. This phase should also provide information on conclusion, limitations, and recommendations. The sources of uncertainty and methodological choices made shall be assessed and disclosed. The interpretation shall include a sensitivity check of the significant inputs and outputs. For detailed information see ISO 14044 [4] and Recommendation ITU-T L.1410 [1].

5.4 One Parameter LCA method (1PLCA)

5.4.1 General introduction to 1PLCA

The one Parameter LCA (1PLCA) methodology is a way to estimate the environmental impact of ICT goods by using one or a few parameters to calculate new LCA results from an existing LCA of a similar good/service.

The use stage related emissions can often be estimated or measured, see clause 5.1.2, while the embodied or cradle to gate emissions can be calculated by using only one emission factor. Examples of product parameters in a 1PLCA that can be used are product weight, size, quantity, performance, but also share of total and economic value. Table 2 shows product parameters and relating emissions factors.

Table 2: Product parameters and relating emissions factor units

Parameter	Emission factor unit	Comment
Product weight	kg CO_2e / kg product	the most often used parameter
Product size	kg CO_2e / "size"	e.g. display area for displays, "size" are typically length, area, or volume
Quantity	kg CO_2e / quantity	e.g. number of ports for a switch
Performance	e.g. kg CO_2e / GB for networks/storage or kg CO_2e / TFLOPS for servers	e.g. amount of data or computing power
Economic value or price	kg CO_2e / product value in $	can be based on GHG/price, an EEIO-based factor, or another source, e.g. GHG/revenue
Embodied carbon footprint factor		using the ratio embodied emissions and use stage emissions (see clause 5.3)

5.4.2 General requirement of 1PLCA

The 1PLCA rely on the existence of a previous LCA of a similar good/service. For best accuracy there are two requirements. Firstly the existing LCA needs to be of sufficient quality and covering the intended scope. Secondly the good/service under test and the good/service in the existing LCA needs to be similar enough. Reusing data for similar products is further described in clause 4.4.2.

When the product system under study consists of products or modules for which LCA results are already available, then the study may be conducted with more than one input parameter. Care needs to be taken with system boundaries and other assumptions being applicable between different input parameters.

5.4.3 Goal and scope definition of 1PLCA

If deemed that the 1PLCA method is applicable (see clause 4.3) to the intended use of the results, the goal and scope will be inherited from the existing LCA of a similar good/service.

5.4.4 Life Cycle Inventory (LCI) of 1PLCA

For 1PLCA methodology, the use stage data is calculated as described in clause 5.1.2, while the other data is what was already collected for the existing LCA of a similar product/service.

5.4.5 Life Cycle Impact Assessment (LCIA) of 1PLCA

The LCIA impact categories possible to calculate will be determined by what was included in the existing LCA. Climate change impact (Global Warming Potential) is the most common impact category that is usually used for the impact assessment with this methodology.

5.4.6 Life cycle interpretation of 1PLCA

In the life cycle interpretation, the results are evaluated to answer questions raised in the goal definition.

For improving 1PLCA results based on only one parameter, it is possible to combine two or several parameters. One parameter can be used as a baseline, e.g. size, and then another parameter can be used as an adjustment parameter, e.g. price. An example of this is seen in Annex L. First, different model types are estimated based on "size", then models of a similar "size" can be further differentiated by their price.

An LCA of an ICT good can also be split into several key parts that are simply added together. For example, a laptop can be split into e.g. five parts: display, chip sets, PCBs, mechanics, and battery. Examples of a PC display are described in Annex M, where it is also shown how parameters can be combined. When combining more than five product parameters, the 1PLCA approach described here becomes more like the PP method described in clause 5.2, that require at least ten parameters. It is recommended to not go via another product LCA to create more than five product parameters, but instead use the PP method and use EFs directly from available sources. These EFs are also based on LCA studies of individual parts, processes, materials, etc., or can come directly from suppliers of these parts, processes, materials, etc.

5.4.7 Considerations for different parameters using 1PLCA

The PC display example in Annex M shows that different EFs for different product parameters applied to another PC display to estimate its embodied GHG emissions typically lead to various results. The same embodied GHG emissions result (100 kg CO_2e) used to create different EFs that are then applied to another PC display resulted in embodied GHG emissions in the range 140 kg CO_2e to 398 kg CO_2e. Depending on type of product parameter there are certain things to consider listed below.

Weight or "size": To use weight is by far the most common way to parametrize any LCA result. For a similar product the weight is often a good parameter to use. "Size" (length, area, volume) is also common, and in the PC display example, the display size (area) is recommended to use.

Performance: To use performance-based EFs is not recommended as the performance improvements over time of electronics is so rapid. Any performance-based EF quickly becomes outdated. Due to the rapid technology development and change in performance, the use of performance metrics can lead to inaccurate results. This is especially true for "digital performance", e.g. memory size, data rate, computing power/rate, and similar.

Price: Price-based EFs may work well for some products, but in general a large variation in price do not translate to a large variation in embodied emissions, where the variation is typically smaller. Price, many times reflect immaterial values including the high value of human work and knowledge (R&D) that do not scale like material values. Price may be used with caution in combination with another EF to further differentiate between similar products in weight or size, but with different prices.

5.5 Environmentally Extended Input Output (EEIO) analysis

5.5.1 General introduction to EEIO

Environmentally Extended Input-Output (EEIO) models estimate environmental impacts resulting from the production and upstream supply chain activities of different sectors and products within an economy. It provides simple and robust methodology for assessing the linkages between economic consumption activities and environmental impact of the product and services. The EEIO emission factors can be used to estimate environmental impact for a given industry or product category.

EEIO models are derived by allocating environmental impact values (e.g. GHG emissions) to group of finished products based on economic flows among industry sectors. EEIO data is often comprehensive, but the quality of data is low and does not fulfil the data quality requirements of detailed LCA assessment.

EEIO is useful for representing basic commodities / materials industries like plastics or metals manufacturing, However, it may not be very representative for capturing the complexities of high-tech industries like microprocessors and fibre optic lasers manufacturing and other complex ICT goods. EEIO method may not work so well for new technologies because of the non-availability of the data for these. Furthermore, as the methodology does not, without adaptation, cover all life cycle stages (use stage and EoLT) EEIO can result in misleading conclusions about a product environmental footprint in ICT products where these life cycle stages can have significant contributions. EEIO environmental impact values may include components that are usually excluded from LCAs (e.g. construction of offices, factories, and transport infrastructure like roads, airports), which may result in higher environmental impacts. In addition, because EEIO is based on GHG impact per monetary unit, it is also prone to other uncertainties such as variation in currency exchange rates, inflation, temporal and regional variation in prices and differences between nominal prices and purchase prices. Lastly, infrastructure investments, are usually fully accounted for upfront rather than being amortized over the full lifetime of these assets, which in the context of the ICT sector can lead to disproportionately high environmental impacts being attributed to the construction of new manufacturing facilities and equipment. Nevertheless, in special cases such as [i.10] the application of EEIO shows good precision.

The so called spend-based (supplier-level allocation) method used for Scope 3 quantification is an application of the EEIO modelling.

Moreover, the spend-based (supplier-level allocation) application is demonstrated in the Appendix of [i.11] and for laptops and smartphones in [i.10].

An example GWP calculation using EEIO method is described in Annex N.

5.5.2 General requirement for EEIO

In case of EEIO methodology, the most significant part of the assessment is goods raw material acquisition stage as embodied environmental impact of the supply chain activities, e.g. materials and components used in the production, assessed based on the economic flow in the industry.

5.5.3 Goal and Scope definition of EEIO

As with the LCSRP and other Simplified LCA methodologies, the goal is to perform a screening assessment, product environmental footprint, or embodied emission estimation to provide input to the scope 3 assessment or other studies. EEIO is not suitable for external communication and comparative assertions intended to be disclosed to the public. The data quality for those purposes is not sufficient enough in EEIO methodology. For that, more suitable is detailed LCA (e.g. following Recommendation ITU-T L.1410 [1]) which has specific requirements intended for external public communication. Comparative assertions usually also require comparable conditions such as a PCR or PSR.

5.5.4 Life Cycle Inventory (LCI) of EEIO

For EEIO methodology, the data collection consists basically of two types of data: economic data and environmental data. The economic data is based on the transaction of material and resources. LCA practitioner needs to determine the monetary value of the inputs and where the relevant data needed can be found.

First step is to identify the product, product category, or sector which is relevant for the needed data. The products within a category can vary in their level of similarity, depending on how they are grouped together. For example, an EEIO table may have different values for copper, aluminium, and precious metals, or it may encompass all or some of these categories under a broader classification of "nonferrous metals".

Monetary value and the materials associated with a specific ICT goods could be obtained using Bill of materials and purchase invoices. The purchase value shall be converted from actual (purchase) prices to basic prices by subtracting taxes and distributors' trading margins. The environmental data include environmental impact associated with the materials and resources (e.g. GHG emissions). These emission factors represent the total upstream production impact per monetary unit of a product, product category, or sector. Such factors can be obtained from available data sources. (for example, Life Cycle Databases | GHG Protocol for a list of third-party secondary databases, some of which include EEIO data). When applicable, data quality requirements from section 6.2.5 of Recommendation ITU-T L.1410 [1] and ISO 14044 [4], clause 4.2.3.6 should be followed.

5.5.5 Life Cycle Impact Assessment (LCIA) of EEIO

In case of EEIO assessment, the monetary value of the input is multiplied with the respective EEIO-based emission factors for each input to obtain the total impact associated with the upstream processes.

5.5.6 Life cycle interpretation of EEIO

In any LCA assessment using financial data for calculating the impact, it is important to consider the impact of inflation and exchange rates. As inflation can influence the result, where relevant, inflation data shall be used to convert market values between the year of the EEIO emissions factors and the year of the activity data. Likewise, if financial data is taken from different counties, the differences in exchange rate fluctuations need to be considered, which can also affect the accuracy of results. LCA practitioner should convert all data into a common currency using appropriate exchange rates for relevant period. The uncertainty and sensitivity analysis due to these factors shall be included in the interpretation of the results.

6 Reporting

Reporting is essential to ensure transparency, accountability and effective engagement with stakeholders. Reporting of simplified LCA results shall follow the guidance given in Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2] and the present document. In case of any discrepancy between the two, the text in the present document takes precedence.

The assessment report shall address the data, methods and assumptions applied in the assessment, and the limitations thereof. The reporting of results using simplified LCA approaches shall include:

- date of report;
- studied product system name and description;
- type of inventory (i.e. cradle-to-grave or cradle-to-gate inventory);
- goal and scope of the study;
- name of the simplified LCA method applied;
- data sources and data age;
- selected environmental impact categories;
- results in the selected environmental impact categories;
- cut offs and limitations;
- sensitivity and uncertainty of the results as applicable.

Depending on the purpose of the study and the simplified method used for the study, the impacts may be:

- reported as total impact with a single number;
- reported using a breakdown to different life cycle stages, some of which may be combined:
    - for example breakdown to embodied emissions and use stage emissions;
- reported using a breakdown to different life cycle stages.

Optionally other data, diagrams, statements, etc. may be added to the assessment report based on the scope and purpose of the Simplified LCA assessment.

When the result of a comparative analysis (as described in Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2]) between an ICT system and a reference product system (another ICT system or a non-ICT system) is reported, the results may either be given as absolute amounts or as a relative difference between the systems (possibly as a percentage). In case the difference in product system impacts is leading to significantly high or low percentage values, it should be accompanied with the absolute values.

Practitioner needs to indicate whether location or market-based data has been used in the assessment.

Annex A (informative): Data availability - detailed view of applicability, purpose and limitations of LCA approaches

As a practitioner new to LCA, the best way to build LCA knowledge is to perform a new LCA study. The method described in Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2] or the simplified LCA PP method could be applied and LCA data collected from suppliers, existing LCA databases or published LCA studies are used with LCA tools. Results from such studies could later be used for similar products using simplified approaches using one or few parameters like the 1PLCA and LCSRP. This is indicated in Figure A.1.

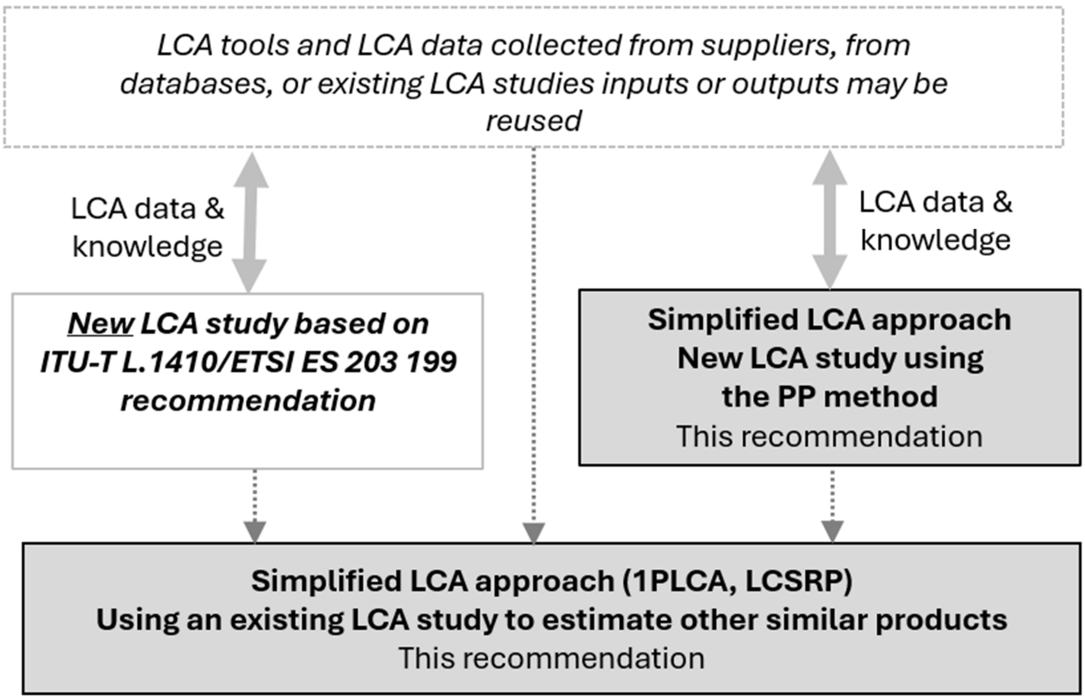


Figure A.1: Relationship between LCA and simplified LCA approaches

New LCA study

A new LCA can be made either by performing a comprehensive LCA study using typically over100 Product Parameters (PPs) with limited simplifications, or an LCA study using a limited number of PPs ("PP method", from typically ~10 to < 100 PPs) representing a simplification of the product/system/ service.

A new LCA gives detailed results for the following purposes:

- Understanding of the potential impact of existing products/systems/services and new products/systems/ services.
- Understanding of improvements between generations and finding future opportunities for improvements.
- Development of Product Carbon Footprint (PCF), or Product Environmental Footprint (PEF), or other information for products/systems/services to facilitate collaborations and data exchanges between vendors/manufacturers and their suppliers and customers, and for information to decision-makers in industry, government or non-government organizations.

Reuse of an existing LCA study

Using a similar existing LCA study is an approach typically used to estimate the embodied life cycle part (or cradle to gate, excluding future EoLT) using only one or a few PPs.

Quick total estimates like this make it possible to cover many products/systems/services. These are typically used for:

- Cases where products/systems/services exist in many versions, but differences are small.
- Companies/organizations scope 3 reporting.
- Studies of ICT products/systems/services and ICT sector studies on country/regional/global level where the embodied footprint of individual products are insignificant and an average market estimate is sufficient.

Table A.1: Overview of the two approaches for new LCAs and reusing existing LCA studies

	New LCA based on Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2]	New LCA based on the PP method	Reuse of LCA study
General	Good for a deeper understanding of LCA and the investigated product/system/service, which provides a good input to the simplified LCA approaches	Simplification through parametrizing the product and focus on primary data collection for main impact contributors	Not an LCA study of its own, as it needs to be based on an existing LCA study of a similar product/system/ service
Resource needs	A lot of time/resources are needed and typically external LCA tool/database(s) are also needed	More limited time/resources are needed per product/system/service and spreadsheets can be used	Very little time/resources are needed per product/system/service and spreadsheets can be used
Primary data collection	Many suppliers may be requested to collect data (depending on time/resources available)	Key suppliers may be requested to collect key data	No suppliers need to be involved
Accuracy	A high accuracy can be achieved	Focus on key parameters simplifies, but still gives good accuracy	Accuracy acceptable for listed purposes (depending on the original LCA and the similarity of the products/systems/services)

When choosing the approach, an important consideration for a company/organization is how many products/systems/services need to be covered by their LCA work. A comprehensive LCA study based on Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2] is time and resource consuming. The same time spent on several simplified LCAs using the PP method and thereafter extending its results by using the other simplified LCA approaches using one or a few parameters (1PLCA or LCSRP) to cover many more products/systems/services can be a good strategy. However, performing a more comprehensive LCA study based on Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2] will increase the knowledge and understanding of the product and LCA methodology in general, which will be of great value for the simplified LCA approaches.

Annex B (informative): Example of global GHG Emission Factors (EFs)

Table B.1 shows key parameters and typical emission factors for an average IC, display, and PCB derived from [i.8] presenting global average figures for year 2020 based on data that cover about 75 % of IC and display, and about 20 % of PCB manufacturing.

Table B.1: The key electronic components and their global average EFs 2020 based on [i.7]

Component	Global average	Global Average EF
Displays	55 Mt CO_2e / 250 million m^2	2,2 kg CO_2e/dm^2
PCBs	21 Mt CO_2e / 60 billion m^2	3 kg CO_2e/dm^2
ICs (+OSAT)	128 Mt CO_2e / 50 million m^2	2,6 kg CO_2e/cm^2
Standard components	20 Mt CO_2e (excluding OSAT) / 625 kt	32 kg CO_2e/kg
Manufacturer activities	77 Mt CO_2e (see split on user devices, network, and data center equipment in [Embodied]/ 12 Mt product weight (excluding packaging)	6 kg CO_2e/kg (excluding packaging) (see note)
NOTE: Wide range for various products.		

Outsourced Semiconductor Assembly & Test (OSAT) is a special production stage for ICs where the semiconductor dies are tested and assembled into a final IC component by a third-part (outsourced). Note that no IC substrate PCB is included in the IC (+OSAT) data, and that no PCB or IC is included in the display module data in Table B.1, hence the component data are separated from each other.

Table B.1 only list the global average EF, but different key types of displays, PCBs, and ICs have also been estimated in [i.7].

Annex C (informative): Expanding the number of parameters in the PP method

The PP method can be used for each key part of a product/service to be able to visualize how much each part contributes. A supplier may also use the PP method for their part and report its total. It is also practical for any large company/organization to be able to more easily work together on different parts to investigate how various design and supplier choices impact their products/services.

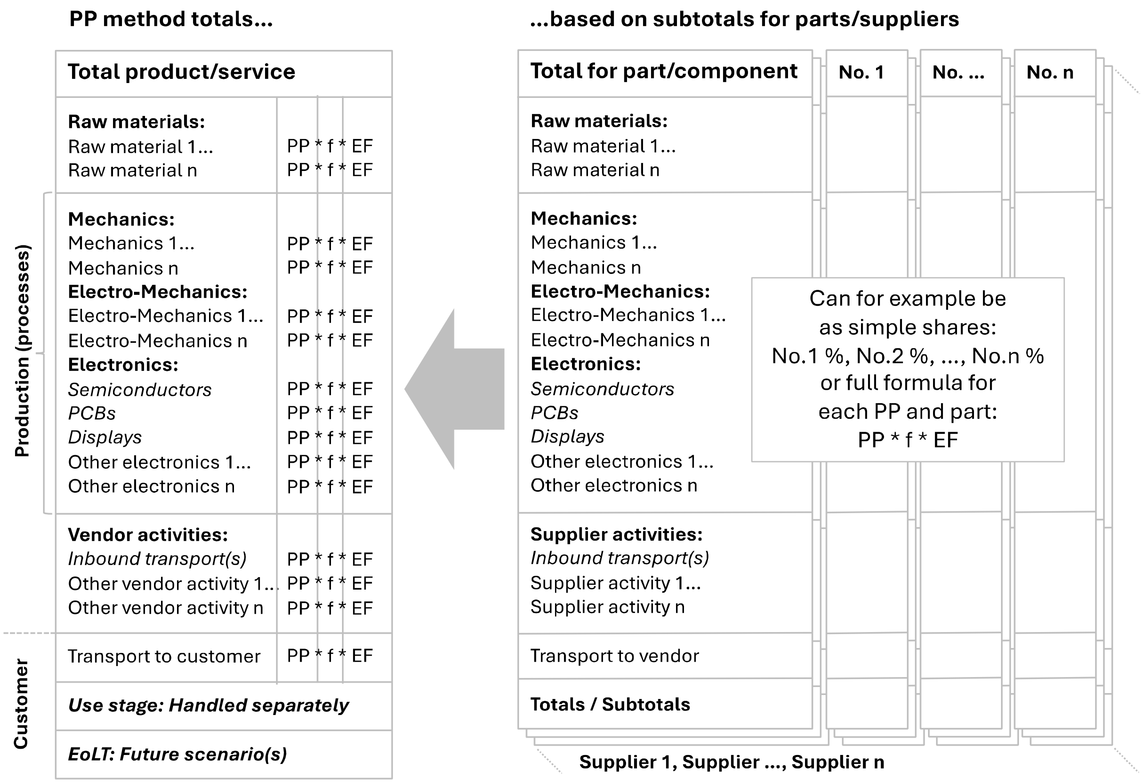
All the smaller non-key parts can still be aggregated and handled together to keep the intended overall simplification idea of the PP method.

Key motivations for expanding the PP method can be summarized as:

- To be able to calculate and report subtotal results for specific parts, which may also be used by suppliers of complex parts.
- To be able to use specific adjustment factors and EFs for one or several parts and/or individual suppliers - to be able to adopt a product/service to local/regional suppliers using specific EFs for e.g. electricity.
- To be able to compare parts internally depending on design and supplier choices.

The disadvantage of adding parameters and complexity is that more time and resources are required.

Figure C.1 shows how an expansion of the PP method may be done using a typical spreadsheet structure. A practical way of expanding the PP method is to add a column for each extra part the product/service is separated into. It can be a simple split with percentage shares or using the full formula with specific values for PP, f, and EF. Extra sheets and workbooks may add to the complexity which can grow fast measured as number of PPs.



Annex D (informative):
Example - Simplified LCA of a Smartphone

This is an example of methodology application on a smartphone produced in 2020 using global average data. This smartphone example has also been used in [i.7] and is in turn based on global data described in [i.8]. It is also based on a more detailed but older (2016) LCA [i.12].

The intention with this smartphone example is to show what can be described as the minimum level of simplification. But even this minimum level of simplification provides the essential information needed to understand a simplified LCA of a smartphone. Table D.1 shows the smartphone product parameters, calculations, results, and some additional information.

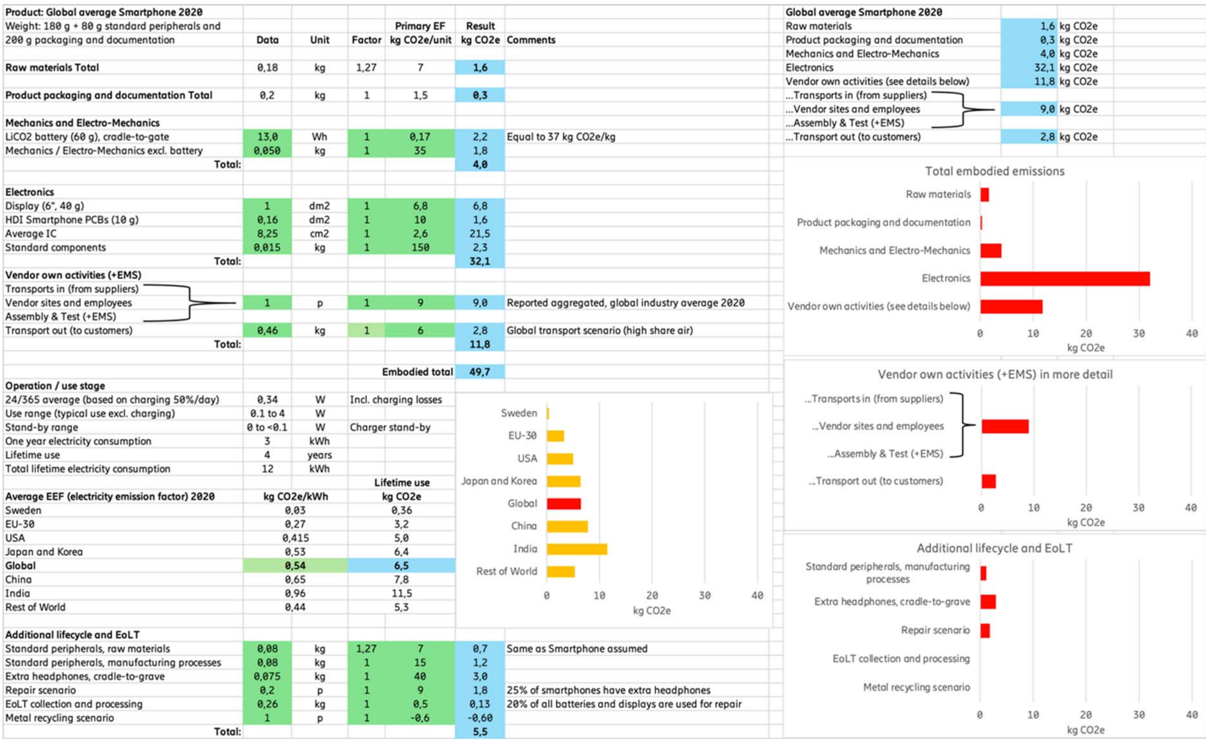
Smartphone key data summary: 180 g weight, 6 inch screen, +80 g standard peripherals, +200 g packaging and documentation, 50 % charging every day including charger losses and charger stand-by (plugged-in).

Table D.1: Global average smartphone (produced in 2020) product parameters, calculations, results, and additional information in a simplified LCA

Smartphone, global average 2020, 180 g	PP	Unit	Factor f	Primary EF kg CO_2e /unit	Result kg CO_2e	Comments
Raw Materials Total	0,18	kg	1,3	7	**1,6**	All raw materials aggregated
Packaging & doc. Total	0,20	kg	1	1.5	**0,3**	
Mechanics and Electro-Mech						
Battery module	13,0	Wh	1	0,17	2,2	22 g $LiCO_2$ (Lithium Cobalt Oxide), Total 60 g, Alt. EF = 37 kg CO_2e/kg
All remaining mech & e-mech	0,050	kg	1	35	1,8	Cameras, mic, speakers, other comp.
Total					**4,0**	
Electronics						
Display module	1,0	dm^2	1	6,8	6,8	Total 40 g, 6 inch
HDI Smartphone PCB	0,16	dm^2	1	10	1,6	Total 10 g, High Density Interconnect
Average semiconductors (ICs)	8,25	cm^2	1	2,6	21,5	
Standard components	0,015	kg	1	150	2,3	
Total					**32,1**	
Vendor activities						R&D, assembly & test (inclunding EMS), etc.
Vendor activities (excluding trp out)	1	p	1	9	9	Industry average based on [i.8]
Transport out (to customers)	0,46	kg	1	6	2,8	Global trp out scenario (high air share)
Total					**11,8**	
Use stage						
AEC	3	kWh	AEC = Annual Electricity Consumption, including charger losses and stand-by			
ALY	4	years	ALY = Active Lifetime Years			
LEC = AEC × ALY	12	kWh	LEC = Lifetime Electricity Consumption			

Note that the vendor activities are an industry average based on [i.7] that includes all assembly & test, R&D, market and sales, SW development, and other support activities related to the smartphone industry, also including third-party activities like EMS.

Figure D.1 show how the simplified LCA calculations and how the result presentation can look like using a common spreadsheet tool. It is the same structure as in the radio example in Annex H. The use stage and impact of different electricity EFs are also shown.



Product: Global average Smartphone 2020 Weight: 180 g + 80 g standard peripherals and 200 g packaging and documentation	Data	Unit	Factor	Primary EF kg CO2e/unit	Result kg CO2e	Comments
Raw materials Total	0,18	kg	1,27	7	1,6	
Product packaging and documentation Total	0,2	kg	1	1,5	0,3	
Mechanics and Electro-Mechanics						
LiCO2 battery (60 g), cradle-to-gate	13,0	Wh	1	0,17	2,2	Equal to 37 kg CO2e/kg
Mechanics / Electro-Mechanics excl. battery	0,050	kg	1	35	1,8	
Total:					4,0	
Electronics						
Display (6", 40 g)	1	dm2	1	6,8	6,8	
HDI Smartphone PCBs (10 g)	0,16	dm2	1	10	1,6	
Average IC	8,25	cm2	1	2,6	21,5	
Standard components	0,015	kg	1	150	2,3	
Total:					32,1	
Vendor own activities (+EMS)						
Transports in (from suppliers) Vendor sites and employees Assembly & Test (+EMS)	1	p	1	9	9,0	Reported aggregated, global industry average 2020
Transport out (to customers)	0,46	kg	1	6	2,8	Global transport scenario (high share air)
Total:					11,8	
				Embodied total	49,7	

Operation / use stage			
24/365 average (based on charging 50%/day)	0,34	W	Incl. charging losses
Use range (typical use excl. charging)	0.1 to 4	W	
Stand-by range	0 to <0.1	W	Charger stand-by
One year electricity consumption	3	kWh	
Lifetime use	4	years	
Total lifetime electricity consumption	12	kWh	

Average EEF (electricity emission factor) 2020	kg CO2e/kWh	Lifetime use kg CO2e
Sweden	0,03	0,36
EU-30	0,27	3,2
USA	0,415	5,0
Japan and Korea	0,53	6,4
Global	0,54	6,5
China	0,65	7,8
India	0,96	11,5
Rest of World	0,44	5,3

Additional lifecycle and EoLT	Data	Unit	Factor	Primary EF kg CO2e/unit	Result kg CO2e	Comments
Standard peripherals, raw materials	0,08	kg	1,27	7	0,7	Same as Smartphone assumed
Standard peripherals, manufacturing processes	0,08	kg	1	15	1,2	
Extra headphones, cradle-to-grave	0,075	kg	1	40	3,0	
Repair scenario	0,2	p	1	9	1,8	25% of smartphones have extra headphones
EoLT collection and processing	0,26	kg	1	0,5	0,13	20% of all batteries and displays are used for repair
Metal recycling scenario	1	p	1	-0,6	-0,60	
Total:					5,5	

Global average Smartphone 2020		
Raw materials	1,6	kg CO2e
Product packaging and documentation	0,3	kg CO2e
Mechanics and Electro-Mechanics	4,0	kg CO2e
Electronics	32,1	kg CO2e
Vendor own activities (see details below)	11,8	kg CO2e
...Transports in (from suppliers) ...Vendor sites and employees ...Assembly & Test (+EMS)	9,0	kg CO2e
...Transport out (to customers)	2,8	kg CO2e

Figure D.1: The Smartphone product parameters in Table D.1 implemented as a spreadsheet tool

Additional use and EoLT stage also consider basic peripherals, average repair/replacement of batteries and displays, and that a user adds peripherals, e.g. extra headphones. This type of additional use is not mandatory to include in a simplified LCA as described in clause 5.2.3.3.1 Additional impacts in use stage, but it has been included here as an example of what could be added in a simplified LCA.

Figure D.2 shows a comparison between the simplified LCA on a global average smartphone (2020) data [i.8] and the full LCA [i.12] (2016).

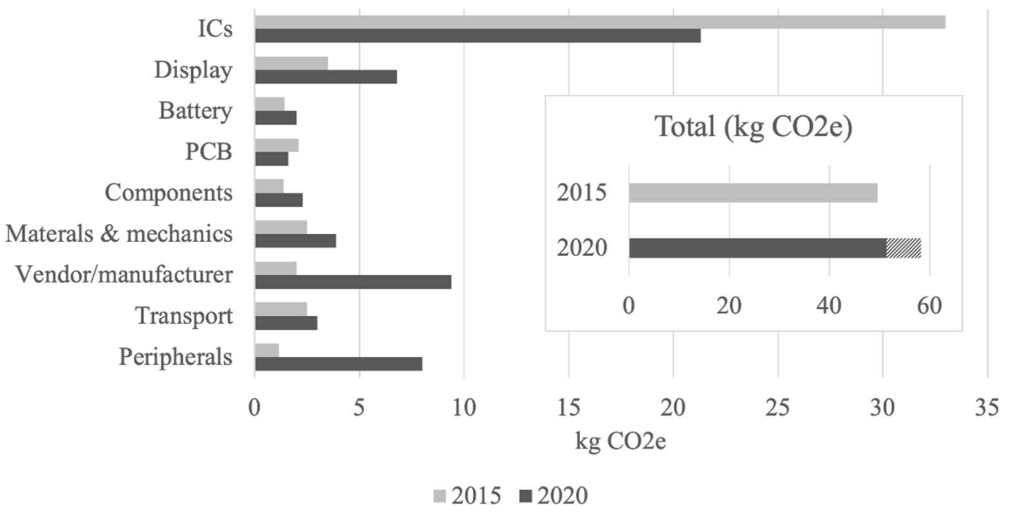


Figure D.2: Comparison between the detailed Smartphone LCA [Smartphone] and the global average smartphone produced in 2020 described in Figure D.1 above and used here in this annex

Annex E (informative): Clarification of PP method and unit processes in Recommendation ITU-T L.1410

Recommendation ITU-T L.1410 [1] lists a number of mandatory and optional unit processes, as well as a list of material groups that is mandatory to include if applicable to the studied ICT product system. The main difference between an Recommendation ITU-T L.1410 [1] LCA and a simplified LCA using the PP method is the simplification that not all flows and parts need to be included separately. In the PP method, instead of including a specific material flow in each part containing that specific material, the total mass of that material is calculated, and the total material sum is then multiplied with applicable material EF. The PP method allows for "black-boxes" just as Recommendation ITU-T L.1410 [1]. Hence, it is possible to use an EF for e.g. a battery that covers both material, transport and production, without knowing the details. For parts contributing considerable to the result, it is recommended to understand the details and thereby also divide the input into materials and other processes. Exactly which processes to include in a PP calculation will depend on the assessed ICT good, network or service and its impact on the result, but the list in Appendix III gives an indication.

Tables E.1 and E.2 show an extract of unit processes derived from the lists in Recommendation ITU-T L.1410 [1] (Annexes D to F) and indicate how these are included in the PP method.

Regarding which materials to include in a simplified LCA study using the PP method, the same minimum raw material' groups (chemicals, fuels, metals, plastics, packaging materials, and additives) as listed in Annex H in Recommendation ITU-T L.1410 [1] need to be taken into account when deemed to influence the results. The raw material groups are either part of the material content of the ICT goods/support goods or used as ancillary materials throughout the life cycle. Exactly which materials to include will depend on the assessed ICT good, network or service.

Table E.1: Unit processes, mandatory/optional and process categories from Recommendation ITU-T L.1410 [1], Table D.1 (column 1 to 3) and comments related to the PP method in the present document (column 4)

Unit processes (in Recommendation ITU-T L.1410 [1])	Mandatory /optional -status (in Recommendation ITU-T L.1410 [1])	Process category (in Recommendation ITU-T L.1410 [1])	PP method comments
Direct emissions	Mandatory	Transport and travel	Inbound and outbound transport EFs from the manufacturer's point of view included specifically. Transport from raw material supplier to parts production is included in the EFs for processes. Travel is included in the support activities for the manufacturer. Support activities need also to be included in the process emission factors for electronics, while optional for other suppliers.
		Electricity	Electricity EF for the use stage.
		Fuels	EFs as applicable.
		Other energy (note 2)	EFs as applicable.
Fuel supply chain (Extraction and production and distribution)	Mandatory	Transport and travel	Included in the travel and transport EFs.
		Electricity	Included in electricity EF.
		Fuels (note 1)	Included in fuel EFs as applicable.
		Other energy (note 2)	EFs as applicable.
Vehicle production	Optional	Transport and travel	Optional. May not be significant in LCA of ICT.
Infrastructure production	Optional	Transport and travel Electricity (note 3) Other energy (note 2)	Optional for most types of buildings, roads and other infrastructure. However production of specific-purpose buildings like data centers and IC manufacturing facilities, which have significant impact on the results, should be included.

Unit processes (in Recommendation ITU-T L.1410 [1])	**Mandatory /optional -status (in Recommendation ITU-T L.1410 [1])**	**Process category (in Recommendation ITU-T L.1410 [1])**	**PP method comments**
Local renewable electricity generation: Raw Material Acquisition + Production + Distribution	Mandatory	Electricity	EFs as applicable.
Raw material extraction	Mandatory	Raw material acquisition	Material EFs cover both extraction and processing.
Raw material processing	Mandatory	Raw material acquisition (see Annex H)	
Environmentally hazardous waste recovery/ treatment (G6.1) (note 4)		End-of-life treatment	EFs as applicable.
Recycling/ recovery/treatment of other waste (G6.2)		End-of-life treatment, see Annex F (note 6)	EFs as applicable.
Metal recycling - smelting	Mandatory		EFs as applicable.
Metal recycling - refining	Mandatory		EFs as applicable.
Other material recycling	Optional	Raw material recycling	EFs as applicable.
NOTE 1: Added direct emission from fuels as that was missing in Table D.1 in Recommendation ITU-T L.1410 [1]. NOTE 2: District heating (hot water), District heating (steam), District cooling (cold water) as electricity. NOTE 3: Power plant production, dam production, the grid production, nuclear waste treatment. NOTE 4: G6.1 EHW (Environmentally hazardous waste) treatment: EHW (destruction and energy recovery), Special EHW landfill. NOTE 5: G6.2 Other waste treatment: Diverse material recycling, Energy recovery (e.g. incineration, Energy recovery of incineration processes is optional), Landfill. NOTE 6: Process categories: for reuse of ICT goods, ICT-specific EoLT, Storage/Disassembly/ Dismantling/Shredding, Recycling, Battery recycling, *ICT-specific metal/mechanical parts/fractions EoLT,* PCBA recycling, Cable recycling, Mechanics recycling, Other ICT recycling, Other EoLT.			

NOTE: Direct emission from fuels is missing from Table D.1 in Recommendation ITU-T L.1410 [1], but it has been added to Table E.1.

Table E.2: Unit processes and mandatory process categories from Recommendation ITU-T L.1410 [1], Table E.1 (columns 1 and 2) and comments related to the PP method in the present document (column 3)

Unit processes (in Recommendation ITU-T L.1410 [1])	Process category (in Recommendation ITU-T L.1410 [1])	PP method comments
Raw material acquisition	Batteries	Included as a black box EF for battery, or as materials and production processes specifically. It is important not to double count material if included as black box.
	Cables	Cables are treated as material and general electromechanics production, but it can be included as black box.
	Electromechanics	Each material is separately summed before calculating the environmental impact.
	IC frontend materials	
	IC backend materials	
	Mechanics	
	Displays	Included as a black box EF for display or as materials and production processes specifically. It is important not to double count material if included as black box.
	Special display panel materials	Included as described in Displays above.
	PCB	Each material is separately summed before calculating the environmental impact.
	Special PCB materials	
	PCB semi-produced composite materials	
	PCBA components	
	Packaging material	
Part final assembly	Battery cell assembly	Included as a black box EF for battery or EF for battery production (excluding the raw material) and separate handling of the raw materials.
	Battery module (pack) assembly	
	Electromechanics part final assembly	Included as general electromechanics component process EF.
	Cable final assembly	Calculated with general electromechanics production EF, or as a specific cable production EF.
	IC wafer production	Included in IC EF. ICs can be either included as one average IC type or divided into several, from high-end to low-end ICs. EF per die area is recommended. The EF needs to include support activities from IC manufacturers. See note 3.
	IC chip production	
	IC encapsulation	
	Mechanics part final assembly	Included as general mechanics process EF.
	Display module assembly	Included in EF for display as black box or specific EF for display production created (excluding the raw material) and separate handling of the display raw materials.
	Display panel assembly	
	PCB final assembly	Included in PCB EF can either be one average or divided into different modules. EF per area and number of layers is recommended.
	PCBA components part final assembly	Included in electrical components average EF.
"Cradle-to-gate" LCA from supplier	"Black box" modules	Creating "black box" EFs can be an efficient way to cover different parts in a simplified LCA using the PP method.
Software development (note 1)	Software module	Included as software support and development in the manufacturer support activities EF in the production stage.
Software production (note 2)	Software module	
Assembly process	Assembly	Included in average assembly EF for the manufacturer.
Warehousing	Assembly	
Packaging	Assembly	

Unit processes (in Recommendation ITU-T L.1410 [1])	Process category (in Recommendation ITU-T L.1410 [1])	PP method comments
NOTE 1: E.g. daily way to work for programmer, business trips for programmer, electricity usage of ICT goods used by programmer, office lighting. NOTE 2: Production: e.g. manuals production, data medium production, download size if software is available as download [1], mass-based approaches are alternatives to die area measurement approaches.		

Annex F (informative): Emission Factors (EF) template

Following table summarizes a list of materials and processes to be included in a simplified LCA using the PP method. The raw material Emission Factors (EF) can be presented per weight of each material included in the product (e.g. kg CO_2e per kg copper). The EF related to production of mechanics and electromechanics are presented as weight of that part/category included in the final product. For electronics production the EF are presented per die area for IC, display area, or per layer times area for PCBs.

A raw material EF may be for *Primary material production* and based on production from ore or other natural resources, or it can be for *Secondary material production* including also recycled content. The LCA practitioner may collect an EF from a specific supplier that may or may not contain recycled material and use it in the calculations. Otherwise, an EF can be created by combining a primary material production EF and a secondary material production EF and the share of recycled content.

Primary data collected from suppliers is recommended for key parts/contributors to the investigated environmental impact. Secondary data, like global average emission factors, can be used when no primary data is available, or the part/contributor is less impactful in the result. Global average EF are a good starting point for any LCA practitioner and useful also to validate collected supplier data. The used EF are likely a mix of primary and secondary data sources.

LCA practitioner should update the emission factors regularly, e.g. once a year, and look for the most up to date values.

Table F.1: Emission factor template for a simplified LCA using the PP method

	Raw materials - metals and metal alloys	Unit	Primary material production EF	Secondary material production EF	Comments (range, source, global average, supplier specific, etc.)
Raw materials - metals and metal alloys	Aluminium	per weight			
	Copper				
	Magnesium				
	Iron/steel				
	Zinc				
	Chromium				
	Tin				
	Silver				
	Gold				
Raw materials - other materials	Plastics (divided into PC, PE, PS, epoxy, etc.)				
Raw materials - packaging	Packaging cardboard, wood, paper				
Production - mechanics and electromechanics	Aluminium die cast	per weight			
	Magnesium die cast				
	Aluminium filters				
	Antenna assembly				
	General mechanical parts				
	Batteries				
	Chargers				
	Cameras				
Production - electronics	ICs	per die area			
	PCBs	per layer x area			
	Components and IC packaging	per weight			
	Displays	per display area			
Production - vendor & assembly	Inbound transport	per weight of final product and packaging			
	Outbound transport				
	Assembly & test (including outsourced)				
	Vendor sites & travel				
Use stage - electricity	Electricity in use stage	per kWh			
EoLT	EoLT - general processing	per weight of final product and packaging			

Table F.2 is a longer more detailed list of EF that can be of interest depending on the use of the results and the level of details needed.

Table F.2: Detailed emission factor template

Raw materials	Primary material production EF		Secondary material production EF (average recycling)	
Metals and metal alloys	**kg CO2e**	**per unit**	**kg CO2e**	**per unit**
Steel in basic production form				
Pig iron (cast iron)				
Stainless steel				
Aluminum				
Copper				
Zinc				
Magnesium				
Chromium (ferrochrome)				
Nickel				
Cobalt				
Lithium Cobalt Dioxide (LiCoO2)				
Tin				
Silicon (metallurgical grade)				
Silicon (semiconductor grade, i.e. raw material before wafer)				
Tantalum				
Titanium				
Indium (largely based on recovery related to other metal production)				
Tungsten (often including recycling)				
Antimony				
Silver				
Gold				
Palladium				
Platinum				
Other materials				
Plastics average				
PE plastics				
PS plastics				
PC plastics				
PMMA plastics				
Epoxy				
Glass wool/glass fiber				
Paper				
Cardboard				
Wood				
Wood pallet (including reuse)				

Electronics	Primary material production EF		Secondary material production EF (average recycling)	
Integrated circuits (ICs)	**kg CO2e**	**per unit**	**kg CO2e**	**per unit**
Average low end IC				
Average memory IC				
Average IC				
High-end ASIC/processor				
New technology unmature process, low yields				
Displays				
TV display				
Average display				
PC				
Displays				
Laptop display				
Tablet display				
Smartphone display				
Printed Circuit Boards (PCBs)				
Rigid/flex, 1-2 layers				
Average multilayer, <8 layers				
Average 8-12 layers multilayer (average PCB)				
Average multilayer, >12 layers				
High Density Interconnect, HDI				
IC substrate				
Other components				
Standard components				
Smartphone special components (cameras, mic/speaker, sensors)				

Electricity consumption	Process only EF (G-t-G)		Cradle-to-Gate (C-t-G) EF	
	kg CO2e	**per unit**	**kg CO2e**	**per unit**
Global				
EU-27				
USA				
Japan and Korea				
China				
India				
...				

Mechanics	Process only EF (G-t-G)		Cradle-to-Gate (C-t-G) EF	
	kg CO2e	**per unit**	**kg CO2e**	**per unit**
Ceramics manufacturing (RF ceramics)				
Small complex special, weight <0.1kg (e.g. connectors, shields)				
Stainless steel screws				
Medium size mechanics, average weight 5kg (modules, units)				
Large size mechanics, average weight 75kg (cabinets, racks)				
Very large mechanics, >1ton (towers, containers)				
Aluminium extrusion				
Aluminium extrusion with anodization/lacquering				
Injection molded plastics, complex final parts				
Cast iron (<50kg)				
Cast iron (>50kg)				
Galvanized steel plate, average				
Galvanized steel plate, 2mm				
Galvanized steel plate, 3mm				
Galvanized steel plate, 4mm				
Galvanized steel plate, 5mm				
Sheet metal forming				
Machining - milling				
Powder coating (painting)				
Zinc die casting				
Special radio mechanics				
Aluminium die cast (heatzink parts with surface finishing)				
Complex aluminium filters (+assembly with surface finishing)				
Magnesium die cast (average F-gas used)				

Electro-Mechanics, cables and batteries	Process only EF (G-t-G)		Cradle-to-Gate (C-t-G) EF	
	kg CO2e	**per unit**	**kg CO2e**	**per unit**
Cable (power, signal/data/network)				
Cabel (coax)				
Fiber				
Fiber cable (fiber+cable/protection)				
Fiber cable (fiber+cable/protection+plastic tube)				
Power supply unit				
Fan unit				
Climate unit (not incl. cooling media)				
Lead-acid backup battery				
Lithium backup battery (Li-MNC type)				
Smartphone lithium-ion battery (LiCoO2 type)				
Semi-equipped cabinet (e.g. power, fans/climate)				
Antenna PCB substrate				
Antenna module				

Infrastructure	Process only EF (G-t-G)		Cradle-to-Gate (C-t-G) EF	
	kg CO2e	**per unit**	**kg CO2e**	**per unit**
Trenching (per km)				
Concrete pre-fabricated parts (heavy)				
Concreate on-site casting				

Transports	No fuel supply EF (T-t-W)		EF incl. fuel supply (W-t-W)	
	kg CO2e	**per unit**	**kg CO2e**	**per unit**
Airfreight, long				
Airfreight, short				
Truck, average local				
Truck, average regional				
Train, average regional				
Containership				

Travel	No fuel supply EF (T-t-W)		EF incl. fuel supply (W-t-W)	
	kg CO2e	**per unit**	**kg CO2e**	**per unit**
Air travel, average				
Air travel, short				
Car travel				
Train travel				

Other energy consumption	No fuel supply EF (G-t-G)		EF incl. fuel supply (C-t-G)	
	kg CO2e	**per unit**	**kg CO2e**	**per unit**
Gas, CNG, LNG				
Gasoline, petrol				
Diesel				
Fuel oil				
Coal				

District heating	No fuel supply EF (G-t-G)		EF incl. fuel supply (C-t-G)	
	kg CO2e	**per unit**	**kg CO2e**	**per unit**
Sweden				
Finland				
Germany				
Hungary				
Netherlands				

District cooling
Can be created as a factor between cooling energy and actual electricity

Annex G (informative): Parametrized Product Characteristics Approach (PPCA) - a Product Parameter method for simplified LCA

G.1 Characteristics of Parametrized Product Characteristics Approach (PPCA)

Here follows an example of an application of the Product Parameter method principles for Simplified LCA described in clause 5.2 and mentioned in clause 5.2.7.

The method at hand, called Parametrized Product Characteristics Approach (PPCA) includes the life cycle stages Raw material acquisition (A), Production (B), Use (C) and End of Life Treatment (D).

The studied product system to be assessed with PPCA are defined in Tables G.1 and G.2 with examples in Tables G.3a to d and G.4a-d.

Software component impacts associated with the ICT product at hand is not yet considered within PPCA.

The operating life time is considered with the Lifetime parameter as expressed in Tables G.1 and G.2 with examples (in Tables G.3a-d and G.4a-d).

The functional unit for the PPCA method is: total ICT product use per lifetime of ICT product.

Data used are from literature with adequate quality for the purpose of PPCA. While PPCA allows flexible exchange for each Input whenever better-quality data are available, the initial values for the CO_2e, antimony equivalents and Comparative Toxic Unit (CTU) and Water scarcity flows in Tables G.1 are adequate for e.g. hotspot finding, early design stage trade-offs (between the use stage and embodied) and also for Scope 3 reporting.

Data collection for PPCA for the CO_2e, antimony-equivalents CTU intensity and water scarcity flows is done from literature. For the activity flows the data are collected directly on the product to be assessed.

Data calculation for PPCA is described in Tables G.3a-d and G.4a-d based on values from Table G.1.

The impact categories considered are climate change with mass-based GWP100 mid-point indicator, resource use with mass-based antimony-equivalent indicator and ecotoxicity with CTU-based indicator, and water scarcity with m^3-based indicator.

The uncertainty analysis method is not standardized in PPCA. However, it can be performed with the values for standard deviation (Ơ) given in Tables G.2, G.3a-d and G.4a-d.

Moreover, the uncertainty assessment handling in LCA is an emerging topic and handled differently in various applications.

However, ETSI TS 104 134 [i.13] focusing on simplified methods for sensitivity and uncertainty calculations for avoided emissions could be used to explore this topic as the methods introduced in [i.13] are relatively general. clause G.5 provides further guidance on how the sensitivity and uncertainty calculation for a fictive ICT infrastructure product (described in clause G.3) can be performed. The absolute scores, sensitivities and uncertainties in clause G.5 should not be taken as general guidance for all kinds of ICT infrastructure products.

Reporting is done according to structure of Figures G.1a-d and G.2a-d. For those examples the reporting should contain filled in Tables G.3a-d and G.4a-d for the ICT product at hand.

Critical review can be performed by checking which values from Tables G.1, G.2, G.3a-d, G.4a-d the LCA practitioner used for the PPCA calculation.

The PPCA method has the following main use case: making trade-offs between some high-level processes and life-cycle stages especially when relatively limited information is available for the design concepts. Hence, PPCA (depending on the accuracy of the activity flow values) can be used to conclude whether Part Production is more important than Raw Material Production for any ICT product, and if the use stage is more important than the embodied.

The product system to be assessed with PPCA is defined in Tables G.1 and G.2 with examples in Tables G.3a-d and G.4a-d.

Therefore, cut-off rules are not relevant for PPCA itself as the studied product system is defined fully by Tables G.1 and G.2. All parameter inputs need to be used if applicable to the ICT product at hand.

Recycling benefits are not yet included in PPCA.

G.2 Studied product system and calculation framework for Parametrized Product Characteristic Approach

Here follows more details of the studied product system and calculation method for PPCA which can guide ICT product manufacturers on how to carry out Simplified LCA to achieve initial reasonable results intended for non-certification applications.

The method consists of an input by input calculation scheme which can be used by ICT product manufacturers - and others by interest and application - to estimate the lifetime CO_2e, antimony equivalents and Comparative Toxic Units (CTUs) and water scarcity (m^3) of the ICT product at hand for the whole life cycle.

The results obtained with the method will be useful for non-certification applications such as hotspot finding and Scope 3 reporting.

By no means of course does this kind of Simplified LCA method replace neither LCA according to Recommendation ITU-T L.1410 [1] / ETSI ES 203 199 [2] nor PEFCR LCA where those are necessary for product certification applications.

The proposed method needs the inputs shown in Table G.1.

Table G.1: Inputs and contemporary midpoint intensities for proposed simplified LCA method PPCA for ICT products

Main life cycle stage sections	Input	Unit used	Proxy value (kgCO_2e/unit) for simplified LCA (mean value, μ)	Proxy value (kg Antimony equivalents/unit) for simplified LCA (mean value, μ)	Proxy value (Comparative Toxic Units, CTU/unit) for simplified LCA (mean value, μ)	Proxy value (m^3/unit) for simplified LCA (mean value, μ)	Comment on which data are needed
Raw Materials	Packaging materials, average, mass	kg	2 [i.14]	3E-06 [i.14]	1 [i.14]	3 [i.14]	Mass of all packaging.
	Packaging materials, primary, mass	kg	4 [i.14]	6E-6 [i.14]	3 [i.14]	5 [i.14]	Mass of all packaging materials from primary sources.
	Packaging materials, secondary, mass	kg	0,2 [i.14]	1E-7 [i.14]	0,3 [i.14]	1 [i.14]	Mass of all packaging materials from secondary sources.
	Aluminium, average, mass	kg	17 [i.14]	8E-05 [i.14]	4,9E-2 [i.14]	10 [i.14]	Mass of aluminium.
	Aluminium, primary, mass	kg	30 [i.14]	2E-4 [i.14]	0,08 [i.14]	15 [i.14]	Mass of aluminium from primary sources.
	Aluminium, secondary, mass	kg	1 [i.14]	1E-6 [i.14]	0,008 [i.14]	1,5 [i.14]	Mass of aluminium from secondary sources.
	Steel, average, mass	kg	1,5 [i.14]	2E-05 [i.14]	0,7 [i.14]	19 [i.14]	Mass of Steel.
	Steel, primary, mass	kg	2 [i.14]	3E-5 [i.14]	1 [i.14]	25 [i.14]	Mass of Steel from primary sources.
	Steel, secondary, mass	kg	0,7 [i.14]	1E-6 [i.14]	0,1 [i.14]	2,5 [i.14]	Mass of Steel from secondary sources.
	Stainless steel, average, mass	kg	4 [i.14]	8E-05 [i.14]	3 [i.14]	1 [i.14]	Mass of Steel.
	Stainless steel, primary, mass	kg	6,15 [i.14]	3E-4 [i.14]	8 [i.14]	3 [i.14]	Mass of Steel from primary sources.
	Stainless steel, secondary, mass	kg	1 [i.14]	1E-8 [i.14]	0,8 [i.14]	0,3 [i.14]	Mass of Steel from secondary sources.
	Plastics, average, mass	kg	5 [i.14]	6E-07 [i.14]	5 [i.14]	2,5 [i.14]	Mass of plastics.
	Plastics, primary, mass	kg	7 [i.14]	8E-7 [i.14]	7 [i.14]	5 [i.14]	Mass of Plastics from primary sources.
	Plastics, secondary, mass	kg	2 [i.14]	3E-7 [i.14]	1 [i.14]	1 [i.14]	Mass of Plastics from secondary sources.
	Gold, average, mass	kg	18 800 [i.14]	12 [i.14]	1E+5 [i.14]	4,1E+4 [i.14]	Mass of all gold.
	Gold, primary, mass	kg	30 000 [i.14]	18 [i.14]	6,5E+5 [i.14]	8E+5 [i.14]	Mass of Gold from primary sources.
	Gold, secondary, mass	kg	400 [i.14]	5 [i.14]	87 [i.14]	8E+4 [i.14]	Mass of Gold from secondary sources.

Main life cycle stage sections	Input	Unit used	Proxy value ($kgCO_2e$/unit) for simplified LCA (mean value, μ)	Proxy value (kg Antimony equivalents/unit) for simplified LCA (mean value, μ)	Proxy value (Comparative Toxic Units, CTU/unit) for simplified LCA (mean value, μ)	Proxy value (m^3/unit) for simplified LCA (mean value, μ)	Comment on which data are needed
Components & Parts	PCBs, no components, average, area	m^2	250 [i.14]	0,06 [i.14]	15 [i.14]	300 [i.14]	Area of all PCBs.
	ICs with dies, average, mass	kg	1 300 [i.14]	0,08 [i.14]	0,7 [i.14]	600 [i.14]	Mass of all ICs with dies.
	ICs without dies, average, mass	kg	160 [i.14]	0,02 [i.14]	10 [i.14]	200 [i.14]	Mass of all ICs without dies.
	Silicon dies, average, mass	kg	30 000 [i.14]	0,05 [i.14]	14 [i.14]	10 000 [i.14]	Mass of all Si dies (to be used instead of "ICs with dies" if available together with "ICs without dies").
	Electronic components except ICs and PCBs, , average, mass	kg	30 [i.14]	0,04 [i.14]	30 [i.14]	250 [i.14]	Mass of all electronics except ICs and PCBs.
	Displays, average, area	cm^2	0,03 [i.14]	8E-06 [i.14]	0,068 [i.14]	0,01 [i.14]	Area of display if product is a consumer ICT product which uses displays.
	Batteries, average, mass	kg	50 [i.14]	0,02 [i.14]	74 [i.14]	10 [i.14]	Mass of battery if applicable.
	Chargers, average, mass	kg	35 [i.14]	0,005 [i.14]	65 [i.14]	12 [i.14]	Mass of charger if applicable.
	Cameras, average, mass	kg	1 500 [i.14]	0,05 [i.14]	9 [i.14]	450 [i.14]	Mass of cameras if applicable.
Mechanical Processing	Aluminium die casting, average, mass	kg	5 [i.14]	3E-05 [i.14]	4 [i.14]	17,5 [i.14]	Mass of mechanical Aluminium parts
	Non Aluminium Mechanical Part Production, average, mass	kg	2 [i.14]	9E-06 [i.14]	4 [i.14]	26 [i.14]	Mass of non aluminium mechanical parts.
Transports	Transport of components & parts to final assembly, average, mass	kg	5 [i.14]	9,3E-07 [i.14]	1,2 [i.14]	2 [i.14]	Mass of product.
	Transport to final customer, Consumer products, average, mass	kg	10 [i.14]	1,9E-06 [i.14]	2,4 [i.14]	2 [i.14]	Mass of product and packaging materials.
	Transport to final customer, Network	kg	2 [i.14]	3,7E-07 [i.14]	0,47 [i.14]	1 [i.14]	Mass of product and packaging materials.

Main life cycle stage sections	Input	Unit used	Proxy value ($kgCO_2e$/unit) for simplified LCA (mean value, μ)	Proxy value (kg Antimony equivalents/unit) for simplified LCA (mean value, μ)	Proxy value (Comparative Toxic Units, CTU/unit) for simplified LCA (mean value, μ)	Proxy value (m^3/unit) for simplified LCA (mean value, μ)	Comment on which data are needed
	products, average, mass						
Final assembly	Product final assembly, average, mass	kg	2 [i.14]	3E-07 [i.14]	0,8 [i.14]	1,5 [i.14]	Mass of product and packaging materials.
	Outsourced production, average, mass	kg	2 [i.14]	3E-07 [i.14]	0,8 [i.14]	1,5 [i.14]	Mass of product and packaging materials.
	PCBA assembly, average, area	m^2	10 [i.14]	8E-4 [i.14]	24 [i.14]	1 [i.14]	Area of all PCBs.
Use stage	Power consumption, average, power	W					Average power consumption of product.
	Electricity	kWh	0,5 [i.14]	1E-07 [i.14]	0,02 [i.14]	0,1 [i.14]	World average carbon intensity. If feasible, the values should be changed according to the relevant market in which the ICT product is used.
	Lifetime	years					Total lifetime of product.
End-of-life treatment	Disposal, average, mass	kg	1,7 [i.14]	2E-8 [i.14]	0,25 [i.14]	0,3 [i.14]	Mass of product and packaging materials.
NOTE: The average values are taken from the literature.							

The method is explained for two fictive ICT products, one ICT Network infrastructure product and one ICT consumer product.

Table G.2 provides some rationale for the proxy CO_2e values shown in Table G.1 and some more granularity regarding typical uncertainty and literature sources. The uncertainty associated with each proxy value in Tables G.2, G.3a-d, and G.4a-d is given as one lognormal standard deviation (σ). This means that the mean value (µ) with a probability of 95 % will be within $\times/\div e^{(2\sigma)}$. For example, in Table G.2, there is a 95 % probability that the value will be between 1 and 3 kg CO_2e/kg for "Packaging materials, average, mass" and between 12,59 and 22,95 kg CO_2e/kg for "Aluminium, average, mass".

Table G.2: Description of rationale for CO_2e intensities for proposed simplified LCA method PPCA for ICT products

Input	Unit used	Proxy value (kgCO_2e/unit) for simplified LCA (mean value, µ)	Uncertainty for CO_2e flow value (lognormal σ)	System boundary	Rationale/Source
Packaging materials, average, mass	kg	1	0,203	Cradle-to-gate	Typical composition of packaging materials such as cardboard, pallets, and plastics, see [i.15].
	kg	2	0,203	Cradle-to-gate	Electricity used, kWh/kg.
Packaging materials, primary, mass	kg	2	0,203	Cradle-to-gate	Typical composition of packaging materials such as cardboard, pallets, and plastics, see [i.15].
	kg	4	0,203	Cradle-to-gate	Electricity used, kWh/kg.
Packaging materials, secondary, mass	kg	0,1	0,203	Cradle-to-gate	Typical composition of packaging materials such as cardboard, pallets, and plastics, see [i.15].
	kg	0,2	0,203	Cradle-to-gate	Electricity used, kWh/kg
Aluminium, average, mass	kg	8,5	0,15	Cradle-to-gate	A mixture of primary and secondary aluminium.
	kg	17	0,15	Cradle-to-gate	Electricity used, kWh/kg.
Aluminium, primary, mass	kg	15	0,091	Cradle-to-gate	See [i.16].
	kg	30	0,048	Cradle-to-gate	Electricity used, kWh/kg.
Aluminium, secondary, mass	kg	0,5	0,168	Cradle-to-gate	See [i.17].
	kg	1	0,131	Cradle-to-gate	Electricity used, kWh/kg.
Steel, average, mass	kg	0,75	0,168	Cradle-to-gate	A mixture of primary and secondary steel.
	kg	1,5	0,131	Cradle-to-gate	Electricity used, kWh/kg.
Steel, primary, mass	kg	1	0,131	Cradle-to-gate	See [i.18], [i.19].
	kg	2	0,203	Cradle-to-gate	Electricity used, kWh/kg.
Steel, secondary, mass	kg	0,35	0,125	Cradle-to-gate	See [i.19].
	kg	0,7	0,178	Cradle-to-gate	Electricity used, kWh/kg.
Stainless steel, average, mass	kg	2	0,111	Cradle-to-gate	See [i.20].
	kg	4	0,111	Cradle-to-gate	Electricity used, kWh/kg.
Stainless steel, primary	kg	3,075	0,143	Cradle-to-gate	See [i.20].
	kg	6,15	0,143	Cradle-to-gate	Electricity used, kWh/kg.
Stainless steel, secondary	kg	0,5	0,143	Cradle-to-gate	See [i.20].
	kg	1	0,143	Cradle-to-gate	Electricity used, kWh/kg.
Plastics, average, mass	kg	2,5	0,168	Cradle-to-gate	See [i.20].
	kg	5	0,168	Cradle-to-gate	Electricity used, kWh/kg.
Plastics, primary	kg	3,5	0,178	Cradle-to-gate	See [i.20].
	kg	7	0,178	Cradle-to-gate	Electricity used, kWh/kg.
Plastics, secondary	kg	1	0,203	Cradle-to-gate	See [i.21].
	kg	2	0,203	Cradle-to-gate	Electricity used, kWh/kg.
Gold, average, mass	kg	9 400	0,213	Cradle-to-gate	See [i.20].
	kg	18 800	0,213	Cradle-to-gate	Electricity used, kWh/kg.
Gold, primary, mass	kg	25 000	0,091	Cradle-to-gate	See [i.20].
	kg	30 000	0,143	Cradle-to-gate	Electricity used, kWh/kg.
Gold, secondary, mass	kg	200	0,112	Cradle-to-gate	See [i.20].
	kg	400	0,112	Cradle-to-gate	Electricity used, kWh/kg.
	m^2	125	0,168	Cradle-to-gate	See [i.22].

Input	Unit used	Proxy value ($kgCO_2e$/unit) for simplified LCA (mean value, μ)	Uncertainty for CO_2e flow value (lognormal σ)	System boundary	Rationale/Source
PCBs, no components, average, area	m^2	250	0,168	Cradle-to-gate	Electricity used, kWh/m^2.
ICs with dies, average, mass	kg	650	0,135	Cradle-to-gate	See [i.23].
	kg	1300	0,135	Cradle-to-gate	Electricity used, kWh/kg.
ICs without dies, average, mass	kg	80	0,159	Cradle-to-gate	See [i.23] and [i.20].
	kg	160	0,136	Cradle-to-gate	Electricity used, kWh/kg.
Silicon dies, average, mass	kg	15 000	0,203	Cradle-to-gate	See [i.23].
	kg	30 000	0,203	Cradle-to-gate	Electricity used, kWh/kg.
Electronic components except ICs and PCBs, mass	kg	15	0,143	Cradle-to-gate	See [i.20].
	kg	30	0,143	Cradle-to-gate	Electricity used/kg.
Displays, average, area	cm^2	0,015	0,143	Cradle-to-gate	See [i.15].
	cm^2	0,03	0,143	Cradle-to-gate	Electricity used, kWh/cm^2.
Batteries, average, mass	kg	25	0,235	Cradle-to-gate	See [i.15].
	kg	50	0,235	Cradle-to-gate	Electricity used, kWh/kg.
Chargers, average, mass	kg	17,5	0,125	Cradle-to-gate	See [i.20].
	kg	35	0,125	Cradle-to-gate	Electricity used, kWh.
Cameras, average, pieces	piece	1	0,203	Cradle-to-gate	See [i.15].
	piece	2	0,203	Cradle-to-gate	Electricity used, kWh/piece.
Aluminium die casting, average, mass	kg	2,5	0,168	Gate-to-gate	Energy for process and loss of Aluminium included, see [i.20].
	kg	5	0,168	Cradle-to-gate	Electricity used, kWh/kg
Non-Aluminium Mechanical Part Production, average, mass	kg	1	0,203	Gate-to-gate	Energy for process and loss of Steel included, see [i.20].
	kg	2	0,203	Cradle-to-gate	Electricity used, kWh/kg.
Transport of components & parts to final assembly, average, mass	kg	4,75	0,175	Cradle-to-gate	See [1].
	kg	0,5	0,0476	Cradle-to-gate	Electricity used, kWh/kg.
Transport to final customer, Consumer products, average, mass	kg	9,75	0,0932	Cradle-to-gate	Based on typical transport distances and transport modes of different product masses. Air transport focused, see [i.20].
	kg	0,5	0,0476	Cradle-to-gate	Electricity used, kWh/kg
Transport to final customer, Network products, average, mass	kg	1,9	0,117	Cradle-to-gate	Based on typical transport distances and transport modes of different product masses. Ship transport focused, see [i.20].
	kg	0,2	0,091	Cradle-to-gate	Electricity used, kWh/kg.
Product final assembly, average, mass	kg	1	0,203	Gate-to-gate	Mounting of different types of products, see [i.24], [i.25], [i.26].
	kg	2	0,203	Cradle-to-gate	Electricity used, kWh/kg
Outsourced production, average, mass	kg	1	0,203	Gate-to-gate	Mounting of different types of products, see [i.24], [i.25], [i.26].
	kg	2	0,203	Cradle-to-gate	Electricity used, kWh/kg
PCBA assembly, average, area	m^2	5	0,111	Gate-to-gate	Mounting of different types of PCBAs, see [i.27].
	m^2	10	0,111	Cradle-to-gate	Electricity used, kWh/m^2.
Power consumption, average, power	W				The average power consumption of the product.
Electricity	kWh	0,5	0,168	Cradle-to-gate	The intensity of the source(s) used is flexible, see [i.28].
Lifetime	years				The lifetime is flexible.

Input	Unit used	Proxy value ($kgCO_2e$/unit) for simplified LCA (mean value, μ)	Uncertainty for CO_2e flow value (lognormal Ꝺ)	System boundary	Rationale/Source
Disposal, average, mass	kg	0,85	0,081	Gate-to-gate	Reflect processes such as landfill and incineration when the cut-off method is used. Emissions due to waste collection, transport, intermediate and final treatment operations are considered, see [i.29].
	kg	1,7	0,081	Cradle-to-gate	Electricity used, kWh/kg.
NOTE: The average values are taken from the literature.					

While the final results obtained by using the proxy values of Tables G.1 and G.2 will be precise enough for several applications, the proxy values could be updated once other data are available.

G.3 Method explained for a fictive ICT Network infrastructure product

G.3.1 GWP100 CO_2e

Table G.3a shows the CO_2e values used to calculate the final values for the fictive ICT Network infrastructure product.

Table G.3a: Inputs and CO_2e intensities for simplified LCA method PPCA for ICT infrastructure product example

Input	Unit used	Proxy value ($kgCO_2e$/unit) for simplified LCA (mean value, μ)	Uncertainty for CO_2e flow value (lognormal Ʊ)	Activity flow value used by fictive product at hand	Uncertainty for activity flow value (lognormal Ʊ)	Final value kg CO_2e	Stage
Packaging materials, average, mass	kg	2	0,203	3 kg	0,024	6	A
Aluminium, average, mass	kg	17	0,151	10 kg	0,024	170	A
Steel, average, mass	kg	1,5	0,255	1 kg	0,024	1,5	A
Plastics, average, mass	kg	5	2	0,2 kg	0,024	1	A
Gold, average, mass	kg	18 800	0,213	2E-3 kg	0,111	37,6	A
PCBs with no components, area	m^2	250	0,168	0,1 m^2	0,024	25	B
ICs with dies, mass	kg	1 300	0,135	N.A.		0	B
ICs without dies, mass	kg	160	0,136	0,05 kg	0,024	8	B
Silicon dies, average, mass	kg	30 000	0,203	0,002 kg		60	B
Electronic components except ICs and PCBs, average, mass	kg	30	0,203	0,7 kg	0,024	21	B
Displays, average, area	cm^2	0,03	0,203	N.A.		0	B
Batteries, average, mass	kg	50	0,235	N.A.		0	B
Chargers, average, mass	kg	35	0,125	N.A.		0	B
Cameras, average, pieces	piece	2	0,203	N.A.		0	B
Aluminium die casting, average, mass	kg	5	0,168	10 kg	0,024	50	B
Non Aluminium Mechanical Part Production, average, mass	kg	2	0,203	1 kg	0,024	2	B
Transport of components & parts to final assembly, average, mass	kg	5	0,168	17 kg	0,024	85	B
Transport to final customer, Consumer products, average, mass	kg	10	0,005	N.A.			B

Input	Unit used	Proxy value (kgCO_2e/unit) for simplified LCA (mean value, μ)	Uncertainty for CO_2e flow value (lognormal Ʊ)	Activity flow value used by fictive product at hand	Uncertainty for activity flow value (lognormal Ʊ)	Final value kg CO_2e	Stage
Transport to final customer, Network products, average, mass	kg	2	0,111	20 kg	0,024	40	B
Product final assembly, average, mass	kg	2	0,203	20 kg	0,024	40	B
Outsourced production, average, mass	kg	2	0,203	20 kg	0,024	40	B
PCBA assembly, average, area	m^2	10	0,111	0,1 m^2	0,024	1	B
Power consumption, average, power	W			1 000 W	0,131		C
Electricity	kWh	0,5	0,168				C
Lifetime	years			10 years	0,047	1 kW × 8 760 hours × 10 years × 0,5 = 43 800	C
Disposal, average, mass	kg	1,7	0,081	20 kg	0,024	34	D
NOTE 1: The column "stage" refers to LCA stages as defined in Recommendation ITU-T L.1410 [1]. NOTE 2: The average values are taken from the literature.							

Figures G.1a and G.1b show the graphical result of the self-explanatory calculation in Table G.3a.

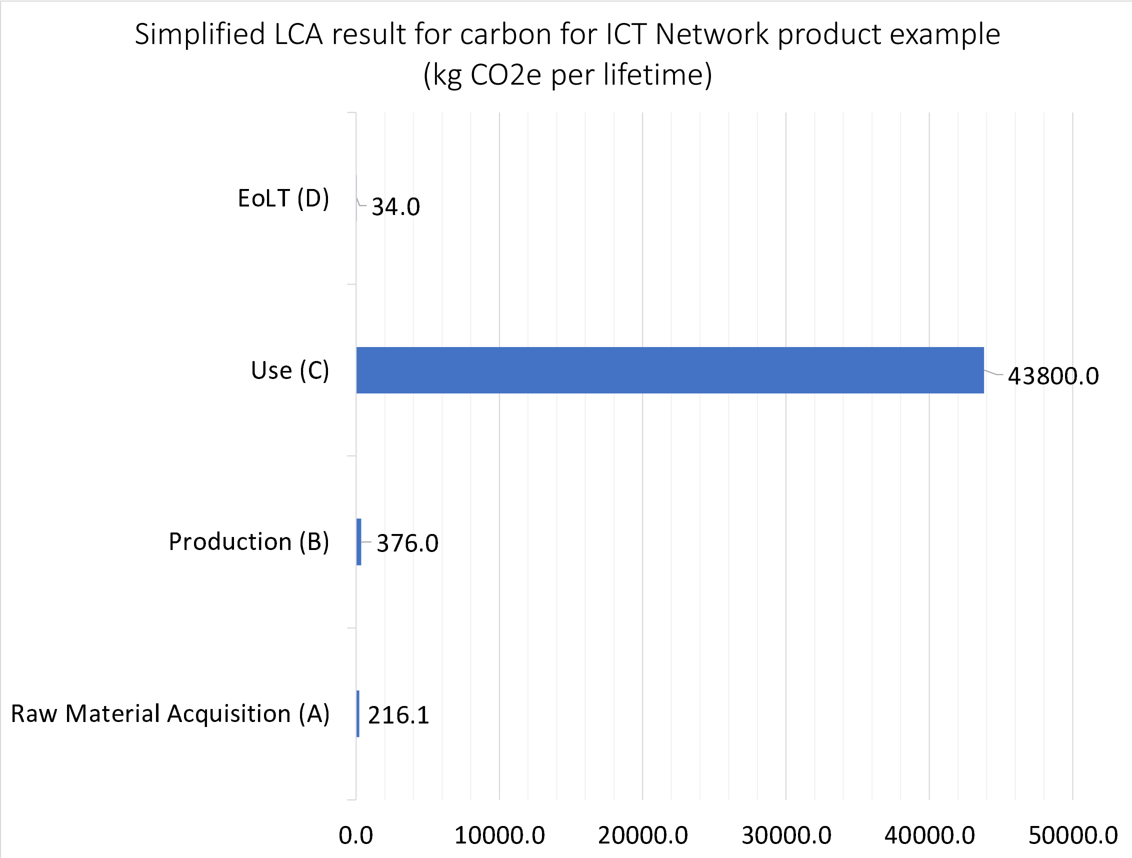


Figure G.1a: Summary result for CO_2e for the ICT Network product example expressed per main life cycle stage

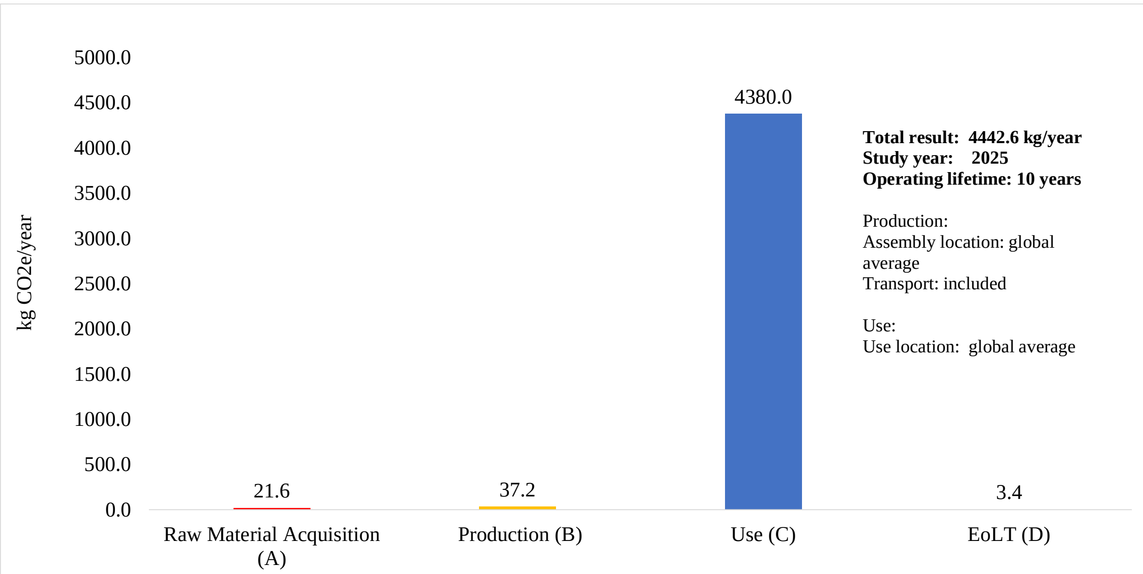


Figure G.1b: Summary result using Figure 14a in ETSI ES 203 199 [2] for CO_2e for the ICT Network product example

G.3.2 Resource depletion

Next in Table G.3b follows the calculation for another impact category, the resource depletion.

Table G.3b: Inputs and antimony equivalents intensities for simplified LCA method PPCA for ICT infrastructure product example

Input	Unit used	Proxy value (kg Antimony equivalents/unit) for simplified LCA (mean value, µ)	Uncertainty for Antimony equivalents flow value (lognormal Ʊ)	Activity flow value used by fictive product at hand	Uncertainty for activity flow value (lognormal Ʊ)	Final value kg Antimony equivalents	Stage
Packaging materials, average, mass	kg	3E-06	0,173	3 kg	0,024	9E-6	A
Aluminium, average, mass	kg	8E-05	0,173	10 kg	0,024	8E-4	A
Steel, average, mass	kg	2E-05	0,275	1 kg	0,024	2E-5	A
Plastics, average, mass	kg	6E-07	0,175	0,2 kg	0,024	1,2E-7	A
Gold, average, mass	kg	12	0,128	2E-3 kg	0,111	2,4E-2	A
PCBs with no components, area	m^2	0,06	0,0841	0,1 m^2	0,047	6E-3	B
ICs with dies, mass	kg	0,08	0,128	N.A.		0	B
ICs without dies, mass	kg	0,02	0,275	0,05 kg	0,024	0,001	B
Silicon dies, average, mass	kg	0,05	0,128	2E-3 kg	0,024	1E-4	B
Electronic components except ICs and PCBs, average, mass	kg	0,04	0,128	0,7 kg	0,024	2,8E-02	B
Displays, average, area	cm^2	8E-06	0,0628	N.A.		0	B
Batteries, average, mass	kg	0,02	0,128	N.A.		0	B
Chargers, average, mass	kg	5E-3	0,101	N.A.		0	B
Cameras, average, mass	piece	0,05	0,101	N.A.		0	B
Aluminium die casting, average, mass	kg	3E-05	0,173	10 kg	0,024	3E-4	B
Non Aluminium Mechanical Part Production, average, mass	kg	9E-06	0,558	1 kg	0,024	9E-6	B
Transport of components & parts to final assembly, average, mass	kg	9,3E-07	0,0558	17 kg	0,024	1,6E-05	B
Transport to final customer, Consumer products, average, mass	kg	1,9E-06	0,275	N.A.		0	B
Transport to final customer, Network products, average, mass	kg	3,7E-07	0,229	20 kg	0,024	7,4E-06	B
Product final assembly, average, mass	kg	3E-07	0,173	20 kg	0,047	6E-6	B
Outsourced production, average, mass	kg	3E-07	0,173	20 kg	0,047	6E-6	B
PCBA assembly, average, area	m^2	8E-4	0,128	0,5 m^2	0,024	4E-4	B

Input	Unit used	Proxy value (kg Antimony equivalents/unit) for simplified LCA (mean value, μ)	Uncertainty for Antimony equivalents flow value (lognormal Ʊ)	Activity flow value used by fictive product at hand	Uncertainty for activity flow value (lognormal Ʊ)	Final value kg Antimony equivalents	Stage
Power consumption, average, power	W			1 000 W	0,131		C
Electricity	kWh	1E-7	0,346				C
Lifetime	years			10 years	0,047	1 kW × 8 760 hours × 10 years × 1E-7 = 8,76E-3	C
Disposal, average, mass	kg	2E-08	0,275	20 kg	0,01	4E-7	D
NOTE 1: The column "stage" refers to LCA stages as defined in Recommendation ITU-T L.1410 [1]. NOTE 2: The antinomy equivalent score for disposal is not reduced by recycling which usually is significant for resource depletion impact categories.							

The final results for minerals resource depletion are shown in Figure G.1c.

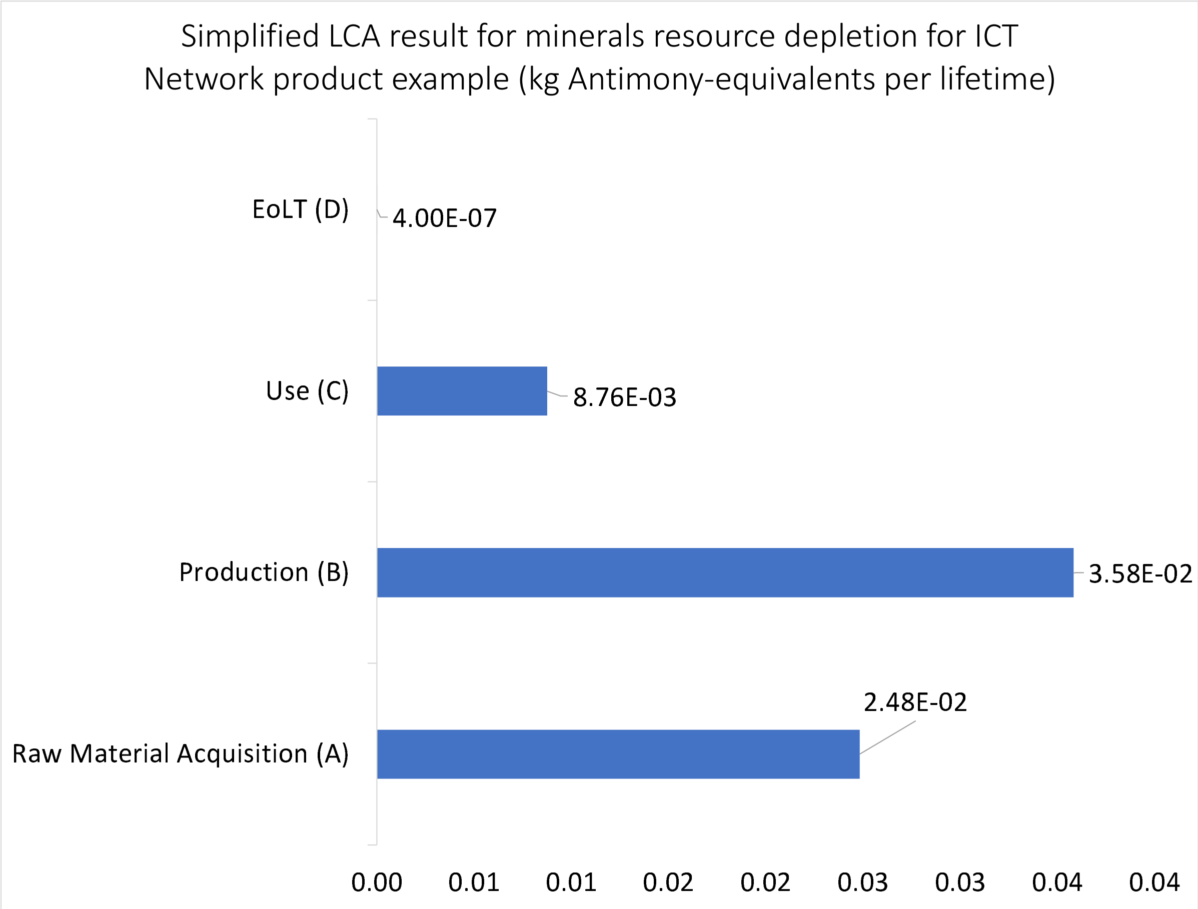


Figure G.1c: Summary result for minerals resource depletion for the ICT Network product example expressed per main life cycle stage

G.3.3 Ecotoxicity

Next in Table G.3c follows the calculation for another impact category, ecotoxicity.

Table G.3c: Inputs and Comparative Toxic Units intensities for simplified LCA method PPCA for ICT infrastructure product example

Input	Unit used	Proxy value (Comparative Toxic Units, CTU/unit) for simplified LCA (mean value, μ)	Uncertainty for CTU flow value (lognormal Ʊ)	Activity flow value used by fictive product at hand	Uncertainty for activity flow value (lognormal Ʊ)	Final value CTUs	Stage
Packaging materials, average, mass	kg	1	0,346	3 kg	0,024	3	A
Aluminium, average, mass	kg	4,9E-2	0,313	10 kg	0,024	0,49	A
Steel, average, mass	kg	0,7	0,173	1 kg	0,024	0,7	A
Plastics, average, mass	kg	5	0,313	0,2 kg	0,024	1	A
Gold, average, mass	kg	1E+5	0,347	2E-3 kg	0,024	200	A
PCBs with no components, area	m^2	15	0,173	0,1 m^2	0,047	1,5	B
ICs with dies, mass	kg	0,7	0,173	N.A.		0	B
ICs without dies, mass	kg	10	0,191	0,05 kg	0,024	0,5	B
Silicon dies, average, mass	kg	14	0,173	2E-3 kg	0,024	0,028	B
Electronic components except ICs and PCBs, average, mass	kg	30	0,245	0,7 kg	0,024	21	B
Displays, average, area	cm^2	0,068	0,173	N.A.		0	B
Batteries, average, mass	kg	74	0,173	N.A.		0	B
Chargers, average, mass	kg	65	0,173	N.A.		0	B
Cameras, average, mass	kg	9	0,275	N.A.		0	B
Aluminium die casting, average, mass	kg	4	0,173	10 kg	0,024	40	B
Non Aluminium Mechanical Part Production, average, mass	kg	4	0,173	1 kg	0,024	4	B
Transport of components & parts to final assembly, average, mass	kg	1,2	0,173	17 kg	0,024	20	B
Transport to final customer, Consumer products, average, mass	kg	2,4	0,275	N.A.		0	B
Transport to final customer, Network products, average, mass	kg	0,47	0,474	20 kg	1 kg	9,5	B
Product final assembly, average, mass	kg	0,8	0,346	20 kg	1 kg	16	B

Input	Unit used	Proxy value (Comparative Toxic Units, CTU/unit) for simplified LCA (mean value, μ)	Uncertainty for CTU flow value (lognormal Ʊ)	Activity flow value used by fictive product at hand	Uncertainty for activity flow value (lognormal Ʊ)	Final value CTUs	Stage
Outsourced production, average, mass	kg	0,8	0,346	20 kg	0,024	16	B
PCBA assembly, average, area	m^2	24	0,211	0,1 m^2	0,047	2,4	B
Power consumption, average, power	W			1 000 W	0,131		C
Electricity	kWh	0,02	0,275				C
Lifetime	years			10 years	0,047	1 kW × 8 760 hours × 10 years × 0,02 = 1 752	C
Disposal, average, mass	kg	0,25	0,346	20 kg	0,047	5	D
NOTE: The column "stage" refers to LCA stages as defined in Recommendation ITU-T L.1410 [1].							

The final results for ecotoxicity are shown in Figure G.1d.

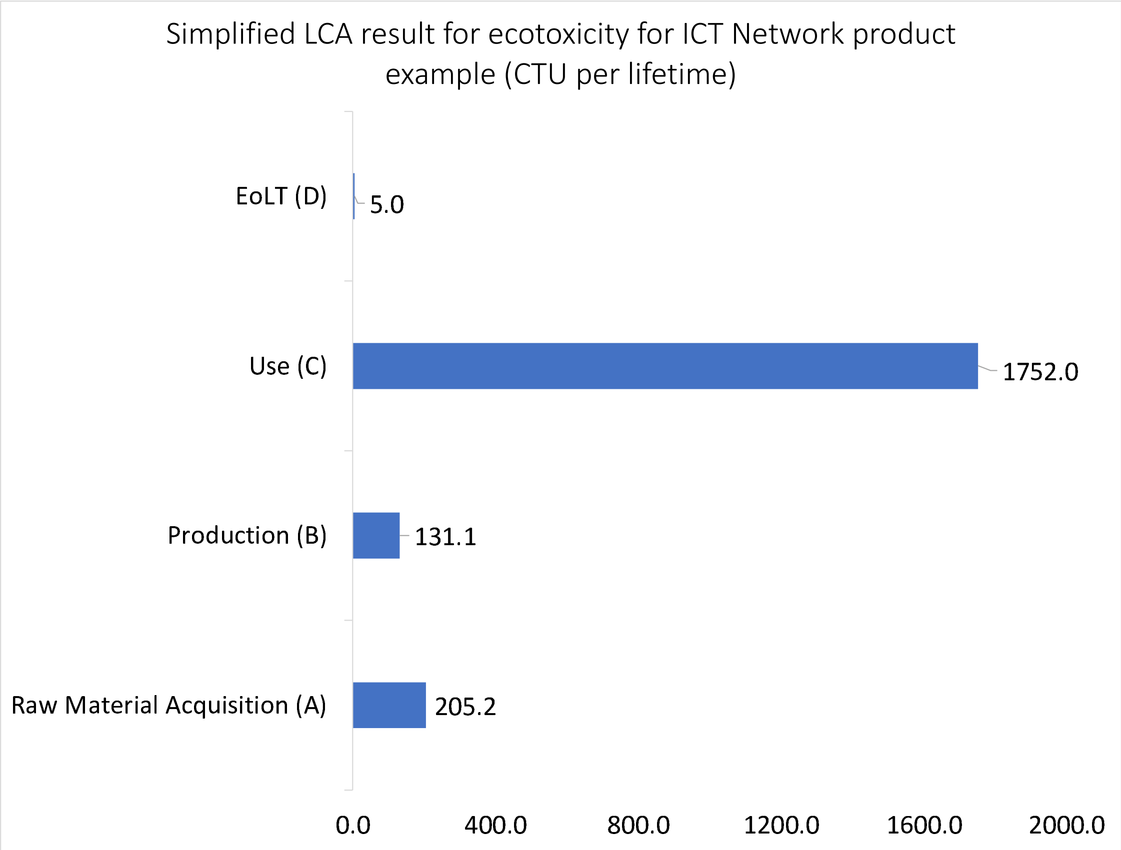


Figure G.1d: Summary result for ecotoxicity for the ICT Network product example expressed per main life cycle stage

G.3.4 Water scarcity

Next in Table G.3d follows the calculation for another impact category, water scarcity.

Table G.3d: Inputs and water (m^3) intensities for simplified LCA method PPCA for ICT infrastructure product example

Input	Unit used	Proxy value (m^3/unit) for simplified LCA (mean value, μ)	Uncertainty for m^3 proxy flow value (lognormal Ʊ)	Activity flow value used by fictive product at hand	Uncertainty for activity flow value (lognormal Ʊ)	Final value m^3	Stage
Packaging materials, average, mass	kg	3	0,402	3 kg	0,024	9	A
Aluminium, average, mass	kg	10	0,275	10 kg	0,024	100	A
Steel, average, mass	kg	19	0,183	1 kg	0,024	19	A
Plastics, average, mass	kg	2,5	0,173	0,2 kg	0,024	0,5	A
Gold, average, mass	kg	4E+4	0,275	2E-3 kg	0,024	80	A
PCBs with no components, area	m^2	300	0,173	0,1 m^2	0,047	30	B
ICs with dies, mass	kg	600	0,140	N.A.		0	B
ICs without dies, mass	kg	200	0,173	0,05 kg	0,024	25	B
Silicon dies, average, mass	kg	1E+4	0,275	2E-3 kg	0,024	20	B
Electronic components except ICs and PCBs, average, mass	kg	250	0,313	0,7 kg	0,024	175	B
Displays, average, area	cm^2	0,01	0,347	N.A.		0	B
Batteries, average, mass	kg	10	0,347	N.A.		0	B
Chargers, average, mass	kg	12	0,347	N.A.		0	B
Cameras, average, mass	kg	450	0,174	N.A.		0	B
Aluminium die casting, average, mass	kg	17,5	0,275	10 kg	0,024	175	B
Non Aluminium Mechanical Part Production, average, mass	kg	26	0,245	1 kg	0,024	26	B
Transport of components & parts to final assembly, average, mass	kg	2	0,275	17 kg	0,024	43	B
Transport to final customer, Consumer products, average, mass	kg	2	0,275	N.A.		0	B
Transport to final customer, Network products, average, mass	kg	1	0,275	20 kg	0,024	209	B
Product final assembly, average, mass	kg	1,5	0,173	20 kg	0,024	300	B
Outsourced production, average, mass	kg	1,5	0,173	20 kg	0,024	300	B
PCBA assembly, average, area	m^2	1	0,347	0,5 m^2	0,024	100	B

Input	Unit used	Proxy value (m^3/unit) for simplified LCA (mean value, µ)	Uncertainty for m^3 proxy flow value (lognormal Ʊ)	Activity flow value used by fictive product at hand	Uncertainty for activity flow value (lognormal Ʊ)	Final value m^3	Stage
Power consumption, average, power	W			1 000 W	0,131		C
Electricity	kWh	0,1	0,693				C
Lifetime	years			10 years	0,024	1 kW × 8 760 hours × 10 years × 0,1 = 8,76E+3	C
Disposal, average, mass	kg	0,3	0,402	20 kg	0,024	6	D
NOTE : The column "stage" refers to LCA stages as defined in Recommendation ITU-T L.1410 [1].							

The final results for water scarcity are shown in Figure G.1e.

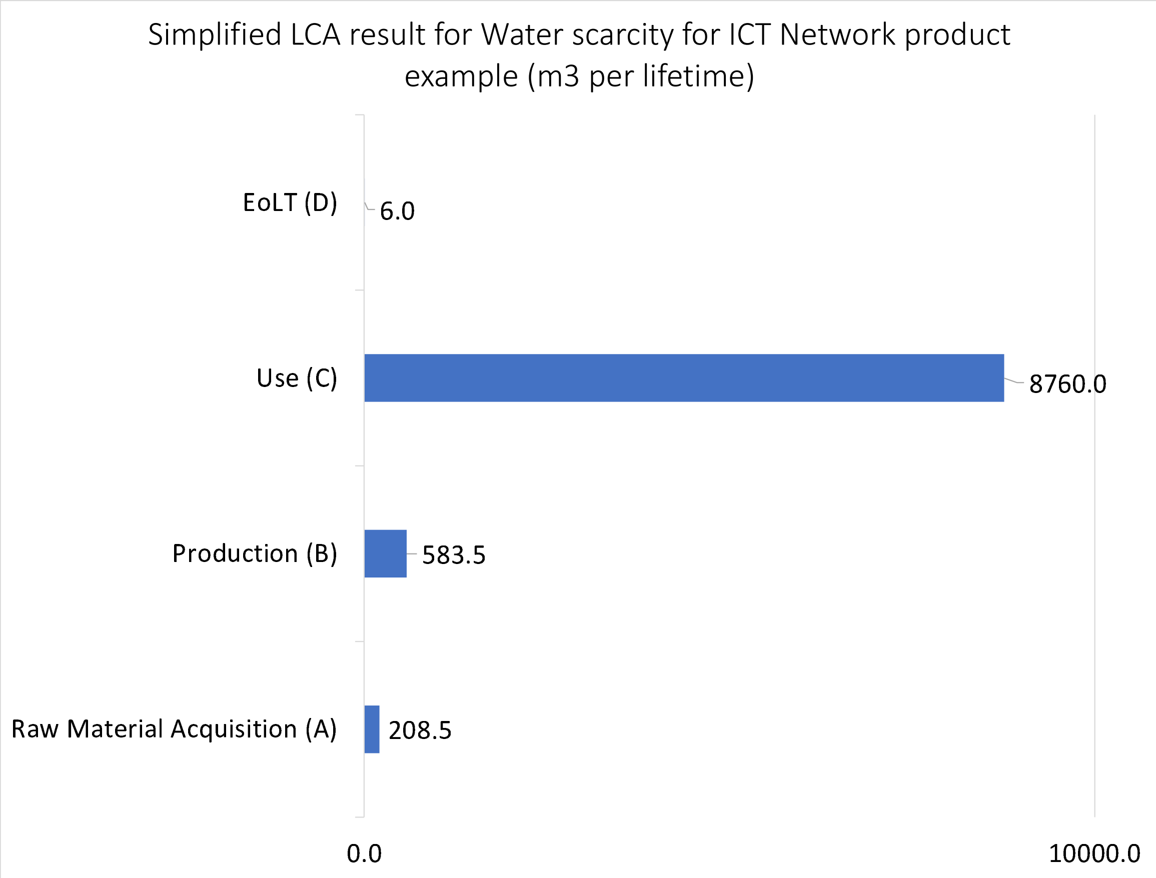


Figure G.1e: Summary result for water scarcity for the ICT Network product example expressed per main life cycle stage

In certain LCA tools the coefficients of variation (Ơ for total score/mean of total score, e.g. 44,4 tonnes total score for GWP100 for ICT infrastructure product) - based on Tables G.2, G.3a-d and one simulation of 5 000 Monte Carlo runs - are for ICT infrastructure products ≈ 25 % (GWP100), ≈ 8 % (antimony-equivalents), ≈ 27 % (CTU) and ≈ 75 % (water). These particular calculations - and uncertainty contribution and sensitivity analyses - are explored further in clause G.5.3.

G.4 Method explained for a fictive ICT consumer product

G.4.1 GWP100 CO_2e

Table G.4a shows the CO_2e values used to calculate the final values for the fictive ICT consumer product.

Table G.4a: Inputs and CO_2e intensities for simplified LCA method PPCA for ICT consumer product example

Input	Unit used	Proxy value (kgCO_2e/unit) for simplified LCA (mean value, μ)	Uncertainty for CO_2e flow value (lognormal Ʊ)	Activity flow value used by product at hand	Uncertainty for activity flow value (lognormal Ʊ)	Final value, kg CO_2e	Stage
Packaging materials, average, mass	kg	2	0,203	0,15 kg	0,024	0,3	A
Aluminium, average, mass	kg	17	0,151	0,02 kg	0,024	0,2	A
Steel, average, mass	kg	1,5	0,255	2E-4 kg	0,024	3E-4	A
Plastics, average, mass	kg	5	2	0,02 kg	0,024	0,1	A
Gold, average, mass	kg	18 800	0,213	2×10^{-5} kg	0,024	0,376	A
PCBs with no components, average, area	m^2	250	0,168	4E-3 m^2	0,024	1	B
ICs with dies, average, mass	kg	1 300	0,135	N.A.		0	B
ICs without dies, average, mass	kg	160	0,136	0,02 kg	0,024	3,2	B
Silicon dies, average, mass	kg	30 000	0,203	1E-3 kg	0,024	30	B
Electronic components except ICs and PCBs, average, mass	kg	30	0,203	0,01 kg	0,024	0,3	B
Displays, average, area	cm^2	0,03	0,203	100 cm^2	0,024	3	B
Batteries, average, mass	kg	50	0,235	0,05 kg	0,024	2,5	B
Chargers, average, mass	kg	35	0,125	0,05 kg	0,024	1,75	B
Cameras, average, mass	kg	1 500	0,203	2E-3 kg	0,047	3	B
Aluminium die casting, average, mass	kg	5	0,168	0,02 kg	0,024	0,1	B
Non Aluminium Mechanical Part Production, average, mass	kg	2	0,203	0,02 kg	0,024	0,04	B
Transport of components & parts to final assembly, average, mass	kg	5	0,168	0,3 kg	0,024	1,5	B
Transport to final customer, Consumer products, average, mass	kg	10	0,005	0,45 kg	0,024	4,5	B
Transport to final customer, Network products, average, mass	kg	2	0,111	N.A.	N.A.	0	B
Product final assembly, average, mass	kg	2	0,203	0,45 kg	0,024	0,9	B
Outsourced production, average, mass	kg	2	0,203	0,45 kg	0,024	0,9	B

Input	Unit used	Proxy value ($kgCO_2e$/unit) for simplified LCA (mean value, μ)	Uncertainty for CO_2e flow value (lognormal Ʊ)	Activity flow value used by product at hand	Uncertainty for activity flow value (lognormal Ʊ)	Final value, kg CO_2e	Stage
PCBA assembly, average, area	m^2	10	0,111	4E-3 m^2	0,024	0,04	B
Power consumption, average, power	W			0,4 W	0,131		C
Electricity	kWh	0,5	0,168				C
Lifetime	years			5 years	0,047	0,0004 kW × 8 760 hours × 5 years × 0,5 = 8,76	C
Disposal, average, mass	kg	1,7	0,081	0,45 kg	0,024	0,765	D
NOTE 1: The column "stage" refers to LCA stages as defined in Recommendation ITU-T L.1410 [1]. NOTE 2: The average values are taken from the literature.							

Figure G.2a shows the graphical result of the self-explanatory calculation in Table G.4a.

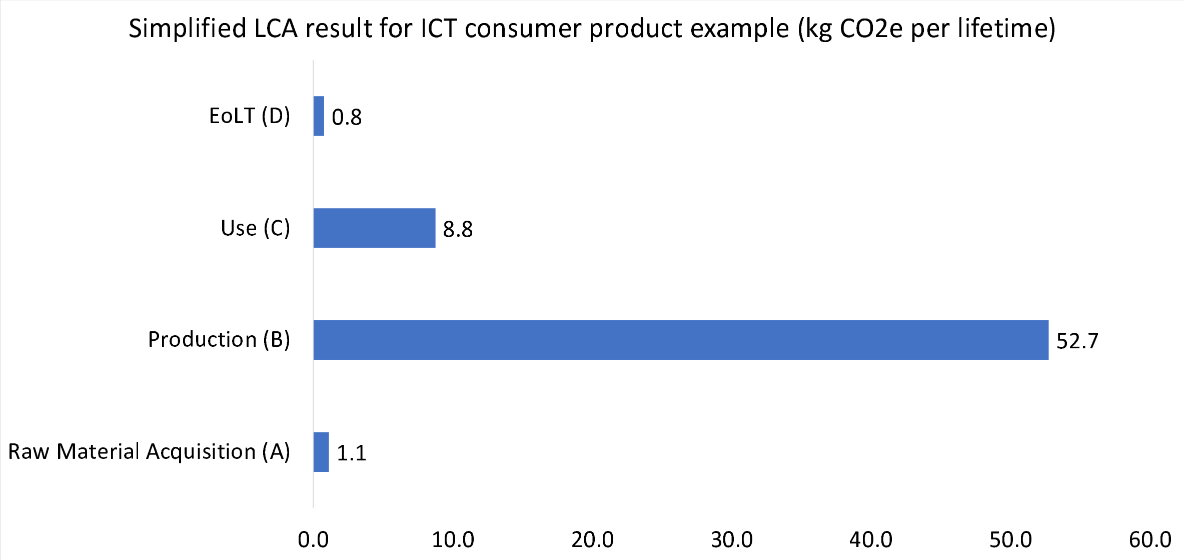


Figure G.2a: Summary result for CO_2e for the ICT consumer product example expressed per main life cycle stage

G.4.2 Resource depletion

Next in Table G.4b follows the calculation for another impact category, the resource depletion.

Table G.4b: Inputs and antimony equivalents intensities for simplified LCA method PPCA for ICT consumer product example

Input	Unit used	Proxy value (kg Antimony equivalents/unit) for simplified LCA (mean value, μ)	Uncertainty for Antimony equivalents flow value (lognormal Ơ)	Activity flow value used by fictive product at hand	Uncertainty for activity flow value (lognormal Ơ)	Final value kg Antimony equivalents	Stage
Packaging materials, average, mass	kg	3E-06	0,173	0,15 kg	0,024	4,5E-7	A
Aluminium, average, mass	kg	8E-05	0,173	0,02 kg	0,024	1,6E-6	A
Steel, average, mass	kg	2E-05	0,275	2E-4 kg	0,024	4E-9	A
Plastics, average, mass	kg	6E-07	0,175	0,02 kg	0,024	1,2E-8	A
Gold, average, mass	kg	12	0,128	2,00E-05 kg	0,024	2,4E-4	A
PCBs with no components, area	m^2	0,06	0,0841	4E-3 m^2	0,047	2,4E-4	B
ICs with dies, mass	kg	0,08	0,128	0		0,00	B
ICs without dies, mass	kg	0,02	0,275	0,02 kg	0,024	4E-04	B
Silicon dies, average, mass	kg	0,05	0,128	1E-3 kg	0,047	5E-5	B
Electronic components except ICs and PCBs, average, mass	kg	0,04	0,128	0,01 kg	0,047	4E-4	B
Displays, average, area	cm^2	8E-6	0,0628	100 cm^2	0,01	8E-4	B
Batteries, average, mass	kg	0,02	0,128	0,05 kg	0,047	1E-3	B
Chargers, average, mass	kg	5E-3	0,101	0,05 kg	0,047	2,5E-4	B
Cameras, average, mass	kg	0,05	0,101	2E-3		1E-4	B
Aluminium die casting, average, mass	kg	3E-05	0,173	0,02 kg	0,047	6E-7	B
Non Aluminium Mechanical Part Production, average, mass	kg	9E-06	0,0558	0,02 kg	0,047	1,8E-7	B
Transport of components & parts to final assembly, average, mass	kg	9,3E-07	0,0558	0,3 kg	0,091	2,8E-7	B
Transport to final customer, Consumer products, average, mass	kg	1,8E-06	0,275	0,45 kg	0,024	8,4E-7	B
Transport to final customer, Network products, average, mass	kg	3,7E-07	0,229	N,A			B
Product final assembly, average, mass	kg	3E-07	0,173	0,45 kg	0,091	1,4E-7	B
Outsourced production, average, mass	kg	3E-07	0,173	0,45 kg	0,091	1,4E-7	B
PCBA assembly, average, area	m^2	8E-4	0,128	4E-3 m^2	0,01	3,2E-6	B

Input	Unit used	Proxy value (kg Antimony equivalents/unit) for simplified LCA (mean value, μ)	Uncertainty for Antimony equivalents flow value (lognormal Ʊ)	Activity flow value used by fictive product at hand	Uncertainty for activity flow value (lognormal Ʊ)	Final value kg Antimony equivalents	Stage
Power consumption, average, power	W			0,4 W	0,091		C
Electricity	kWh	1E-7	0,346				C
Lifetime	years			5 years	0,047	0,0004 kW × 8 760 hours × 5 years × 1E-7 = 1,75E-6	C
Disposal, average, mass	kg	2E-08	0,275	0,45 kg	0,091	9E-9	D
NOTE 1: The column "stage" refers to LCA stages as defined in Recommendation ITU-T L.1410 [1]. NOTE 2: The antinomy equivalent score for disposal is not reduced by recycling which usually is significant for resource depletion impact categories.							

The final results for minerals resource depletion are shown in Figure G.2b.

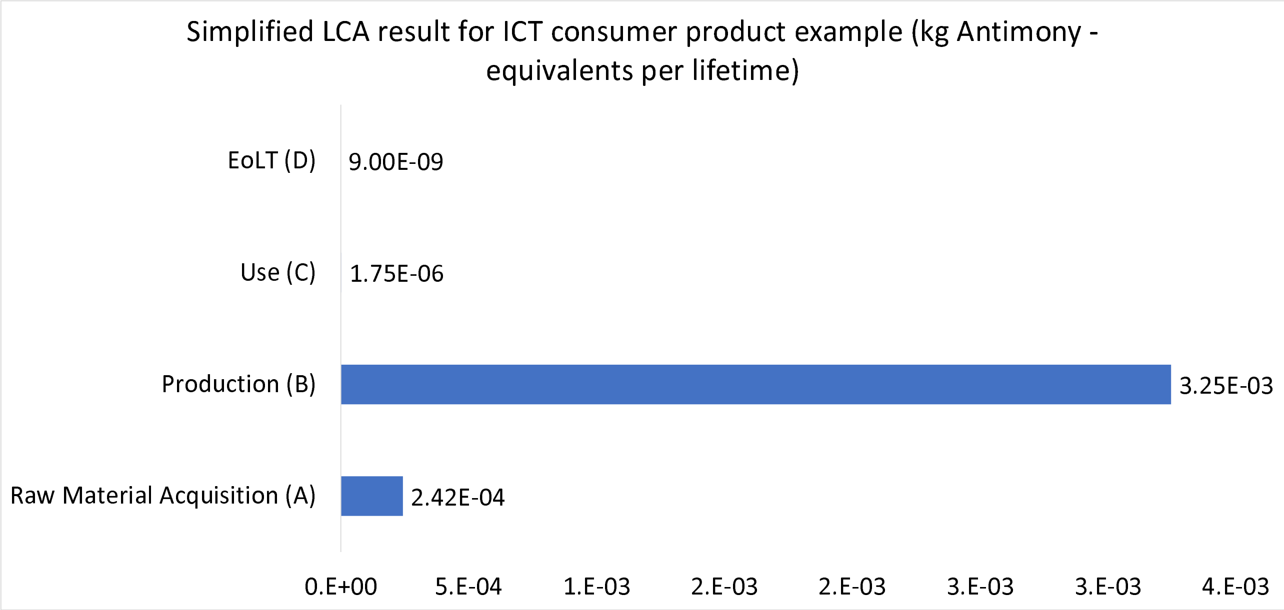


Figure G.2b: Summary result for minerals resource depletion for the ICT consumer product example expressed per main life cycle stage

G.4.3 Ecotoxicity

Next in Table G.4c follows the calculation for another impact category, ecotoxicity.

Table G.4c: Inputs and Comparative Toxic Units intensities for simplified LCA method PPCA for ICT consumer product example

Input	Unit used	Proxy value (Comparative Toxic Units, CTU/unit) for simplified LCA (mean value, μ)	Uncertainty for CTU flow value (lognormal Ʊ)	Activity flow value used by fictive product at hand	Uncertainty for activity flow value (lognormal Ʊ)	Final value CTUs	Stage
Packaging materials, average, mass	kg	1	0,346	0,15 kg	0,024	0,15	A
Aluminium, average, mass	kg	4,9E-2	0,313	0,02 kg	0,024	9,8E-4	A
Steel, average, mass	kg	0,7	0,173	2E-4 kg	0,024	1,4E-4	A
Plastics, average, mass	kg	5	0,313	0,02 kg	0,024	0,1	A
Gold, average, mass	kg	1E+5	0,347	2,00E-05 kg	0,024	2	A
PCBs with no components, area	m^2	15	0,173	4E-3 m^2	0,047	0,062	B
ICs with dies, mass	kg	0,7	0,173	0		0	B
ICs without dies, mass	kg	10	0,191	0,02 kg	0,024	0,2	B
Silicon dies, average, mass	kg	14	0,173	1E-3 kg	0,047	0,014	B
Electronic components except ICs and PCBs, average, mass	kg	30	0,245	0,01 kg	0,047	0,3	B
Displays, average, area	cm^2	0,068	0,173	100 cm^2	0,01	6,8	B
Batteries, average, mass	kg	74	0,173	0,05 kg	0,047	3,75	B
Chargers, average, mass	kg	65	0,173	0,05 kg	0,047	3,25	B
Cameras, average, mass	kg	9	0,275	2E-3		0,018	B
Aluminium die casting, average, mass	kg	4	0,173	0,02 kg	0,047	0,08	B
Non Aluminium Mechanical Part Production, average, mass	kg	4	0,173	0,02 kg	0,047	0,08	B
Transport of components & parts to final assembly, average, mass	kg	1,2	0,173	0,3 kg	0,091	0,35	B
Transport to final customer, Consumer products, average, mass	kg	2,4	0,275	0,45 kg	0,024	1,1	B
Transport to final customer, Network products, average, mass	kg	0,47	0,474	N.A.		0	B
Product final assembly, average, mass	kg	0,8	0,346	0,45 kg	0,091	0,36	B
Outsourced production, average, mass	kg	0,8	0,346	0,45 kg	0,091	0,36	B
PCBA assembly, average, area	m^2	24	0,211	4E-3 m^2	0,01	0,096	B

Input	Unit used	Proxy value (Comparative Toxic Units, CTU/unit) for simplified LCA (mean value, μ)	Uncertainty for CTU flow value (lognormal Ʊ)	Activity flow value used by fictive product at hand	Uncertainty for activity flow value (lognormal Ʊ)	Final value CTUs	Stage
Power consumption, average, power	W			0,4 W	0,091		C
Electricity	kWh	0,02	0,275				C
Lifetime	years			5 years	0,047	0,0004 kW × 8 760 hours × 5 years × 0,02 = 0,35	C
Disposal, average, mass	kg	0,25	0,346	0,45 kg	0,091	0,11	D
NOTE: The column "stage" refers to LCA stages as defined in Recommendation ITU-T L.1410 [1].							

The final results for ecotoxicity are shown in Figure G.2c.

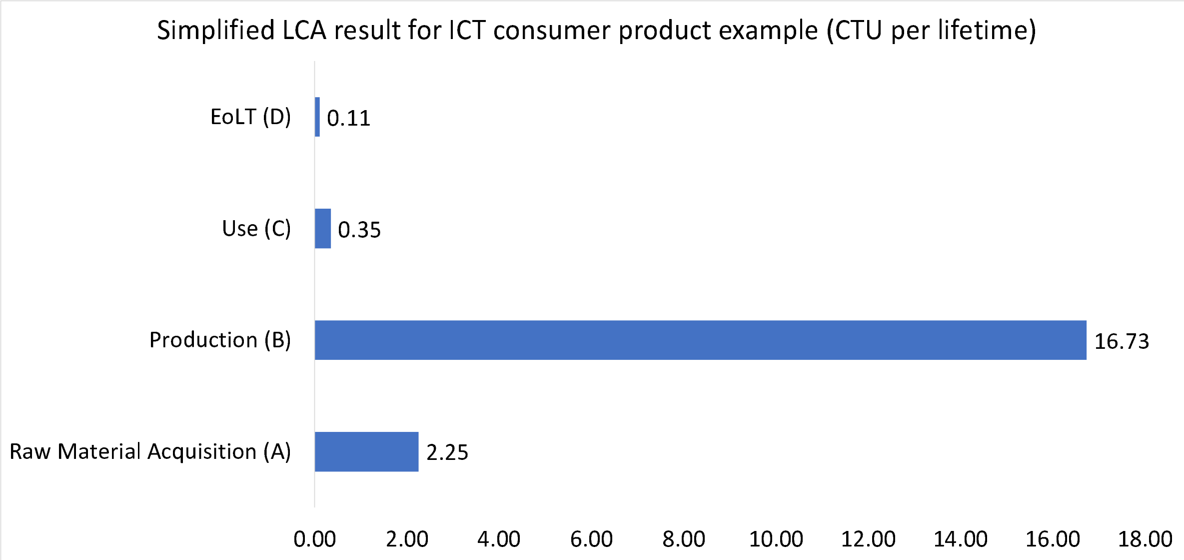


Figure G.2c: Summary result for ecotoxicity for the ICT consumer product example expressed per main life cycle stage

G.4.4 Water scarcity

Next in Table G.4d follows the calculation for another impact category, water scarcity.

Table G.4d: Inputs and m^3 water scarcity intensities for simplified LCA method PPCA for ICT consumer product example

Input	Unit used	Proxy value (m^3/unit) for simplified LCA (mean value, μ)	Uncertainty for m^3 proxy flow value (lognormal Ʊ)	Activity flow value used by fictive product at hand	Uncertainty for activity flow value (lognormal Ʊ)	Final value CTUs	Stage
Packaging materials, average, mass	kg	3	0,402	0,15 kg	0,024	0,45	A
Aluminium, average, mass	kg	10	0,275	0,02 kg	0,024	0,2	A
Steel, average, mass	kg	19	0,183	2E-4 kg	0,024	0,004	A
Plastics, average, mass	kg	2,5	0,173	0,02 kg	0,024	0,05	A
Gold, average, mass	kg	4E+4	0,275	2,00E-05 kg	0,024	8	A
PCBs with no components, area	m^2	300	0,173	4E-3 m^2	0,047	1,2	B
ICs with dies, mass	kg	600	0,140	0		0	B
ICs without dies, mass	kg	200	0,173	0,02 kg	0,024	4	B
Silicon dies, average, mass	kg	1E+4	0,275	1E-3 kg	0,047	10	B
Electronic components except ICs and PCBs, average, mass	kg	250	0,313	0,01 kg	0,047	2,5	B
Displays, average, area	cm^2	0,01	0,347	100 cm^2	0,01	1	B
Batteries, average, mass	kg	10	0,347	0,05 kg	0,047	0,5	B
Chargers, average, mass	kg	12	0,347	0,05 kg	0,047	70,6	B
Cameras, average, mass	kg	450	0,174	0,003 kg		1,35	B
Aluminium die casting, average, mass	kg	17,5	0,275	0,02 kg	0,047	0,35	B
Non Aluminium Mechanical Part Production, average, mass	kg	26	0,245	0,02 kg	0,047	0,52	B
Transport of components & parts to final assembly, average, mass	kg	2	0,275	0,3 kg	0,091	0,6	B
Transport to final customer, Consumer products, average, mass	kg	2	0,275	0,45 kg	0,024	0,9	B
Transport to final customer, Network products, average, mass	kg	1	0,275	N.A.		0	B
Product final assembly, average, mass	kg	1,5	0,173	0,45 kg	0,091	0,68	B
Outsourced production, average, mass	kg	1,5	0,173	0,45 kg	0,091	0,68	B
PCBA assembly, average, area	m^2	1	0,347	4E-3 m^2	0,01	0,4	B

Input	Unit used	Proxy value (m^3/unit) for simplified LCA (mean value, μ)	Uncertainty for m^3 proxy flow value (lognormal σ)	Activity flow value used by fictive product at hand	Uncertainty for activity flow value (lognormal σ)	Final value CTUs	Stage
Power consumption, average, power	W			0,4 W	0,091		C
Electricity	kWh	0,1	0,693				C
Lifetime	years			5 years	0,047	0,0004 kW × 8 760 hours × 5 years × 0,1 = 1,7	C
Disposal, average, mass	kg	0,3	0,402	0,45 kg	0,091	0,14	D
NOTE: The column "stage" refers to LCA stages as defined in Recommendation ITU-T L.1410 [1].							

The final results for water scarcity are shown in Figure G.2d.

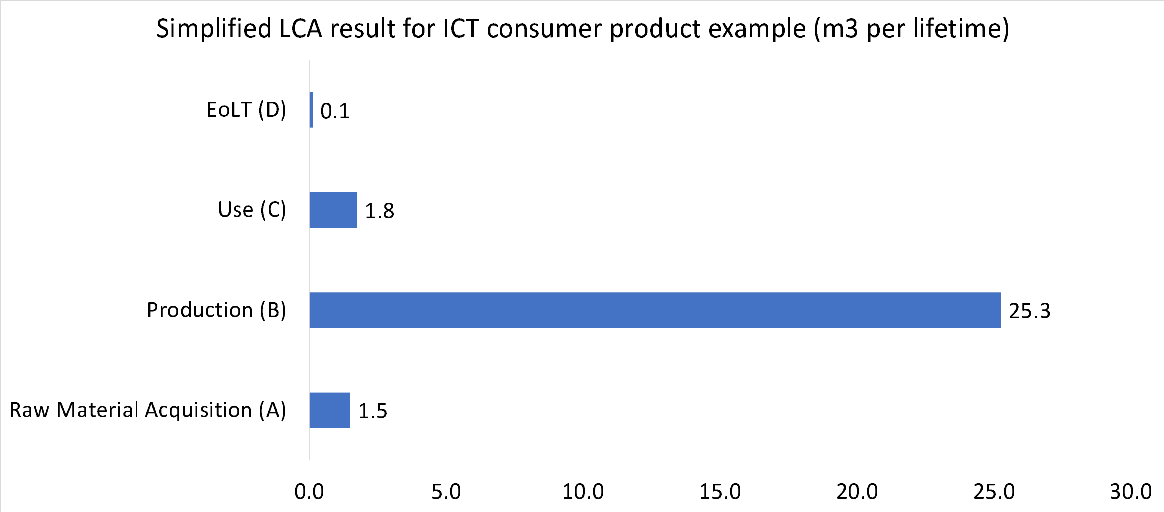


Figure G.2d: Summary result for water scarcity for the ICT consumer product example expressed per main life cycle stage

G.5 Sensitivity and uncertainty analysis

G.5.0 Background considerations

Sensitivity and uncertainty analysis have not been standardized for product LCA of ICT products. Anyway ETSI TS 104 134 [i.13] introduced approaches for sensitivity and uncertainty analysis of simplified avoided emission assessments. To some degree such approaches could be tested on simplified LCA of ICT products.

G.5.1 Sensitivity analysis

Generally, the flows (activity flows or CO_2e, antimony-equivalents, CTU, or water scarcity intensity flows) contributing the most to the total CO_2e, antimony-equivalents, CTU, or water scarcity score are also the most sensitive.

Clause G.5.3 shows how graphs can be generated which shows for each impact category included in clause G.3 which process has the strongest impact on the results, i.e. which processes are the most sensitive.

For GWP100 the conclusion is - for the ICT infrastructure product example in clause G.3.1 - that the GWP100 intensity of the electricity in the use stage and the amount of electricity used in the use stage are the most sensitive flows which have the strongest relation with the output.

G.5.2 Uncertainty analysis

Usually for the most sensitive flows the uncertainty should be minimized the most to increase the confidence the most. The individual values for uncertainty used in Tables G.2, G.3a-d and G.4a-d can e.g. be added to different LCA tools to calculate the total uncertainty for the total CO_2e, antimony-equivalents, CTU, or water scarcity score, respectively.

For GWP100 the conclusion - for the ICT infrastructure product example in clause G.3.1 - is that the GWP100 intensity of the electricity in the use stage and the amount of electricity used in the use stage are the parameters which contribute the most to the total uncertainty of the output.

G.5.3 Example of code for implementation of clause G.3

G.5.3.0 Example code

Apart from traditional LCA tools, the PPCA calculation can be done analytically in free software programs for numerical calculations. One such program is GNU Octave [https://octave.org] which was also used in ETSI TS 104 134 [i.13].

A code which can be used (i.e. copy and pasted in the Command Window) in the program GNU Octave to calculate the total results per impact category, the life cycle stage results per impacts category, the sensitivity factors, the contribution to uncertainty and generate graphs for better understanding is:

```
% ICTNI_mc_full_explicit_factors.m
% -------------------------------------------------------------
% ICT network infrastructure (ICTNI) product using the PPCA Simplified LCA method with explicit per-
input (A) and per-entry (B) lognormal uncertainties. A represents the activity data in Tables G3.a
to d e.g. amount PCB area used. B represents the environmental data e.g. GWP100 intensity per area
PCB.
% Prints deterministic BASELINE first (p0 and beta0), then MC p0.5/mean/p99.5/CV.
% No statistics package needed.
% -------------------------------------------------------------

format long g;
rand("seed", 42); % reproducible draws

% ---------- Process names (rows 1..19) Here abbreviations are used such as Pack mtr instead of
Packaging materials, average, mass, ALU instead of Aluminium, average, mass etc----------
proc = { ...
'Pack mtr','ALU','Steel','Plastics','Gold','PCBs','ICs','Dies','Elcomp', ...
'Aldiecast','NonAlu','TrpC','TrpF','PfiA','Outs','PCBA','ElGlo','Disp','ICTNI'};

cats = {'GWP100','Sb-eq','CTU','Water'};

% ---------- Technology matrix A (19x19). Activity flows arranged in a square matrix. See example
definition in section 4.2 and example of A in Table 2 in ETSI TS 104 134 (V1.1.1) ----------
A = eye(19);
A(1,19) = -3; A(2,19) = -10; A(3,19) = -1; A(4,19) = -0.2;
A(5,19) = -0.002; A(6,19) = -0.1; A(7,19) = -0.05; A(8,19) = -0.002;
A(9,19) = -0.7; A(10,19) = -10; A(11,19) = -1; A(12,19) = -17;
A(13,19) = -20; A(14,19) = -20; A(15,19) = -20; A(16,19) = -0.1;
A(17,19) = -87600; A(18,19) = -20; % A(19,19)=1

% ---------- Functional unit. For the ICTNI in Section A.3 the f.u. is "Total ICT good use per
lifetime of ICT good." ---------
alfa = zeros(19,1); alfa(19) = 1; % 1 unit of ICTNI

% ---------- Environmental matrix B (19x4): [GWP100, Sb-eq, CTU, Water]. See example in Table 3 in
ETSI TS 104 134 (V1.1.1) ----------
B = [
2, 3.00e-06, 1, 3; % Pack mtr
17, 8.00e-05, 4.90e-02, 10; % ALU
1.5, 2.00e-05, 0.7, 19; % Steel
5, 6.00e-07, 5, 2.5; % Plastics
18800, 12, 1.00e5, 40000; % Gold
250, 6.00e-02, 15, 300; % PCBs
160, 2.00e-02, 10, 200; % ICs
30000, 5.00e-02, 14, 10000; % Dies
30, 4.00e-02, 30, 250; % Elcomp
5, 3.00e-05, 4, 17.5; % Aldiecast
2, 9.00e-06, 4, 26; % NonAlu
5, 9.30e-07, 1.2, 2; % TrpC
2, 3.70e-07, 0.47, 1; % TrpF
2, 3.00e-07, 0.8, 1.5; % PfiA
2, 3.00e-07, 0.8, 1.5; % Outs
10, 8.00e-04, 24, 1; % PCBA
0.5, 1.00e-07, 0.02, 0.1; % ElGlo
1.7, 2.00e-08, 0.25, 0.3; % Disp
0, 0, 0, 0 % ICTNI
];

% ==================== UNCERTAINTY: explicit 2σ factors. Here the uncertainty of the amounts in
Tables G.3a to d are handled. ==================
% A inputs (18 rows feeding ICTNI). Edit any entry to customise per-input uncertainty.
f2_Avec = [
```

```
1.049; % Pack mtr
1.049; % ALU
1.049; % Steel
1.049; % Plastics
1.049; % Gold
1.049; % PCBs
1.049; % ICs
1.049; % Dies
1.049; % Elcomp
1.049; % Aldiecast
1.049; % NonAlu
1.049; % TrpC
1.049; % TrpF
1.049; % PfiA
1.049; % Outs
1.049; % PCBA
1.32; % ElGlo. From power use and lifetime, ((ln 1.3)/2)^2)+((ln 1.098)/2)^2) = 0.0194. combined
exp(2*sqrt(0.0194))=1.32
1.049 % Disp
];

% B intensities: 18×4 table (process rows 1..18 × categories [GWP,Sb,CTU,Water]). These values show
the uncertainty factor as exp (2*sigma) for the impact intensity.
% Override any cell to make it process-specific if desired.
f2_Bmat = [
1.73, 1.41, 2.00, 2.23; % Pack mtr
1.35, 1.41, 1.87, 1.73; % ALU
1.52, 1.73, 1.41, 1.44; % Steel
1.52, 1.41, 1.87, 1.41; % Plastics
1.81, 1.29, 2.00, 1.73; % Gold
1.53, 1.18, 1.41, 1.41; % PCBs
1.38, 1.73, 1.47, 1.41; % ICs
1.73, 1.29, 1.41, 1.73; % Dies
1.41, 1.29, 1.63, 1.87; % Elcomp
1.53, 1.41, 1.41, 1.73; % Aldiecast
1.73, 1.12, 1.41, 1.63; % NonAlu
1.53, 1.12, 1.41, 1.73; % TrpC
1.29, 1.58, 2.58, 1.73; % TrpF
1.73, 1.41, 2.00, 1.41; % PfiA
1.73, 1.41, 2.00, 1.41; % Outs
1.29, 1.29, 1.52, 2.00; % PCBA
1.53, 2.00, 1.73, 4.00; % ElGlo
1.20, 1.73, 2.00, 2.23 % Disp
];

% --- Show all uncertainty factors explicitly (18 + 72) ---
disp('f2_Avec (18×1, per input A(i,19) for rows 1..18):'); disp(f2_Avec.');
disp('f2_Bmat (18×4, per-entry B uncertainty factors):'); disp(f2_Bmat);

% ==================== HELPERS (no stats package necessary) ===========================
% Scalar lognormal factor given 2σ multiplicative factor f2
function f = lgn_scalar(f2)
sigma = log(f2) / 2; mu = -0.5 * sigma^2;
f = exp(mu + sigma * randn());
end
% Percentile without prctile (linear interpolation)
function v = pctile_np(x, p)
x = sort(x(:)); n = numel(x);
if n==0, v=NaN; return; end
if p<=0, v=x(1); return; end
if p>=100, v=x(end); return; end
r = 1 + (p/100)*(n-1); i=floor(r); j=ceil(r);
if i==j, v=x(i); else, w=r-i; v=(1-w)*x(i)+w*x(j); end
end


% ==================== MONTE CARLO. This segment helps perform the Monte Carlo sampling simulation
based on the input uncertainty information=====================
Nmc = 5000;

N_A = length(f2_Avec); % 18
N_B = numel(f2_Bmat); % 72
Nin = N_A + N_B; % 90

beta_hist = zeros(Nmc,4); % outputs per run [GWP, Sb, CTU, Water]
X_hist = zeros(Nmc,Nin); % sampled multipliers per run (A first, then B)

for k = 1:Nmc
```

```
As = A; Bs = B;
col = 1;

% --- Sample A (18 inputs feeding ICTNI) ---
for i = 1:N_A
fa = lgn_scalar(f2_Avec(i));
if A(i,19) ~= 0
As(i,19) = A(i,19) * fa;
end
X_hist(k,col) = fa; % store
col = col + 1;
end

% --- Sample B (rows 1..18, cols 1..4) ---
for i = 1:18
for j = 1:4
fb = lgn_scalar(f2_Bmat(i,j));
if B(i,j) ~= 0
Bs(i,j) = B(i,j) * fb;
end
X_hist(k,col) = fb; % store
col = col + 1;
end
end

% --- Solve & record totals ---
ps = As \ alfa;
beta_hist(k,:) = (ps.' * Bs);
end


% ==================== BASELINE ==========================
p0 = A \ alfa; % activity levels
beta0 = (p0.' * B); % [GWP, Sb, CTU, Water]

fprintf('\n=== BASELINE (deterministic) ===\n');
fprintf('Activity vector p0 (19 processes):\n');
for i = 1:19
fprintf(' %-10s : %.12g\n', proc{i}, p0(i));
end
fprintf('Impact totals [GWP100, Sb-eq, CTU, Water]:\n');
for j = 1:4
fprintf(' %-6s : %.12g\n', cats{j}, beta0(j));
end

% ==================== SENSITIVITY ANALYSIS + CONTRIBUTION TO UNCERTAINTY. This section handles the
sensitivity calculation and contribution to total uncertainty analysis. These calculations are based
on the framework presented in ETSI TS 104 134 (V1.1.1). ===========
TopN = 10; % change to 5 tighter plots
% --- Build input names (A factors + B factors) ---
N_A = length(f2_Avec); % 18
N_B = numel(f2_Bmat); % 72
Nin = N_A + N_B; % 90

names_inputs = cell(1, Nin);
for i = 1:N_A
names_inputs{i} = sprintf('A:%s', proc{i});
end
idx = N_A;
for i = 1:18
for jcat = 1:4
idx = idx + 1;
names_inputs{idx} = sprintf('B:%s × %s', proc{i}, cats{jcat});
end
end

for j = 1:4
y = beta_hist(:,j);
my = mean(y); sy = std(y);

% ---- build relevant set: all 18 A + the 18 B entries for this category j ----
names_relevant = cell(1, 18+18);
rvals = zeros(18+18,1);

% A-factors (always relevant)
for i = 1:18
x = X_hist(:, i); % columns 1..18 are A factors
mx = mean(x); sx = std(x);
```

```
if sx == 0 || sy == 0
r = 0;
else
r = sum((x - mx) .* (y - my)) / ((numel(x)-1) * sx * sy);
end
rvals(i) = r;
names_relevant{i} = names_inputs{i}; % "A:Process"
end

% B-factors for this category j only
% column index in X_hist: N_A + (i-1)*4 + j (i=1..18)
for i = 1:18
col = N_A + (i-1)*4 + j;
x = X_hist(:, col);
mx = mean(x); sx = std(x);
if sx == 0 || sy == 0
r = 0;
else
r = sum((x - mx) .* (y - my)) / ((numel(x)-1) * sx * sy);
end
rvals(18+i) = r;
names_relevant{18+i} = names_inputs{col}; % "B:Process × cats{j}"
end

% ---- sort for sensitivity (|r|) and contribution (r^2 normalized) ----
[sens_sorted, idx_sens] = sort(abs(rvals), 'descend');
r2 = rvals.^2;
denom = max(sum(r2), eps);
contrib = 100 * r2 / denom;
[contrib_sorted, idx_contrib] = sort(contrib, 'descend');

nall = numel(rvals);
nshow = min(TopN, nall);

% ---Sensitivity (labels: 2 decimals, font 8) ---
figure;
sens_vals = sens_sorted(1:nshow);
bar(sens_vals);
set(gca,'XTick',1:nshow, ...
'XTickLabel',names_relevant(idx_sens(1:nshow)), ...
'XTickLabelRotation',45, 'FontSize',14,'FontWeight','bold');
ylabel('|corr|','FontSize',14,'FontWeight','bold');
title(sprintf('Sensitivity for %s', cats{j}), ...
'FontSize',14,'FontWeight','bold');

yoff = 0.02 * max(1, max(sens_vals));
for k = 1:nshow
text(k, sens_vals(k) + yoff, sprintf('%.2f', sens_vals(k)), ...
'HorizontalAlignment','','VerticalAlignment','bottom','FontSize',14);
end
ylim([0, max(sens_vals)*1.15 + eps]);

% --- Uncertainty Contribution (labels: integer %, font 8) ---
figure;
contrib_vals = contrib_sorted(1:nshow);
bar(contrib_vals);
set(gca,'XTick',1:nshow, ...
'XTickLabel',names_relevant(idx_contrib(1:nshow)), ...
'XTickLabelRotation',45, 'FontSize',14,'FontWeight','bold');
ylabel('% of variance','FontSize',14,'FontWeight','bold');
title(sprintf('Uncertainty Contribution for %s', cats{j}), ...
'FontSize',14,'FontWeight','bold');

yoff = 0.02 * max(1, max(contrib_vals));
for k = 1:nshow
text(k, contrib_vals(k) + yoff, sprintf('%d%%', round(contrib_vals(k))), ...
'HorizontalAlignment','centre','VerticalAlignment','bottom','FontSize',14);
end
ylim([0, max(contrib_vals)*1.15 + eps]);
end

% ==================== INDIVIDUAL GRAPHS PER IMPACT CATEGORY ==================

% Stage group indices
stage_names = {'Raw Materials','Production','Use','EoLT'};
stage_idx = {
[1,2,3,4,5], % (A) Raw Materials
[6,7,8,9,10,11,12,13,14,15,16],% (B) Production
```

```
[17], % (C) Use
[18,19] % (D) EoLT
};

% Calculate stage contributions
stage_impacts = zeros(length(stage_names),4);
for s = 1:length(stage_names)
idx = stage_idx{s};
B_stage = zeros(size(B));
B_stage(idx,:) = B(idx,:);
stage_impacts(s,:) = p0.' * B_stage;
end

% Custom titles and y-axis labels
titles = {'GWP100 CO2e','Resource Depletion','Ecotoxicity','Water Scarcity'};
units = {'kg CO2e','kg Sb-e','CTU','m^3'};

% For each category, make a separate figure with 5 bars and labels
for j = 1:4
values = [beta0(j), stage_impacts(:,j)']; % total + 4 stages
figure;
bar(values);
set(gca,'XTickLabel',{'Total','RawMat','Production','Use','EoLT'});
ylabel(units{j});
title(titles{j});

% --- Add large labels above each bar ---
xt = 1:length(values);
for k = 1:length(values)
text(xt(k), values(k)*1.02, sprintf('%.3g', values(k)), ...
'HorizontalAlignment','centre', 'VerticalAlignment','bottom', ...
'FontSize',20, 'FontWeight','bold');
end
end

% ===================== BASELINE RESULTS===========================
p0 = A \ alfa; % activity levels
beta0 = (p0.' * B); % [GWP, Sb, CTU, Water]

fprintf('\n=== BASELINE (deterministic) ===\n');
fprintf('Activity vector p0 (19 processes):\n');
for i = 1:19
fprintf(' %-10s : %.12g\n', proc{i}, p0(i));
end
fprintf('Impact totals [GWP100, Sb-eq, CTU, Water]:\n');
for j = 1:4
fprintf(' %-6s : %.12g\n', cats{j}, beta0(j));
end

% ==================== SUMMARY OF MONTE CARLO SIMULATIONS =======================================
p_lo = 0.5; p_hi = 99.5;
fprintf('\n=== MONTE CARLO (n=%d) — p0.5 / mean / p99.5 / CV ===\n', Nmc);
for j = 1:4
vals = beta_hist(:,j);
m = mean(vals); s = std(vals); cv = s / max(m, eps);
fprintf('%-6s : p0.5=%.6g mean=%.6g p99.5=%.6g CV=%.4f\n', ...
cats{j}, pctile_np(vals,p_lo), m, pctile_np(vals,p_hi), cv);
end
```

G.5.3.1 Baseline and uncertainty range results

Here follow some results generated from the script in clause G.5.3.

First the total absolute results:

```
GWP100 : 44422.1
Sb-eq  : 0.06911373
CTU    : 2093.418
Water  : 9524.6
```

Next follows the uncertainty range results where:

- p0,5 is the lower percentile level where 0,5 % of the Monte Carlo runs are below;
- p99,5 is the upper percentile level where 99,5 % of the Monte Carlo simulations are below;

- the mean is the average value of all Monte Carlo runs;
- CV is the coefficient of variation which is a measure of the spread of the result. CV is defined as one standard deviation divided by the mean; and
- CV < 0,05 suggests very low uncertainty, CV 0,05-0,15 points to moderate uncertainty and CV > 0,15 suggests high uncertainty.

```
GWP100 : p0.5=22151.5 mean=44542.5 p99.5=85816.2 CV=0.2611
Sb-eq  : p0.5=0.0557742 mean=0.068957 p99.5=0.0864286 CV=0.0852
CTU    : p0.5=1078.65 mean=2091.81 p99.5=4081.34 CV=0.2682
Water  : p0.5=1815.4 mean=9462.06 p99.5=41243.3 CV=0.7417
```

G.5.3.2 Selected graphs generated from script in clause G.5.3

Here follow three graphs generated from the script in clause G.5.3. In total 12 graphs (three for each impact category) are generated by the script in clause G.5.3 however only GWP100 CO_2e graphs are shown. Figure G.3a is similar to Figure G.1a but includes also the total result for GWP100.

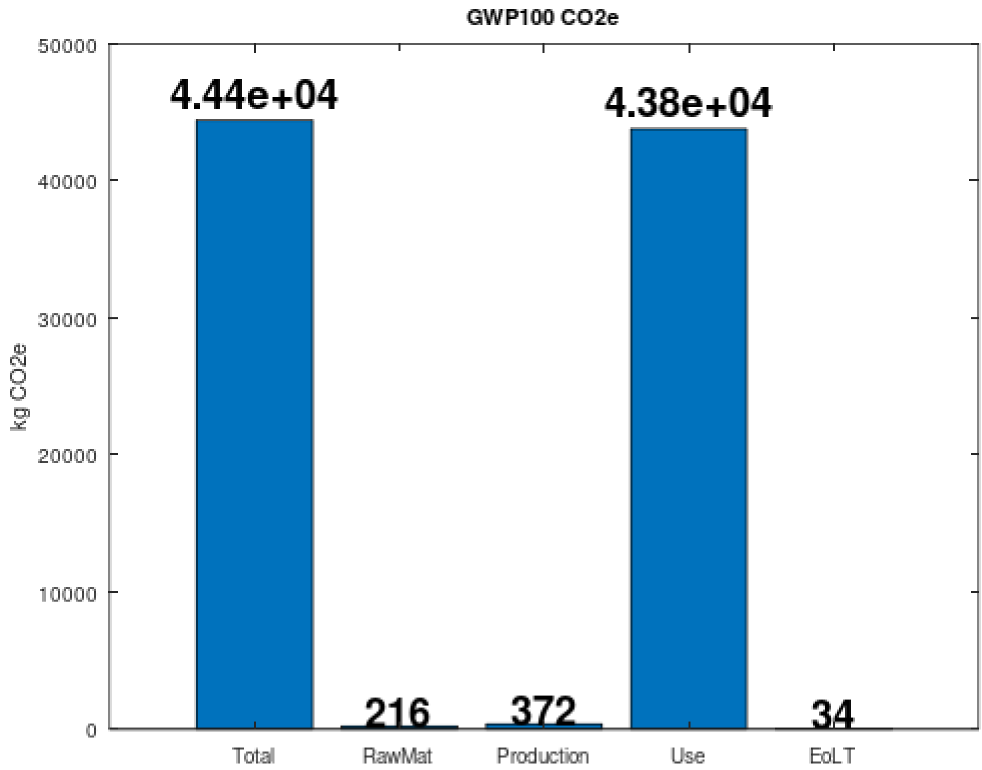


Figure G.3a: Summary result for CO_2e for the ICT Network product example expressed per main life cycle stage as generated by the code

Figure G.3b shows which data are most sensitive in for the GWP100 score for the example in clause G.3.1.

NOTE 1: The B notation refers to the impact intensity and A refers to the amount.

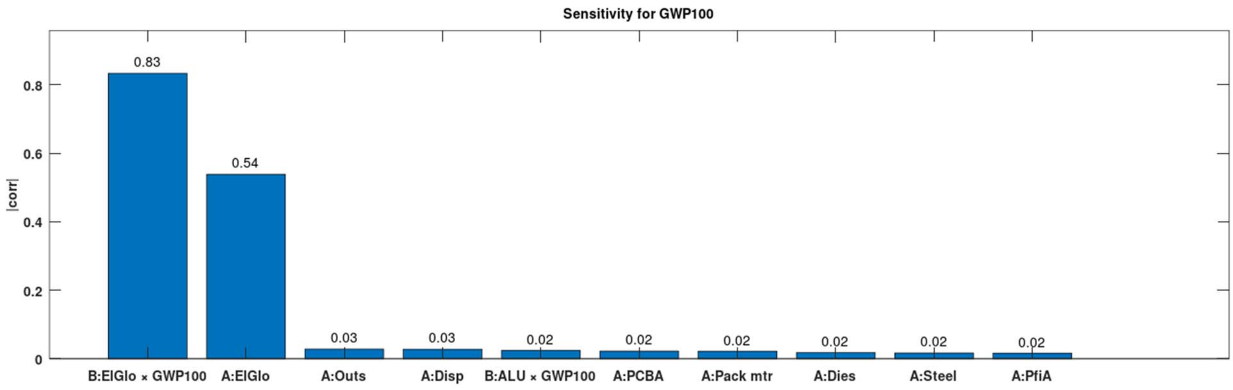


Figure G.3b: Summary result for CO_2e sensitivity for the ICT Network product example expressed per main life cycle stage as generated by the code

Figure G.3c shows which data contribute most to the total uncertainty of the GWP100 score for the example in clause G.3.1.

NOTE 2: The B notation refers to the impact intensity and A refers to the amount.

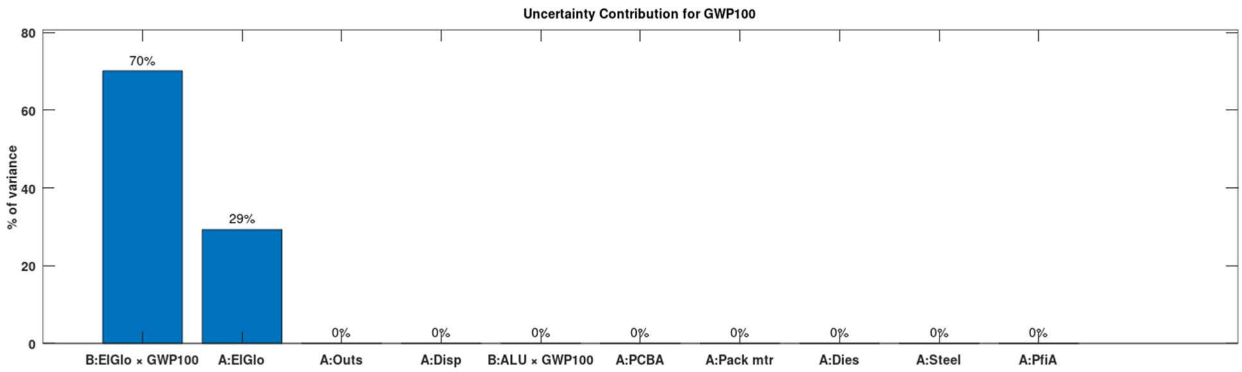


Figure G.3c: Summary result for CO_2e uncertainty contributions for the ICT Network product example expressed per main life cycle stage as generated by the code

As suspected the most sensitive flows are also those contributing most to the total uncertainty.

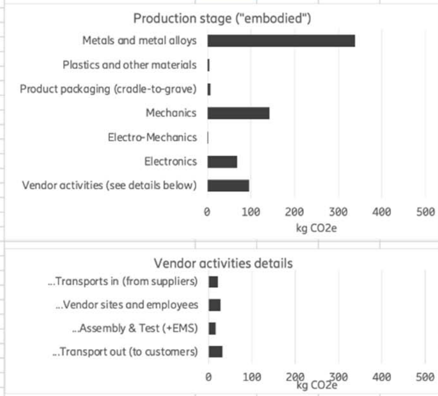
Annex H (informative): Example - Simplified LCA of a typical mobile network radio

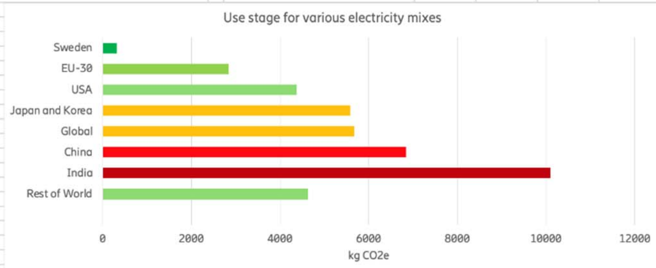
This is an example of methodology application on a network radio or Radio Access Network (RAN) radio on the GWP impact category. The example has been presented in [i.7] where more information can be found about range of GHG emissions depending on where it is produced, how different LCA and supplier data can impact the results, and how recycling of metals in/out of its lifecycle has a large impact on the results. Outcomes for the global average with no recycling is shown here. How recycling can be calculated is further described in Annex I. The radio can be labelled as a typically installed radio in year 2020, see further [i.7].

Figure H.1 shows how the simplified LCA GHG calculations and how the result presentation can look for the mobile network radio using a common spreadsheet tool.

Product: RAN Radio 2G-4G 2 x 80 W	PP					
Weight: 18.5 kg (18 to 19 kg, packaging +2.75 kg)	Product Parameter			EF	Result	
	Data	Unit	Factor	kg CO2e/unit	kg CO2e	Key information
Metals and metal alloys						
Aluminum alloys	17,0	kg	1,25	15	318,8	No recycling in/out have been included in any metals
Iron/Steel and Copper alloys	0,60	kg	1,30	5,2	4,1	
Tin, Silver, and Gold	0,025	kg	1,25	500	15,6	
Other metals	0,10	kg	1,30	5	0,65	
Total:					338,4	
Plastics and other materials						
Epoxy plastics	0,25	kg	1,40	7	2,5	No recycling in/out have been included in any metals and metal alloys.
Other plastics	0,20	kg	1,30	3,5	0,91	
Glass fiber (other ceramics)	0,30	kg	1,40	3,1	1,3	
Total:					4,7	
Product packaging						
Plastics packaging	0,75	kg	1,30	3,5	3,4	No recycling in/out have been included for plastics and cardboard packaging.
Cardboard packaging	1,5	kg	1,30	1,7	3,3	
Wood pallet (with reuse)	0,50	kg	1,30	0,34	0,22	Reuse of the wood pallet is included (20 times)
Total:					6,9	
Mechanics						
Die cast aluminum parts	11,1	kg	1,00	7,5	83,3	Full gate-to-gate, from basic raw materials to final part.
Complex aluminum filter	5,6	kg	1,00	10	56,0	
Medium mech parts	0,65	kg	1,00	4	2,6	
Total:					141,9	
Electro-Mechanics						
Small special (connectors, shields, 0.1 kg)	0,20	kg	1,00	10	2,0	
Total:					2,0	
Electronics						
Average IC	7,9	cm2	1,00	2,6	20,5	
Multilayer PCBs (8-12 layers)	9,3	dm2	1,20	3	33,5	
Standard components	0,44	kg	1,00	32	14,1	
Total:					68,1	
Vendor own activities (+EMS)						
Transports in (from suppliers)	21,2	kg	1,00	1	21,2	Somewhat specific for each product depending on where it is produced and where the customer is located.
Vendor sites and employees	21,2	kg	1,00	1,25	26,5	
Assembly & Test (+EMS)	21,2	kg	1,00	0,74	15,7	
Transport out (to customers)	21,2	kg	1,00	1,5	31,8	Specific for each customer, average shown here
Total:					95,2	
				Embodied total (not incl. EoLT)	657	kg CO2e
Operation / use stage						
365/24 average	150	W	Average AC input to the radio			
Site-factor (e.g. cooling and power losses)	1		No additional AC power losses included			
Annual Electricity Consumption (AEC)	1315	kWh	No additional cooling needed			
Active Lifetime Years (ALY)	8	years	(outdoor radio)			
Lifetime Electricity Consumption (LEC)	10519	kWh				
			Lifetime			
Electricity Emission Factor (EEF)	kg CO2e/kWh		kg CO2e			
Embodied CF			*657*	ECF	No recycling included!	
Sweden	0,03		316	UCF		
EU-30	0,27		2840			
USA	0,415		4365			
Japan and Korea	0,53		5575			
Global	0,54		5680			
China	0,65		6837			
India	0,96		10098			
Rest of World	0,44		4628			
End-of-Life Treatment (EoLT) stage						
Collection and mechanical scrap processing	18,5	kg	1	0,2	3,7	
Metal recycling lifecycle adjustment	18,5	kg	1	-7,1	-131,4	
Total:					-127,7	
Total lifecycle summary						
Raw materials stage	218,7	131,4				
Supply chain stage	212,0					
Vendor stage	95,2					
Use stage (global)	5680					
EoLT stage	3,7	-131,4				
Total:	6210					

RAN Radio 2G-4G 2 x 80 W		
Metals and metal alloys	338,4	kg CO2e
Plastics and other materials	4,7	kg CO2e
Product packaging (cradle-to-grave)	6,9	kg CO2e
Mechanics	142	kg CO2e
Electro-Mechanics	2,0	kg CO2e
Electronics	68,1	kg CO2e
Vendor activities (see details below)	95,2	kg CO2e
...Transports in (from suppliers)	21,2	kg CO2e
...Vendor sites and employees	26,5	kg CO2e
...Assembly & Test (+EMS)	15,7	kg CO2e
...Transport out (to customers)	31,8	kg CO2e





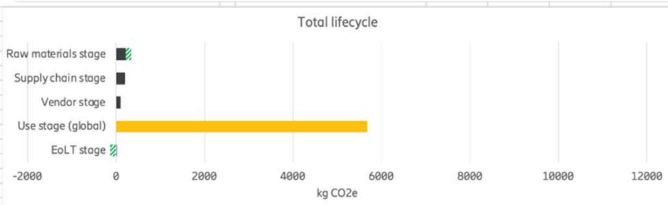


Figure H.1: The mobile network radio product parameters implemented as a simple Excel tool

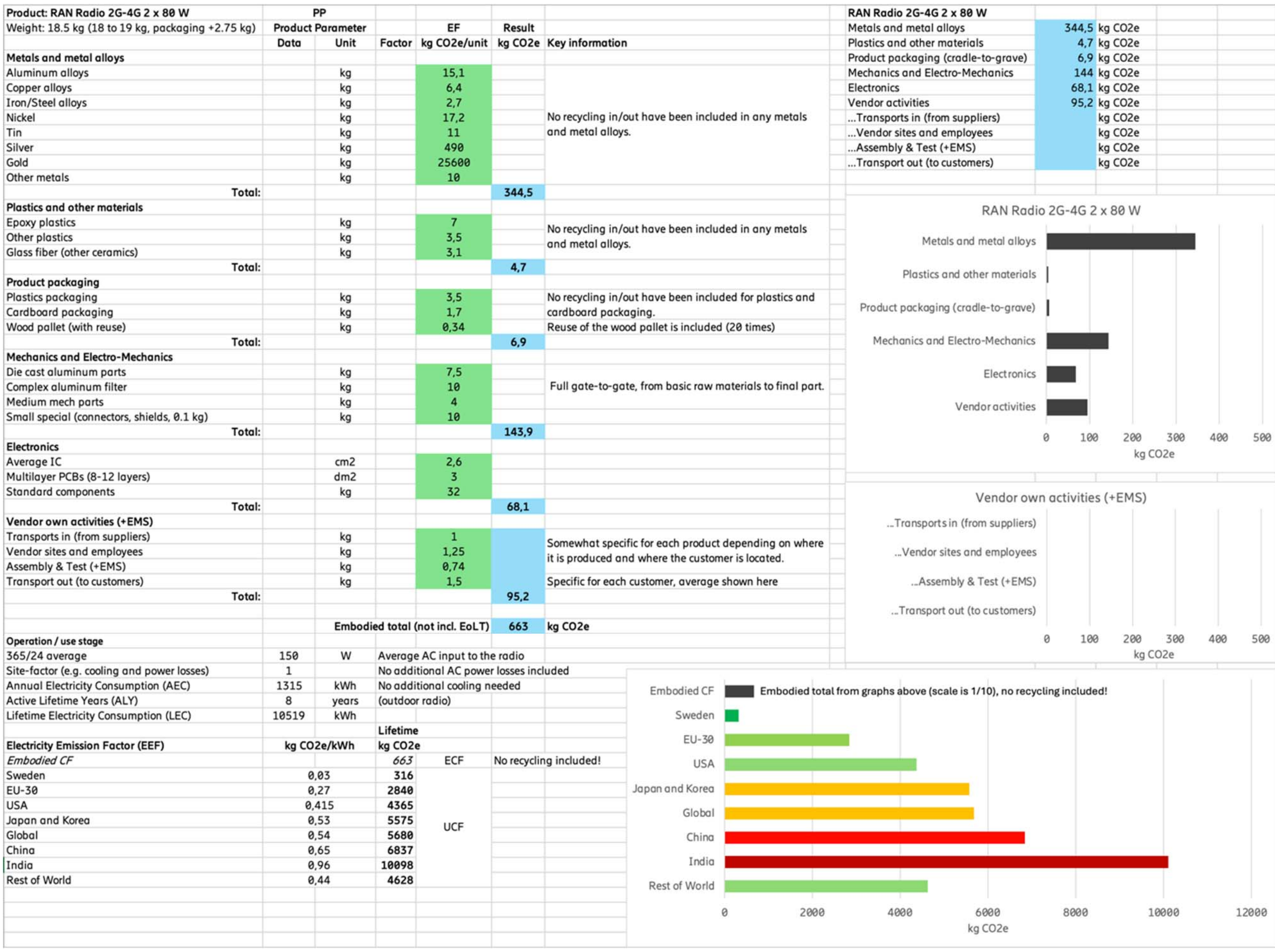
For the radio in this example, the embodied Carbon Footprint (CF) is typically in the order of 1/10[th] of the use stage CF in a global scenario using the global average electricity mix and the global EEF. Most network and data equipment in operation 24/365 has this ratio embodied/use. There is a large range for the Use stage Carbon Footprint (UCF) when using country specific electricity EFs.

As product parameters and related factors can be company and/or market sensitive, especially for new products, they cannot be made mandatory to report externally. However, the product parameter description and used EF is mandatory to report to allow a minimum understanding of results.

Figure H.2 shows how sensitive data in Figure H.1 can just be hidden. If a part has too few product parameters, they can be aggregated, and this have already been shown for raw materials in Figure H.1. Figure H.2 also shows a simpler lifecycle view without recycling of metals accounted for.

More detailed data may only be shown to an external party under NDA, e.g. in a critical review process. A company may also have even more detailed data and calculations they use internally, e.g. involving sensitive supplier data that cannot be shared in detail to any external party.

A very important key aspect in a simplified LCA is to just keep it simple. The simplified radio LCA could have been made simpler by aggregating more PPs, but there is also a strength in showing that individual parts, e.g. metals like iron/steel, nickel, and tin, have been included and not been just aggregated in "Other metals".



Product: RAN Radio 2G-4G 2 x 80 W	PP					
Weight: 18.5 kg (18 to 19 kg, packaging +2.75 kg)	Product Parameter			EF	Result	
	Data	Unit	Factor	kg CO2e/unit	kg CO2e	Key information
Metals and metal alloys						
Aluminum alloys		kg		15,1		No recycling in/out have been included in any metals and metal alloys.
Copper alloys		kg		6,4		
Iron/Steel alloys		kg		2,7		
Nickel		kg		17,2		
Tin		kg		11		
Silver		kg		490		
Gold		kg		25600		
Other metals		kg		10		
Total:					344,5	
Plastics and other materials						
Epoxy plastics		kg		7		No recycling in/out have been included in any metals and metal alloys.
Other plastics		kg		3,5		
Glass fiber (other ceramics)		kg		3,1		
Total:					4,7	
Product packaging						
Plastics packaging		kg		3,5		No recycling in/out have been included for plastics and cardboard packaging.
Cardboard packaging		kg		1,7		
Wood pallet (with reuse)		kg		0,34		Reuse of the wood pallet is included (20 times)
Total:					6,9	
Mechanics and Electro-Mechanics						
Die cast aluminum parts		kg		7,5		Full gate-to-gate, from basic raw materials to final part.
Complex aluminum filter		kg		10		
Medium mech parts		kg		4		
Small special (connectors, shields, 0.1 kg)		kg		10		
Total:					143,9	
Electronics						
Average IC		cm2		2,6		
Multilayer PCBs (8-12 layers)		dm2		3		
Standard components		kg		32		
Total:					68,1	
Vendor own activities (+EMS)						
Transports in (from suppliers)		kg		1		Somewhat specific for each product depending on where it is produced and where the customer is located.
Vendor sites and employees		kg		1,25		
Assembly & Test (+EMS)		kg		0,74		
Transport out (to customers)		kg		1,5		Specific for each customer, average shown here
Total:					95,2	
				Embodied total (not incl. EoLT)	663	kg CO2e

Operation / use stage			
365/24 average	150	W	Average AC input to the radio
Site-factor (e.g. cooling and power losses)	1		No additional AC power losses included
Annual Electricity Consumption (AEC)	1315	kWh	No additional cooling needed
Active Lifetime Years (ALY)	8	years	(outdoor radio)
Lifetime Electricity Consumption (LEC)	10519	kWh	

Electricity Emission Factor (EEF)	kg CO2e/kWh	Lifetime kg CO2e		
Embodied CF		*663*	ECF	No recycling included!
Sweden	0,03	316	UCF	
EU-30	0,27	2840		
USA	0,415	4365		
Japan and Korea	0,53	5575		
Global	0,54	5680		
China	0,65	6837		
India	0,96	10098		
Rest of World	0,44	4628		

RAN Radio 2G-4G 2 x 80 W		
Metals and metal alloys	344,5	kg CO2e
Plastics and other materials	4,7	kg CO2e
Product packaging (cradle-to-grave)	6,9	kg CO2e
Mechanics and Electro-Mechanics	144	kg CO2e
Electronics	68,1	kg CO2e
Vendor activities	95,2	kg CO2e
...Transports in (from suppliers)		kg CO2e
...Vendor sites and employees		kg CO2e
...Assembly & Test (+EMS)		kg CO2e
...Transport out (to customers)		kg CO2e

Figure H.2: Same as Figure H.1 but with sensitive product data hidden, however showing product parameters and corresponding EFs, and not just aggregated results

For network and data center equipment/devices that run on DC or require indoor climate (cooling), a Site-factor that combine the extra electricity needed for power and climate (cooling) can be added. In data centers the PUE factor is essentially a Site-factor but on an average higher level (the whole data center).

When doing a simple LCA on network and data center equipment, a *Site-factor* may be included but it is not mandatory. It is important to describe if a *Site-factor* have been used and what it includes, or what the included operation cover for informed further use by e.g. a customer.

For mobile network radios it is common today to run on AC and to not need any extra cooling. A Site-factor describing power losses in e.g. cables may still be relevant, but it has not been included here, see Figure H.1 and Figure H.2 and the description of the operation / use stage for the radio.

Note that while the extra UCF from extra electricity needed have been included in some previous LCAs, the extra embodied CF for the extra power and/or cooling equipment is not, the reason is simply that it is assumed to be insignificant.

There are other additional use stage activities like maintenance, repair, and refurbishment before second use. These activities are hard to quantify but typically do not add up to a significant CF compared to the UCF based on the lifetime electricity consumption. Therefore, these activities are best quantified by the customer / operator on a total network level.

The operation of network and data center equipment may also in full or partly come from on-site generated electricity, e.g. diesel generators or solar panels, but these special cases do not need to be included as part of the operation / use in a simplified LCA.

Annex I (informative): Example of approaches for input data and recycling

I.0 Primary and secondary raw materials

The End-of-Life Treatment (EoLT) stage is optional for a simplified LCA, but it is mandatory to include a description of it and how the use of primary and secondary material and recycling has or has not been considered. The result of any LCA will depend on the use of primary and secondary material use and recycling input/output percentage figures.

I.1 Taking recycling into account in the raw material stage

For raw materials, the content in the final product is the key Product Parameter (PP). But more material input is typically needed as material is lost in production and the total input can be described by multiplying the material PP with a factor f > 1.

For clarity purposes throughout this annex Aluminium used in a product is used as example. In what follows Aluminium production waste and losses are summarized over the whole supply chain:

Product content of Aluminium (including alloys): 10 kg (PP_{Al} = 10 kg)
Needed material input: 12 kg (f_{Al} = 1,2)
Production waste recycled: 1 kg
Losses during production: 1 kg
Product content recycled at EoLT: 9 kg (90 % recycled)
Product content lost at EoLT: 1 kg (10 % lost)

Raw material losses during the raw material stage are not included, they happen before the studied lifecycle and are included in the raw material EF (all impacts are related to output of the raw material in a basic product form). Aluminium losses in the example above can come from alloying, melting and melt holding when die casting resulting in burn-off and slag. Other losses come from mechanical processing and scrapping/recycling of failed parts. A few % is typically lost each time Aluminium is melted/recycled as Aluminium oxidize easily.

NOTE 1: Internal recycling should be included based on continuously production. For example, in die casting processes typically 30 % is lost in one "shot", but as these losses is continuously recycled internally, the losses are typically about 10 % over time when continuously die casting, and the input factor can be rounded to 1,1 (not 1,3). However, if the recycled material cannot be used in the product under study due to e.g. contamination or degraded material properties, all of it should be counted as production waste, even if it is recycled internally, then the factor becomes 1,3 in this example.

NOTE 2: Production waste cannot become 100 % recycled material in a following product, internal or external, it should apply the same proportions of recycled material as the "starting" material.

The difference between primary and secondary raw material sources around the world is very large. Below are typical primary and secondary average EFs for Aluminium used with the example above including a primary worst case (with coal electricity):

Aluminium:
100 % recycled *Secondary*: 0,5 kg CO_2e/kg × 12 kg = 6 kg CO_2e
Global average *Primary*: 15 kg CO_2e/kg × 12 kg = 180 kg CO_2e
Worst case *Primary*: 25 kg CO_2e/kg × 12 kg = 300 kg CO_2e

By combining the global average primary and secondary EFs above, the use of recycled material as input can be accounted for in a simple way:

75 % recycled material: (0,5 × 0,75 + 15 × 0,25) × 12 = 49,5 kg CO_2e (EF = 4,1 kg CO_2e/kg)
50 % recycled material: (0,5 × 0,5 + 15 × 0,5) × 12 = 93 kg CO_2e (EF = 7,75)
25 % recycled material: (0,5 × 0,25 + 15 × 0,75) × 12 = 136,5 kg CO_2e (EF = 11,4)

Production waste can be accounted for in a simple way, for example using 11 kg as the input instead of 12 kg as 1 kg becomes production waste that are recycled for use in another product (which then accounts for the recycling in its raw material stage).

It is natural to stop at the gate and only consider the production stage for raw materials. The customer can then finish the lifecycle calculation based on own data.

I.2 EoLT stage, metal recycling, and connecting it to the raw material stage

This stage is optional to include and is also a bit complex to include as metal recycling in the EoLT stage is not straight-forward.

There are many existing ways of doing it and many examples of LCAs where recycling at EoLT is used to "sign off" primary raw material input, the burden of raw material production is passed on to "the next" product. To lose metal is then defined as the worst case, disregarding if 100 % primary metal is used as input. However, the opposite, to use 100 % recycled metal and not accounting for losses at EoLT (e.g. by mixing it with other materials to intimate or use it for packaging that do not get recycled), can also be seen as "escaping" the burden of primary production (to replace what is lost in this case). Even examples of false claims that recycling has a positive net reduction of emissions exist, e.g. use 100 % recycled material and then claim that EoLT recycling is a reduction in emissions equal to primary production.

I.3 The 50/50 method

To counter that little or no responsibility for any primary raw material production is accounted for as described above, the so called 50/50 method was developed and it is also described in Recommendation ITU-T L.1410 [1].

In the 50/50 method, primary production impact is split 50/50 between the product lifecycle that first introduce and use the primary metal (product under study in this case), and the future lifecycle(s) that lose the metal. For lost metal, the global average EF at the time of study is appropriate to use for products on a global market. Also, secondary recycling is split 50/50. Only for the Raw Material Depletion (RMD) indicator it is suggested that only losses are considered.

The formulas get more complicated with the 50/50 method and can look like this:

Input "side" and 25 % recycled material:
Recycled/secondary material: 3 kg × 0,5 × 0,5 = 0,75 kg
Primary material: 9 kg × 15 × 0,5 = 67,5 kg
Total for the input side: 68,25 kg

Output "side":
Total recycling: 10 kg × 0,5 × 0,5 = 2,5 kg
Total losses: 2 kg × 15 × 0,5 = 15 kg
Total for the output side: 17,5 kg CO_2e

Total input + output: 85,75 ~86 kg CO_2e

It is possible to simply use the average % figures for primary/secondary material in a short and fast version of the 50/50 method. Note that this fast method only works for the global primary average EF (same input/output). In the example above with 25% recycled input material and 10/12 = 83,3 % recycling of production waste and EoLT waste, the resulting simpler formula become:

54 % recycled material: (0,5 × 0,54 + 15 × 0,46) × 12 = 86 kg CO_2e (EF = 7,17)

It is also possible to account for the production waste/losses at the input side:

Production waste output: 1 kg × 0,5 × 0,5 = 0,25 kg CO_2e
Production losses: 1 kg × 15 × 0,5 = 7,5 kg CO_2e

Total for the input side including production waste/losses: 68,25 + 7,75 = 76 kg CO_2e
Total for the output side excluding production waste/losses: 17,5 - 7,75 = 9,75 ~10 kg

These results are shown below in Figure I.1 as a graph.

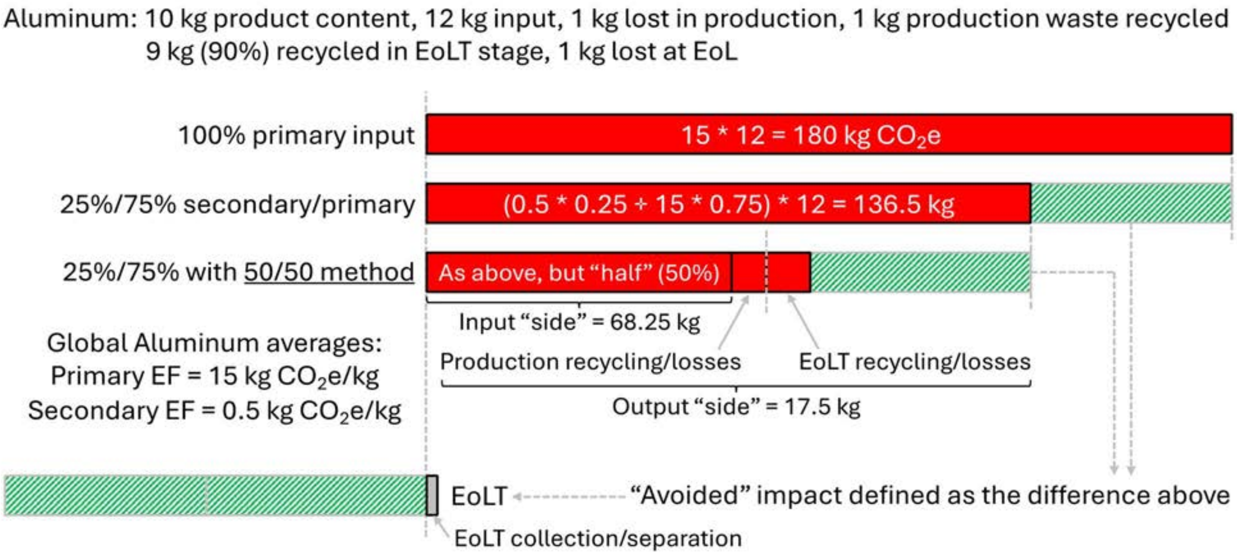


Figure I.1: The 50/50 example described in text above shown as a graph

It is possible to show the impact of recycling as the "avoided" impact. Avoided impact is defined as the difference between recycling and no recycling and is only a way to show the importance of recycling and should not be used as a result of its own out of context.

A product with no recycling in/out is equal to using the global average primary EF:

Global average *Primary*: 15 kg CO_2e/kg × 12 kg = 180 kg CO_2e

A product with only recycling in/out is equal to using the global average secondary EF:

100 % recycled *Secondary*: 0,5 kg CO_2e/kg × 12 kg = 6 kg CO_2e

The 50/50 method should result anywhere in between these two values unless the primary input has a higher impact than the global average.

NOTE: The global average Primary EF should be used for both production and EoLT losses. It can be motivated by that the product is spread on a global market and EoLT is local. To use a specific input should not be done. Otherwise, a product with 100 % recycled content could skip to recycle the metals as they "was already" recycled in the first place. But that is not the correct way of thinking.

Figure I.2 shows an example of the Aluminium part of the radio network equipment example (Annex H), and the different possible results based on many combinations of EFs and recycling/loss percentages.

Aluminium content, kg	16,7	Primary EF (global average, no recycling)	15,1	kg CO2e/kg	Primary EF (coal worst case)	25	kg CO2e/kg
Input factor	1,25	Average EF (global average, 30% recycling)	10,8	kg CO2e/kg	Primary EF ("Green primary Alu")	4	kg CO2e/kg
Aluminium input need, kg	20,9	Secondary EF (recycling, global average)	0,5	kg CO2e/kg			

						Input (50% allocation)		Output (50% allocation)				Total	
	Prim in EF	Prim out EF	Secondary EF	Recycling	Loss-	Primary	Secondary	Primary	Secondary	**Total**	**Resulting EF**	Primary	Secondary
	kg CO2e/kg	kg CO2e/kg	kg CO2e/kg	input	factor	kg CO2e	kg CO2e	kg CO2e	kg CO2e	**kg CO2e**	**kg CO2e/kg**	kg CO2e	kg CO2e
Worst case, no recyling, 100% coal, 25 kg CO2e/kg	25	25	0,5	0%	100%	260,9	0,0	260,9	0,0	**521,9**	**25,00**	521,9	0,0
No recyling, 100% coal, 25/15.1 kg CO2e/kg	25	15,1	0,5	0%	100%	260,9	0,0	157,6	0,0	**418,5**	**20,05**	418,5	0,0
No recyling, 15.1 kg CO2e/kg (global average)	15,1	15,1	0,5	0%	100%	157,6	0,0	157,6	0,0	**315,2**	**15,10**	315,2	0,0
0% / 10% recycling in/out (production waste recycling)	15,1	15,1	0,5	0%	90%	157,6	0,0	141,8	0,5	**300,0**	**14,37**	299,5	0,5
0% / 85% recycling in/out, typical "whole" life cycle	15,1	15,1	0,5	0%	15%	157,6	0,0	23,6	4,4	**185,7**	**8,90**	181,2	4,4
30% / 85% recycling in/out, typical "whole" life cycle	15,1	15,1	0,5	30%	15%	110,3	1,6	23,6	4,4	**140,0**	**6,71**	134,0	6,0
0% / 85% recycling in/out, 10.8 kg CO2e/kg (recycling included)	10,8	15,1	0,5	0%	15%	112,7	0,0	23,6	4,4	**140,8**	**6,75**	136,4	4,4
30% / 85% recycling in/out, 10.8 kg CO2e/kg (recycling included)	10,8	15,1	0,5	30%	15%	78,9	1,6	23,6	4,4	**108,6**	**5,20**	102,5	6,0
0% / 85% recycling in/out, 4 kg CO2e/kg ("Green primary Al")	4	15,1	0,5	0%	15%	41,8	0,0	23,6	4,4	**69,8**	**3,35**	65,4	4,4
30% / 85% recycling in/out, 4 kg CO2e/kg	4	15,1	0,5	30%	15%	29,2	1,6	23,6	4,4	**58,9**	**2,82**	52,9	6,0
100% / 85% recycling in/out, reasonable best case	0,5	15,1	0,5	100%	15%	0,0	5,2	23,6	4,4	**33,3**	**1,60**	23,6	9,7
100% recycling in/out, only in theory...	0,5	0,5	0,5	100%	0%	0,0	5,2	0,0	5,2	**10,4**	**0,50**	0,0	10,4

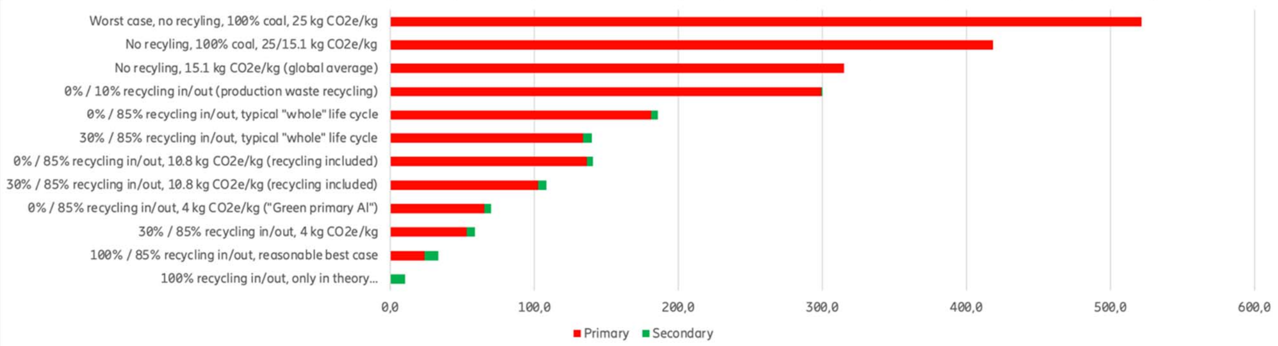


Figure I.2: Different possible results based on many combinations of EFs and recycling/loss percentages

Annex J (informative): Component Characterization

J.1 General about component characterization

An example of a component characterization approach is iNEMI's estimator tool [i.30]. It focuses on the key parameters of ICT components that has significant environmental impact based on past LCA data. It defines key elements within ICT product types based on their relative importance in contributing to overall environmental impact and provides a simple mechanism for evaluating environmental impact (initially GWP). ICT products can be classified into distinct categories with common attributes that produces certain level of environmental impact regarding their component makeup, assembly, usage, and design life which can then be further sorted into components categories comprised of similar materials and manufacturing processes. The categorized components offer a means of producing a concise list that can be analysed for common environmental impact attributes which can be rationalized, normalized, and modelled to derive their level of impact within the LCA estimator tool. The major component / subassembly categories for ICT products used in iNEMI's estimator tool include printed wiring boards, integrated circuits, electro-mechanical assemblies such as cooling fans, metallic components, polymeric components, displays, cables, batteries, and specialized components such as optical and radio frequency devices, and disc drives.

J.2 Example case of using iNEMI's estimator tool: Printed wiring boards

This example is based on [i.31].

The environmental impact (in this case, GHG emissions) of a Printed Wiring Board (PWB) could be calculated using the common components attributes classification as follows.

First, the following information should be collected to be used as an input to the algorithm defining the common component group.

- Board area (e.g. square centimetres) and type (main boards, mother boards, daughter boards and ancillary boards)
- Number of board layers
- Type of board surface finish (e.g. HASL-hot air solder levelling, OSP-Organic solderability preservative Ni/Au overlay, immersion silver)
- Algorithm: simple summation model, pattern recognition/regression:

$$GWP_{PWB} = A_B\,[\alpha + (\beta\, S_F) + (\gamma\, B_L)] \qquad (J.1)$$

Where:

GWP_{PWB} is the Global Warming Potential of the PWB being evaluated;

A_B is the area of the PWB;

α is the "intercept" coefficient for this linear regression equation;

β is the "PWB surface finish type" coefficient for this linear regression equation;

S_F is the PWB surface finish type (e.g. HASL → $S_F = 1$; ENIG → $S_F = 2$);

γ is the "PWB layer" coefficient for this linear regression equation;

B_L is the number of PWB layers.

Therefore, for a double-sided PWB made of FR4 epoxy resin, measuring 20 cm by 20 cm, with 8 layers and HASL finish, the estimated GHG emission of its production will be:

$$GWP_{PWB} = 400\ cm^2\ [0{,}0135 + (0{,}00498 \times 1\{HASL\}) + (0{,}002769 \times 8\ layers)] \quad (J.2)$$

$$GWP_{PWB} = 16{,}25\ kg\ CO_2e$$

NOTE: Values of constants will be based on specific data sets provided in the analysis and algorithm development.

Annex K (informative): Example of GHG estimation using LCSRP

Product: A typical mobile network radio product X with typical active power consumption of 35 000 kWh with product lifetime of 10 years.

The use stage GHG emissions = 35 000 kWh × 0,6 kg CO_2e / kWh = 21 000 kg CO_2e

Use stage GHG emissions = 21 000 kg CO_2e

NOTE 1: For the sake of this example, 0,6 kg CO_2e / kWh is used for the electricity grid emissions factor, however, LCA practitioner should use the electricity grid emission factor for appropriate region where the product is used.

The LCSRP method relies on a previous LCA of a similar enough product, as described in clause 5.3. For this example, a previous LCA of a similar mobile network radio product in operation 24/7 had a lifetime of 10 years and life cycle stage ratios of 93 % for the use stage and 7 % for the embodied GHG emissions [2].

Embodied GHG emissions = [(21 000 kg CO_2e / (93/100)] x [7/100] = 1 581 kg CO_2e

Hence, Embodied GHG emissions = 1 581 kg CO_2e

Total Life cycle GHG emissions of this example mobile network radio product X

= Embodied emissions + Use stage emissions

= 1 581 kg CO_2e + 21 000 kg CO_2e

= 2 2581 kg CO_2e

Using correct regional electricity mix in the assessment is crucial for getting representative results when using LCSRP method. If the target region is not exactly known at the time of the assessment, then the assessment should be done using different scenarios with globally low/typical/high electricity emission factors.

NOTE 2: For consumer products the use and lifetime might vary considerably, therefore it is important to fully understand the source where the life cycle stage ratios origin.

Annex L (informative): Additional information with examples regarding the similarity of products

High-level studies using the 1PLCA/LCSRP simplified LCA methods

In high-level studies like e.g. the ICT sector's carbon footprint on a global, regional, or national level, the 1PLCA/LCSRP simplified LCA methods can be used to estimate the embodied carbon footprints of similar products. For example, all smartphones can be estimated using an average based on LCA or Product Carbon Footprint (PCF) figures from one or a few large manufacturers instead of trying to get more precise figures for all models by all manufacturers. In this case, the requirement on similarity is lower. All TVs can in the same way be estimated using average LCA/PCF-figures.

To improve the accuracy of these high-level estimates, a category can be split into several subcategories e.g. TVs can be split into several subcategories based on technology being used (e.g. LCD/LED and OLED) and size (e.g. up to 42in and 43in and up).

Also scope 3 category 1 and 2 estimates by companies may use the 1PLCAor the LCSRP approach to estimate some or all the embodied carbon footprint of purchased goods and services and capital goods.

Going from one to more product parameters

The requirement on similarity is higher for estimates on a product level, especially for manufacturers. Increasing the number of product parameters can increase the accuracy of estimates substantially. The reason is that many electronic products are made of common parts that are similar for many models/versions, and then other parts vary depending on the exact model.

For example, TV and PC displays consist of typically an input/control module (and remote control for TVs), main processing unit or main PBA, power supply, connectors, and housing and mounting kit. Then the display module, frame and stand vary with size. A two-parameter model is enough to capture this behaviour. One parameter is fixed and can be changed to another fixed model, and then the display module, frame and stand vary with the display size.

Another common example is a smartphone model that can be equipped with memories of various sizes. An embodied carbon footprint formula can look like this:

Model: smartphone, except the memory (common parts)	40 kg CO_2e
Model: memory, depending on size	+5 kg CO_2e per every 128GB
Result: embodied emissions of 128GB smartphone	45 kg CO_2e
Result: embodied emissions of 256GB smartphone	50 kg CO_2e
Result: embodied emissions of 512GB smartphone	60 kg CO_2e

Displays

Different product types cannot be used to estimate other product types, e.g. a TV LCA is not suitable to estimate a PC display. Furthermore, the display technology should be similar. An LCD-TV LCA is not recommended to estimate an OLED TV. Neither is an old OLED TV LCA recommended to estimate a new OLD LCA. Preferably a new OLED TV LCA is used to estimate new OLED TVs of various sizes. If the production electricity consumption and electricity emission factors are also known, differences between various countries/regions in the world can also be accounted for.

The area of a PC display or TV can be used to scale LCA results quite well, and if the thickness is similar even the weight may scale with sufficient result. By going from one parameter to a two-parameter model increase the accuracy of the estimate as described in the clause above.

Servers

An LCA of a basic blade server is not suitable to use to estimate a high-end rack server due to the difference in how they are typically built.

A server can be equipped in many ways, and it may be better to use a model based on a few key parameters than to scale on only one parameter. Given the complexity of new AI servers with AI GPUs, it can quickly become more appropriate to use the PP method with 10 or more parameters.

Mobile network radios

Even mobile network radios that look very similar from the outside can be quite different on the inside due to differences in supported frequencies/standards, RF output power and the number of TX/RX (transmitters/receivers). A radio with high power, low frequency, and a few TX/RX may appear similar to a radio with low power (per TX), high frequency, and many TX/RX, but the share of electronics (e.g. PCBs, semiconductors) can be quite different which has a large impact on the results.

Just like servers, a model based on a few key parameters is better than scaling on only one parameter.

In a high-level study of mobile network services also including second and higher order impacts, the first order embodied impact is typically small and can therefore be roughly estimated with one parameter as in 1PLCA/LCSRP.

Smartphone (similar strategy and practice for tablets and laptops)

A good strategy and practice by manufacturers can be to use the PP method (or a similar method) for key products and then use the results to estimate other similar products, e.g. all models/versions related to the key products. If the products are very similar (e.g. same screen size and technology and battery capacity), only one parameter may be sufficient to estimate a similar product such as memory size.

- Memory size (GB)

By increasing the number of parameters, the accuracy can be increased. For a smartphone memory size can be accompanied by:

- Display size (cm^2)
- Processor (e.g. type, cores, performance)
- Camera module(s)
- Battery size (mAh or Wh)

Alternatively, the above parameters can also be combined into several smartphone models and then the memory can be added to increase accuracy. For example, developing three base models depending on specific combinations of the above parameters and then adding memory:

- Three base models
- Memory size (GB):
  - Basic model: 40 kg CO_2e + 5 kg CO_2e / 128 GB
  - Advanced model: 50 kg CO_2e + 5 kg CO_2e / 128 GB
  - Expert model: 60 kg CO_2e + 5 kg CO_2e / 128 GB

Using individual parameters and increasing the number of parts/parameters increases the accuracy of the model further. Then the LCA data used is typically no longer limited to only one LCA study and considering number of parameters and data sources, the model now corresponds to the PP method:

- Other chip sets
- All other parts
- Charger
- USB cable
- Packaging
- R&D
- Assembly location
- Transport to market

- Electricity data to be able to do regional or country specific estimates

Similar strategies and practice can be adopted by manufacturers of tablets and laptops as they are constructed like smartphones.

Annex M (informative): Example of GHG estimation for a display applying different parameters using the 1PLCA method

Considering an LCA of a 24" PC display has resulted in embodied GHG emissions of about 100 kg CO_2e.

The use stage GHG emissions have been measured and estimated (~25 W, 5 h/day) resulting in about 190 kg CO_2e (lifetime use), assuming a lifetime of 7 years and using a global electricity emission factor of 0,54 kg CO_2e/kWh to represent an average use on a global market.

$$50 \text{ kWh/year} \times 7 \text{ years} \times 0{,}54 \text{ kg } CO_2\text{e/kWh} = \sim 190 \text{ kg } CO_2\text{e (lifetime use)}$$

Based on this PC display LCA, the embodied GHG emissions of many similar PC displays can be estimated using only one characteristic product parameter as described in the 1PLCA approach, described in clause 5.4. In this example all different product parameters that could be used are presented. Normally only one parameter will be used by the LCA practitioner.

Table M.1 shows several common product parameters and resulting GHG emission factors that can be derived from the same PC display LCA. If the analysed product has similar characteristics to the parameter of the PC display studied by the LCA, the result will be about the same. The EFs are calculated by dividing the reference product GHG emissions (embodied or use stage) by the product parameter.

Table M.1: Examples of parameters and derived embodied emission factors from an existing LCA and resulting embodied GHG emissions for a 24" display

Product Parameter (PP)		Emission Factor (EF)	Resulting embodied GHG emissions
Weight	5 kg	20 kg CO_2e/kg	PP x EF = ~100 kg CO_2e for all pairs of PP x EF
Size	16 dm^2 (24")	6,25 kg CO_2e/dm^2	
Performance	1 920 × 1 080 pixels ~ 2,1 Mpixels	48 kg CO_2e / Mpixels	
Price (LCA based)	200 $	0,5 kg CO_2e/$	
Life cycle stage ratio (embodied/use)	53 % is related to use stage	0,53 x use stage emissions (kg CO_2e)	

If the analysed product has characteristics that diverse regarding the parameter of the PC display studied by the LCA, the result can vary significantly.

Taking the example of a larger PC display with a 30" screen, the different parameters' EFs will result in various results. Using the same lifetime and electricity grid emission factor result use stage GHG emissions of about 240 kg CO_2e (35 W × 1 825 h × 7 yrs = 447 kWh × 0,54 kg CO_2e/kWh = ~241 kg CO_2e).

Applying the same GHG emission factors to the larger PC display will result embodied GHG emissions varying between 140 kg and 398 kg CO_2e, as shown in Table M.2. It can be difficult to judge which parameters will result in the most accurate embodied GHG emission value.

Table M.2: Embodied GHG emissions for a 30" PC display using the 1PLCA approach for different parameters

Product Parameter (PP)		Emission Factor (EF)	Resulting embodied GHG emissions
Weight	10 kg	20 kg CO_2e/kg	200 kg CO_2e
Size	25 dm^2 (30")	6,25 kg CO_2e/dm^2	156 kg CO_2e
Performance	3 840 × 2 160 pixels ~ 8,3 Mpixels	48 kg CO_2e / Mpixels	398 kg CO_2e
Price (LCA based)	600 $	0,5 kg CO_2e/$	300 kg CO_2e
Life cycle stage ratio (embodied/use)	58 % of 241 kg CO_2e is related to use stage	0,58 x use stage emissions (kg CO_2e)	140 kg CO_2e

For PC displays, the size of a display is the primary key product parameter and therefore best suited to use in 1PLCA estimates. For the 30" PC display example presented the embodied GHG emissions, using the display size, can be estimated to 156 kg CO_2e.

Weight probably also scales well, but size is most likely better to use. Performance cannot be recommended to use as the embodied GHG emissions do not scale with performance as there are quick evolvements. For example, a display with a similar size and weight but with ultra-high definition (UHD 8,3 Mpixels) instead of high definition (HD 2,1 Mpixels), will not have embodied GHG emissions about four times higher than a HD display of similar size and weight.

It is also possible to combine parameters. To differentiate between PC display models of the same display size, it is better to use the price as a second parameter instead of performance, as different prices reflecting different performance like quality, resolution and additional features like display refresh time. To give an example, based on weight and price, the embodied GHG emissions of the 30" PC display can be adjusted to 228 kg CO_2e. How to create an adjustment formula is beyond the scope of the present document, but if it is used it should be described. In this example a simple average between a size-based and a price-based EF was used.

Not mentioned in the above example, is the importance of display technology. At least the general technology should be similar to apply 1PLCA. Clause 4.4.1 provides more details on the reusing data for similar products.

Annex N (informative): Example of GWP calculation using EEIO

The company's purchase price for the semiconductor product was 50 000$.

High level GHG emissions from the Korean electronics sector from 2017 [i.32] are used in this example.

From [i.32], the GHG intensity of semiconductor was 362 metric tons per million dollars (MT/$M) in 2017, which results in an EF of 0,362 kgCO_2e/$.

The GHG emissions associated in this example to the semiconductor is:

$$= 50\,000\ \$ \times 0{,}362\ \text{kgCO}_2\text{e/\$}.$$

$$= 18\,100\ \text{kgCO}_2\text{e}.$$

Depending on the number of semiconductors used in the ICT goods assessed, the respective GHG emissions associated with the included semiconductors can be estimated.

This process can be used to calculate the GHG emissions of other materials and components to estimate the total GHG emissions of a selected ICT goods.

Annex O (informative): Bibliography

- Recommendation ITU-T L.1430 (2013): "Methodology for assessment of the environmental impact of information and communication technology greenhouse gas and energy projects".
- Recommendation ITU-T L.1470 (2020): "Greenhouse gas emissions trajectories for the information and communication technology sector compatible with the UNFCCC Paris Agreement".

Annex P (informative): Change history

Date	Version	Information about changes
July 2023	V0.0.1	First draft aligned with ITU-T L.SimplifiedLCA
Sept 2023	V0.0.2	Agreed output from meeting 23.08.2023 (Doc02rev) incorporated
Oct 2023	V0.0.3	Agreed output from meeting 15.09.2023 (Doc04rev/EEPS(23)50r1) incorporated
Dec 2023	V0.0.4	OUTPUT OF 21 December 2023 meeting
Feb 2024	V0.0.5	Aligned with ITU-T L.SimplifiedLCA version
March 2024	V0.0.6	Output of 8 March Meeting
April 2024	V0.0.7	Output of 25 March 2024 meeting
April 2024	V0.0.8	Output of 18 April 2024 meeting
June 2024	V0.0.9	Output of 22 May 2024 meeting
June 2024	V0.0.10	Editorial update to include Document history information
November 2024	V0.0.11	Output of 24 October 2024 meeting
December 2024	V0.0.12	Output of 28 November 2024 meeting
February 2025	V0.0.13	Output of 23 January 2025 meeting
March 2025	V0.0.14	Output of 17 March 2025 meeting
April 2025	V0.0.15	Output of April 7 and 10 2025 meetings
May 2025	V0.0.16	Output of May 2 and 9 2025 meetings
June 2025	V0.0.17	Output of 5 June 2025 meeting
July 2025	V0.0.18	Output of 7 July 2025 meeting
August 2025	V0.0.19	Output of 29 July 2025 meeting
August 2025	V0.0.20	Output of 22 August 2025 meeting
September 2025	V0.0.21	Output of 18 September 2025 meeting
October 2025	V0.0.22	Output of 3 October 2025 meeting, stable draft
October 2025	V0.0.23	Output of 9 October 2025 meeting
October 2025	V0.0.24	Output of 30 October 2025 meeting
November 2025	V0.0.25	Output of 4 November 2025, final draft
November 2025	V0.0.26	Final draft, editorial clean-up

History

Version	Date	Status	
V1.1.0	April 2026	MAP process	MV 20260607: 2026-04-08 to 2026-06-08