Draft ETSI EN 304 132 V1.1.0 (2026-05)

EUROPEAN STANDARD

Environmental Engineering (EE); Mobile ICT devices (M-ICT); Product Specific Requirements for Life Cycle Assessment (LCA) of Smartphones

Reference

DEN/EE-MICT6

Keywords

LCA, smartphone

ETSI

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Sous-Préfecture de Grasse (06) N° w061004871

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Foreword

This draft European Standard (EN) has been produced by ETSI Technical Committee Environmental Engineering (EE), and is now submitted for the combined Public Enquiry and Vote phase of the ETSI EN Approval Procedure (ENAP).

Proposed national transposition dates	
Date of latest announcement of this EN (doa):	3 months after ETSI publication
Date of latest publication of new National Standard or endorsement of this EN (dop/e):	6 months after doa
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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).

"**must**" and "**must not**" are **NOT** allowed in ETSI deliverables except when used in direct citation.

Introduction

The present document defines Product Specific Requirements (PSR) for the Life Cycle Assessment (LCA) of smartphones to ensure that LCA studies conducted on smartphone models, including at the SKU level (e.g. different memory configurations and form factors such as foldables) are comparable, objective, and transparent.

Based on the LCA framework outlined in [1] and [i.1], as well as ideas and results presented in [i.2] and [i.3], the present document provides methodology guidance specific to smartphones, enhancing harmonization and communication of LCA results. It applies to all types of smartphones and sets requirements for conducting LCAs that allow valid comparisons between different device models.

The goals of the present document are to:

- Establish smartphone-specific LCA method and standard that builds upon and enhances existing general LCA standards by providing more specific and targeted guidelines for smartphones.
- Ensure consistent and comparable LCA studies across the industry.
- Improve the transparency and interpretation of smartphone LCA studies.
- Facilitate clear and standardized communication of LCA results at the SKU level for both manufacturers and distributors as part of their sustainability reporting, but not restricted to this application.

In addition, the present document should allow impact forecast and simulation already in the device design phase to help make conscious decisions in material and part/component selection for the reduction of the ecological footprint.

Background

The earth climate is affected by a human-caused climate change, which results in global warming. Global warming will have severe effects, even affecting possibly habitability in some parts, unless serious efforts are undertaken to limit the rise of the global temperatures.

The earth is in a radiation equilibrium given by the radiation it receives from the sun (149,6 million km average distance) and the radiation back into space, which leads to an equilibrium temperature. Unfortunately, this counter radiation happens predominantly in wavelength ranges where certain gases absorb, such as Carbon Dioxide or Methane (collectively Greenhouse Gases (GHG)), reducing the energy that is radiated back into space and thereby increasing the level of energy kept on the earth surface and atmosphere. The concentration of such gases has thus an immediate impact on that equilibration temperature. Mankind is using fossil carbon for energy generation and as a raw material for a multitude of applications. This activity causes the concentration of GHG to rise in the atmosphere which in turn fuels global warming.

To limit global warming and its associated negative consequences, the emissions of GHG should be limited. Therefore, many nations have come together to limit global warming to 1,5 °C in the Paris Climate Agreement. This requires a vigorous decarbonization of continents, nations and industries alike.

The manufacturing, transportation, use and disposal of smartphones are inevitably associated with GHG emissions. Seen globally the impact of Smartphone production and use is substantial. In 2023 alone, more than 1,3 billion smartphones were sold globally. This is only the number that is accumulated year on year into the connected base. Counting all smartphones in use, around 580 million tonnes of GHG are emitted annually which is ca. 1 % of all worldwide emissions. These should be reduced. The first step to the reduction of emissions is an inventory of what is currently emitted to define the basis from which emissions need to be reduced, and then a reliable measure is required to gauge the progress of emission reduction beyond effects of just different ways to calculate. This requires a standard for the calculation of emissions on a common basis that allows a fair comparison of emissions of the players in the industry and credible tracking of successes in reductions.

However, GHG emissions are only one of several impact categories considered in an LCA. A relevant category for Smartphones is also resource use. Resources are limited and conservation as well as recycling is paramount. Most elements of the periodic table are represented in smartphones. These elements need to be taken out of the soil unless taken from secondary (recycled sources). Mining of minerals and their subsequent processing in turn consumes land and causes the risk of pollution and natural habitat impediment or even destruction. Likewise, the resource use needs to be reduced, and primary sources replaced by secondary ones wherever that is possible. There is also a commercial and supply chain related side-effect to this. Some of the elements used in Smartphones are only available from a very few countries or with limited deposits which has an impact on supply risks and future price development. The present document will allow a comparable assessment of the resources used for any particular Smartphone design. By way of such comparison the progress of the industry in resource conservation will be made transparent.

Exemplified by two of the impact categories analogous considerations are also applicable and valid for the other impact categories.

Corporations in the ICT sector do not live in a societal vacuum. Their success depends on a friendly societal environment in which to operate. Modern societies increasingly demand corporate responsibility and a positive contribution to communities. Perception and acceptance of industry players is more and more influenced by these factors. Commitment to climate protection is an important, if not the most important element of it. A widely accepted standard for emission calculation associated with Smartphones is needed to serve as a fair, transparent and credible way to show to the public the industry contribution to climate protection.

Existing standards today are either not smartphone specific or allow a variance in methodology so that comparability is not possible. The present document closes this gap by creating Product Specific Requirements for Life Cycle Assessment (LCA) of smartphones.

Objectives of the present document

The present document allows performing LCA for Smartphones according to a common methodology. The results will allow an inventory of existing emissions for multi-vendor portfolios without the uncertainty of interpretation caused by variances in methodology application by different vendors or sources. Also, the results can directly be usable for financial statements, business and sustainability or any other reporting in relation to climate or environmental protection which may be legally mandatory in some jurisdictions. The present document will be readily acceptable to third parties auditing such reports.

The present document will also make emission reductions transparent achieved by players in the industry. These achievements will not disappear into differences in results just caused by different methodology application or calculations. If the latter were to happen no conclusion would be possible if a low emission value is due to real reduction or just a result of "optimized" calculation. Therefore, the present document will contribute to increased trust in the public that any reported emission reduction is real and not just apparent by different ways of calculation. Players achieving real emission reductions will be rewarded by making it transparent, as unambiguously as this is reasonably possible, and others encouraged to follow. Therein, the present document will already account for the coming Empowering the Consumer and Green Claims directives.

However, due to fundamentals of nature, no measurement and no calculation is completely free of uncertainties. Nevertheless, the ambition is to keep those as small as possible to allow valid comparisons between and/or predictions for different Smartphone models and portfolios to help making optimizations for emission reductions. Therefore, the present document also contains a semi-quantitative assessment of the uncertainty margin based on the expectable variance in input parameters.

Relationship to Existing LCA Standards

The present document is more specific than the "PCR" [1] (but reuses some its terminology for life cycle stages), the PCR guidance for electrical products [i.1] and the application of [1] to a mobile phone, [i.3]. The present PSR document is the first of its kind in the ICT industry.

1 Scope

The present document defines Product Specific Requirements for Life Cycle Assessment (LCA) of Smartphones so that it is possible to compare the LCA between different smartphone models on SKU level (e.g. considering different memory configurations). The present document provides a methodology for evaluating the environmental impact of smartphones objectively and transparently and is based upon the Life Cycle Assessment (LCA) framework standardized in ETSI ES 203 199 [1] and IEC 63366 [i.1]. The purpose of the present document is to:

- Provide smartphone-specific requirements, i.e. Product Specific Rules (PSR), in addition to those of ETSI ES 203 199 [1] and IEC 63366 [i.1] to ensure comparability of LCA studies of smartphones on SKU level.
- Harmonize the LCAs of smartphones.
- Increase the transparency and facilitate the interpretation of LCA studies of smartphones.
- Facilitate the communication of LCA studies of smartphones on SKU level.

The present document is valid for all types of smartphones. Moreover, the present document defines a set of requirements for which the LCA practitioners will comply. Comparisons of results from LCA studies of smartphones which belong to the same product family, including assessments which have been performed by different organizations, are within the scope of the present document.

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] 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".

[2] GSMA™ TS.09 v13.0: "Battery Life Measurement and Current Consumption Technique".

[3] ISO 14083:2023: "Greenhouse gases — Quantification and reporting of greenhouse gas emissions arising from transport chain operations".

[4] Global Logistics Emissions Council (GLEC) Framework v3.2.

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] IEC 63366:2025: "Product category rules for life cycle assessment of electrical and electronic product and systems".

[i.2] ETSI TR 103 679 (V1.1.1): "Environmental Engineering (EE); Explore the challenges of developing product group-specific Product Environmental Footprint Category Rules (PEFCRs) for smartphones".

[i.3] ETSI TR 104 080 (V1.1.1): "Environmental Engineering (EE); Example of a Life Cycle Assessment (LCA) of a mobile phone".

[i.4] M. Billaud, C. Clemm, D. Sánchez, M. Proske, M. Jügel, L. Stobbe, N. F. Nissen, M. Schneider-Ramelow: "ICs as drivers of ICT carbon footprint: an approach to more accurate die size assessment".

[i.5] Eynard U., Ardente F., Gama Caldas M., Spiliotopoulos C. and Mathieux F.: "Ecoreport tool - Manual", Publications Office of the European Union, Luxembourg, 2024.

[i.6] Commission Recommendation C(2021)9332 on the use of the Environmental Footprint methods to measure and communicate the life cycle environmental performance of products and organisations. Sections 4.4.8 and 4.4.9 in Annex I.

[i.7] Weltweite und europäische Kunststoffproduktion in den Jahren von 1950 bis 2024.

[i.8] Aktuelle Zahlen zur Kunststoffproduktion - Anteil fossiler Rohstoffe in Kunststoffproduktion rückläufig.

[i.9] Developer Environmental Footprint (EF).

[i.10] "Ecoreport tool - Manual", Publications Office of the European Union, 2024.

[i.11] 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.12] GSMATerminals - Battery-Life-Measurement-Test-Files-Public.

[i.13] imec.netzero.

[i.14] Vanhouche, B., Cardinael, P., Boakes, L., Ragnarsson, L. Å., Rolin, C., Raskin, J. P., & Parvais, B. (2024, June): "Environmental Analysis of RF Substrates". In 2024 Electronics Goes Green 2024+(EGG) (pp. 1-8). IEEE™.

[i.15] Andrae, A. S., & Vaija, M. S. (2017): "Precision of a streamlined life cycle assessment approach used in eco-rating of mobile phones". Challenges, 8(2), 21.

[i.16] How Sustainable are Our OLED Lighting Panels? LCA Study Shows Benefits.

[i.17] A. Holo, C. Dubarry, J.-C. Lopes Barbosa, M. Dupont, S. Chabaud, F. Templier: "45-4: MicroLED Display Life Cycle Assessment".

[i.18] Ellingsen, L. A. W., Majeau-Bettez, G., Singh, B., Srivastava, A. K., Valøen, L. O., & Strømman, A. H.: "Life cycle assessment of a lithium-ion battery vehicle pack". Journal of Industrial Ecology, 18(1), pp. 113-124, 2014.

[i.19] Peters, J. F., Baumann, M., Zimmermann, B., Braun, J., & Weil, M.: "The environmental impact of Li-Ion batteries and the role of key parameters-A review". Renewable and Sustainable Energy Reviews, 67, pp. 491-506, 2017.

[i.20] Romare, M., & Dahllöf, L.: "The life cycle energy consumption and greenhouse gas emissions from lithium-ion batteries", 2017.

[i.21] Dai, Q., Kelly, J. C., Gaines, L., & Wang, M.: "Life Cycle Analysis of Lithium-Ion Batteries for Automotive Applications". Batteries, 5(2), p. 48, 2019.

[i.22] Sustainability Impact Metrics:"Idemat and Ecoinvent, and eco-costs midpoint tables".

[i.23] Tin Sustainable Production.

[i.24] A.S.G Andrae: "A Comprehensive LCA method Addressing Uncertainty, Sensitivity, Rebound and Cut-off assumptions", 2025. DOI: 10.13140/RG.2.2.16390.89929.

[i.25] Commission Regulation (EU) 2023/1670 of 16 June 2023 laying down ecodesign requirements for smartphones, mobile phones other than smartphones, cordless phones and slate tablets pursuant to Directive 2009/125/EC of the European Parliament and of the Council and amending Commission Regulation (EU) 2023/826.

[i.26] Salonitis, K., Jolly, M. R., Zeng, B., & Mehrabi, H.: "Improvements in energy consumption and environmental impact by novel single shot melting process for casting". Journal of Cleaner Production, 137, pp. 1532-1542, 2016.

[i.27] ETSI ES 204 085 (V1.1.1): "Environmental Engineering (EE); Guidance on simplified Life Cycle Assessments (LCA) of Information and Communication Technologies (ICT)".

[i.28] Commission Regulation (EU) 2019/1782 of 1 October 2019 laying down ecodesign requirements for external power supplies pursuant to Directive 2009/125/EC of the European Parliament and of the Council and repealing Commission Regulation (EC) No 278/2009.

3 Definition of terms, symbols and abbreviations

3.1 Terms

3.1.1 Definition of covered product group: Smartphones

For the purposes of the present document, the terms given in Commission Recommendation C(2021)9332 [i.6] and the following apply:

A: allocation factor of burdens and credits between supplier and user of recycled materials

B: allocation factor of energy recovery processes: it applies both to burdens and credits

E^*_v: specific emissions and resources consumed (per functional unit) arising from the acquisition and pre-processing of primary material assumed to be substituted by recyclable materials

E_D: specific emissions and resources consumed (per functional unit) arising from disposal of waste material at the EoL of the analysed product, without energy recovery

E_{ER}: specific emissions and resources consumed (per functional unit) arising from the energy recovery process (e.g. incineration with energy recovery, landfill with energy recovery, etc.)

$E_{recycled}$: specific emissions and resources consumed (per functional unit) arising from the recycling process of the recycled (reused) material, including collection, sorting and transportation process

$E_{recyclingEoL}$: specific emissions and resources consumed (per functional unit) arising from the recycling process at EoL, including collection, sorting and transportation process

$E_{SE,heat}$ and $E_{SE,elec}$: specific emissions and resources consumed (per functional unit) that would have arisen from the specific substituted energy source, heat and electricity respectively

Lower Heating Value (LHV): material in the product that is used for energy recovery

Q_{sin}: quality of the ingoing secondary material, i.e. the quality of the recycled material at the point of substitution

Q_{sout}: quality of the outgoing secondary material, i.e. the quality of the recyclable material at the point of substitution

Q_p: quality of the primary material, i.e. quality of the primary material

R_1: proportion of material in the input to the production that has been recycled from a previous system

R_2: proportion of the material in the product that will be recycled (or reused) in a subsequent system. R2 shall therefore take into account the inefficiencies in the collection and recycling (or reuse) processes. R2 shall be measured at the output of the recycling plant

R_3: proportion of the material in the product that is used for energy recovery at EoL

smartphone: cordless handheld electronic device, which has the following characteristics [i.25]:

- It is designed for long-range voice communication over either a cellular telecommunications network or a satellite-based telecommunications network, requiring a SIM card, eSIM or similar means to identify the connected parties.
- It is designed for battery mode usage, while connection to mains via an external power supply and/or wireless power transmission is mainly for battery charging purposes.
- It is not designed to be worn on the wrist.
- It is characterized by wireless network connection, mobile use of internet services, an operating system optimized for handheld use and the ability to accept original and third-party software applications.
- It has an integrated touch screen display with a viewable diagonal size of 10,16 centimetres (or 4,0 inches) or more, but less than 17,78 centimetres (or 7,0 inches).
- Where the device has a foldable display or has more than one display, at least one of the displays falls into the size range in either opened or closed mode.

$X_{ER,heat}$ and $X_{ER,elec}$: efficiency of the energy recovery process for both heat and electricity

3.1.2 Out of scope

All devices that do not comply with clause 3.1 of the present document shall be considered to be out of scope. Additionally, mobile phones using satellite-based telecommunications network as its primary form of communication are out of scope.

3.2 Symbols

Void.

3.3 Abbreviations

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

5G	5th Generation
A2DP	Advanced Audio Distribution Profile
AAC	Advanced Audio Coding
ABS	Acrylonitrile Butadiene Styrene
ADP	Abiotic Depletion Potential
AP	Access Point
BOF	Basic Oxygen Furnace
BSI	Back-Side Illumination
CED	Cumulative Energy Demand
CFF	Circular Footprint Formulae
CO	Cobalt
COM	COMpleteness
CPU	Central Processing Unit
DASH	Dynamic Adaptive Streaming over HTTP
DQR	Data Quality Rating
DUT	Device Under Test
EDR	Enhanced DataRate

EF	Elementary File
EoL	End of Life
EoLT	End of Life Treatment
ErP	Energy related Products
eSIM	embedded Subscriber Identity Module
EU	European Union
E-UTRA	Evolved UMTS Terrestrial Radio Access
FPC	FingerPrint Cards
GaA	Gallium Arsenide
GaN	Gallium Nitride
GAN	Generic Access Network
GER	Geographical Representativeness
GFLOPS	Giga Floating Point Operations Per Second
GHG	GreenHouse Gas
GLEC	Global Logistic Emissions Council
GPRS	General Packet Radio Service
GPS	Global Positioning System
GPU	Graphics Processing Until
GSM	Global System for Mobile communications
GVW	GROOS Vehicle Weight
GWP	Global Warming Potential
GWP100	Global Warming Potential over a century
HDI	High Density Interconnector
HDPE	High Density PolyEthylene
HTML	HyperText Markup Language
HTTP	HyperText Transfer Protocol
HVAC	Heat Ventilation Air Conditioning
ICT	Information Communication Technology
IEA	International Energy Agency
IMEC	Interuniversity MicroElectronics Centre
IPA	IsoPropyl Alcohol
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCD	Liquid Crystal DIsplay
LDPE	Low Density PolyEthylene
LHV	Lower Heating Value
LLDPE	Linear Low Density PolyEthylene
LNM	Logic and Non Memory
LTE	Long Term Evolution
LTPS	Low Temperature Polycrystalline Silicon
MAG	Metal Active Gas
MCD	Material Content Declaration
MIG	Metal Inert Gas
MJ	MegaJoule
OLED	Organic Light Emitting Diode
PC	PolyCarbonate
PCB	Printed Circuit Board
PCBA	Printed Circuit Board Assembly
PCR	Product Category Rules
PET	PolyEthyleneTerphtalate
PLMN	Public Land Mobile Network
PR	Precision
PSR	Product Specific Rules
RAM	Random Access Memory
RF	Radio Frequency
RR	Recycling Rate
SBR	Spectral Band Replication
SiC	Silicon Carbide
SIM	Subscriber Identity Module
SKU	Stock-Keeping Unit
SMT	Surface Mounting Technology
TB	TeraByte

TER	Technological Representativeness
TEU	Twenty foot Equivalent Unit
TFLOPS	Tera Floating point Operations Per Second
TIR	Time Representativeness
UE	User Equipment
USB	Universal Serial Bus
VoLTE	Voice over LTE
VoNR	Voice over New Radio
VoWiFi	Voice over Wi-Fi®
VPN	Virtual Private Network
WCDMA	Wideband Code Division Multiple Access
WLAN	Wireless Local Area Network
WTW	Well-To-Wheel

4 LCA requirements for Smartphones

4.1 Smartphone Specific Rules

4.1.1 Functional Unit Description

The functional unit serves as the baseline for the Lifecycle Assessment (LCA) of smartphones. It provides a standardized measure of the device's functionality, ensuring that environmental impacts are evaluated on a consistent and comparable basis across different devices. The functional unit shall define the expected usage scenario, encompassing the primary functions of a smartphone over its assumed lifetime.

This clause outlines the functional unit that shall be used when conducting LCA studies for smartphones under the present document. The defined functional unit captures typical smartphone usage and reflects both the product's functionality and its environmental impacts over its operational life.

For the purposes of the present document, the functional unit for a smartphone shall be defined as:

"Enable 3G/4G/5G access for 5,6 hours of daily use including call (0,16 hours), streaming content (1,2 hours), application software (1,2 hours), camera (0,1 hours), Bluetooth® interface (0,2 hours), GPS tracking (0,3 hours), browsing (1,34 hours) and idle(1,1 hours) over a period of 5 years."

The functional unit shall represent:

- Core Communication Functions: The ability to conduct voice calls for 0,16 hours daily over any mobile network (3G/4G/5G).
- Streaming content Usage: The ability to stream including video progressive steaming, dynamic adaptive streaming over HTTP(DASH), audio streaming for 1,2 hours daily.
- Application software: the ability to use common applications for 1,2 hours daily.
- Camera: the ability to use camera operation and video recording for 0,1 hours daily.
- Bluetooth interface: the ability to use Bluetooth headset for 0,2 hours daily.
- GPS tracking: The ability to utilize geo-navigation for 0,3 hours daily.
- Browsing: The ability to access and browse the internet for 1,34 hours daily.
- Idle Usage: The ability to standby time for 1,1 hours daily.
- Lifetime Expectancy: A functional service life of 5 years, representing the expected period of regular use.

Moreover, the defined functional unit shall be applied uniformly to all LCA studies conducted under the present document. Also, the functional unit shall be used to model energy consumption, material use, and environmental impacts over the smartphone's defined lifetime.

This functional unit reflects typical consumer usage patterns and aligns with the expected technological and functional performance of smartphones. The 5-year timeframe ensures that the LCA considers the impacts over a realistic period, accounting for both production and operational phases.

4.1.2 System Boundary

4.1.2.0 Introduction

This section cover System Boundaries for the PSR.

4.1.2.1 General

The system boundary establishes the scope of the Life Cycle Assessment (LCA) for smartphones, detailing the lifecycle stages, part/components, and processes included in the analysis.

The LCA shall include the following parts/components as part of the studied product system:

1) Smartphone: The core product, including all internal parts/components (e.g. display, battery, printed circuit boards, integrated circuits, antennas, and cameras).
2) Product Packaging: All materials used for packaging the smartphone, such as boxes, protective inserts, and labels.
3) Inbox Materials: All items included in the product package, which can include but is not limited to:
    a) Charger.
    b) USB cable.
    c) Headset.
    d) Instruction leaflets and warranty cards.
    e) Protective Cover.
    f) SIM Extraction Tool.

These elements shall be analysed for their contribution to the lifecycle environmental impacts.

The approach shall follow a cradle-to-grave perspective, encompassing all phases of the product lifecycle, from raw material acquisition to end-of-life treatment.

The following structure integrates generalized lifecycle categories for clarity while aligning with ETSI ES 203 199 [1] for subcategories and lifecycle stages.

4.1.2.1.0 Life cycle stages

4.1.2.1.1 Raw Material Acquisition

This stage as defined by ETSI ES 203 199 [1] encompasses the extraction and processing of all raw materials required for the production of the smartphone, its packaging, and inbox materials:

- A1 Raw Material Extraction: Includes the sourcing of metals (e.g. gold for connectors, lithium and cobalt for batteries, rare earth elements for displays) and non-metals (e.g. silicon for integrated circuits, polymers for covers). The impacts primarily relate to resource depletion and material acquisition processes.
- A2 Raw Material Processing: Covers the transformation of raw materials into intermediate materials or parts/components for further manufacturing.

4.1.2.1.2 Production

This stage as defined by ETSI ES 203 199 [1] involves the production of smartphone parts/components, their assembly into a final product, and the inclusion of all packaging and inbox accessories:

- B1.1 Parts Production: Includes the manufacturing of Printed Circuit Boards (PCBs), batteries, displays, antennas, cameras, covers, and other key parts/components. Here also the transportation of materials, components, and subassemblies from the supplier's production site to the assembly site(s) and/or packaging site(s) is included.
- B1.2 Assembly: Comprehends the final assembly of all parts/components into the finished product. It also includes the production of packaging materials (e.g. boxes, protective inserts) and inbox accessories (e.g. chargers, USB cables, headsets, instruction leaflets).

4.1.2.1.3 Transport Distribution

This stage accounts for the transportation of the finished product from the assembly location to the country of sale:

- G Transport:
  - Processes Included: Shipping, air freight, and road transportation based on the distance travelled and the transportation method.
  - Impacts Considered: Emissions, energy consumption, and resource use during transportation.

4.1.2.1.4 Use Phase

The use phase as defined by ETSI ES 203 199 [1] captures the environmental impacts associated with the operation of the smartphone during its lifetime:

- C1 ICT Goods Use:
  - Energy Consumption: Includes energy required for charging the device during daily use.
  - Spare Parts Production: Covers the manufacturing and transportation of spare parts used for repair, reuse, or upgrades. Extending device service life through repair is emphasized as a sustainable practice.

4.1.2.1.5 End-of-Life Treatment

This stage as defined by ETSI ES 203 199 [1] addresses the processes involved in managing the smartphone, packaging, and inbox materials after their operational life has ended:

- D2.1 Storage/Disassembly/Dismantling/Shredding: Includes the collection, sorting, and preparation of materials for recycling.
- D2.2 Recycling: Focuses on recovering valuable materials (e.g. metals and plastics) for reuse.
- D3 Other End-of-Life Treatment: Addresses the disposal of non-recyclable parts/components through incineration or landfill.

4.1.2.2 Exclusions from System Boundary

The following stages and processes as defined by ETSI ES 203 199 [1] are not included in the present studied product system of one smartphone:

- B1.3 ICT Manufacturer Support Activities: Processes such as office energy consumption, and administrative tasks related to manufacturing are excluded.
- B3 ICT Specific Site Construction: Construction of facilities for manufacturing is excluded.
- C2, C3, and C4: Support goods use, operator support activities, and service provider support activities are excluded, as they are not applicable to the studied product system.

- D1 Preparation for Extended Operating Lifetime: Processes to prepare the device for extended use are excluded from the boundary.

Examples (IEC 63366 [i.1]):

- Lighting, heating, sanitary facilities and infrastructure cleaning.
- Employee transport.
- Manufacture and maintenance of the manufacturing facility and machines if their environmental impacts are not contributing to significant proportion to the environmental impact share of the reference flow.
- Construction and maintenance of the infrastructure if their environmental impacts are not proportional to the reference flow.
- Transport systems and infrastructure if their environmental impacts are not proportional to the reference flow.
- Marketing activity related to the product.
- Staff catering facilities.

4.1.2.3 Cut-off criteria

The cut-off used is clear from the parametric set-up of the present document.

4.1.3 Life Cycle Inventory

4.1.3.0 General

The impacts are expressed for manufacturing processes of parts/components and raw materials.

4.1.3.1 Production

4.1.3.1.1 Mechanical parts

The amount of electricity used per kg for mechanical parts processing vary considerably depending on material and process listed in Table 1. Applicable processes shall be used and default electricity GWP100: 0,7 kg CO_2e/kWh and Default electricity ADP: 5E-7 kg Sb-e/kWh shall be used unless proven otherwise. The mass of the mechanical part shall be multiplied according to Equations (1) and (2) with each applicable process in Table 1. See Annex I-H for further details about default values.

The Mechanical parts for the smartphone at hand shall use Equations (1) and (2) as applicable:

$$GWP_{\text{Mechanical part}}\ \{\text{kg } CO_2\text{e}\} = \text{Mass of Mechanical part } \{\text{kg}\} \times El_{\text{processing Mechanical part,GWP}} \quad (1)$$

$$ADP_{\text{Mechanical part}}\ \{\text{kg Sb-e}\} = \text{Mass of Mechanical part } \{\text{kg}\} \times El_{\text{processing Mechanical part,ADP}} \quad (2)$$

where:

- $GWP_{\text{Mechanical part}}$ = kg CO_2e for a Mechanical part
- $ADP_{\text{Mechanical part}}$ = kg Sb-e for a Mechanical part
- $El_{\text{manufacturing Mechanical part,GWP}}$ = kg CO_2e/kWh for electricity mix eSIM. Default: 0,7
- $El_{\text{manufacturing Mechanical part,ADP}}$ = kg Sb-e/kWh for electricity mix eSIM. Default: 5E-7

Table 1: Applicable processing electricity use for mechanical parts

Process	Electricity used, kWh/kg
Fiber laser cutting, Al, 1 mm	0,004
Fiber laser cutting, Al, 10 mm	0,241
Forging aluminium	1,08
Machining aluminium	0,321
Rolling aluminium foil	7,53
Rolling aluminium sheet	2,58
Scouring aluminium	4,16
Welding aluminium arc	1,3
Die casting aluminium	8
Steel welded pipes, 8,5 % scrap BOF	14,97
Rolling steel	0,802
Fiber laser cutting steel, 1 mm	0,00268
Fiber laser cutting steel, 10 mm	0,1338
Electric MIG welding, 4 mm steel	6,52
Welding steel, MAG	1,21
Welding steel, autogenous	0,993
Injection moulding - machine only	2,24
Injection moulding - production site	5,71
Film HDPE 50 µm (extrusion)	0,53
Film LDPE 50 µm (extrusion)	0,54
Film PC 50 µm (extrusion)	1,19
Film PET 50 µm (extrusion/cast film)	0,92

4.1.3.1.2 Displays

Cradle-to-gate modelling of displays.

Total active area (A) of a display shall be calculated according to Equations (3) to (5) as:

$$A = Height \times Width \tag{3}$$

$$Height = \frac{D}{\sqrt{\left(\frac{W}{H}\right)^2 + 1}} \tag{4}$$

$$Width = Height \times \frac{W}{H} \tag{5}$$

Where:

- A = active area of display (in^2)
- D = Screen size diagonal in inches (e.g. 6,8)
- W = Width factor of screen aspect ratio (e.g. 20)
- H = Height factor of screen aspect ratio (e.g. 9)

EXAMPLE: With D = 6,8, W = 20, H = 9 → *Height*: 2,79 inches and *Width*: 6,2 inches and A = 17,3 in^2 {1 in^2 = 6,4516 cm^2} = 111,62 cm^2.

Default electricity GWP100: 0,7 kg CO_2e/kWh, Default electricity ADP: 5E-7 kg Sb-e/kWh.

The displays in the smartphone at hand shall use Equations (6) to (17) as applicable:

LTPS LCD

total active area display (cm^2) × ((0,003 + 0,01 kWh electricity × electricity mix upstream kgCO_2e/kWh + 3,3E-6 kg × (340 + 680 kWh electricity × electricity mix upstream kgCO_2e/kWh + 670 kWh electricity × electricity production kgCO_2e/kWh) + 0,005 kWh electricity × electricity mix display assembly kgCO_2e/kWh)) (6)

and

total active area display (cm^2) × ((2E-7 + 0,01 kWh electricity × electricity mix upstream kgSb-e/kWh + 3,3E-6 kg × (2E-8 + 680 kWh electricity × electricity mix upstream kgSb-e/kWh + 670 kWh electricity × electricity production kgSb-e/kWh) + 1,3E-9 kWh electricity × electricity mix display assembly kgSb-e/kWh)) (7)

OLED rigid

total active area display (cm^2) × ((0,0048 + 0,016 kWh electricity × electricity mix upstream kgCO_2e/kWh + 5,7E-6 kg × (340 + 680 kWh electricity × electricity mix upstream kgCO_2e/kWh + 670 kWh electricity × electricity production kgCO_2e/kWh) + 0,005 kWh electricity × electricity mix display assembly kgCO_2e/kWh)) (8)

and

total active area display (cm^2) × ((3E-7 + 0,016 kWh electricity × electricity mix upstream kgSb-e/kWh + 5,7E-6 kg × (3E-8 + 680 kWh electricity × electricity mix upstream kgSb-e/kWh + 670 kWh electricity × electricity production kgSb-e/kWh) + 0,005 kWh electricity × electricity mix display assembly kgSb-e/kWh)) (9)

OLED flexible

total active area display (cm^2) × ((0,0075 + 0,025 kWh electricity × electricity mix upstream kgCO_2e/kWh + 8,5E-6 kg × (340 + 680 kWh electricity × electricity mix upstream kgCO_2e/kWh + 670 kWh electricity × electricity production kgCO_2e/kWh) + 0,013 kWh electricity × electricity mix display assembly kgCO_2e/kWh)) (10)

and

total active area display (cm^2) × ((7E-7 + 0,025 kWh electricity × electricity mix upstream kgSb-e/kWh + 8,5E-6 kg × (6E-8 + 680 kWh electricity × electricity mix upstream kgSb-e/kWh + 670 kWh electricity × electricity production kgSb-e/kWh) + 0,013 kWh electricity × electricity mix display assembly kgSb-e/kWh)) (11)

miniLED

total active area display (cm^2) × ((0,0081 + 0,027 kWh electricity × electricity mix upstream kgCO_2e/kWh + 9,5E-6 kg × (340 + 680 kWh electricity × electricity mix upstream kgCO_2e/kWh + 670 kWh electricity × electricity production kgCO_2e/kWh) + 0,014 kWh electricity × electricity mix display assembly kgCO_2e/kWh)) (12)

and

total active area display (cm^2) × ((5E-7 + 0,027 kWh electricity × electricity mix upstream kgSb-e/kWh + 9,5E-6 kg × (6E-8 + 680 kWh electricity × electricity mix upstream kgSb-e/kWh + 670 kWh electricity × electricity production kgSb-e/kWh) + 0,014 kWh electricity × electricity mix display assembly kgSb-e/kWh)) (13)

microLED

total active area display (cm^2) × ((0,0129 + 0,043 kWh electricity × electricity mix upstream kgCO_2e/kWh + 1,5E-5 kg × (340 + 680 kWh electricity × electricity mix upstream kgCO_2e/kWh + 670 kWh electricity × electricity production kgCO_2e/kWh) + 0,023 kWh electricity × electricity mix display assembly kgCO_2e/kWh)) (14)

and

total active area display (cm^2) × ((9E-7 + 0,043 kWh electricity × electricity mix upstream kgSb-e/kWh + 1,5E-5 kg × (9E-8 + 680 kWh electricity × electricity mix upstream kgSb-e/kWh + 670 kWh electricity × electricity production kgSb-e/kWh) + 0,023 kWh electricity × electricity mix display assembly kgSb-e/kWh)) (15)

Displays which cannot be characterized by any of these shall use this formula:

total active area display (cm^2) × ((0,0075 + 0,025 kWh electricity × electricity mix upstream kgCO_2e/kWh + 8,5E-6 kg × (340 + 680 kWh electricity × electricity mix upstream kgCO_2e/kWh + 670 kWh electricity × electricity production kgCO_2e/kWh) + 0,013 kWh electricity × electricity mix display assembly kgCO_2e/kWh)) (16)

and

total active area display (cm^2) × ((7E-7 + 0,025 kWh electricity × electricity mix upstream kgSb-e/kWh + 8,5E-6 kg × (6E-8 + 680 kWh electricity × electricity mix upstream kgSb-e/kWh + 670 kWh electricity × electricity production kgSb-e/kWh) + 0,013 kWh electricity × electricity mix display assembly kgSb-e/kWh)) (17)

See Annex I-C (informative) for further details.

4.1.3.1.3 Batteries

For batteries the cradle-to-gate impact shall be expressed per Wh nominal battery energy capacity.

Default electricity GWP100: 0,7 kg CO_2e/kWh, Default electricity ADP: 5E-7 kg Sb-e/kWh

$$Battery_{Wh} = \text{Vb} \times \text{nominal charging capacity (Ah).}$$

The batteries in the smartphone at hand shall use Equations (18) to (21) as applicable:

$$GWP_{per\ Wh} = \frac{10{,}5 + 27{,}5x_{upstream,batt} + 30x_{cell} + 10x_{module}}{E} \quad (18)$$

$$GWP_{battery,Wh} = GWP_{per\ Wh} \times Battery_{Wh} \quad (19)$$

$$ADP_{per\ Wh} = \frac{0{,}00002 + 27{,}5x_{upstream,batt} + 30x_{cell} + 10x_{module}}{E} \quad (20)$$

$$ADP_{battery,Wh} = ADP_{per\ Wh} \times Battery_{Wh} \quad (21)$$

Where:

- Vb = Nominal battery voltage measured in Volts
- $GWP_{battery,Wh}$= kg CO_2e for battery in phone based on energy density
- $GWP_{per\ Wh}$= kg CO_2e/Wh for battery in phone
- $Battery_{Wh}$= Nominal energy capacity (Wh) of battery in phone
- $ADP_{battery,Wh}$= kg Sb-e for battery in phone based on energy density
- $ADP_{per\ Wh}$= kg Sb-e/Wh for battery in phone
- x_{cell}= kg CO_2e/kWh for electricity mix used in cell assembly. Default: 0,7 kg Sb-e/kWh for electricity mix used in cell assembly. Default: 5E-7
- x_{module}= kg CO_2e/kWh for electricity mix used in module assembly. Default: 0,7 kg Sb-e/kWh forelectricity mix used in cell assembly. Default: 5E-7
- $x_{upstream,batt}$ = kg CO_2e/kWh for electricity mix used in the upstream from cell assembly. Default: 0,7 kg Sb-e/kWh for electricity mix used in cell assembly. Default: 5E-7
- E = Battery energy density Wh/kg for battery used in phone.

Batteries which cannot be characterized by Equations (18) to (21) shall use (22) to (25):

$$GWP_{per\ mass} = 10{,}5 + 27{,}5x_{upstream,batt} + 30x_{cell} + 10x_{module} \quad (22)$$

$$GWP_{battery,mass} = GWP_{per\ mass} \times Battery_{mass} \quad (23)$$

$$ADP_{per\ mass} = 0{,}00002 + 27{,}5x_{upstream,batt} + 30x_{cell} + 10x_{module} \quad (24)$$

$$ADP_{battery,mass} = ADP_{per\ mass} \times Battery_{mass} \quad (25)$$

Where:

- $GWP_{battery,mass}$= kg CO_2e for battery in phone based on mass
- $GWP_{per\ mass}$= kg CO_2e/kg for battery in phone
- $ADP_{battery,mass}$= kg Sb-e for battery in phone based on mass
- $ADP_{per\ mass}$= kg Sb-e/kg for battery in phone
- $Battery_{mass}$ = mass of Battery (kg)

See Annex I-D (informative) for further details.

4.1.3.1.4 Integrated Circuits

The emissions of integrated circuits are mostly parametrized by the silicon die area of the chip inside the package. This is not to be mistaken with the overall area of the complete chip package as this includes the plastic housing into which the silicon chip is embedded. Using this as the basis for LCA would yield systematically too high values as results. More accurate ways to determine the silicon die area are x-raying or mechanical decapping and microscopical inspection. For details, see [i.4].

In summary die area is in theory arguably the correct functional unit of ICs as the die area is linked to the production processes more strongly than other bases. However, the die areas are difficult to measure fairly and the procedure is not standardized. Die area measurements, while seemingly precise, often require detailed proprietary fabrication data, limiting broader accessibility. Moreover, the so-called die to package ratios can vary significantly which makes it a non-robust approach. Evidently, the current approaches (for IC quantification in LCA) cannot be used equally by all manufacturers of smartphones and beyond. Anyway, a certain number of parameters, for which data can be collected equally by each manufacturer, should be the basis of any approach which solves the dilemma. The following approaches are focusing on practical applicability and data accessibility. The methods for cradle-to-gate footprint assessment of ICs are based on equal information availability.

Cradle-to-gate modelling of memories

The default electricity mix has these characteristics: 0,7 kg CO_2e/kWh and 5E-7 kg Sb-e/kWh.

The memory chips in the smartphone at hand shall use Equations (26) to (31) as applicable:

Back-end production cradle-to-gate for any kind of memory for GWP100 = total mass memories (kg) × (24 + 63 kWh electricity × electricity mix upstream kgCO_2e/kWh + 670 kWh electricity × electricity mix back end kgCO_2e/kWh) (26)

Back-end production cradle-to-gate for any kind of memory for ADP = total mass memories (kg) × (3E-5 + 63 kWh electricity × electricity mix upstream kgSb-e/kWh + 670 kWh electricity × electricity mix back end kgSb-e/kWh) (27)

RAM

Front-end production cradle-to-gate for RAM memories GWP100 = RAM (GB) × (0,198 + 0,524 kWh electricity × electricity mix upstream kgCO_2e/kWh + 0,77 kWh electricity × electricity mix production wafer fab kgCO_2e/kWh) (28)

Front-end production cradle-to-gate for RAM memories ADP = RAM (GB) × (3,5E-7 + 0,524 kWh electricity × electricity mix upstream kgSb-e/kWh + 0,77 kWh electricity × electricity mix production wafer fab kgSb-e/kWh) (29)

NAND Internal memory

Front-end production cradle-to-gate for internal memories GWP100 = Internal memory (GB) × (0,008 + 0,0213 kWh electricity × electricity mix upstream kgCO_2e/kWh + 0,032 kWh × electricity mix wafer fab kgCO_2e/kWh) (30)

Front-end production cradle-to-gate for internal memories ADP = Internal memory (GB) × (1,4E-8 + 0,0213 kWh electricity × electricity mix upstream kgSb-e/kWh + 0,032 kWh × electricity mix wafer fab kgSb-e/kWh) (31)

Cradle-to-gate modelling of logic chips and non-memory chips

The logic and non-memory (LNM) chips in the smartphone at hand shall use Equations (32) to (47) as applicable:

1a) Back-end production cradle-to-gate for any kind of logic & non-memory (LNM) chip for GWP100 = total mass LNM chip (kg) × (24 + 63 kWh electricity × electricity mix upstream kgCO_2e/kWh + 670 kWh electricity × electricity mix back end kgCO_2e/kWh) (32)

1b) Back-end production cradle-to-gate for any kind of logic & non-memory (LNM) chip for ADP = total mass LNM chip (kg) × (3E-5 + 63 kWh electricity × electricity mix upstream kgSb-e/kWh + 670 kWh electricity × electricity mix back end kgSb-e/kWh) (33)

2a) Front-end production cradle-to-gate for Si wafer for phone chips GWP100 = Chip performance (TFLOPS) × (0,207 + 0,547 kWh electricity × electricity mix upstream kgCO_2e/kWh + 1,28 kWh × electricity mix wafer fab kgCO_2e/kWh) (34)

2b) Front-end production cradle-to-gate for Si wafer for phone chips ADP = Chip performance (TFLOPS) × (3,7E-7 + 0,547 kWh electricity × electricity mix upstream kgSb-e/kWh + 1,28 kWh × electricity mix wafer fab kgSb-e/kWh) (35)

3a) Front-end production cradle-to-gate for Si wafer, CPUs, GWP100 = Chip performance (TFLOPS) × (0,41 + 1,1 kWh electricity × electricity mix upstream kgCO_2e/kWh + 2,55 kWh × electricity mix wafer fab kgCO_2e/kWh) (36)

3b) Front-end production cradle-to-gate for Si wafer, CPUs, ADP = Chip performance (TFLOPS) × (7,3E-7 + 1,1 kWh electricity × electricity mix upstream kgSb-e/kWh + 2,55 kWh × electricity mix wafer fab kgSb-e/kWh) (37)

4a) Front-end production cradle-to-gate for Si wafer, GPUs, GWP100 = Chip performance (TFLOPS) × (0,04 + 0,1 kWh electricity × electricity mix upstream kgCO_2e/kWh + 0,24 kWh × electricity mix wafer fab kgCO_2e/kWh) (38)

4b) Front-end production cradle-to-gate for Si wafer, GPUs, ADP = Chip performance (TFLOPS) × (7E-8 + 0,1 kWh electricity × electricity mix upstream kgCO_2e/kWh + 0,24 kWh × electricity mix wafer fab kgCO_2e/kWh) (39)

5a) Front-end production cradle-to-gate for Si wafer, CPU core, GWP100 = CPU Cores × (0,02 + 0,05 kWh electricity × electricity mix upstream kgCO_2e/kWh + 0,12 kWh × electricity mix wafer fab kgCO_2e/kWh) (40)

5b) Front-end production cradle-to-gate for Si wafer, CPU core, ADP = CPU Cores × (3,5E-8 + 0,05 kWh electricity × electricity mix upstream kgSb-e/kWh + 0,12 kWh × electricity mix wafer fab kgSb-e/kWh) (41)

6a) Front-end production cradle-to-gate for ICs which are neither processors, CPUs, GPUs nor memories, GWP100 = IC mass (kg) × (80 + 200 kWh electricity × electricity mix upstream kgCO_2e/kWh kgCO_2e/kWh + 500 kWh × electricity mix wafer fab kgCO_2e/kWh) (42)

6a) Front-end production cradle-to-gate for ICs which are neither processors, CPUs, GPUs nor memories, ADP = IC mass (kg) × (1,6E-4 + 200 kWh electricity × electricity mix upstream kgSb-e/kWh + 500 kWh × electricity mix wafer fab kgSb-e/kWh) (43)

7a) Front-end production cradle-to-gate for GaAs wafer for phone chips, GWP100 = Chip performance (TFLOPS) × (0,26 + 0,7 kWh electricity × electricity mix upstream kgCO_2e/kWh + 1,28 kWh × electricity mix wafer fab kgCO_2e/kWh) (44)

7b) Front-end production cradle-to-gate for GaAs wafer for phone chips, ADP = Chip performance (TFLOPS) × (1,1E-6 + 4,1 kWh electricity × electricity mix upstream kgSb-e/kWh + 1,28 kWh × electricity mix wafer fab kSb-e/kWh) (45)

8a) Front-end production cradle-to-gate for GaN on SiC wafer for phone chips, GWP100 = Chip performance (TFLOPS) × (0,9 + 2,4 × kWh electricity × electricity mix upstream kgCO_2e/kWh + 1,28 kWh × electricity mix wafer fab kgCO_2e/kWh) (46)

8b) Front-end production cradle-to-gate for GaN on SiC wafer for phone chips, ADP = Chip performance (TFLOPS) × (9,9E-7 + 3,69 × kWh electricity × electricity mix upstream kgSb-e/kWh + 1,28 kWh × electricity mix wafer fab kgSb-e/kWh) (47)

1a-b, Equations (32) and (33), shall be used for all logic ICs.

For processor ICs which have dies made of Si, 2a-b, Equations (34) and (35), shall be used.

For CPUs, 3a-b (Equations (36) and (37)) and 5a-b (Equations (40) and (41)) shall be used.

For GPUs, 4a-b (Equations (38) and (39)) shall be used.

For ICs which are neither memories, processors, CPUs nor GPUs, 6a-b (Equations (42) and (43)) shall be used.

If the IC has a die made of GaAs, 7a-b b (Equations (44) and (45)) shall be used.

If the IC has a die made of GaN on SiC, 8a-b b (Equations (46) and (47)) shall be used.

See Annex I-A (informative) for further details.

4.1.3.1.5 Printed Circuit Boards

Cradle-to-gate modelling of printed circuit boards

Table 2 shows generalized formulae which shall be used to determine the GWP100 scores of PCBs. Default values are $E_{PCB,assembly}$ = 0,7 gCO_2e/Wh and $E_{PCB,upstream}$ = 0,7 gCO_2e/Wh.

Table 2: Generalized Emission Formulae with Variable Electricity for GWP100 of PCBs

Type	Material	Electricity Term, $gCO_2e/(cm^2 \times layer)$, E=Electricity intensity (gCO_2e/Wh)	Remainder Term, ($gCO_2e/(cm^2 \times layer)$)	General Formula, y (gCO_2e/cm^2)
Rigid	FR4	$5{,}450 \times E_{PCB,assembly}$	$0{,}956 + 2{,}53 \times E_{PCB,upstream}$	$y = (5{,}450 \times E_{PCB,assembly} + 0{,}956 + 2{,}53 \times E_{PCB,upstream}) \times layers$
Rigid	Halogen-Free FR4	$5{,}450 \times E_{PCB,assembly}$	$1{,}02 + 2{,}71 \times E_{PCB,upstream}$	$y = (5{,}450 \times E_{PCB,assembly} + 1{,}02 + 2{,}71 \times E_{PCB,upstream}) \times layers$
Rigid	Polyimide	$5{,}450 \times E_{PCB,assembly}$	$1{,}2 + 3{,}16 \times E_{PCB,upstream}$	$y = (5{,}450 \times E_{PCB,assembly} + 1{,}2 + 3{,}16 \times E_{PCB,upstream}) \times layers$
Rigid	Metal-Core	$5{,}450 \times E_{PCB,assembly}$	$1{,}29 + 3{,}41 \times E_{PCB,upstream}$	$y = (5{,}450 \times E_{PCB,assembly} + 1{,}29 + 3{,}41 \times E_{PCB,upstream}) \times layers$
Flex	FR4	$5{,}995 \times E_{PCB,assembly}$	$1{,}05 + 2{,}78 \times E_{PCB,upstream}$	$y = (5{,}995 \times E_{PCB,assembly} + 1{,}05 + 2{,}78 \times E_{PCB,upstream}) \times layers$
Flex	Halogen-Free FR4	$5{,}995 \times E_{PCB,assembly}$	$1{,}12 + 2{,}98 \times E_{PCB,upstream}$	$y = (5{,}995 \times E_{PCB,assembly} + 1{,}12 + 2{,}98 \times E_{PCB,upstream}) \times layers$
Flex	Polyimide	$5{,}995 \times E_{PCB,assembly}$	$1{,}31 + 3{,}47 \times E_{PCB,upstream}$	$y = (5{,}995 \times E_{PCB,assembly} + 1{,}31 + 3{,}47 \times E_{PCB,upstream}) \times layers$
Flex	Metal-Core	$5{,}995 \times E_{PCB,assembly}$	$1{,}41 + 3{,}75 \times E_{PCB,upstream}$	$y = (5{,}995 \times E_{PCB,assembly} + 1{,}41 + 3{,}75 \times E_{PCB,upstream}) \times layers$
Rigid-Flex	FR4	$6{,}540 \times E_{PCB,assembly}$	$1{,}15 + 3{,}04 \times E_{PCB,upstream}$	$y = (6{,}54 \times E_{PCB,assembly} + 1{,}15 + 3{,}04 \times E_{PCB,upstream}) \times layers$
Rigid-Flex	Halogen-Free FR4	$6{,}540 \times E_{PCB,assembly}$	$1{,}22 + 3{,}24 \times E_{PCB,upstream}$	$y = (6{,}54 \times E_{PCB,assembly} + 1{,}22 + 3{,}24 \times E_{PCB,upstream}) \times layers$
Rigid-Flex	Polyimide	$6{,}540 \times E_{PCB,assembly}$	$1{,}43 + 3{,}79 \times E_{PCB,upstream}$	$y = (6{,}54 \times E_{PCB,assembly} + 1{,}43 + 3{,}79 \times E_{PCB,upstream}) \times layers$
Rigid-Flex	Metal-Core	$6{,}540 \times E_{PCB,assembly}$	$1{,}55 + 4{,}09 \times E_{PCB,upstream}$	$y =(6{,}54 \times E_{PCB,assembly} + 1{,}55 + 4{,}09 \times E_{PCB,upstream}) \times layers$
HDI	FR4	$7{,}085 \times E_{PCB,assembly}$	$1{,}24 + 3{,}29 \times E_{PCB,upstream}$	$y = (7{,}085 \times E_{PCB,assembly} + 1{,}24 + 3{,}29 \times E_{PCB,upstream}) \times layers$
HDI	Halogen-Free FR4	$7{,}085 \times E_{PCB,assembly}$	$1{,}33 + 3{,}52 \times E_{PCB,upstream}$	$y = (7{,}085 \times E_{PCB,assembly} + 1{,}33 + 3{,}52 \times E_{PCB,upstream}) \times layers$
HDI	Polyimide	$7{,}085 \times E_{PCB,assembly}$	$1{,}55 + 4{,}11 \times E_{PCB,upstream}$	$y = (7{,}085 \times E_{PCB,assembly} + 1{,}55 + 4{,}11 \times E_{PCB,upstream}) \times layers$
HDI	Metal-Core	$7{,}085 \times E$	$1{,}68 + 4{,}44 \times E_{PCB,upstream}$	$y = (7{,}085 \times E_{PCB,assembly} + 1{,}68 + 4{,}44 \times E_{PCB,upstream}) \times layers$

NOTE 1: An example of using Table 2 is for a 30 cm^2 Rigid FR4 PCB with 12 layers.
CO_2e (g)=(5,45 × 0,7 + 0,956 + 2,53 × 0,7)×12 layers × 30 cm^2 = 2 355,12 g (≈ 2,35 kg).

Table 3 shows generalized formulae which shall be used to determine the ADP scores of PCBs. Default values are $E_{PCB,assembly}$ = 5E-7 g Sb-e/Wh and $E_{PCB,upstream}$ = 5E-7 g Sb-e/Wh.

Table 3: Generalized Emission Formulae with Variable Electricity for ADP of PCBs

Type	Material	Electricity Term, gSb-e/(cm^2×layer), E=Electricity intensity (gCO_2e/Wh)	Remainder Term, (gSb-e/(cm^2×layer)	General Formula, y (gSb-e/cm^2)
Rigid	FR4	5,450 × $E_{PCB,assembly}$	5E-6 + 2,53 × $E_{PCB,upstream}$	y = (5,450 × $E_{PCB,assembly}$ + 5E-6 + 2,53 × $E_{PCB,upstream}$) × layers
Rigid	Halogen-Free FR4	5,450 × $E_{PCB,assembly}$	5,35E-6 + 2,7 × $E_{PCB,upstream}$	y = (5,450 × $E_{PCB,assembly}$ + 5,35E-6 + 2,7 × $E_{PCB,upstream}$) × layers
Rigid	Polyimide	5,450 × $E_{PCB,assembly}$	6,25E-6 + 3,16 × $E_{PCB,upstream}$	y = (5,450 × $E_{PCB,assembly}$ + 6,25E-6 + 3,16 × $E_{PCB,upstream}$) × layers
Rigid	Metal-Core	5,450 × $E_{PCB,assembly}$	6,75E-6 + 3,41 × $E_{PCB,upstream}$	y = (5,450 × $E_{PCB,assembly}$ + 6,75E-6 + 3,41 × $E_{PCB,upstream}$) × layers
Flex	FR4	5,995 × $E_{PCB,assembly}$	5,5E-6 + 2,78 × $E_{PCB,upstream}$	y = (5,995 × $E_{PCB,assembly}$ + 5,5E-6 + 2,78 × $E_{PCB,upstream}$) × layers
Flex	Halogen-Free FR4	5,995 × $E_{PCB,assembly}$	5,9E-6 + 2,98 × $E_{PCB,upstream}$	y = (5,995 × $E_{PCB,assembly}$ + 5,9E-6 + 2,98 × $E_{PCB,upstream}$) × layers
Flex	Polyimide	5,995 × $E_{PCB,assembly}$	6,9E-6 + 3,47 × $E_{PCB,upstream}$	y = (5,995 × $E_{PCB,assembly}$ + 6,9E-6 + 3,47 × $E_{PCB,upstream}$) × layers
Flex	Metal-Core	5,995 × $E_{PCB,assembly}$	7,45E-6 + 3,75 × $E_{PCB,upstream}$	y = (5,995 × $E_{PCB,assembly}$ + 7,45E-6 + 3,75 × $E_{PCB,upstream}$) × layers
Rigid-Flex	FR4	6,540 × $E_{PCB,assembly}$	1,2E-5 + 3,04 × $E_{PCB,upstream}$	y = (6,54 × $E_{PCB,assembly}$ + 1,2E-5 + 3,04 × $E_{PCB,upstream}$) × layers
Rigid-Flex	Halogen-Free FR4	6,540 × $E_{PCB,assembly}$	1,28E-5 + 3,24 × $E_{PCB,upstream}$	y = (6,54 × $E_{PCB,assembly}$ + 1,28E-5 + 3,24 × $E_{PCB,upstream}$) × layers
Rigid-Flex	Polyimide	6,540 × $E_{PCB,assembly}$	1,5E-5 + 3,79 × $E_{PCB,upstream}$	y = (6,54 × $E_{PCB,assembly}$ + 1,5E-5 + 3,79 × $E_{PCB,upstream}$) × layers
Rigid-Flex	Metal-Core	6,540 × $E_{PCB,assembly}$	1,62E-5 + 4,09 × $E_{PCB,upstream}$	y =(6,54 × $E_{PCB,assembly}$ + 1,62E-5 + 4,09 × $E_{PCB,upstream}$) × layers
HDI	FR4	7,085 × $E_{PCB,assembly}$	6E-6 + 3,29 × $E_{PCB,upstream}$	y = (7,085 × $E_{PCB,assembly}$ + 6E-6 + 3,29 × $E_{PCB,upstream}$) × layers
HDI	Halogen-Free FR4	7,085 × $E_{PCB,assembly}$	6,95E-6 + 3,52 × $E_{PCB,upstream}$	y = (7,085 × $E_{PCB,assembly}$ + 6,95E-6 + 3,52 × $E_{PCB,upstream}$) × layers
HDI	Polyimide	7,085 × $E_{PCB,assembly}$	8,15E-6 + 4,11 × $E_{PCB,upstream}$	y = (7,085 × $E_{PCB,assembly}$ + 8,15E-6 + 4,11 × $E_{PCB,upstream}$) × layers
HDI	Metal-Core	7,085 × $E_{PCB,assembly}$	8,8E-6 + 4,44 × $E_{PCB,upstream}$	y = (7,085 × $E_{PCB,assembly}$ + 8,8E-6 + 4,44 × $E_{PCB,upstream}$) × layers

NOTE 2: An example of using Table 3 is for a 30 cm^2 Rigid FR4 PCB with 12 layers.
Sb-e (g) = (5,45 × 5E-7 + 5E-6 + 2,53 × 5E-7) × 12 layers × 30 cm^2 ≈ 3,24E-3 g.

NOTE 3: Sb-e impacts from Gold, Copper, Tin etc are excluded as they belong to the impact calculation based on their total mass contents in the entire phone at hand.

See Annex I-B (informative) for further details.

4.1.3.1.6 Cameras

For cameras the cradle-to-gate impact shall be expressed per piece for each camera included in the phone.

The cameras in the smartphone at hand shall use Equations (48) and (49) as applicable:

$$GWP_{camera} = \left(\frac{128}{x^2} + \frac{22{,}62}{x} + 1\right) \times \left(0{,}0305 \times El_{wafer\ fab,GWP} + 0{,}0049 + 0{,}013 \times El_{IC\ front-end,upstream,GWP}\right) \quad (48)$$

$$ADP_{camera} = \left(\frac{128}{x^2} + \frac{22{,}62}{x} + 1\right) \times \left(0{,}0305 \times El_{wafer\ fab,ADP,Sb} + 2{,}5E - 8\right) \quad (49)$$

Where:

- GWP_{camera}= kg CO_2e for camera in phone based on sensor size
- ADP_{camera}= kg Sb-e for camera in phone based on sensor size
- x = denominator in inches, e.g. x = 2,55 for a 1/2,55" sensor.

- $El_{wafer,GWP}$= kg CO_2e/kWh for electricity mix wafer fab. Default: 0,7
- $El_{IC\ front-end,upstream,GWP}$= kg CO_2e/kWh for electricity mix upstream. Default: 0,7
- $El_{wafer,ADP,Sb}$= kg Sb-e/kWh for electricity mix wafer fab. Default: 5E-7

See Annex I-E (informative) for further details.

4.1.3.1.7 Audio components

The impacts for the audio components within the phone at hand are based on their material contents and is captured by the raw materials impact calculation, see clause 4.1.3.2.17.

4.1.3.1.8 Antennas

The impacts for the antennae are based on its material contents and is captured by the raw materials impact calculation, see clause 4.1.3.2.17.

4.1.3.1.9 Finger Print Cards

The impacts for the FPC is based on its material contents and is captured by the raw materials impact calculation, see clause 4.1.3.2.17.

4.1.3.1.10 eSIMs

For eSIM the cradle-to-gate impact shall be expressed per mass for each eSIM included in the phone.

The eSIMs in the smartphone at hand shall use Equations (50) and (51) as applicable:

$$GWP_{eSIM}\ \{kg\ CO_2e\} = Mass\ of\ eSIM\ \{kg\} \times (109 \times El_{manufacturing\ eSIM,GWP}) \quad (50)$$

$$ADP_{eSIM}\ \{kg\ Sb\text{-}e\} = Mass\ of\ eSIM\ \{kg\} \times (109 \times El_{manufacturing\ eSIM,ADP}) \quad (51)$$

Where:

- $El_{manufacturing\ eSIM,GWP}$ = kg CO_2e/kWh for electricity mix eSIM. Default: 0,7
- $El_{manufacturing\ eSIM,ADP}$ = kg Sb-e/kWh for electricity mix eSIM. Default: 5E-7

See Annex I-G (informative) for further details.

4.1.3.1.11 Chargers

For Chargers the cradle-to-gate impact shall be expressed per mass for each Charger included with the inbox equipment for the smartphone at hand.

The Chargers for the smartphone at hand shall use Equations (52) and (53) as applicable:

$$GWP_{Charger}\ \{kg\ CO_2e\} = Mass\ of\ Charger\ \{kg\} \times (3{,}5 + 9{,}29 \times El_{upstream,Charger,GWP} + 14{,}28 \times El_{manufacturing\ Charger,GWP}) \quad (52)$$

$$ADP_{Charger}\ \{kg\ Sb\text{-}e\} = Mass\ of\ Charger\ \{kg\} \times (9{,}29 \times El_{upstream,Charger,ADP} + 14{,}28 \times El_{manufacturing\ Charger,ADP}) \quad (53)$$

Where:

- $El_{manufacturing\ Charger,GWP}$ = kg CO_2e/kWh for electricity mix Charger manufacturing. Default: 0,7
- $El_{upstream,Charger,GWP}$ = kg CO_2e/kWh for electricity mix Charger upstream. Default: 0,7
- $El_{manufacturing\ Charger,ADP}$ = kg Sb-e/kWh for electricity mix Charger manufacturing. Default: 5E-7
- $El_{upstream,Charger,ADP}$ = kg Sb-e/kWh for electricity mix Charger upstream. Default: 5E-7

NOTE: As for all part/component manufacturing, the parametrized equations only covers the non-material content related impacts. The MCD related impacts for the charger will be part of the raw materials impact calculation.

4.1.3.1.12 USB Cables

The impacts for the USB Cable are based on its material contents and are captured by the raw materials impact calculation, see clause 4.1.3.1.17.

NOTE: [i.5] is used to confirm the reasonableness of the approach.

4.1.3.1.13 Headsets

The impacts for the headset are based on its material contents and are captured by the raw materials impact calculation, see clause 4.1.3.1.17.

4.1.3.1.14 Instruction leaflets and warranty cards

The impacts for the instruction leaflets and warranty cards are based on its material contents and are captured by the raw materials impact calculation, see clause 4.1.3.1.17.

4.1.3.1.15 Protective Covers

The impacts for the protective cover are based on its material contents and are captured by the raw materials impact calculation, see clause 4.1.3.1.17.

4.1.3.1.16 SIM Extraction tools

The impacts for the SIM extraction tool are based on its material contents and are captured by the raw materials impact calculation, see clause 4.1.3.1.17.

4.1.3.1.17 Raw Materials

The following default values (for primary and secondary production when applicable) shall be used to capture the impact of some raw materials impact.

The impact shall be calculated for each material in Table 4 using the Circular Footprint Formulae (CFF) [i.6] according to Equation (54):

$$mass,RawMat,i\{kg\} \times [(1-R1) \times E_v + R1 \times ((A \times E_{recycled} + (1-A) \times E_v \times Q_{sin}/Q_p)) + (1-A) \times R2 \times (E_{recycled,\ EoL} - E_v \times Q_{sout}/Q_p) + (1-R2-R3) \times E_D] \quad (54)$$

NOTE 1: Energy recovery impacts are excluded meaning that the full CFF has been simplified.

E_v default values to be used are the ones for primary materials (e.g. Aluminium, primary; Copper, primary, etc.).

For default values for $E_{recycled}$ and $E_{recycled,\ EoL}$ see values for secondary materials (e.g. Aluminium, secondary; Copper, secondary, etc.).

In the present document $E_{recycled}$ and $E_{recycled,\ EoL}$ will use the same default values for the same Raw Material.

For $E_{D,\ GWP}$ for remaining raw materials not listed in Table 4 the default 1 kg CO_2e/kg shall be used.

Table 4: Default Cradle-to-gate intensities and CFF parameter values for Raw Materials

Raw Material	GWP100 (kg CO_2e/kg)	ADP (kg Sb-e/kg)	R1	R2	R3	A	$E_{D, GWP, kg CO2e/kg}$	Q_{sin}	Q_{sout}	Q_p
ABS	2,69	3,66E-14	0	0	0	0,5	3,13	0,9	0,9	1
Aluminium, primary	11,76	3,89E-07	0	0,85	0	0,2	0	1	1	1
Aluminium, secondary	0,75	8,14E-09	0	0,85	0	0,2	0	1	1	1
Cobalt, primary	37,20	1,12E-05	0	0,32	0	0,2	0	1	1	1
Cobalt, secondary	0,372	1,12E-7	0	0,32	0	0,2	0	1	1	1
Copper, primary	3,45	1,25E-03	0	0,8	0	0,2	0	1	1	1
Copper, secondary	0,47	8,14E-09	0	0,8	0	0,2	0	1	1	1
Gold, primary	47 790,30	4,73E+01	0	0,9	0	0,2	0	1	1	1
Gold, secondary	750,62	9,56E-13	0	0,9	0	0,2	0	1	1	1
Indium, primary	117,52	6,27E-03	0	0	0	0,2	0	1	1	1
Indium, secondary	0,11752	6,27E-5	0	0	0	0,2	0	1	1	1
Paperboard, primary	1,3	1E-07	0	0,62	0	0,2	0	0,85	0,85	1
Paperboard, secondary	0,013	5E-8	0	0,62	0	0,2	0	0,85	0,85	1
Corrugated cardboard, primary	0,8	6E-8	0	0,62	0	0,2	0	0,85	0,85	1
Corrugated cardboard, secondary	0,008	6E-10	0	0,62	0	0,2	0	0,85	0,85	1
LDPE film, primary	2,2	1E-7	0	0,29	0	0,5	2,94	0,9	0,9	1
LDPE film, secondary	0,022	1E-9	0	0,29	0	0,5	2,94	0,9	0,9	1
PET, primary	2,8	1,2E-7	0	0,29	0	0,5	2,94	0,9	0,9	1
PET, secondary	0,028	1,2E-8	0	0,29	0	0,5	2,94	0,9	0,9	1
Wood pallet, primary	1	5E-8	0	0,62	0	0,2	0	0,85	0,85	1
Wood pallet, secondary	0,01	5E-10	0	0,62	0	0,2	0	0,85	0,85	1
LLDPE stretch film, primary	2,5	1E-7	0	0,29	0	0,5	2,94	0,9	0,9	1
LLDPE stretch film, secondary	0,025	1E-9	0	0,29	0	0,5	2,94	0,9	0,9	1
Platinum, primary	33 300,00	2,02E+00	0	0,54	0	0,2	0	1	1	1
Platinum, secondary	1 100,05	1,40E-12	0	0,54	0	0,2	0	1	1	1
Polycarbonate, primary	3,40	3,66E-14	0	0,29	0	0,5	2,94	0,9	0,9	1
Polycarbonate, secondary	0,34	3,66E-16	0	0,29	0	0,5	2,94	0,9	0,9	1
Silver, primary	449,39	1,07E+00	0	0,9	0	0,2	0	1	1	1
Silver, secondary	14,37	1,01E-14	0	0,9	0	0,2	0	1	1	1
Stainless steel, primary	5,08	4,36E-05	0	0,85	0	0,2	0	1	1	1
Stainless steel, secondary	0,0508	4,36E-07	0	0,85	0	0,2	0	1	1	1
Steel, primary	1,59	2,04E-08	0	0,85	0	0,2	0	1	1	1
Steel, secondary	0,159	2,04E-10	0	0,85	0	0,2	0	1	1	1
Tantalum, primary	144,50	3,21E-05	0	0,4	0	0,2	0	1	1	1
Tantalum, secondary	1,445	3,21E-07	0	0,4	0	0,2	0	1	1	1
Tin, primary	10,30	4,70E-02	0	0,9	0	0,2	0	1	1	1
Tin, secondary	2,06	0	0	0,9	0	0,2	0	1	1	1

NOTE 2: R1 and R3 are by default equal to 0 for all the materials, unless evidence for a specific value is provided.

NOTE 3: References for R2 default values are [i.9] and EOL (Recycling Rate) RR from Ecoreport-tool-2021 [i.10].

NOTE 4: $E_{D,ADP}$ is assumed to be negligible for the materials included.

EXAMPLE 1: Here follows an example for GWP100 using default values of Table 4 in Equation (54) for a gold content of 20 mg. 2E-5{kg}×[(1-0) × 47 790,30 + 0 × ((0,2 × 750,62 + (1 - 0,2) × 47 790,30 × 1/1)) + (1-0,2) × 0,9 × (750,62 - 47 790,30 ×1/1) + (1-0,9-0) × 0] = 0,956 kgCO_2e - 0,677 kgCO_2e = 0,279 kgCO_2e.

EXAMPLE 2: Here follows an example for ADP using default values of Table 4 in Equation (54) for a cobalt content of 10 g. 0,01{kg}×[(1-0) × 1,12E-05 + 0 × ((0,2 × 1,12E-7 + (1-0,2) × 1,12E-5 × 1/1)) + (1-0,2) × 0,32 × (1,12E-5 - 1,12E-7 ×1/1) + (1-0,32-0) × 0] = 1,12e-7 kg Sb-e - 2,84E-8 kgCO_2e = 8,36E-8 kg Sb-e.

See Annex I-F (informative) for further details.

4.1.3.1.18 Other parts not covered in previous clauses

It is challenging to come up with a robust model for all other parts listed in clauses .1.3..1-16. These parts are not part of the methodology. The GWP100 and Sb-e results are based on the included parts and the total material contents of specified raw materials (Table 4) in the phone. Raw materials not listed in Table 4 are not part of the methodology.

4.1.3.1.19 Final Assembly

This clause covers the assembly site before the distribution to the country of sale.

Scope

This clause defines requirements and default data for the smartphone final assembly. The boundary covers all manufacturing and testing operations that integrate sub-assemblies and parts/components into a complete functional smartphone. Packaging and transport/distribution are excluded, as they are covered in separate clauses.

Processes that shall be included:

- Mechanical and electrical assembly of sub-modules (SMT line processes, PCBA insertion, housing assembly, display bonding, battery mounting, camera and antenna fitting, sealing, screwing, adhesive application).
- Software flashing, calibration, and end-of-line testing.
- Cleaning, inspection, and final quality control.
- Facility utilities directly supporting the assembly line (electricity, compressed air, process gases, HVAC, lighting directly related to assembly lines).
- Minor consumables used during assembly (adhesives, solder paste residues, wipes, solvents).
- Waste and rework within assembly yield.

Calculation Method

For each smartphone i, the Final Assembly impacts shall be calculated with Equations (55) and (56) as follows:

$$GWP_{FA,i} = E_{FA} \times EF_{elec,GWP} + \sum\left(m_m \times EF_{m,GWP}\right) + F_{FA} \times EF_{fuel,GWP} \quad (55)$$

$$ADP_{FA,i} = E_{FA} \times EF_{elec,ADP} + \sum\left(m_m \times EF_{m,ADP}\right) + F_{FA} \times EF_{fuel,ADP} \quad (56)$$

Table 5 shows parameters and default guidance for final assembly impact calculations.

Table 5: Parameters and default guidance for final assembly impact calculations

Symbol/Parameter	Description	Unit	Default / Guidance
E_{FA}	Electricity consumed for assembly per smartphone	kWh/device	2,5
$EF_{elec,GWP}$	Grid-specific electricity emission factor	kg CO_2e/kWh	Region-specific; default 0,7
$EF_{elec,ADP}$	Grid-specific abiotic depletion factor	kg Sb-eq/kWh	5×10^{-7}
F_{FA}	Direct fossil fuel energy (if any)	MJ/device	0,05
$EF_{fuel,GWP}$	Fuel emission factor	kg CO_2e/MJ	0,074 (natural gas)
$EF_{fuel,ADP}$	Fuel abiotic factor	kg Sb-eq/MJ	2×10^{-8}
m_m	Mass of material m added during assembly	kg/device	See Table 6
$EF_{m,GWP}$	GWP_{100} factor for material m	kg CO_2e/kg	See Table 6
$EF_{m,ADP}$	ADP factor for material m	kg Sb-eq/kg	See Table 6

Table 6: Default Material and Process Inputs (per smartphone) in final assembly

Material / Process	Default quantity [g]	GWP_{100} (kg CO_2e/kg)	ADP (kg Sb-eq/kg)	Notes
Adhesives / glue	1,5	3,0	$5×10^{-8}$	Display & housing bonding
Cleaning solvent (IPA or mix)	0,6	2,5	$1×10^{-7}$	Line cleaning
Wipes / cloths (non-woven)	0,3	2,0	$1×10^{-7}$	Consumable
Nitrogen (purge)	10	1,9	-	≈0,01 kg per device (if applied)
Electricity (use)	2,5 kWh	0,7	$5×10^{-7}$	Per device average

Assembly yield adjustment

Assembly yield represents the proportion of smartphones successfully produced without rework or rejection.
Raw Material and Production impacts for the smartphone at hand shall be adjusted by the inverse of the assembly yield to reflect production losses (57):

$$I_{adj} = \frac{I_{nominal}}{\text{yield}} \quad (57)$$

where I_{adj} is the adjusted impact per functional smartphone, and $I_{nominal}$ is the nominal impact calculated from measured or default data.

NOTE 1: Raw material upstream impact, production of parts and components and the final assembly impacts are in scope for the yield adjustment. Distribution, use and end-of-life treatment are not in scope for this adjustment. Annex I shows an example on how this calculation is handled.

When no primary yield data is available, a default yield of 99 % (i.e. 1 % scrap) shall be used.

This corresponds to an approximate 1 % increase in manufacturing-phase burdens. This means that all raw materials and parts/components impacts shall be multiplied by 1,01.

NOTE 2: While affecting upstream impact as a whole, the default yield 99 % is a simplification which mainly refers to the final assembly, and does not refer to yields of individual unit processes such as Machining aluminium. The pre-set default values are assumed to include losses. However, some of the present semiconductor models have indirectly used a unit process yield assumption (75 %) as explained in Annex I-A. This 75 % assumption can be changed according to clause 4.3.1 rules. Same principle is valid for mechanical and other parts if the user of the present document attempts to derive new coefficients, such as alternate kWh/kg data according to clause 4.3.1. See also clause 4.1.3.9.

Inventory and Reporting Requirements

Manufacturers shall provide at minimum:

- Measured electricity consumption per assembly line and grid mix.
- Type and mass of consumables (adhesives, solder paste, solvents, cloths).
- Assembly yield.
- Energy source factors used (grid region, renewable procurement).

If primary measurements are unavailable, the default parameters of Table 6 shall be used and explicitly declared in the LCA report.

Example Calculation

Using defaults (E_{FA}=2,5 kWh, $EF_{elec,GWP}$=0,7, plus materials per Table 6):

- GWP_FA,default ≈ 1,78 kg CO_2e/device

- ADP_FA,default ≈ $1,25 \times 10^{-6}$ kg Sb-eq/device

4.1.3.1.20 Packaging

Scope

This clause defines requirements and default data for the smartphone packaging, covering all packaging elements required to protect and deliver one smartphone unit to the end user.

The packaging system shall include:

- Primary packaging: the phone box containing the smartphone and accessories.
- Secondary packaging: boxes modules grouping multiple phone boxes.
- Tertiary packaging: cartons (shipping boxes) and pallets used for bulk transport.

All results shall be expressed per smartphone unit and include proportional allocation of higher-level packaging (modules, cartons, pallets).

Reusable tertiary packaging (e.g. wooden pallets) shall be modelled on a per-use basis.

Simplified Approach

For the calculation, manufacturers shall use the mass of packaging materials. For all other parameters conservative default values shall be used.

Substitution of default value is permitted if specific, verifiable, and auditable data is available.

Inventory Requirements

Each functional packaging element shall be represented by the following parameters (Table 7):

Table 7: Functional packaging elements

Element	Typical material composition	Default allocation	Notes
Phone box	Paperboard, printed cover, thin LDPE film	1 per smartphone	Primary packaging
Boxes module	Corrugated board	1 per 5 phones	Secondary packaging
Carton	Corrugated board, labels, tape	1 per 20 phones	Shipping box
Pallet	Wood, stretch film (LLDPE)	1 per 1 200 phones	Reused 10×

Mass of each element shall be recorded or estimated from Table 8 defaults.

Table 8: Default Material Mass Fractions per Functional Packaging Element

Functional element	Material	Typical mass fraction (%)	Default total mass (g per phone)
Phone box	Paperboard	90	180
	LDPE film	10	20
Boxes module	Corrugated cardboard	100	300 / 5 = 60
Carton	Corrugated cardboard	100	400 / 20 = 20
Pallet	Wood (reused 10×)	98	(25 000 / 1 200)/10 = 2,1
	LLDPE stretch film	2	0,5

Calculation Methodology

For each material *m* used in the packaging system impact shall be calculated according to Equation (58):

$$\text{Impact}_m = m_m \times EF_m \tag{58}$$

Where:

- m_m = mass of material [kg per phone]

- EF_m = default emission factor [kg CO_2e / kg]

Total packaging impact according shall be calculated according to Equations (59) and (60):

$$\mathrm{GWP}_{\mathrm{pack}} = \sum_m m_m \times EF_m \quad (59)$$

$$\mathrm{ADP}_{\mathrm{pack}} = \sum_m m_m \times EF_{m,\mathrm{ADP}} \quad (60)$$

Manufacturers may replace defaults (Table 9) with primary data if verified and auditable and < 3 regarding data quality rating according to clause 4.1.3.10.

Table 9: Default Emission Factors for Packaging Materials (Cradle-to-Gate)

Raw Material	GWP_{100} (kg CO_2e / kg)	ADP (kg Sb-eq / kg)
Paperboard	See Table 4 in clause 4.1.3.1.17	
Corrugated cardboard		
LDPE film		
PET		
Wood pallet		
LLDPE stretch film		

4.1.3.1.21 Consideration of recycled material content

Plastics

In 2023 world-wide around 413,8 million tonnes of plastics were produced with a strong monotonous increase since 1950 [i.7]. Some 90,6 % of that amount is still fossil based [i.8]. Between 30 % and 80 % of the original emissions can be saved when plastic is recycled and reused. Some 17 % of the mass of a typical Smartphone consists of plastics. Hence the origin of plastics also matters, and so to improve LCA performance fossil sources should be avoided.

The recycled content (R1) is considered by the use of the CFF as described in the Raw Materials clause 4.1.3.1.17.

Metals

The recycled content (R1) is considered by the use of the CFF as described in the Raw Materials clause 4.1.3.1.17.

4.1.3.2 Distribution

Scope

This clause covers the transportation of finished smartphones from the assembly site to the country of sale. It includes multimodal logistics and may involve up to three legs: origin-site to hub, hub-to-hub international transport, and destination hub to final distribution centre.

Simplified Approach

To enable consistency, scalability, and comparability across smartphone LCAs, a simplified transport emission calculation approach shall be used. The following parameters shall be included:

- Transport mode (air, road, sea, rail).
- Distance (km).
- Load factor (0-1).
- Emission factor (g CO_2e/tkm).
- Weight of unit transported (kg).
- Volume of unit transported (m^3).

Default Values and Substitution Rules

A three-leg transport route shall be considered as default for finished smartphone logistics:

1) From origin factory to hub in the country of assembly.

2) From origin hub to destination country hub (intercontinental).

3) From destination hub to final delivery centre.

Conservative default values shall be used for each transport parameter (see Annex B). Manufacturers may substitute any default with a specific value if the following conditions are met:

- The substituted data is based on verifiable and auditable sources.
- The value applies to the product in scope and transport leg.
- Data quality for the value is equivalent to Tier 2 or Tier 3 as defined in ISO 14083 [3] and < 3 according to clause 4.1.3.10.

Calculation Method

For each transport leg $i \in \{1, 2, 3\}$, the emissions shall be calculated as follows.

If the Emission Factor EF is provided in g CO_2e/tkm according to Equations (61) and (62):

$$Emissions_i = \frac{m_i \times d_i \times EF_i}{1000 \times LF_i} \quad (61)$$

If the Emission Factor EF is provided in g CO_2e/TEU-km (e.g. for Container Ocean Freight):

$$Emissions_i = \frac{v_i \times d_i \times EF_i}{33 \times LF_i} \quad (62)$$

Where:

- m_i: mass of unit transported in kg.
- d_i: distance in km.
- v_i = volume of the smartphone including sales packaging [m^3].
- EF_i: emission factor (g CO_2e/tkm) or (g CO_2e/TEU-km).
- LF_i: load factor (0-1).

Total transport emissions shall be calculated with Equation (63):

$$TotalEmissions_{\text{transport}} = \sum_{i=1}^{3} \text{Emissions}_i \quad \text{[in kg } CO_2\text{e]} \quad (63)$$

4.1.3.3 Use

Based on the user's usage habits, conduct daily power consumption calculation and obtain the product energy consumption within a 5-year usage cycle. Equation (64) shall be used to calculate the energy consumption:

$$Eu = Eper \times Vb \times 365 \times Yu/Ec \quad (64)$$

Where:

- *Eu:* main electricity consumed measured in mWh.
- *Eper*: Daily Charge Consumption measured in mAh, Equation (65) shall be used for the calculation.
- *Vb*: Nominal battery voltage measured in Volts.
- *Yu*: Lifetime Expectancy (year), 5 years.

- *Ec*: Charging Efficiency of the charger, the default value is 88 %, which is the minimum average active efficiency required from ErP requirements (EU) 2019/1782 [i.28] for the external power supply whose output power is more than 49 W.

$$Eper = Acal \times 0{,}16 + Astr \times 1{,}2 + Aapp \times 1{,}2 + Acam \times 0{,}1 + Ablu \times 0{,}2 + Agps \times 0{,}3 + Abro \times 1{,}34 + Aidl \times 1{,}1 \quad (65)$$

Where:

- A*cal*: average measured current during different network calling tests, which is the average value of GSM talk, WCDMA talk, VoWiFi Talk, VoLTE Talk.

- A*str*: average measured current during streaming content test in mA, which is the average value of Video Progressive Streaming, Dynamic Adaptive Streaming over HTTP (DASH), Audio.

- A*app*: average measured current during application software test in mA, which is the average value of Music Playback, Video Playback and Camera Operation.

- A*cam*: average measured current during camera operation and video recording in mA.

- A*blu*: average measured current for Bluetooth interface test in mA, which is the average value of headset-music player.

- A*gps*: average measured current for tracking test in mA.

- A*bro*: average measured current for HTML browsing test in mA.

- A*idl*: average measured current for idling test during different network mode test in mA, which is the average value of GSM idle, GSM/GPRSidle, WCDMAidle, (GSM/GPRS)/WCDMAidle, E-UTRAidle and 5G-NRidle.

The average measured current test method for the detailed scenario is described in Table A.1 attached in Annex A, which averages over a defined period.

4.1.3.4 End-of-Life

4.1.3.4.1 Scope

This clause covers the End-of-Life (EoL) stage of smartphones, defined as the management of the device and its parts/components after the use phase. It includes material recycling, and disposal processes.

4.1.3.4.2 General Requirements

The environmental impact of the EoL phase shall be calculated per raw material in the smartphone material content declaration, product packaging and inbox materials.

Impacts considered shall include:

- Recycling (credits and burdens).

- Disposal (landfilling or incineration without energy recovery).

NOTE: Clause 4.1.3.2.17 including Equation 54 explains further the impact calculation per raw material.

4.1.3.4.3 Simplified Approach

For the calculation, manufacturers shall use the mass of raw materials according to the amounts of the Material Content Declaration (MCD). For all other parameters the default values shall be used (see clause 4.1.3.1.17).

Substitution of default values is permitted if specific, verifiable, and auditable data is available. Both burdens (e.g. recycling energy use) and credits (e.g. avoided primary production,) shall be included.

4.1.3.4.4 Calculation Methodology

See clause 4.1.3.1.17 which includes the calculation methodology for recycling and disposal. Energy recovery impacts are excluded from the present document.

4.1.3.5 Allocation between co-products

The allocation approaches used are clear from the parametric set-up of the present document.

4.1.3.6 Allocation for recovery operations

The allocation approaches used are clear from the parametric set-up of the present document.

4.1.3.7 Units

The units used are clear from the parametric set-up of the present document.

4.1.3.8 Primary Data

The primary data are the amounts used in the parametric equations, e.g. mass of raw materials and GB RAM memory.

NOTE: The user of the present document is under specific circumstances allowed to use own coefficients (such as those reflected by primary data) in applicable equations, such as emission factors for electricity. See clause 4.3.1 Deviations from Default Values.

4.1.3.9 Data Quality

The data quality of the parameters (e.g. another GWP100 value for electricity than the default) which are non-default shall be estimated with the following method.

Calculate the DQR score of the declared value of the parameter as: (COM + PR + TIR + GER + TER)/5.

The DQR score shall be < 3 to comply with the present document.

The criteria for each DQR indicator are shown in Table 10 to Table 14.

1) **Completeness (COM)**

Table 10: Data quality criteria for COM

Score				
1	**2**	**3**	**4**	**5**
Description for Completeness				
Representative data from all sites relevant for the market considered, over an adequate period to even out normal fluctuations.	Representative data from > 50 % of the sites relevant for the market considered, over an adequate period to even out normal fluctuations.	Representative data from only some of the sites (< 50 %) relevant for the market considered, or > 50 %of sites but from shorter periods.	Representative data from only one site relevant for the market considered or from some sites from shorter periods.	Representativeness unknown or data from small number of sites and from shorter periods.
NOTE: 1, 2, 3, 4, or 5 (very good; good; fair; poor; very poor).				

2) **Precision (PR)**

Table 11: Data quality criteria for PR

Score				
1	**2**	**3**	**4**	**5**
Description for Precision				
Measured, calculated and verified. Very low uncertainty (< 7 %).	Measured, calculated or from literature and plausibly checked by reviewer.	Measured, calculated or from literature but plausibly not checked by reviewer OR qualified estimate based on calculations checked by reviewer.	Qualified estimate based on calculations, plausibly not checked by reviewer.	Rough estimate with known deficits.
NOTE: 1, 2, 3, 4, or 5 (very good; good; fair; poor; very poor).				

3) **Time representativeness**

Table 12: Data quality criteria for TIR

Score				
1	**2**	**3**	**4**	**5**
Description for Time representativeness				
The data (collection date) can be maximum 2 years old compared to the manufacturing date of the phone at hand.	The data (collection date) can be maximum 4 years old compared to the manufacturing date of the phone at hand.	The data (collection date) can be maximum 6 years old compared to the manufacturing date of the phone at hand.	The data (collection date) can be maximum 8 years old compared to the manufacturing date of the phone at hand.	The data (collection date) is older than 8 years compared to the manufacturing date of the phone at hand.
NOTE: 1, 2, 3, 4, or 5 (very good; good; fair; poor; very poor).				

4) **Geographic representativeness (GER)**

Table 13: Data quality criteria for GER

Score				
1	**2**	**3**	**4**	**5**
Description for Geographical representativeness				
The data are fully representative for the geography stated in the LCA report.	The data are well representative for the geography stated in the LCA report.	The data are sufficiently representative for the geography stated in the LCA report.	The data are only partly representative for the geography stated in the LCA report.	The data are not representative for the geography stated in the LCA report.
NOTE: 1, 2, 3, 4, or 5 (very good; good; fair; poor; very poor).				

5) **Technological representativeness (TER)**

Table 14: Data quality criteria for TER

Score				
1	**2**	**3**	**4**	**5**
Description for Technological representativeness				
Technology aspects have been modelled without any significant need for improvement compared to the exact technology at hand.	Technology aspects have been modelled with limited need for improvement compared to the exact technology at hand.	Technology aspects merit improvements. Some of the relevant processes are not modelled with specific data but uses proxies compared to the exact technology at hand.	Technology aspects require major improvements compared to the exact technology at hand.	Technology aspects require substantial improvements compared to the exact technology at hand.
NOTE: 1, 2, 3, 4, or 5 (very good; good; fair; poor; very poor).				

4.2 Life cycle Impact Assessment

The life cycle impact assessment is based on GWP100 and ADP mid-point indicators.

4.3 LCA Report

4.3.1 Minimum Content of LCA Reports

Deviations to default values for emission and resource data shall be presented in the LCA report for the smartphone at hand. Total life cycle GWP100 and ADP scores as well as repartition into life cycle stages, as defined in clauses 4.1.2.1.1 to 4.1.2.1.5.

The LCA report shall include the following mandatory elements:

Identifier

- Manufacturer Name.
- Product Model Name.
- Memory Configuration.
- SKU differentiation, if applicable.
- Unique SKU identifier(s).

Total Life Cycle Impact Scores

- Global Warming Potential (GWP100) expressed in kg CO_2-equivalent.
- Abiotic Depletion Potential (ADP) expressed in kg Sb-equivalent.

Life Cycle Stage Breakdown

The above indicators shall be reported for the following stages:

- Raw Material Acquisition.
- Production.
- Distribution.
- Use.
- End-of-Life.

Part/Component-Level Breakdown

The contribution of each of the entities in clauses 4.1.3.1.1 to 4.1.3.1.21 shall be reported for the above indicators:

- Mechanical parts.
- Display.
- Battery.
- Integrated Circuits.
- Printed Circuit Board.
- Camera.
- eSIM.

- Assembly.
- Packaging.

Raw Material-Level Breakdown

The contribution of applicable raw materials listed in clause 4.1.3.1.17.

Deviations from Default Values

Any deviation from default emission or resource data, as well as coefficients in equations, shall be explicitly documented. However, use stage scenario coefficients (e.g. 0,16 and 1,2 in Equation (65)) cannot deviate.

The LCA report based on the present document shall include:

- Justification for deviation (e.g. regional specificity, updated datasets, supplier-specific data).
- Evidence of relevance of chosen alternative values including coefficients (e.g. DQR relevance according to clause 4.1.3.10).

EXAMPLE 1: Example of coefficients are e.g. in Equation (18); 10,5, 27,5, 30 and 10.

Transparency

The LCA report based on the present document shall include:

- The total energy consumption during the use phase (in Wh).
- The emission factor applied for calculating use-phase emissions (in kg CO_2e/kWh), which substitute default, if any.
- The source of the emission factor (e.g. IEA, national grid data) which substitute default, if any.

Methodology

The LCA report based on the present document shall include:

- Description of deviation from default included Inbox Materials of clause 4.1.2.1.
- Used tools and databases.
- Version of used tools and databases.
- Documentation of each substituted default value's Data Quality Rating according to clause 4.1.3.10.

Certification

The LCA report based on the present document shall include:

- State whether the individual LCA report has been third-party certified.
- Name of certifying body.
- Include a signed statement or certificate reference number.

The present document is applicable to any smartphone with a unique alphanumeric code (e.g. SKU).

Separate reporting shall be provided for:

- Memory capacity variants (e.g. 512 GB vs. 1 TB).
- Other differences that have a significant (> 5 %) impact on life cycle emissions.

Differences that do not significantly affect environmental impact (e.g. colour variants, packaging artwork) shall not require separate reporting.

NOTE: Annex I-I shows an example on how the required GWP100 and ADP scores can be obtained per life cycle stage and per raw material, part/component and process type. Note that this implementation is not mandatory as there are many ways by which the present document can be implemented.

The LCA report based on the present document shall be provided covering all elements of clause 4.3.1.

A single report may cover multiple configurations provided that:

- Common chapters (e.g. methodology, functional unit, general assumptions) shall apply to all configurations.
- Differences shall be documented in tables, showing:
  - Part/Component-level variations (e.g. memory configuration).
  - Impact on total GWP100 and ADP scores.

The LCA report based on the present document shall explicitly state which configurations are included and how differences are represented.

Additionally, to the elements of the Minimum Content of LCA Reports, the Full Report may include supporting visuals.

EXAMPLE 2: A bar chart for the Life Cycle Stage Breakdown.

EXAMPLE 3: A bar chart for the Part/Component-Level Breakdown.

EXAMPLE 4: A bar chart for the Material-Level Breakdown.

For automatic processing additionally to the full report, a subset of the full report shall be provided inf csv format covering the following elements:

- Identifier.
- Total Life Cycle Impact Score GWP 100.
- Life Cycle Stage Breakdown GWP 100.
- Total Life Cycle Impact Scores ADP.
- Life Cycle Stage Breakdown ADP.

4.4 Verification and Validation

4.4.1 Third-Party Verification Requirements

The third-party verification is facilitated by the parametric set-up of the present document.

4.4.2 Validation Processes for Comparability

Based on the present document, the uncertainty for the default GWP100 for any smartphone calculated is around ±15 % for 2Ơ, and for ADP ±25 % for 2Ơ. While ideas have been presented elsewhere [i.11], the uncertainty assessment procedure is beyond the scope of the present document.

Despite that the uncertainty may vary somewhat in between studies, it is still considered low enough. That is, comparability of LCAs performed according to the requirements in the present document is decided to be ensured as:

- the product category definition and description (e.g. function, technical performance and use scenario) are identical;
- the functional unit is identical;
- the system boundary is equivalent, including all life cycle stages;
- the description of data is equivalent;

- the criteria for the inclusion of inputs and outputs are identical;
- the data quality requirements for non-default data including COM, PR, TIR, GER and TER are equivalent;
- the units are identical;
- the methods of data collection are equivalent;
- the calculation procedures are identical;
- the allocation of material and energy flows and releases is equivalent;
- data sources are identified;
- the impact category selection and calculation rules are identical;
- the predetermined impact indicators and the predetermined inventory indicators for reporting of LCA data are identical;
- the requirements for the materials and substances to be declared are equivalent;
- the instructions for producing the data required to create the LCA are equivalent;
- the instructions on the content of the LCA report are identical.

4.4.3 Validity in time of the present document

Due to technological and data evolution the present document is valid for no more than 5 years after the time of its first publication.

Annex A (normative): Average measured current test method

A.0 Test method for current measurement

This annex covers the test method for Current Measurment.

A.1 Current test setting for different usage scenarios

This test method is created based on the user's actual usage scenarios and GSMA TS.0.9 [2]. According to the following steps and DUT settings, the average current in each scene (Table A.1) can be obtained.

Unless indicated otherwise, the simulated radio access technology will be LTE. The following bands will be used for each required technology:

- GSM (GSM1800)
- WCDMA (B1)
- LTE (B1)
- 5GNR (n1)
- Wi-Fi® (5,2 GHz)

Table A.1: Average measured current test method

Scene		The usage time per scene	Operating steps	DUT Setting
Call	GSM talk WCDMATalk VoWiFi Talk VoLTE Talk VoNR Talk	0,16	To simulate a call with a 40/40/20 voice activity pattern (40 % talk / 40 % listen / 20 % silence), 4 s of audio followed by silence is sent on the uplink via the UE audio jack to the test equipment(or via acoustic injection into the UE microphone). The test equipment loops back the packets, introducing a 5 s end-to-end delay. It is tolerated that the jitter of audio packet loopback delays can reach up to 2 ms maximum (measured at the LTE simulator). A 10-second-long reference audio file is provided (see the "Common Parameters" section); it contains a 4 s audio activity followed by silence. This reference audio file is repeatedly injected into the DUT audio input while the current drain is being measured. This methodology yields a global "40 % talk / 40 % listen / 20 % silence" voice activity pattern. The DUT current drain is measured for 10 minutes (The DUT display shall be OFF).	The simulator setting of GSM, WCDMA, VoWiFi, VoLTE, VoNR, refer to GSMA Battery Life Measurement and Current Consumption Technique Version 13.0 section 2. Wi-Fi function shall only be ON for VoWiFi Talk scenario, otherwise it shall be kept off.
	Bluetooth Headset-talk		• This scenario shall be run on top of a singleTalk Time scenario. • The test shall be run with a commercially available Bluetooth®-certified headset. When measuring talk time, a voice signal shall be sent in both directions of the Bluetooth connection. Reasoning: This approach prevents a Bluetooth device from entering sniff mode during silence periods. The test setup simulates a regular call situation with the headset connected to the terminal under test and a regular voice call open to a second terminal. The baseband role (Master\Slave) of the Phone when connected with a Bluetooth headset is another factor that can affect the charge consumption. It is recommended that this parameter is reported (typically Phone is Master of the connection).	It is recommended to set-up the following scenarios with Bluetooth devices associated with the device. The accessory device used shall be Bluetooth-certified and commercially available. The network setting is recommended to use the typical VoLTE Talk scenario.

<table>
<tr><th colspan="2">Scene</th><th>The usage time per scene</th><th>Operating steps</th><th>DUT Setting</th></tr>
<tr><td rowspan="2">treaming Content</td><td>Dynamic Adaptive Streaming over HTTP (DASH)</td><td>1,2</td><td>1) Connect to the Reference Content Portal to obtain the web page content.
2) Start the download by selecting the appropriate video stream. After the connection is successfully established with the streaming server and the download has started, start watching the movie.
3) After 30 s of the start of the video download above, start the charge consumption measurement.
4) The video content shall be downloaded to the DUT as fast as possible with the selected radio profile to reflect how videos are streamed to UEs from public video portals in practice.
5) Stop the charge consumption measurement after 10 minutes (total duration between the time stamps of the first and last power samples).</td><td>Dynamic Adaptive Streaming over HTTP or DASH/HLS video content can be played by loading the provided web page through a web browser. The reference content for DASH Video Streams can be retrieved from the GSMA website, the filename is dash_720p.html.The pre-installed Web Browser of the DUT shall be used for DASH Video Streaming. Full Screen shall be enabled. The Video Stream shall be played using the inbuilt (hands free) speaker of DUT.</td></tr>
<tr><td>Audio</td><td></td><td>1) Connect to the Reference Content Portal to obtain the audio content.
2) The actual playing time shall be 10 minutes.
3) After successfully established the connection to the streaming server, start listening to the audio clip.
4) Start Charge Consumption Measurement.</td><td>The pre-installed Media Player of the DUT shall be used for Audio Streaming.
The Audio Stream shall be played using the inbuilt (hands free) speaker of the DUT.<table><tr><th></th><th>Codec</th><th>Bit Rate</th><th>Sampling Rate</th><th>SBR Signalling</th></tr><tr><td>Audio Stream 1</td><td>AAC</td><td>32 kbps</td><td>44,1 kHz</td><td>0(=implicit)</td></tr><tr><td>Audio Stream 2</td><td>2AAC-LC Stereo</td><td>96 kbps</td><td>44,1 kHz</td><td>Not applicable</td></tr></table></td></tr>
</table>

<table>
<tr><th colspan="2">Scene</th><th>The usage time per scene</th><th>Operating steps</th><th>DUT Setting</th></tr>
<tr><td rowspan="2">Application software test</td><td>Music Playback</td><td rowspan="2">1,2</td><td>1) Save the media file on the DUT (memory selection see above).
2) The actual playing time should be 5 minutes.
3) Set the volume to mid-level and start listening to the audio media clip.
4) Start Charge Consumption Measurement.</td><td>The DUT shall be in idle mode as far as air interface activities are concerned, LTE network connected:
• Bit Rate: 128 kbps.
• Sampling Rate: 44,1 kHz (Stereo).
• Download the reference music file from the GSMA website and store it onto the terminal. The media file shall be stored on the external memory card and played back from there. If the DUT does not support an external memory card, the media file shall be stored in the internal phone memory and played from there.
• The pre-installed Music Player of the DUT shall be used for music playback. Enabling of screensavers shall be set to the default values as delivered from the factory.
• It is recommended that loudspeaker of UE should be used to play music.</td></tr>
<tr><td>Video Playback</td><td>1) Save the media file on the phone.
2) The actual playing time shall be 5 minutes.
3) Set the volume to mid-level and start watching the video media clip.
4) Start Charge Consumption Measurement.</td><td>DUT do support a variety of different Video Playback formats. Most common use is the H.264 media format. If this is not supported, MPEG4 Visual Simple Profile Level 0 media format or H.263 Profile 0 Level 10 shall be used to perform this test. The codecs and resolution used for the test shall be specified in the test results. The media file shall be stored onto the handset on the external memory and played back from there. If the DUT does not support an external memory card, the media file shall be stored in the internal phone memory and played from there.
The pre-installed Media Player of the DUT shall be used for Video playback. Background illumination shall be enabled. The screensaver shall be disabled.
The original stereo cable headset or original Bluetooth headset (or one recommended by the terminal manufacturer) shall be used. Full Screen shall be enabled if supported by the DUT.
<table>
<tr><th>Filename</th><th>Bit Rate (kbps)</th><th>fps</th><th>Resolution/Size</th><th>Video Part</th><th>Audio Part</th></tr>
<tr><td>Video_player_06.mpg</td><td>4 000</td><td>30</td><td>640x480 (VGA)</td><td>H.264</td><td>AAC</td></tr>
<tr><td>Video_player_07.mpg</td><td>8 000</td><td>30</td><td>1280x720 (HD 720p)</td><td>H.264</td><td>AAC</td></tr>
<tr><td>Video_player_08.mpg</td><td>10 000</td><td>30</td><td>1920x1080 (HD 1080p)</td><td>H.264</td><td>AAC</td></tr>
</table>

The DUT shall be in idle mode as far as air interface activities are concerned, LTE network connected.</td></tr>
</table>

Scene		The usage time per scene	Operating steps	DUT Setting
Camera	Camera Operation	0,1	1) The reference image to be photographed shall be downloaded from the GSMA website and displayed on a suitable computer screen. 2) Start taking photos. 3) Take 20 pictures at an interval of 30 s. 4) Measure the current consumption during the period that photographs are being taken and stored.	The taken pictures shall be stored on the external memory card. If the DUT does not support an external memory card, the pictures shall be stored in the internal phone memory. Use the DUT under normal light conditions (bright daylight) in a normal illuminated room. Use no external lamps or flashlight and switch off the internal lamp or flash. Picture size/resolution and quality shall be set to maximum. Use the DUT in airplane mode to have a defined default status.
	Video Recording		1) The default video (video_player_06.mpg in playback folder) at the GSMA website shall be played on a PC with medium volume. 2) Enable Video recording on the terminal. 3) Capture the video clip as full screen on the viewfinder. 4) Start Charge Consumption Measurement. 5) The actual recording time should be 10 minutes. 6) Record the Video Recording time and the settings used in Appendices LINK, respectively.	• If certain parameter data is not defined by the default factory settings at the factory, the measurements shall be made using the setting parameters that the manufacturer assumes will most likely be employed by the users. • Mass storage memory is used for streaming video material. If the DUT does not have an external mass memory extension slot, internal memory shall be used instead. • In case the terminal has two cameras, the highest resolution (main) camera shall be used for recording. • Audio recording shall be on. • Video stabilization, if supported, shall be on. • If the display is equipped with an illumination function (e.g. backlight), this shall be lit for the duration of the test. • If the brightness or contrast of the display is adjustable, the adjustable parameter shall be set at the factory setting when measurement is done. • If the DUT has an ambient light sensor-controlled display, the input of the sensor shall be set to maximum. • Keypad lights: default settings. • Measurements have to be carried out in a light environment (in the region of 500 lux). • Viewfinder on. • The highest video recording quality available on the terminal shall be used. • Use the DUT in flight mode to have a defined default status.
Bluetooth interface test	Headset-Music Player	0,2	• This scenario shall be run on top of the Music Playback scenario. • The test shall be run with a commercially available Bluetooth-certified headset. The test report should specify if the connection between DUT and Headset is an EDR level or non-EDR level connection. Using a Bluetooth A2DP (Advanced Audio Distribution Profile) headset with optimum bit rate can lower the charge consumed.	It is recommended to set-up the following scenarios with Bluetooth devices associated with the device. The accessory device used shall be Bluetooth certified and commercially available. The DUT should be LTE network connected.

Scene	The usage time per scene	Operating steps	DUT Setting
GPS tracking	0,3	1) The default GPS Tracking periodicity shall be used. The value used, if known, shall be noted in the test data for GPS tracking. If adaptive tracking is used, then it shall be noted in the test data for GPS tracking. 2) Navigate to and enable the bundled mapping application. Should no bundled mapping application be available, or should the bundled mapping application not be suitable, any application that can run in the background, without display view and on 1 Hz, could be used. 3) Wait until it is clear that DUT has a valid positioning fix and wait for the backlight to extinguish. 4) Start the measurement, run the measurement for ten minutes and note the average current consumption over this period. 5) Complete the test data for GPS tracking.	Place the terminal in a stationary position. If the test is performed outside ensure the internal GPS antenna has unobstructed line of sight to clear sky conditions. If the test is performed inside then it shall be ensured that the GPS signal is provided to the terminal (for example using a cable connection or use of a GPS antenna repeater). The DUT should be LTE network connected.
Browsing	1,34	1) Open the "index.html" file in the first of the five folders on the web server in the web browser of the device. Ensure that the full page is downloaded, including the pictures and the content of the frames. 2) Ensure that the page is fully loaded before proceeding. Afterwards, scroll down until reach the bottom of the web page using the touch screen, scroll keys or other available methods. 3) After 60 s after the start of the download, open the "index.html" file at the next location on the web server and ensure that the full page is downloaded, including the pictures and the content of the frames. NOTE: By starting the timer at the beginning of the request and NOT after the page has been fully downloaded, it is ensured that the overall test duration is constant, independent of the device's and the network's capabilities to deliver the page at a certain speed. 4) Repeat steps 2 and 3 until the page has been loaded five times. The total test time is therefore five minutes. 5) Measure the current for five minutes.	• Download the ZIP file of the "Kepler reference web page" from http://docbox.etsi.org/STQ/Open/Kepler. • For the execution of this test case, place the content of the ZIP file in five different folders of a web server so the page and its contents are reloaded instead of taken from the cache of the device during the test. • Ensure that the web browser's cache is empty to prevent from locally loading the pages. • Ensure that the device can load the web page in less than 60 s. If the device cannot load the page in this timeframe, this test cannot be performed. • Automated browsing is permitted. The DUT should be LTE network-connected.

Scene		The usage time per scene	Operating steps	DUT Setting
Idle	GSM	1,1	In idle mode, record the current samples over a continuous 30-minute period.	The idle mode simulator setting of GSM, GSM/GPRS, WCDMA, (GSM/GPRS)/WCDMA Dual mode, E-UTRA, 5G-NRpls. Refer to GSMA Battery Life Measurement and Current Consumption Technique Version 13.0, section 2.
	GSM/GPRS			
	WCDMA			
	(GSM/GPRS)/WCDMA Dual mode			
	E-UTRA			
	5G-NR			

A.1.0 Introduction to case study

A.1.1 Case Study

An example of Daily Charge Consumption measured for one smartphone sample is shown in Table A.2.

Table A.2: Average measured current test result

Scene		Average Current (mA)	Average current per item (mA)	The usage time (h)
Call	GSM talk	215,92	318,1	0,16
	WCDMATalk		154,5	
	VoWiFi Talk		209,2	
	VoLTE Talk		232,3	
	Headset-talk		165,5	
Streaming Content	Dynamic Adaptive Streaming over HTTP (DASH)	433,15	481,9	
	Audio		384,4	
Application software test	Music Playback	283,65	97,7	1,2
	Video Playback		469,6	
Camera	Camera Operation	962,5	839,5	0,1
	Video Recording		1085,5	
Bluetooth interface test	Headset-Music Player	58,9	58,9	0,2
GPS tracking		5,3	5,3	0,3
Browser		453,2	453,2	1,34
Idle	GSM	13,48166667	46,4	1,1
	GSM/GPRS		4,2	
	WCDMA		3,6	
	(GSM/GPRS)/WCDMA Dual mode		6,8	
	E-UTRA		12,4	
	5G-NR		7,49	
Daily Charge Consumption measured in mAh			1 626,45	

With the values shown in Table A.2, the energy consumption for this use scenario of this smartphone sample can be calculated as:

(Eu) = $Eper \times Vb \times 365 \times Yu/Ec$ = 1 626,45 × 3,84 × 365 × 5/0,88 = 12 952 416,81 mWh ≈ 12,95kWh

A.2 General parameter settings condition

A.2.1 System Simulator

The system simulator shall have access to the internet. This configuration is required for DUT testing, as in a normal situation, this type of devices send periodical updates and requests to the home servers.

The connection diagram - cellular with WLAN Access Point test set-up for GSM, WCDMA, E-UTRA or 5G-NR Standby / WLAN enabled is shown in Figure A.1.

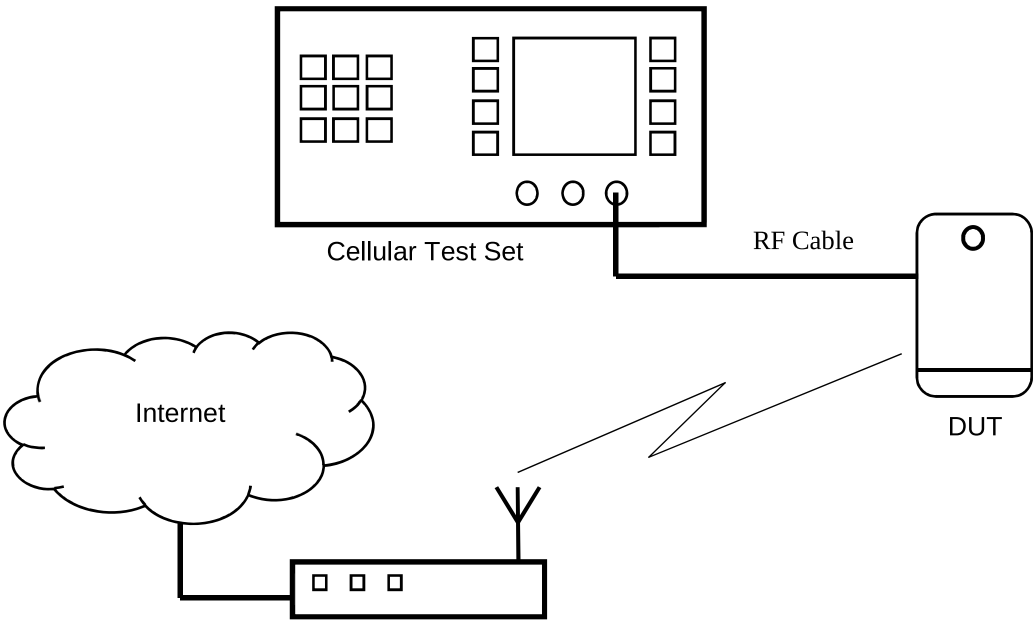

Figure A.1: Test set-up for GSM, WCDMA , E-UTRA or 5G-NR Standby / WLAN enabled

The WLAN AP is directly connected to Public Internet (not GAN, nor VPN).

A.2.2 Common Parameters

There are certain parameters that are common to all modes of operations as shown in Table A.3.

Table A.3: Common parameters to all modes of operations

Item	Parameter
Ambient Temperature	18 - 25 °C
PLMN	Home
Backlight	Default setting Measurements in (any) Idle Mode shall be taken after the backlight went off. Measurements for video, browsing, streaming, etc., the backlight shall be on. Measurements for music, etc., the backlight shall be off.
Cell Broadcast	Not used
Cell Reselection	No
Display Brightness	200nit
Audio Volume	Middle of available UI range

The following external resources provide input files for the tests described in the present document. The files have to be downloaded onto a dedicated media or streaming server before using them for the tests.

The files can be found on GitHub public repository at [i.12].

All relative paths listed in what follows refer to the repository top path.

VoLTE Call:

- ./reference_files/audio/call/volte/volte.wav

Audio stream:

- ./reference_files/audio/streaming/audio_only_stream_aac.3gp

Music:

- ./reference_files/audio/playback/music.mp3

Progressive Video Streaming:

- ./reference_files/video/streaming/progressive/video_stream_480p_30fps_a.mp4
- ./reference_files/video/streaming/progressive/video_stream_720p_30fps_a.mp4
- ./reference_files/video/streaming/progressive/video_stream_720p_30fps_b.mp4
- ./reference_files/video/streaming/progressive/video_stream_720p_30fps_c.webm
- ./reference_files/video/streaming/progressive/video_stream_1080p_30fps_a.mp4
- ./reference_files/video/streaming/progressive/video_stream_1080p_30fps_b.mp4
- ./reference_files/video/streaming/progressive/video_stream_1080p_30fps_c.webm
- ./reference_files/video/streaming/progressive/video_stream_1080p_60fps_b.mp4
- ./reference_files/video/streaming/progressive/video_stream_2160p_30fps_c.webm

DASH (Dynamic Adaptive Streaming over HTTP) Video Streaming:

- ./reference_files/video/streaming/dash/dash_720p.html

Video Playback application:

- ./reference_files/video/playback/video_player_01.3gp
- ./reference_files/video/playback/video_player_02.3gp
- ./reference_files/video/playback/video_player_03.3gp
- ./reference_files/video/playback/video_player_04.3gp
- ./reference_files/video/playback/video_player_05.3gp
- ./reference_files/video/playback/video_player_06.mpg
- ./reference_files/video/playback/video_player_07.mpg
- ./reference_files/video/playback/video_player_08.mpg

Camera:

- ./reference_files/camera/photo.gif

The dummy battery is used for all the scenario's consumption test. The dummy battery fixture and effective battery capacity are referred to GSMA TS.0.9 [2], section 3 and section 4.

Annex B (normative): Default values for transportation phase

B.1 Default Transportation Scenario

This default transportation scenario shall be used:

- Three-Leg transportation
- Origin = Asia
- Destination = Global (see default distances in clause B.3)

B.2 Default Transport Mode

These default transport modes shall be used:

- Leg 1 Transportation Mode: Road
- Leg 2 Transportation Mode: Air
- Leg 3 Transportation Mode: Road

B.3 Default Distances

These default distances (km) shall be used (Table B.1).

Table B.1: Default distances (km)

ORIGIN	DESTINATION	Leg 1	Leg 2				Leg 3
		Road	Air	Sea	Rail	Road	Road
Africa	Africa	150	5 229	7 636	6 829	6 829	350
Africa	Asia	150	11 845	12 817	20 081	20 081	350
Africa	Europe	150	8 713	10 724	12 378	12 378	350
Africa	North America	150	16 493	18 097	Not Possible	Not Possible	350
Africa	South America	150	6 887	6 916	Not Possible	Not Possible	350
Africa	Oceania	150	10 989	11 173	Not Possible	Not Possible	350
Africa	Global	150	10 026	11 227,167	13 096	13 096	350
Asia	Africa	150	11 845	12 817	20 081	20 081	350
Asia	Asia	150	3 725	7 658	4 914	4 914	350
Asia	Europe	150	9 683	14 753	12 048	12 048	350
Asia	North America	150	11 100	11 245	Not Possible	Not Possible	350
Asia	South America	150	11 797	19 547	Not Possible	Not Possible	350
Asia	Oceania	150	7 430	8 281	Not Possible	Not Possible	350
Asia	**Global**	**150**	**9 263,3333**	**12 383,5**	**12 347,667**	**12 347,667**	**350**
Europe	Africa	150	8 713	10 724	12 378	12 378	350
Europe	Asia	150	9 683	14 753	12 048	12 048	350
Europe	Europe	150	1 180	4 334	1 271	1 457	350
Europe	North America	150	9 550	15 446	Not Possible	Not Possible	350
Europe	South America	150	10 802	11 144	Not Possible	Not Possible	350
Europe	Oceania	150	16 903	18 248	Not Possible	Not Possible	350
Europe	Global	150	9 471,8333	12 441,5	8 565,6667	8 627,6667	350
North America	Africa	150	16 493	18 097	Not Possible	Not Possible	350

B.4 Default Emission Factors

Emissions factors shall be used in accordance with Global Logistics Emissions Council (GLEC) [4].

Below are some default values which shall be used unless other methods of transportation as documented in GLEC [4] can be evidenced:

Table B.2: Default emission values for transportation

Transport Mode	Default Emission Factor
Road (Truck)	90 **(g CO_2e/tkm)** - (GLEC - Europe - WTW - Artic truck 40 - 44 t GVW Diesel Traction - Container)
Rail	28,5 **(g CO_2e/tkm)** - (GLEC - Europe - WTW - Diesel Traction - Container)
Sea	72,7 **(g CO_2e/ TEU km) -** (GLEC - Industry Average - WTW - Dry Container)
Air	608 **(g CO_2e/tkm)** (GLEC - WTW - Freighter - Long Haul)

B.5 Default Load Factor

A default load factor of 60 % shall be used → Load factor = 0,6

B.6 Example Calculation

Example Calculation based on default values.

Example Unit Weight: 0,35 kg (smartphone and packaging).

$$Leg\ 1: Truck\ (150\ km) = \frac{0{,}00035 \times 150 \times 90}{1\ 000 \times 0{,}6} = \frac{4{,}725}{600} = 0{,}007875\ \text{kg CO}_{2\text{e}}$$

$$Leg\ 2: Air\ Freight\ (9\ 600\ km) = \frac{0{,}00035 \times 9263 \times 608}{1\ 000 \times 0{,}6} = \frac{1\ 971{,}17}{600} = 3{,}2853\ \text{kg CO}_{2\text{e}}$$

$$Leg\ 3: Truck\ (350\ km) = \frac{0{,}00035 \times 350 \times 90}{1\ 000 \times 0{,}6} = \frac{11{,}025}{600} = 0{,}018375\ \text{kg CO}_{2\text{e}}$$

$$TotalEmissions_{\text{transport}} = 0{,}007875\ \text{kg CO}_{2\text{e}} + 3{,}2853\ \text{kg CO}_{2\text{e}} + 0{,}018375\ \text{kg CO}_{2\text{e}} = 3{,}31155\ \text{kg CO}_{2\text{e}}$$

Annex I-A (informative): Background for IC calculation methods in clause 4.1.3.1.4

I-A.1 Memories

I-A.1.1 Back-end

Back-end production cradle-to-gate for any kind of memory for GWP100 = total mass memories (kg) × (24 + 63 kWh electricity × electricity mix upstream kgCO_2e/kWh + 670 kWh electricity × electricity mix back end kgCO_2e/kWh).

The formula is based on [i.15] and ETSI ES 204 085 [i.27] with material content flows set to zero with the electricity parametrized. Moreover, assumed that 65 % of the remaining upstream is electricity related for GWP100.

I-A.1.2 RAM

Front-end production cradle-to-gate for RAM memories GWP100 = RAM (GB) × (0,198 + 0,524 kWh electricity × electricity mix upstream kgCO_2e/kWh + 0,77 kWh electricity × electricity mix production wafer fab kgCO_2e/kWh).

The formula is based on 40 mm^2 die area/GB, [i.15] and ETSI ES 204 085 [i.27] with the electricity parametrized. Moreover, assumed that 65 % of the remaining upstream is electricity related for GWP100.

The amount of electricity per m^2 for wafer fab is obtained via the cm^2 functional unit from IMEC tool at [i.13] public user with 75 % yield for N14.

I-A.1.3 NAND

Front-end production cradle-to-gate for internal memories GWP100 = Internal memory (GB) × (0,008 + 0,0213 kWh electricity × electricity mix upstream kgCO_2e/kWh + 0,032 kWh × electricity mix wafer fab kgCO_2e/kWh).

The formula is based on 1,6 mm to 1,8 mm^2/GB, [i.15] and ETSI ES 204 085 [i.27] with the electricity parametrized. Moreover, assumed that 65 % of the remaining upstream is electricity related for GWP100.

The amount of electricity per m^2 is obtained from IMEC tool at [i.13] public user with 75 % yield for N14.

I-A.2 Logic chips and non-memory chips

I-A.2.1 Back-end

The Logic and Non-Memory (LNM) chips in the smartphone at hand will use the following formulae as applicable:

1a) Back-end production cradle-to-gate for any kind of logic & non-memory (LNM) chip for GWP100 = total mass LNM chip (kg) × (24 + 63 kWh electricity × electricity mix upstream kgCO_2e/kWh + 670 kWh electricity × electricity mix back end kgCO_2e/kWh).

The formula is based on [i.15] and ETSI ES 204 085 [i.27] with material content flows set to zero with the electricity parametrized. Moreover, assumed that 65 % of the remaining upstream is electricity related for GWP100.

I-A.2.2 Front-end

2a) Front-end production cradle-to-gate for Si wafer for phone chips = Chip performance (TFLOPS) (0,207 + 0,547 kWh electricity × electricity mix upstream kgCO_2e/kWh + 1,28 kWh × electricity mix wafer fab kgCO_2e/kWh).

The formula is based on 24 GFLOPS/mm^2, [i.15] and ETSI ES 204 085 [i.27] with the electricity parametrized. Moreover, assumed that 65 % of the remaining upstream is electricity related for GWP100.

The amount of electricity per m^2 is obtained from IMEC tool at [i.13] public user with 75 % yield for N5.

3a) Front-end production cradle-to-gate for Si wafer, CPUs = Chip performance (TFLOPS) × (0,41 + 1,1 kWh electricity × electricity mix upstream kgCO_2e/kWh + 2,55 kWh × electricity mix wafer fab kgCO_2e/kWh).

The formula is based on 12 GFLOPS/mm^2, [i.15] and ETSI ES 204 085 [i.27] with the electricity parametrized. Moreover, assumed that 65 % of the remaining upstream is electricity related for GWP100.

The amount of electricity per m^2 is obtained from IMEC tool at [i.13] public user with 75 % yield for N5.

4a) Front-end production cradle-to-gate for Si wafer, GPUs = Chip performance (TFLOPS) × (0,04 + 0,1 kWh electricity × electricity mix upstream kgCO_2e/kWh + 0,24 kWh × electricity mix wafer fab kgCO_2e/kWh).

The formula is based on 126 GFLOPS/mm^2, [i.15] and ETSI ES 204 085 [i.27] with the electricity parametrized. Moreover, assumed that 65 % of the remaining upstream is electricity related for GWP100.

The amount of electricity per m^2 is obtained from IMEC tool at [i.13] public user with 75 % yield for N5.

5a) Front-end production cradle-to-gate for Si wafer, CPU core = CPU Cores × (0,02 + 0,05 kWh electricity × electricity mix upstream kgCO_2e/kWh + 0,12 kWh × electricity mix wafer fab kgCO_2e/kWh).

The formula is based on 4 mm^2/Core, [i.15] and ETSI ES 204 085 [i.27] with and the electricity parametrized. Moreover, assumed that 65 % of the remaining upstream is electricity related for GWP100.

The amount of electricity per m^2 is obtained from IMEC tool at [i.13] public user with 75 % yield for N5.

6a) Front-end production cradle-to-gate for ICs which are neither processors, CPUs, GPUs nor memories, GWP100 = IC mass (kg) × (80 + 200 kWh electricity × electricity mix upstream kgCO_2e/kWh kgCO_2e/kWh + 500 kWh × electricity mix wafer fab kgCO_2e/kWh).

The formula is based on [i.15] and ETSI ES 204 085 [i.27] with all flows set to zero except the Wafer for which with the electricity parametrized and assumed that 65 % of the remaining wafer upstream is electricity related for GWP100.

7a) Front-end production cradle-to-gate for GaAs wafer for phone chips, GWP100 = Chip performance (TFLOPS) × (0,26 + 0,7 kWh electricity × electricity mix upstream kgCO_2e/kWh + 1,28 kWh × electricity mix wafer fab kgCO_2e/kWh).

Based on 2a. "Front-end production cradle-to-gate for Si wafer for phone chips" and different CO_2e and Sb-e intensity for the GaAs Wafer input from [i.14].

8a) Front-end production cradle-to-gate for GaN on SiC wafer for phone chips = Chip performance (TFLOPS) × (0,9 + 2,4 × kWh electricity × electricity mix upstream kgCO_2e/kWh + 1,28 kWh × electricity mix wafer fab kgCO_2e/kWh).

Based on 2a. "Front-end production cradle-to-gate for Si wafer for phone chips" and different CO_2e and Sb-e intensity for the GaN on SiC Wafer input from [i.13].

Annex I-B (informative): Background for PCB calculation methods in clause 4.1.3.1.5

The formula is based on 1 m^2 of PCB from ETSI ES 204 085 [i.27].

The dataset can be parametrized 327 kWh × electricity CO_2e mix + 164.

This leads to 5,45 × electricity CO_2e intensity for PCB assembly electricity g CO_2e/(cm^2 layers) and 0,956 + 2,53 × electricity CO_2e intensity for upstream electricity g CO_2e/(cm^2 layers) for remainders.

$$y\ (g\ CO_2e/cm^2) = (5{,}45 \times E_{PCB,assembly} + 0{,}956 + 2{,}53 \times E_{PCB,upstream}) \times layers.$$

$$y\ (g\ Sb\text{-}e/cm^2) = (5{,}45 \times E_{PCB,assembly} + 5E\text{-}6 + 2{,}53 \times E_{PCB,upstream}) \times layers.$$

NOTE: Electricity use per cm^2 layer, (327/(1 0000×6))=0,00545 kWh/(cm^2layer). Electricity emissions g per cm^2×layer, 5,45×E (generalized for any electricity mix). Remainder emissions, (164 × 1 000)/(10 000×6)=2,733 g/(cm^2×layer).

Relative processing multipliers compared to Rigid are assumed as Flex 1.1, Rigid-flex 1.2 and HDI 1.3. These factors are applied both the electricity factor and the remainder factor.

Relative material grade impact for the remainders compared to FR4 are assumed as Halogen-free FR4 1.07, Polyimide 1.25 and Metal-Core 1.35.

As an example of GWP100 for "Flex/Halogen-free FR4" compared to "Rigid/FR4":

- $y\ (g\ CO_2e/cm^2) = (5{,}45 \times 1{,}1 \times E_{PCB,assembly} + 0{,}956 \times 1{,}1 \times 1{,}07 + 2{,}53 \times 1{,}1 \times 1{,}07 \times E_{PCB,upstream}) \times layers = (5{,}995 \times E_{PCB,assembly} + 1{,}12 + 2{,}98 \times E_{PCB,upstream}) \times layers$

As an example of ADP for Flex Halogen-free FR4 compared to Rigid FR4:

- $y\ (g\ Sb\text{-}e/cm^2) = (5{,}45 \times 1{,}1 \times E_{PCB,assembly} + 5E\text{-}6 \times 1{,}1 \times 1{,}07 + 2{,}53 \times 1{,}1 \times 1{,}07 \times E_{PCB,upstream}) \times layers = (5{,}995 \times E_{PCB,assembly} + 5{,}9E\text{-}6 + 2{,}98 \times E_{PCB,upstream}) \times layers$

Annex I-C (informative): Background for Display calculation methods in clause 4.1.3.1.2

The formula is based on ETSI TR 104 080 [i.3], "Precision of a streamlined life cycle assessment approach used in eco-rating of mobile phones" [i.15] and ETSI ES 204 085 [i.27] parametrized for ICs and assembly electricity and combined with cradle-to-gate average CO_2e.

Table I-C.1: Rationale for display calculation

Display technology	Cradle-to-gate average CO_2e, g /cm^2	Source
LTPS LCD	17,5	[i.15]
Rigid OLED	30	[i.16]
Flexible OLED	45	[i.17]
MiniLED	50	[i.17]
MicroLED	80	[i.17]

Example calculation:

For Flexible OLED, 0,7 kgCO_2e/kWh electricity, D = 6,8, W = 20, H = 9

→ *Height*: 2,79 inches and *Width*: 6,2 inches and A = 17,3 in^2 {1 in^2 = 6,4516 cm^2} = **111,62 cm^2,**

total active area display (cm2) × ((0,0075 + 0,025 kWh electricity × electricity mix upstream kgCO_2e/kWh + 8,5E-6 kg × (340 + 680 kWh electricity × electricity mix upstream kgCO_2e/kWh + 670 kWh electricity × electricity production kgCO_2e/kWh) + 0,013 kWh electricity × electricity mix display assembly kgCO_2e/kWh))

111,62 cm^2× ((0,0075 + 0,025 kWh electricity × **0,7** + 8,5E-6 kg × (340 + 680 kWh electricity × **0,7**+ 670 kWh electricity × **0,7**) + 0,013 kWh electricity × **0,7**))

= **5,02 kg CO_2e**

total active area display (cm^2) × ((7E-7 + 0.025 kWh electricity × electricity mix upstream kgSb-e/kWh + 8,5E-6 kg × (6E-8 + 680 kWh electricity × electricity mix upstream kgSb-e/kWh + 670 kWh electricity × electricity production kgSb-e/kWh) + 0,013 kWh electricity × electricity mix display assembly kgSb-e/kWh))

111,62 cm^2× ((7E-7 + 0,025 kWh electricity × **5E-7** + 8,5E-6 kg × (6E-8 + 680 kWh electricity × **5E-7** + 670 kWh electricity × **5E-7**) + 0,013 kWh electricity × **5E-7**))

= **8,1E-5 kg Sb-e**

Annex I-D (informative): Background for Battery calculation methods in clause 4.1.3.1.3

The formulae are based on:

- Typical baseline ≈50 kg CO_2e/kg from product reports.
- Ideas for the shares of cell assembly and module assembly [i.18], [i.19], [i.20] and [i.21]:

Example, 200 Wh/kg and 13 Wh capacity:

$$GWP_{per\ Wh} = \frac{10{,}5 + 27{,}5x_{upstream,batt} + 30x_{cell} + 10x_{module}}{E}$$

$$GWP_{battery,Wh} = GWP_{per\ Wh} \times Battery_{Wh}$$

$$GWP_{per\ Wh} = \frac{10{,}5 + 27{,}5 \times 0{,}7 + 30 \times 0{,}7 + 10 \times 0{,}7}{200}$$

$$= 0{,}289 \text{ kg } CO_2\text{e/Wh}$$

$$GWP_{battery,Wh} = 0{,}289 \times 13 = 3{,}75\ kg\ CO2e$$

$$ADP_{battery,Wh} = \frac{0{,}00002 + 27{,}5 \times 5E-7 + 30 \times 5E-7 + 10 \times 5E-7}{200} \times 13 = 3{,}5E-6\ kg\ Sb-e$$

Annex I-E (informative): Background for Camera calculation methods in clause 4.1.3.1.11

For cameras in smartphones the performance indicator most closely related to the environmental load in manufacturing is sensor size and related pixel size/resolution.

Why?

- Larger sensors → more silicon, more glass and sometimes more metal (e.g. for holding and cooling).
- A larger sensor also requires larger and more complex optics, providing higher material input and more manufacturing energy.
- The number of manufacturing steps is increasing for large sensors, especially if they have high resolution and advanced processes (e.g. BSI - back-side illumination).

Derivation of $GWP_{camera} = \left(\frac{128}{x^2} + \frac{22{,}62}{x} + 1\right) \times \left(0{,}0305 \times El_{wafer\ fab,GWP} + 0{,}0049 + 0{,}013 \times El_{IC\ front-end,upstream}\right)$

Derivation of $ADP_{camera} = \left(\frac{128}{x^2} + \frac{22{,}62}{x} + 1\right) \times \left(0{,}0305 \times El_{wafer\ fab,ADP,Sb} + 2{,}5E - 8\right)$

Step 1 - Active square's size

The "optical format" 1/x" tells about the diagonal of the active area in mm.

Industry shortcut:

$$\text{Diagonal } d_{mm} \approx \frac{16}{x}$$

EXAMPLE: 1/2" ⇒ d ≈ 16/2 = 8 mm.

For 1:1 aspect ratio (square), the width and height are the same:

$$w = h = \frac{d}{\sqrt{2}}$$

Numerically, $\frac{1}{\sqrt{2}} \approx 0{,}7071$

Step 2 - Get active silicon area

Active area = width × height:

$$A_{active} = w \times h = \frac{d^2}{2}$$

Since d=16/x

$$A_{active} = \frac{(16/x)^2}{2} = \frac{128}{x^2} mm2$$

Step 3 - Add the margin *m* around the chip

Real sensor dies have an extra strip all around for bond pads, guard rings, and cutting room. That margin *m* is measured in mm, per side.

If *m* is added to each side, the die's total width = w + 2 m, total height = h + 2 m

Die area:

$$A_{die} = (w + 2m) \times (h + 2m)$$

Step 4 - Expand it into three parts

Substitute:

$$w = h = \frac{16}{x} \times 0{,}707 = \frac{11{,}3137}{x}$$

$$A_{die} = \left(\frac{11{,}3137}{x} + 2m\right)^2$$

Expand:

- Active area term: $\frac{128}{x^2} mm2$ {the active light-sensitive silicon}
- Cross term: $(w + 2m) \times (h + 2m) = (w + 2m) \times (w + 2m) = (w + 2m)^2 = w^2 + 2w2m + (2m)^2$. $2 \times w \times 2m = 2 \times \frac{11{,}3137}{x} \times 2m = \frac{45{,}2548m}{x}$ {extra silicon from margin on the sides}
- Margin-only term: $4m^2$ {corner silicon purely from margin, even if the active area were zero}

Step 5 - Final equation

$$A_{die} = \left(\frac{128}{x^2} + \frac{45{,}2548m}{x} + 4m^2\right)$$

m is assumed 0,5 mm →

$$A_{die} = \left(\frac{128}{x^2} + \frac{22{,}62}{x} + 1\right)$$

Example for a camera with a 1/2,55" sensor:

Derivation of GWP_{camera} $=\left(\frac{128}{2{,}55^2} + \frac{22{,}62}{2{,}55} + 1\right) \times (0{,}0305 \times 0{,}7 + 0{,}0049 + 0{,}013 \times 0{,}7) = 1{,}04\ kg\ CO2e$

Derivation of ADP_{camera} $=\left(\frac{128}{2{,}55^2} + \frac{22{,}62}{2{,}55} + 1\right) \times (0{,}0305 \times 8E - 8 + 2{,}5E - 8) = 1{,}15E - 6\ kg\ Sb - e$

Annex I-F (informative): Materials (polymers, metals, papers) default GWP100 and Sb-e intensities

Table I-F 1
(Source: [i.22], [i.23] for Tin, secondary)

ABS
Aluminium, primary
Aluminium, secondary
Cobalt, European market mix
Copper, primary
Copper, secondary
Gold, primary
Gold, secondary
Indium, European market mix
Paper/Cardboard
Platinum, primary
Platinum, secondary
Polycarbonate
Silver, primary
Silver, secondary
Stainless steel
Steel
Tantalum
Tin, primary
Tin, secondary

NOTE 1: For Sb-e for gold: 61,7076 Points/(17,28 × 0,0755) = 47,29 kg Sb-e.

NOTE 2: 17,28 is from normalization and 0,0755 from weighting for the "Resource use, mineral and metals" impact assessment method.

Annex I-G (informative): eSIM cards production in clause 4.1.3.1.16

Assumed that around 50 % of the total GWP100 score for eSIM is from electricity used in processes which are not raw material production processes. From [i.24] is an estimated value of 122 grams CO_2e for producing one eSIM. The mass of one eSIM is assumed to be 0,8 g. This number leads to the formulae in clause 4.1.3.1.10.

Annex I-H (informative): Mechanical part production in clause 4.1.3.1.1

The models are based on [i.22] and the assumption that electricity makes up the largest share of the impact of these kinds of part production processes. The CED values from [i.22] and [i.26] for primary energy are transformed to kWh electricity/kg.

Table I-H.1

Process	Electricity used, kWh/kg	Source
Fiber laser cutting, Al, 1 mm	0,004	[i.22]
Fiber laser cutting, Al, 10 mm	0,241	[i.22]
Forging aluminium	1,08	[i.22]
Machining aluminium	0,321	[i.22]
Rolling aluminium foil	7,53	[i.22]
Rolling aluminium sheet	2,58	[i.22]
Scouring aluminium	4,16	[i.22]
Welding aluminium arc	1,3	[i.22]
Die casting aluminium	8	[i.26]
Steel welded pipes, 8,5 % scrap BOF	14,97	[i.22]
Rolling steel	0,802	[i.22]
Fiber laser cutting steel, 1 mm	0,00268	[i.22]
Fiber laser cutting steel, 10 mm	0,1338	[i.22]
Electric MIG welding, 4 mm steel	6,52	[i.22]
Welding steel, MAG	1,21	[i.22]
Welding steel, autogenous	0,993	[i.22]
Injection moulding - machine only	2,24	[i.22]
Injection moulding - production site	5,71	[i.22]
Film HDPE 50 µm (extrusion)	0,53	[i.22]
Film LDPE 50 µm (extrusion)	0,54	[i.22]
Film PC 50 µm (extrusion)	1,19	[i.22]
Film PET 50 µm (extrusion/cast film)	0,92	[i.22]

Annex I-I (informative): Example of result generation code for result presentation

The following code helps as an inspiration to generate the information required by clause 4.3.1 the script is rather high-level and does not contain the full parametrization of the present document. However, the input values of the environmental matrix are based on default values.

```
% ======================================================================
%  Code for use in GNU Octave which can help generate some required results of the present document
% ======================================================================

clc; clear; close all force;
format long g;
rand("seed",42);

% ---------- Yield factor, required by clause 4.1.3.2.19 ----------
yield_factor = 0.99; % 99% manufacturing yield
yield_multiplier = 1 / yield_factor; % Scale factor for upstream embodied stages


% ---------- Process names ----------
proc = { ...
 'CAMERA 1.8','CAMERA 2.1','CAMERA 2.4','CAMERA 2','CAMERA 4',...
 'CHARGER','PCB Rigid','PCB Flexible','Battery','Display Flexible OLED','ABS','Al','Co','Cu',...
 'Au','In','Pt','Polycarbonate','Ag','Stainless Steel','Steel','Ta',...
 'Sn','Memory Back End','Memory RAM Front End','Memory NAND Front End','Logic Back End','Logic 2
Front End','Logic 3 Front End','Logic 4 Front End','Logic 5 Front End',...
 'Other IC','Paperboard','Corrugated Cardboard','LDPE film','PET','Wood Pallet','LLPDE stretch
film','Final Assembly', 'Scour Al','Trp Leg1',...
 'Trp Leg2','Trp Leg3','Use','End-of-life','Smartphone'};

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

% ---------- Technology matrix A -Units cm2*layers for PCBs, cm2 for Display Flexible OLED, TFLOPS
for Logic 2 Front End, Logic 3 Front End, Logic 4 Front End CPU Cores for Logic 5 Front End, pieces
for Cameras, Transports, Final Assembly, Use, EoLT. kg for others.--------
A = eye(46);
A(1,46)=-1;   A(2,46)=-1;   A(3,46)=-1; A(4,46)=-1; A(5,46)=-1;
A(6,46)=-0.06528;  A(7,46)=-184.14; A(8,46)=-39.08; A(9,46)=-0.05018;
A(10,46)=-91.3; A(11,46)=-0.001; A(12,46)=-0.02463; A(13,46)=-0.011;
A(14,46)=-0.025; A(15,46)=-25.3e-6; A(16,46)=-9e-8;
A(17,46)=-10e-6; A(18,46)=-0.02447;  A(19,46)=-0.00012567;
A(20,46)=-1e-9; A(21,46)=-5e-4; A(22,46)=-1e-9; A(23,46)=-1.37666e-3;
A(24,46)=-0.002; A(25,46)=-8; A(26,46)=-512; A(27,46)=-0.002;
A(28,46)=-0.4608; A(29,46)=-0.4608; A(30,46)=-0.4608; A(31,46)=-8;
A(32,46)=-0.003; A(33,46)=-0.180; A(34,46)=-0.080; A(35,46)=-0.020;
A(36,46)=-1e-9; A(37,46)=-2.08e-3; A(38,46)=-0.5e-3; A(39,46)=-1; A(40,46)=-0.02463;
A(41,46)=-1; A(42,46)=-1; A(43,46)=-1; A(44,46)=-1; A(45,46)=-1;

% ---------- Functional unit ----------
alfa = zeros(46,1);
alfa(46)=1;

% ---------- Environmental matrix B ----------
B = [
 1.88 2.14e-06; 1.33 1.52e-6; 1.15 1.31e-6; 1.57 1.78e-6; 0.518 5.9e-7;
 20 1.18e-5; 0.00654 5.99e-9; 0.00793 9.99e-9; 57.8 5.37e-5; 0.045 7.25e-7;
 2.69 3.66e-14; 11.8 3.89e-7; 37.2 1.12e-5; 3.45 1.25e-3; 47800 47.3;
 118 6.27e-3; 3.33e4 2.02; 3.4 3.66e-14; 438 1.04;
 5.08 4.36e-5; 1.59 2.04e-8; 145 3.21e-5; 10.3 0.047; 537 3.96e-4;
 1.1 9.97e-07; 0.0453 4.06e-8; 537 3.96e-4; 1.49 1.28e-6; 2.96 2.55e-6;
 0.278 2.4e-7; 0.139 1.2e-7; 570 5.1e-4; 1.3 1e-7; 0.8 6e-8;
 2.2 1e-7; 2.8 1e-7; 1.0 5e-8; 1.86 7.46e-8; 1.78 1.25e-6; 2.912 2.08e-6;
 0.0114 1.27e-9; 4.76 7.83e-8; 0.0266 2.96e-9; 8.4 6e-6;
 -1.04 -8.62e-4; 0 0];

% ================= APPLY YIELD FACTOR =====================

stage_names = {'Raw Materials','Production', 'Distribution','Use','EoLT'};
stage_idx = {
[11,12,13,14,15,16,17,18,19,20,21,22,23,33,34,35,36,37,38], % RawMat
[1,2,3,4,5,6,7,8,9,10,24,25,26,27,28,29,30,31,32,39,40], % Production
[41,42,43], % Distribution
[44], % Use
```

```
[45] % EoLT
};

RM_idx = stage_idx{1};
PROD_idx = stage_idx{2};

% Apply yield to upstream  embodied stages
B_yielded = B;
B_yielded(RM_idx,:) = B(RM_idx,:) * yield_multiplier;
B_yielded(PROD_idx,:) = B(PROD_idx,:) * yield_multiplier;

% ==================== BASELINE ===========================
p0 = A \ alfa;
beta0 = p0.' * B_yielded;

fprintf("\n=== BASELINE IMPACTS WITH YIELD ===\n");
fprintf("Yield factor: %.3f → multiplier %.3f\n", yield_factor, yield_multiplier);
fprintf("GWP100: %.6f kg CO2e\n", beta0(1));
fprintf("ADP: %.6e kg Sb-eq\n", beta0(2));

% ==================== STAGE IMPACTS ======================
stage_impacts = zeros(5,2);
for s = 1:5
idx = stage_idx{s};
B_stage = zeros(size(B));
B_stage(idx,:) = B_yielded(idx,:);
stage_impacts(s,:) = p0.' * B_stage;
end


% ===================== STAGE INDICES =======================
stage_idx = {
  [11,12,13,14,15,16,17,18,19,20,21,22,23,33,34,35,36,37,38],
  [1,2,3,4,5,6,7,8,9,10,24,25,26,27,28,29,30,31,32,39,40],
  [41,42,43],
  [44],
  [45]
};

stage_names = {'Raw Materials','Production', 'Distribution','Use','EoLT'};

% ===================== PROCESS CONTRIBUTIONS =================
RM_idx    = stage_idx{1};
PROD_idx  = stage_idx{2};

proc_RM   = proc(RM_idx);
proc_PROD = proc(PROD_idx);

RM_GWP   = p0(RM_idx) .* B(RM_idx,1);
RM_ADP   = p0(RM_idx) .* B(RM_idx,2);

PROD_GWP = p0(PROD_idx) .* B(PROD_idx,1);
PROD_ADP = p0(PROD_idx) .* B(PROD_idx,2);


% ======================================================================
%                FUNCTION 1 — COLORED STAGE BAR CHART
% ======================================================================
function stage_bar(values, labels, unit, ttl, barcolor)
    figure('Color','w');
    bar(values,'FaceColor',barcolor,'EdgeColor','none');
    grid on;

    set(gca,'XTickLabel',labels);
    ylabel(unit); title(ttl);

    for i = 1:length(values)
        text(i, values(i)*1.02, sprintf('%.3g', values(i)), ...
            'HorizontalAlignment','center','FontWeight','bold','FontSize',30);
    end
end

% ======================================================================
%      FUNCTION 2 — HORIZONTAL ALL-CONTRIBUTOR BAR CHART
% ======================================================================
function bar_all_horizontal(values, labels, ylab, ttl, barcolor)

    [vals_sorted, idx_sorted] = sort(values, 'descend');
```

```
    lbl_sorted = labels(idx_sorted);

    figure('Color','w','Name',ttl);
    barh(vals_sorted,'FaceColor',barcolor,'EdgeColor','none');
    grid on;

    set(gca,'YTick',1:numel(values), ...
            'YTickLabel',lbl_sorted, ...
            'YDir','reverse');

    xlabel(ylab);
    title(ttl);

    xoff = max(vals_sorted)*0.01;

    for i = 1:numel(vals_sorted)
        text(vals_sorted(i)+xoff, i, sprintf('%.3g', vals_sorted(i)), ...
            'HorizontalAlignment','left','FontWeight','bold','FontSize',30);
    end
end


% ======================================================================
%                           STAGE GROUP CHARTS
% ======================================================================

stage_impacts = zeros(5,2);
for s = 1:5
    tmp = zeros(size(B));
    tmp(stage_idx{s},:) = B(stage_idx{s},:);
    stage_impacts(s,:) = p0.' * tmp;
end

% GWP stage chart — RED
stage_bar([beta0(1); stage_impacts(:,1)], ...
    {'Total','RawMat','Prod', 'Distribution','Use','EoLT'}, ...
    'kg CO2e','GWP100 CO2e',[1 0 0]);

% ADP stage chart — YELLOW
stage_bar([beta0(2); stage_impacts(:,2)], ...
    {'Total','RawMat','Prod', 'Distribution','Use','EoLT'}, ...
    'kg Sb-eq','ADP Resource Depletion',[1 1 0]);


% ======================================================================
%                FULL CONTRIBUTOR HORIZONTAL CHARTS
% ======================================================================

% Raw Materials
bar_all_horizontal(RM_GWP, proc_RM, 'kg CO2e', ...
    'GWP100 - Raw Materials (ALL)', [1 0 0]);

bar_all_horizontal(RM_ADP, proc_RM, 'kg Sb-eq', ...
    'ADP - Raw Materials (ALL)', [1 1 0]);

% Production
bar_all_horizontal(PROD_GWP, proc_PROD, 'kg CO2e', ...
    'GWP100 - Production (ALL)', [1 0 0]);

bar_all_horizontal(PROD_ADP, proc_PROD, 'kg Sb-eq', ...
    'ADP - Production (ALL)', [1 1 0]);
```

History

Version	Date	Status	
V1.1.0	May 2026	ENAP Process	AP 20260823: 2026-05-25 to 2026-08-24