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Explore the challenges of developing product group-specific Product Environmental Footprint Category Rules (PEFCRs) for smartphones

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Foreword

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Introduction

In 2013, the European Commission (EC) released a proposal for the use of common methods to measure and communicate the life cycle environmental performance of products and organizations [i.1]. EC started a journey to test the Product and Organization Environmental Footprint methods in action. Together with more than 260 volunteering organizations EC tested how to develop product- and sector-specific rules, how to communicate and verify Environmental Footprint (EF) information. In January 2018 EC announced that the journey is coming to an end [i.2].

It can therefore be concluded that Life Cycle Assessment (LCA) seems to be slowly converging into a useful policy tool. To this end the electronics and ICT industry and others have in recent years started to prepare for possible LCA legislation from the European Commission according to the so called Product Environmental Footprint (PEF) method. The aim of PEF is to enhance the quality of LCAs by harmonization, leading to comparable product environmental footprints within specified product groups in a single market.

Figure 1 shows a set of non-comparable and non-standardized GWP100 results for smartphones for selected life cycle stages.

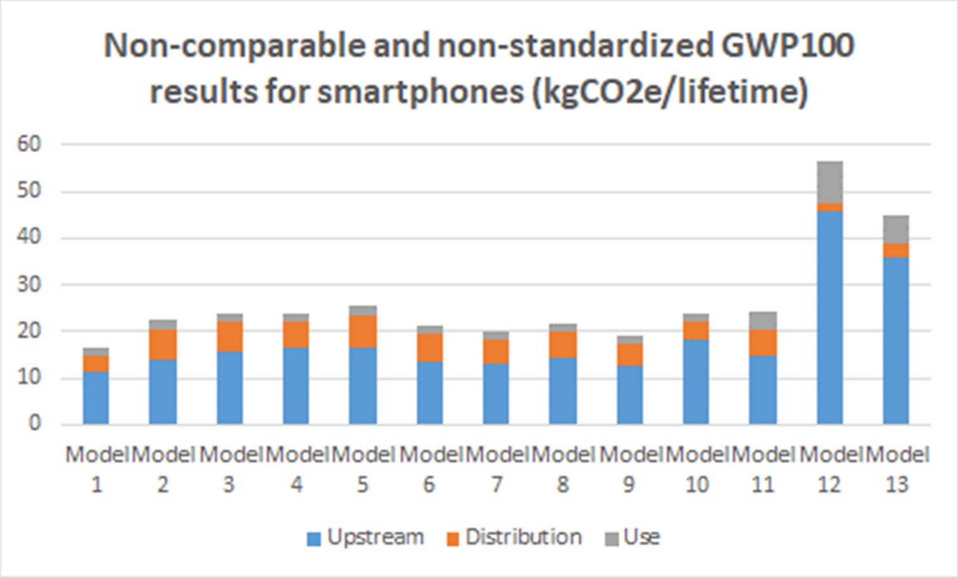

Figure 1: Non-comparable and non-standardized GWP100 results for smartphones

The PEF method might help verify the reliability of the results such as those shown in Figure 1.

Nevertheless, PEF has been questioned for not leading to comparative results but only reproducible results [i.3] and [i.25]. Using PEF, specific features of individual products can seemingly not be reflected (e.g. how to compare "standard" and "durable" devices when the same lifetime is assumed). Still, the PEF Category Rules (PEFCR) Guidance [i.7] states that comparability is possible if the results are based on the same PEFCR.

NOTE: This might be true for PEFCR but it is not true for the EPD System Product Category Rules (PCR) [i.19] which are too flexible regarding data quality and functional unit selection.

Examples of unique features of PEF - compared to e.g. the European Telecommunications Standards Institute (ETSI) standard for LCA [i.4] and [i.5] - are the strict requirements on data quality, definition of exact FU, default end-of-life (EoL) scenario, mid-point impact categories, and that cut-off should be avoided. Moreover - in order to be compliant with PEF - the industry leaders for each product group sold in the EU - such as smartphones - will have to reach consensus on the product category rules (PCR) for these product groups.

Recently IT storage equipment - belonging to classification 26.2 in Statistical Classification of Products by Activity in the European Economic Community [i.6] - was investigated in an official PEF pilot.

In 2017 a guidance document was published including the experience of the PEF pilots [i.7]. Oja et al. argued that it is important to find a balance between comparability, reliability, and costs when performing PEF LCAs [i.8].

The common wisdom is that simplified LCA approaches do not have enough precision compared to Full LCA (FLCA) when applied to the rather complex life cycle of smartphones. Still, there exist several simplified LCA methods for smartphones [i.10]. Andrae identified that there are at least 14 different - simplified and full - methods for LCA of consumer electronics such as smartphones [i.11]. One of the FLCA methods is the PEF method, expected to be the state-of-the-art for FLCA [i.7]. In the present document only FLCA of smartphones will be discussed. PEF has very strict data quality requirements as product comparisons need good quality data. Ojala et al. [i.8] argued that PEFCR developers should devote time to finding the most appropriate methodological choices. There exists no analyses of the degree to which current smartphone Full LCAs fulfil the requirements of the strict PEF Guidance [i.10]. To shed light on that issue is one of the main objectives of the present document.

Moreover, the present document will discuss the discrepancy between FUs currently formulated for smartphones compared with those required by PEF. While comparability is the ultimate aim of the PEF FLCA method, it will require very high data quality lowering the uncertainty. Even with "perfect" data quality, there will be variability of LCA scores for the same type of smartphones.

Andrae and Vaija [i.5] argued that PEF has several strengths and weaknesses. Strengths include guidance and requirements on FU definition. Moreover, PEF demands relatively precise analyses of the supply chains which could lead to eco-innovation. Furthermore, the fact that cut-off is not "allowed" gives an estimation of the truncation error. Another benefit is that the circular footprint formulae should improve the end-of-life modelling for all.

However, again, the PEF method has several weaknesses. First the ambitious data collection targets cannot - by most actors - be applied consistently along the supply chain. Furthermore, the usefulness beyond traditional ISO [i.12] and [i.13] and ETSI FLCA standards [i.14] is in doubt as these data and comparability issues are not solved.

PEF also might threaten the flexibility needed by LCA practitioners in their pursuit to influence the product design holistically. Such worries are echoed by recent research [i.25].

The present document is expected to provide valuable input for all users of LCA within the smartphone sphere and to some degree also for the consumer electronics sphere. Five smartphone manufacturers approaches for FLCA have been analysed based on openly available information.

1 Scope

The present document investigates current approaches, concepts and metrics of LCA as proposed by PEF and their applicability for the smartphones. The present document:

1) searches to identify if Product Category Rules (PCR) and Life Cycle Assessment (LCA) models for the smartphone product category have been developed;

2) explores existing PCRs and LCAs for gaps compared to the PEFCR Guidance requirements;

3) explore the challenges associated with: setting the scope, defining the unit of analysis, reference flow, representative products, product classification, system boundaries, data quality requirements, data collection, benchmark and classes of environmental performance, interpretation, reporting, disclosure, communication, and verification;

4) explores the challenges with PEF Screening (impact assessment, interpretation and conclusion, report).

2 References

2.1 Normative references

Normative references are not applicable in the present document.

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 are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

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3 Definition of terms, symbols and abbreviations

3.1 Terms

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

assessment method: procedure for determining the value of a metric or indicator and validating it

NOTE: The method could include measurement and calculation.

component: part of a product that cannot be taken apart without destruction or impairment of its intended use

indicator: quantifiable representation of a parameter

NOTE: Example includes acidification potential.

material: substance or mixture of substances within a product or product part [i.28]

metric: measurable representation of a parameter or indicator

NOTE: Examples include mass of product, disassembly time, and re-used parts.

parameter: entity representing an aspect

NOTE: Examples include acidification which is an entity representing environmental aspects

product: good or service

product part: sub-unit of a product

substance: chemical element and its compounds in the natural state or obtained by any production process, including any additive necessary to preserve the stability of the product and any impurity deriving from the process used, but excluding any solvent which may be separated without affecting the stability of the declarable substance or changing its composition [i.28]

3.2 Symbols

Void.

3.3 Abbreviations

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

ASIC	Application Specific Integrated Circuit
CFC11E	CFC11 Equivalents
CFF	Circular Footprint Formulae
CO2E	CO2 Equivalents
EF	Environmental Footprint
EPCR	Existing PCR
EPD	Environmental Product Declaration
FLCA	Full LCA
FU	Functional Unit
GPS	Global Positioning System

GWP	Global Warming Potential
IC	Integrated Circuit
ICT	Information Communication Technology
LCA	Life Cycle Assessment
LCD	Liquid Crystal Display
LCI	Life Cycle Inventory
MP	Mega Pixel
OLED	Organic light-emitting diode
PCB	Printed Circuit Board
PCBA	Printed Circuit Board Assembly
PCR	Product Category Rules
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules
RAM	Random Access Memory
RC	Recycled Content
RP	Representative Product
RP	Representative Product
SbE	Sb Equivalents

4 Introduction of Product Environmental Footprint

Product Environmental Footprint (PEF) is a Life Cycle Assessment (LCA) based method to quantify the relevant environmental impacts of products (goods and services) and organizations [i.7]. PEF is an assessment method for FLCA.

5 Product Category Rules (PCR) and Life Cycle Assessment (LCA) models for the smartphone product category

5.0 General

There exist some PCR and FLCA models for smartphones. PCR could define allowed allocation methods exactly for the specific products targeted. More freedom needs to be allowed by pure LCA standards such as ISO 14040 [i.12], ISO 14044 [i.13] and ETSI ES 203 199 [i.14]. The clause will discuss FLCA models only as they are closest to the PEF method for FLCA. This clause would be strengthened if actual LCA practitioners shared their actual working ways beyond the publicly available information. Manufacturers model the smartphone life cycle in different ways. Nevertheless, it is a common approach to perform a tear-down, weigh each module, weigh each part, identify each component and allocate each to appropriate secondary LCI data. Over- and underestimations are common due to a myriad of assumptions. Naturally no valuation is done on which approach is better than another. The hypothesis is that further scope clarifications than those prescribed by ETSI ES 203 199 [i.14] - inspired by the PEFCR Guidance [i.7] - would be valuable for every smartphone manufacturer. However, developing full PEFCR - strictly according to the PEFCR Guidance [i.7] - is not worthwhile at the moment for smartphones.

5.1 Raw Material Acquisition

This clause handles the typical modelling choices of smartphones manufacturers as far as raw material acquisition is concerned. As smartphones usually consist of a large number of materials all manufacturers have chosen to use secondary data for raw material production. The identification of the raw materials is however done differently.

5.2 Pre-processing: Components production

5.2.0 General

This clause handles the typical modelling choices of smartphones manufacturers as far as component production (e.g. printed circuit board, integrated circuit and capacitor production) is concerned. One way is to use the material content of sub-components - of each component - as basis for determining the raw material content [i.27]. Hence the material content is chosen as basis for the environmental impact modelling to get - as close as possible - a unique footprint of the mobile phone at hand. However, for several raw materials losses in the upstream are not accounted for and secondary data are used for gate-to-gate component assembly. The components included by some manufacturers are:

- Integrated Circuits (ICs)
- Printed Circuit Boards (PCBs)
- Aluminium components
- Plastic components
- Steel components
- Capacitors
- Resistors
- Packaging materials
- Documentation
- Silver PCBA components
- Tin PCBA components
- Gold PCBA components (including connectors, ICs, PCBs, etc.)

The recycled content is included where specified by component and part suppliers. Common is to use a blend of primary and secondary data for all parts and components, including cradle-to-gate modelling. Using entirely secondary data for all parts and components will not give very representative results, however, very repeatable results. Such results might be useful for limited sensitivity analysis and broad eco-design recommendations. Another way is to use primary material contents for key components, i.e. not fully relying on secondary LCI modules from LCI databases. Typically systematic approaches mixing primary secondary data for all parts and components is common. Anyway results based entirely on secondary data might be more realistic than using only the material content (primary data) without production and upstream losses.

5.2.1 Active components

5.2.1.1 Integrated Circuits

Integrated Circuits (ICs) are very important to model as precisely as possible. The reason is that they usually stand for a rather large share of the total production environmental impacts of a smartphone, e.g. > 30 % to < 80 % of the cradle-to-gate GWP100 score.

NOTE 1: The share of the IC impacts is dependent on the design characteristics of the phone at hand.

Especially the silicon die manufacturing stands out as being especially sensitive to the precision of the environmental impacts [i.10]. One modelling approach is based on material contents and the impacts per area of processed die, being an important first metric for IC impacts. The approach is to normalize impacts per cm^2 silicon die and use secondary mass-based IC LCI modules (MBICLCI) that contain a certain cm^2 silicon wafer. One way is to exclude gold content from the IC model, and instead include it in "Gold PCBA components". The reason is that gold is normally recovered from the PCBAs as a whole and not from first extracting the ICs.

EXAMPLE: When the MBICLCI {excluding gold, silver} GWP100 score is 800 kg CO2E/kg, and the typical GWP100 score for Silicon die manufacturing is 2 kg CO2E/cm^2, 2/800 = 1/400 kg of MBICLCI is necessary per cm^2 Si die within the mobile phone at hand. So, if the Si die area within the mobile phone is 10 cm^2, 10/400 kg MBICLCI is required.

However, ICs should be more carefully modelled than other components. It is important to use LCI data (e.g. those leading to GWP100 scores) which represent region specific electricity production. Preferably is to categorize the environmental impact per semiconductor technology node rather than approximating all silicon dies as being the same. All materials constituents' impacts, including gold, are then included in the IC models. Excluding the ICs altogether and instead only include secondary display, PCBA and battery models will lead to a low data quality rating notwithstanding non-compliance with e.g. ETSI ES 203 199 [i.14]. Dividing the semiconductors into IC and ASICs and use primary and secondary data to create a range of emissions per area is common. Using the die size as a scaling parameter is typical as well as including front-end and back-end processes for the a specified technology node (e.g. 32 nm). There seems to be several ways for smartphone manufacturers to agree on an appropriate scope for IC modelling for smartphones.

NOTE 2: Available data on ICs are very scarce in databases and academic literature. Primary data from IC manufacturers are problematic to get and smartphones manufacturer mostly do not have access to these data from their suppliers. Most smartphone manufactures are not IC manufactures and even so, they might not have access to the environmental data of the IC production.

Given the occasionally large amount of different ICs in smartphones, hypothetically die-to-package ratios can be used for in the quantification of die areas.

NOTE 3: The die-to-package ratio varies greatly between different ICs. The appropriate way or source to derive die-to-package ratios need to be investigated [i.10].

5.2.1.2 Diodes

Usually diodes are not significantly contributing to any environmental category and manufacturers use secondary data.

5.2.1.3 Transistors

Usually transistors are not significantly contributing to any environmental category and manufacturers use secondary data.

5.2.2 PCBs

Depending on the scope for cradle-to-gate and the data used for the model, the PCBs contribute to around 15% of GWP100 scores for the production of smartphones, but might be more important for other impact categories and single score weighting methods. It is worth mentioning that the yield in the PCB production might be an issue affecting the importance of PCBs.

One model is based on material contents and the impacts per area of PCBs, each with specific number of layers. The approach is to normalize impacts per cm^2 PCB and use secondary mass-based PCB LCI modules (MBPCBLCI). As for all components, the gold content is excluded from the PCB models, and instead included in "Gold PCBA components". This division of raw materials and component/part production is done influenced by the ETSI LCA standard [i.14].

EXAMPLE: When the MBPCBLCI {excluding gold, silver} GWP100 score is 150 kg CO2E/kg, and the typical GWP100 score for 10 layer PCBs is 12 g CO2E/cm^2, 12 / 150 = 2 / 25 g MBPCBLCI is necessary per cm^2 10 layer PCB within the mobile phone at hand. So, if the 10 layer PCB area within the mobile phone is 25 cm^2, 2 g MBPCBLCI is required.

Treating the PCBAs inside the smartphone - possibly including the ICs and PCBs - as one part and base the model on secondary data will lead to a lower data quality rating than appropriate for any advanced PCR. On the other hand, taking into account the real size of the PCB panels used to make the rectangular PCBs - not only the rectangular shape and layers of the PCBs themselves - will lead to a higher data quality rating. As well as for ICs, the PCB modelling requires more investigations before a proper assessment scope can be agreed. Handling the current over- and underestimation of PCB impacts is crucial going forward.

5.2.3 Other components

5.2.3.0 General

This clause refers to modelling choices for all other components than ICs and PCBs. One approach is to base components environmental impacts on their raw material content and cradle-to-gate assembly process (Part final assembly, See annex E in the ETSI LCA standard [i.14]). The Raw Material Acquisition is included via the material content declaration of the entire phone. Most manufacturers however base the environmental impact - of cradle-to-gate assembly of other components - on available secondary LCI data. Commonly cradle-to-gate assembly of other components is not left out.

5.2.3.1 Connectors

Connectors are included as a cradle-to-gate assembly process. Connectors are probably environmentally more important than passive components such as capacitors. Most manufacturers use cradle-to-gate models for all components such as connectors with less focus on the primary material content.

5.2.3.2 Aluminium, plastic and steel components

Aluminium parts - such as casings - are occasionally modelled as a cradle-to-gate assembly process. However, the most common way is to include the impact of aluminium production too.

5.2.3.3 Capacitors

Some manufacturers leave out the component assembly process. However, for capacitors this might be a sensitive assumption as recent research show that ceramic capacitors use plenty of power for their assembly [i.15]. Specific material content declaration is regarded relevant for capacitors impacts.

5.2.3.4 Resistors

Some manufacturers leave out the component assembly process. Specific material content declaration is regarded relevant for resistors impacts.

5.2.3.5 Packaging materials

Some manufacturers leave out the assembly process for packaging materials. Packaging materials are not particularly important in itself, however, it affects the distribution impacts in a wider sense.

5.2.3.6 Documentation

Some manufacturers leave out the component assembly process. Documentation is not particularly important in itself, however, it affects the distribution impacts in a wider sense.

5.2.3.7 Silver, tin and gold PCBA components

This component type includes all of the silver, tin and gold used in the connectors, ICs, PCBs, etc. Some manufacturers include the losses and a mechanical transformation process is added. It looks like most manufacturers use cradle-to-gate modelling - which include secondary material compositions of e.g. IC capsule types and PCBs - rather than gate-to-gate process modules plus "exact" material contents. In summary the high impacts are covered well by all approaches. The "exact" material contents is more commonly used in the End-of-life treatment to understand the economic value and environmental risks.

5.3 Pre-processing: Smartphone Part Production

5.3.0 General

This clause handles the typical modelling choices of smartphones manufacturers as far as Part production (e.g. camera production or display production) is concerned. Smartphones contain many different product parts which are moreover unique for each manufacturer. Apart from components, one way is to list the following non-exhaustive list of product parts:

- Battery
- Camera
- Display
- Charger
- USB cable for Charger

The material content of the sub-parts/components of the product parts can be used as basis for their material content. The product parts can be treated as ICT goods consisting of components such as ICs, PCBs, resistors and capacitors etc. Common is to divide the phone into:

- Batteries
- Glass
- PCBAs
- Frame/casing
- Metal sheets
- Displays
- Cameras
- Transceivers
- Receivers
- Speakers

One approach is to model each of these product parts by different amounts of raw materials and components.

5.3.1 Battery

On way is to use secondary material contents and the impacts per mass LiCo battery, normalizing impacts per mass battery and apply a material content-based LCI value (MBLiCoBaLCI).

EXAMPLE: When the MBLiCoBaLCI GWP100 score is 8 kg CO2E/kg, and the typical GWP100 score for LiCo batteries is 0,029 kg CO2E/g, {(0,029 / [1 × 8]} 29 / 8 000 kg of MBLiCoBaLCI is necessary per gram LiCo battery within the mobile phone at hand. So, if the LiCo battery mass within the mobile phone is 30 g, 87 / 800 kg MBLiCoBaLCI is required.

Else using secondary LCI databases for batteries is less common than a using a mix of primary data (assembly process) and secondary sources. Adaptation occurs of comparable batteries to have them reflect smartphone batteries.

NOTE 1: This approach might lead to an over-estimation of battery impacts.

NOTE 2: Battery metals significance for resource depletion scores - such as SbE - need to be checked carefully.

NOTE 3: It is important to use models which provide flexibility for future battery technologies.

5.3.2 Camera

A model which is based on material contents and the impacts per mass camera can be used. The silicon dies within the camera for the mobile phone at hand are modelled as expressed in clause 5.2.1.

The silicon die size can be measured exactly. The materials contents can be scaled from similar cameras.

Cameras will likely need primary LCI data as they are quite different in between manufacturers.

5.3.3 Display

Displays are still rather important for the production impacts, e.g. commonly at several kg CO2E per smartphone. The GWP100 intensity has decreased rapidly over recent years.

Some manufacturers models are based on secondary material contents and the impacts per area of Liquid Crystal Display (LCD) touchscreens.

The approach is to normalize impacts per cm^2 display and use secondary mass-based LCD screen LCI modules (MBLCDLCI).

EXAMPLE: When the MBLCDLCI GWP100 score is 60 kg CO2E/kg and the typical GWP100 score for LCD touchscreens is 0,05 kg CO2E/cm^2 → 1 / 1 200 kg MBLCDLCI is necessary per cm^2 LCD touchscreen within the mobile phone at hand. So, if the active LCD touchscreen area within the mobile phone is 75 cm^2, 1 / 16 g MBLCDLCI is required.

Commonly is to use primary data for LCD assembly but secondary databases for upstream LCD production.

Agreeing on assessment scope for display cradle-to-gate impacts understanding seems difficult. The variability is high although the CO2E intensity has decreased in the latest years.

More common recently are the Organic light-emitting diode (OLED) displays. OLED technology is thought to be somewhat more CO2E efficient than LCD technology. Other indicators than CO2E might lead to different results and conclusions.

Some recent research suggests that OLED are not as environmentally friendly as previously understood [i.21]. OLED displays were found to have 1 000 - 2 300 times higher resource depletion potentials than the LCD due primarily to the high concentrations of gold, selenium, silver, palladium, and tin. The OLED display also had 2 - 600 times higher toxicity potentials due primarily to the high concentrations of arsenic, cadmium, chromium, and antimony [i.21].

This research underlines the high uncertainty for other indicators than GWP100.

Agreement on the assessment scope for LCD and OLED modelling is required should there be a need to improve the precision of display LCIs.

5.3.4 Charger

The model can be based on secondary material contents and the associated impacts per mass charger. This approach excludes the USB cable, which apparently does not scale linearly by the mass of the charger. ICs and PCBs within the secondary Charger model can be modelled as shown in clause 5.2.1.2.

NOTE: The ICs and PCBs within do not necessarily scale with the mass of the charger.

It is not rare to use primary data for charger assembly.

The eventual assessment scope should probably include silicon die area and PCBs and separate the USB cable and charger.

5.3.5 Cables - USB

The cable LCI model can be based on the material content of cable sub-parts, forming a mass-based model.

5.4 Final assembly - production of the smartphone

This clause handles the typical modelling choices of smartphones manufactures as far as final assembly including the testing. The surveyed manufacturers have included the process of assembling, inspecting and packaging the smartphone, as well as the electricity used directly in the manufacturing facility, as well as the production of compressed air used in the manufacturing process and the amount of electricity consumed in the cooling and heating process. The amount of electricity consumed for the production of one product is allocated based on the number of products produced during the data collection period. The waste generated in the assembly process was excluded from the system boundary due to the small amount of waste. Another method allocates shares of the company's Scope 2 production electricity to smartphone production. The rationale is that such allocation will contain the power consumption used for testing more certainly than secondary data. The electricity used for smartphone production is assumed the same for all phone types. No other energy flows are included. The amount of solder used per smartphone is estimated from material balances. Common is to let final assembly cover energy consumption, generated waste, ancillary products, emissions to soil, air and water and production related transportations. Systematic inclusion of packaging and transport of the components to final assembly is rare.

NOTE: Some assessment scope have led to a high share of final assembly in relation to the total impacts.

There is room for improvement regarding the assessment scope for final assembly of smartphones.

5.5 Distribution and storage

This clause handles the typical modelling choices of smartphones manufacturers as far as distribution and storage (e.g. truck and airplane transport). It is not rare to include three transport distances and two modes of transport, truck and airplane. Usually secondary emissions and resource use data are used. Volume effects of the packaging are omitted by some manufacturers. As linear mass based approach is used, the smaller the mass of the package to be transported, the lower the environmental impacts from transportation. Those assumptions might be quite crude as the financial cost of shipment is not exactly linearly correlated to the mass. That is, if a smartphone shipment mass is reduced by 10 %, the financial cost of the shipment will not be reduced by 10 %. It is however not evident if the environmental impact cost "behaves" similarly to the financial cost. At least for the financial cost of truck logistics, the volume of a package is more important than the mass of the package.

NOTE: Likely the environmental impact costs are reduced somewhat if the mass of the total package is reduced. Therefore the current approaches are a decent first approximation of the environmental impacts of distribution.

Some eco-rating schemes [i.16] recognize the ratio of "volume of package to volume of phone", and gives better "score" for a value close to 1 for this ratio. Almost all LCA assessment scopes include the transport packaging (shipping boxes), let alone the product packaging. Frequently manufacturers include the following in their distribution models:

- Collection of data (volumes, weights and distances) on shipments of units by land, sea, and air.
- Transporting smartphones from manufacturing sites to regional distribution hubs.
- Transporting smartphones from regional distribution hubs to individual customers.

The current logistics modelling can be deemed as somewhat rampant and exploratory - but not necessarily wrong - and more investigations are necessary before a harmonized assessment scope can be agreed. Storage rooms seem neglected.

5.6 Use stage

This clause handles the typical modelling choices of smartphones manufacturers as far as the use stage (includes scenario settings).

Some manufacturers use test values for battery durability, measured by a third party organization.

EXAMPLE: Lifetime electricity use calculation according to Equation 1.

$$USE = ABCD \times \frac{1}{E} \times \frac{F}{G} \tag{1}$$

Where:

USE = Lifetime Wh electricity use of a smartphone

A = Battery capacity [Ah]

B = Voltage [V]

C = Lifetime of smartphone [years]

D = 365 [days per year]

E = energy efficiency of the power adapter [%]

F = 24 [hours per day]

G = time between having to fully charge the battery if doing 1 hour 3G calls, 1 hour web browsing and 1 hour video playing [hours]. *G* can measured by 3rd party organizations.

Inserting some values into Equation 1 lead to Equation 2 {*A*=3,9 Ah, *B*=3,82 V, *C*=4 years, *E*=78 %, *G*=87 hours}

$$\rightarrow USE = 3{,}9 \times 3{,}82 \times 4 \times 365 \times \frac{1}{78\,\%} \times \frac{24}{87} = \frac{223\,088}{29} Wh \sim 7\,693 Wh \qquad (2)$$

The proposed approach - for estimating lifetime electricity in the use stage - seems fair as all factors are measurable, including *G*. The difficulty might lie in deciding the normal behaviour scenario. Still *G* will scale equal for all smartphones independent of *G* settings.

There are other approaches such as measuring the *time a user can use the smartphone to do web surfing over wireless until the battery is close to 0 %.*

NOTE 1: The latter approach seems quite precise, but on the other hand this would require an even more explicit measuring procedure (web-browsing in Wi-Fi or mobile network, video stored or as stream, quality of the network signal, etc.) to be really comparable.

Other manufacturers chose different lifetimes, such as three years. The average replacement period is generally estimated to around 2 years and 7 months [i.20] and [i.22]. Lifetime is usually understood as the total time in which the phone is used by first, second, etc., user.

NOTE 2: For the overall impact (per year of use), the assumed lifetime is far more important than the assumed use pattern.

Other approaches include:

- Measuring the scenario-based power consumed by the smartphone.
- Assumptions of the first owner use time.
- Calculations of the annual kWh electricity of a smartphone via the number of hours per year in use power mode - and hours per year in standby power - according to consumers' smartphone usage patterns (hours per day).
- Adding the associated usage of the mobile network infrastructure.
- Representative use cases based on collected data for charging time and energy consumption during charging and for chargers in stand-by.
- Assumptions of representative user charging the device.
- Inclusion of the degree to which users leave the charger plugged or not, charger efficiency, no-load loss of charger, battery capacity and voltage.

As shown there are several ways which lead to the annual or lifetime electricity use of smartphones. Extensive discussions would be required to agree on a proper assessment scope for the use stage. Any credible approach - towards PEFCR for the use stage and beyond - need to be able to be verified by a third party laboratory. Moreover, wireless charging calculation rules are yet to be discussed.

The flexibility of own use scenarios is an issue.

NOTE 3: Daily usage patterns are precise for each smartphone and a mixture of actual and modelled customer data should be used.

5.7 End-of-life treatment

This clause handles the typical modelling choices of smartphones manufacturers as far as end-of-life (includes scenario choices for product / part reuse, recovery / recycling).

The issue of the actual benefits obtained by material recycling in LCA is still somewhat equivocal. However, perhaps the PEF Guidance [i.7] could streamline the process for LCA practitioners [i.9].

The EoLT can be modelled as a disposal scenario. Such scenarios can consist of two waste scenarios: collection and hoarding at home.

The collection waste scenario can contain a truck transport and the following processes:

- Energy recovery of the plastic components
- Incineration of the packaging materials
- Recycling of:
    - the aluminium in the charger and the chassis
    - the gold in the PCBA and USB Cable
    - the cobalt, copper and lithium in the battery
    - the silver in the PCBA

One option is to use the so called 100/0 for upstream raw materials acquisition ("production burdens"), i.e. $R_1 = 0$, and the so called 50/50 allocation method at end-of-life material recycling ("Burdens and benefits related to secondary materials input and output"), i.e. $A = 0{,}5$, and a 95 % recycling rate at the smelter, i.e. $R_2 = 0{,}95$ [i.17], are used.

NOTE 1: If the collection rate is to be included in R_2, the value becomes much lower than 0,95. It is to be discussed if R_2 refers to the overall recycling rate (or reuse rate) of the material and not just the smelter recycling rate. Depending on the modelling possibilities in different LCA tools the collection rate and smelter recycling rate can be set separately.

This approach fits well with the PEF circular footprint formulae [i.7], Equations 3 to 7:

$$(1 - R_1) \times E_p + R_1 \times E_{recycled} \tag{3}$$

$$-(1 - A) \times R_1 \times \left(E_{recycled} - E_p \times \frac{Q_{sin}}{Q_p}\right) \tag{4}$$

$$(1 - A) \times R_2 \times \left(E_{recyclingEoL} - E_p^* \times \frac{Q_{sout}}{Q_p}\right) \tag{5}$$

$$(1 - B) \times R_3 \times \left(E_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,electricity} \times E_{SE,electricity}\right) \tag{6}$$

where:

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

E_p= specific emissions and resources consumed (per functional unit) arising from the acquisition and pre-processing of primary material.

NOTE 2: This refers to e.g. extraction, acquisition, mining, smelting for metals.

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

NOTE 3: This refers to e.g. smelting when e.g. gold is recycled from a PCBA.

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

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

Q_p= quality of the primary material

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

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

NOTE 4: This refers to dismantling, disassembly, preparation for reuse, etc.

E_p^*= 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.

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

B = allocation factor of energy recovery processes: it applies both to burdens and credits. It should be set to zero for all PEF studies.

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

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

LHV = Lower Heating Value of the material in the product that is used for energy recovery.

$X_{ER,heat}$= the efficiency of the energy recovery process for heat.

$E_{SE,heat}$= specific emissions and resources consumed (per functional unit) that would have arisen from the specific substituted heat.

$X_{ER,electricity}$= the efficiency of the energy recovery process for electricity.

$E_{SE,electricity}$= specific emissions and resources consumed (per functional unit) that would have arisen from the specific substituted electricity.

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.

NOTE 5: This refers to e.g. landfill.

It is also possible to model the EoLT disposal as a process in which the main part (e.g. display or battery) is replaced (with an unimpaired secondary or new spare part) and the smartphone is reused. The disposal scenario then consists of a disassembly process and a "reuse of the smartphone" model [i.26]. The disassembly process consist in turn of a disposal scenario model for the main part (e.g. battery or display). The best would be to base the EoLT scenario on current best practice. This practice might be manufacturer dependent. The assumptions can be checked for alignment with the PEFCR Guidance when no primary data are used.

Other approaches include:

- Transporting products from final customers to recycling facilities.
- Treatment steps carried out by the recycler to obtain metal, plastic, and glass material streams.
- Phones collected and repaired.
- Assumptions that the packaging material - emerging in the early use stage - is discarded.

- The ratio of incineration, reclamation, and recycling of packaging materials determined using statistical data on the disposal of municipal waste and packaging materials.
- Assumptions that smartphones to be discarded after being abandoned by users.
- Assumptions that discarded smartphones are classified according to the materials obtained through the decomposition and crushing process.
- Classification of materials according to in IEC TR 62635 [i.23].
- Mobile phone subscription counts to weight each country's estimated percentage of generated smartphone waste.
- Estimates of the overall recycling rate compared to landfill rate.
- Transports and metal recycling.
- Exclusion of battery recycling.
- Assumptions that all smartphones are collected and enter a recycling stream.
- Repair scenarios and lifetime extension.

The starting point can be the circular footprint formulae [i.7]. It could be agreed which of the factors in Equations 3 to 7 to be included in the assessment scope.

A future setting of assessment scope for EoLT could consider that manufacturers have less control of the smartphones after they are sold.

NOTE 6: A further discussion concerns whether emissions related to remelting belong to Raw Materials Acquisition emissions, E_p, or end-of-life processing emissions, $E_{recycled}$.

Including corporate practice of refurbish/upgrade in the EoLT calculations can be promoted. Such approaches fit well with the circular economy global megatrend.

6 Comparison of gaps between existing PCRs/FLCAs and the PEFCR Guidance requirements

6.0 General

Seemingly only one PCR document exists for smartphones, here called Existing PCR (EPCR) [i.18]. EPCR is here compared with the PEFCR Guidance [i.7]. EPCR and the PEFCR Guidance are also compared with current contemporary smartphone FLCA modelling as outlined in clause 5 in the present document.

EPCR is a relatively detailed PCR guide with 52 requirements. Still, EPCR allows secondary data anyway, e.g. if suppliers fail to provide primary data. Moreover, EPCR is based on the EPD® System requirements for PCR [i.19] and not the PEFCR Guidance requirements. Scope setting, data quality, and impact assessment methods required are three important aspects which can be compared in between EPCR, PEFCR Guidance and current FLCA approaches which are not using PCR.

6.1 Scope setting

Table 1 lists some choices for the scope required by EPCR, the PEFCR Guidance and choices made by current FLCA practitioners in the smartphone industry.

Table 1: Summary of scope requirements of EPCR in relation to the requirements of the PEFCR Guidance and current FLCA modelling of smartphones

Life Cycle Stage	EPCR for smartphones	PEFCR Guidance requirements on PCR	Current FLCA modelling practice for smartphones	Comments
Raw Material Acquisition	Cut-off those materials which are<1% of mass	Mandatory depending on the purpose	Included	This means - for EPCR - that certain important metals could be left out of the impact assessment
Transport	Voluntary	---"----	Included if in database	Mining downstream
Pre-processing: Material forming	Voluntary	---"----	Included if in database	Sub-component upstream
Transport	Voluntary	---"----	Included if in database	Sub-component upstream
Pre-processing: Sub-component production	Not clear	---"----	Included	
Transport	Voluntary	---"----	Included if in database	Component upstream
Pre-processing: Component production	Not clear	---"----	Included	
Transport	Not clear	---"----	Included with primary data for some Parts	Component downstream
Pre-processing: Product Part Production	Mandatory incl. Charger	---"----	Included	
Transport	Mandatory	---"----	Included for some Parts	Clear difference between current practice on one hand, and EPCR and PEFCR Guidance on the other
Final Assembly	Mandatory	---"----	Included	
Distribution and Storage: Transport	Mandatory	---"----	Included	
Distribution and Storage: Storage room	Not included	---"----	Not included	
Distribution and Storage: Transport	Not clear.	---"----	Not included	
Marketing	Optional	Not included	Not included	Marketing phase
Transport	Optional	Mandatory depending on the purpose	Included	Manufacturers include some truck and air transport from the assembly nation to the use nation.
Use stage	Included as scenario	---"----	Included as scenario by all manufacturers, See clause 5.6	*"customer designated locations"* is not evident in EPCR
Transport	Mandatory	---"----	Included as scenarios	

Life Cycle Stage	EPCR for smartphones	PEFCR Guidance requirements on PCR	Current FLCA modelling practice for smartphones	Comments
End-of-life treatment	Mandatory	---"----	Included as scenarios	*"environmental impact shall be calculated based on the declared recycling rate."* [i.18] in EPCR is limited as no formulae are listed to be used for the calculation. The PEFCR Guidance contain such formulae.

Furthermore, the PEFCR Guidance does not mention *marketing* as a voluntary inclusion. The data sources required/suggested by EPCR also seem obsolete. Moreover, the use stage scenario proposed by EPCR is not relevant anymore.

6.2 Data quality

Table 2 shows a summary of the data quality requirements of EPCR, PEFCR Guidance and the data quality used in contemporary approaches.

Table 2: Summary of data quality requirements of EPCR in relation to the requirements of the PEFCR Guidance and current FLCA modelling of smartphones

Life Cycle Stage	EPCR for smartphones	PEFCR Guidance requirements on PCR	Current FLCA modelling practice for smartphones	Comments
Raw Material Acquisition	Secondary data may be used	Primary data should [i.7] be used if the process contribute to more than 80 % of the most important mid-point categories.	Secondary data are used, See clause 5.1.	The method for determining the most import mid-point categories in the PEFCR Guidance is not yet available.
Transport	Secondary data may be used	---"---	Secondary data are used if the process is included.	
Pre-processing: Material forming	Secondary data may be used	---"---	Secondary data are used if the process is included.	
Transport	Secondary data may be used	---"---	Secondary data are used if the process is included.	
Pre-processing: Sub-component production	Secondary data may be used	---"---	Secondary data are used if the process is included.	
Transport	Secondary data may be used	---"---	Secondary data are used if the process is included.	

Life Cycle Stage	EPCR for smartphones	PEFCR Guidance requirements on PCR	Current FLCA modelling practice for smartphones	Comments
Pre-processing: Component production	Secondary data may be used	---"---	Primary and Secondary data are used in combination. See clause 5.2.	The meaning of "*When secondary data are used, the equivalence between the chemical and/or physical process of referred systems shall be considered."* [i.18] is not evident in EPCR.
Transport		---"---	Secondary data are used if the process is included.	
Pre-processing: Product Part Production	Primary data to be used for "main Parts". *"if secondary data are used in place of primary data, their combined contribution for all life cycle stages shall not be greater than 20% of total impacts for each impact category"* [i.18]	---"---	Primary and secondary data are used in combination. See clause 5.3.	Each manufacturer models the upstream differently.
Transport	Not clear.	---"---	Included by some manufacturers.	
Final Assembly	Primary data to be used	---"---	Primary allocated data. See clause 5.4.	
Distribution and Storage: Transport	Primary data to be used	---"---	Primary and secondary data are used in combination. See clause 5.5.	
Distribution and Storage: Storage room	Not clear.	---"---	Secondary data are used if the process is included.	
Distribution and Storage: Transport	Not clear.	---"---	Secondary data are used if the process is included.	
Marketing	Not clear.	---"---	Secondary data are used if the process is included.	
Transport	Not clear	---"---	Not only primary data are used.	
Use stage	Primary data according to test standards and present method	---"---	Primary data according to 3rd party test scenario.	
Transport	Secondary data	---"---	Secondary data are used.	
End-of-life treatment	Secondary data	---"---	Primary data are occasionally used for disassembly. Secondary data are used. See clause 5.7.	

PEFCR Guidance is rather unique with "very good, good, fair, poor, very poor" grading of data quality. A minimum of "fair" quality (according to the definition in PEFCR Guidance) is required for data contributing to at least 90 % of the impact estimated for each impact category. PEFCR Guidance contains procedures to determine the data quality grade. The assessment scope - to be developed for e.g. a smartphone - should specify the minimum set of processes for which primary data are required - including requirements for assessment of data quality.

6.3 Impact assessment methods used

The PEFCR Guidance states in section 7.4.1 of [i.7]:

"The most relevant impact categories shall be identified as all impact categories that cumulatively contribute to at least 80% of the total environmental impact (excluding toxicity related impact categories." [i.7]. The most important midpoint categories can be determined if the weighting and normalization factors are agreed. It has shown to be difficult to determine the total environmental impact consistently. However, the International Life Data System 2011 Midpoint+ version 1.08 - the environmental impact evaluation method recommended by PEFCR Guidance - includes normalization but not weighting. The normalization is based on the annual average impact of a European citizen, e.g. 9 200 kg CO2E. A more recent global person Normalization Factor for PEF is 7 760 kg. The weighting of the normalized results is at the point of being set [i.7]. Using these weighting factors, the product assessment in the EU could be done with one indicator instead of 15.

The environmental impact categories to be reported - without normalization - in EPCR are different to those required by the PEFCR Guidance.

Smartphone manufacturers use different impact assessment methodologies - mid-point or end-point - which fit the business at hand. GWP100 is very common, and International Life Data System 2011 Midpoint+ version 1.08 too.

Currently - due to data unavailability - no other mid-points indicators than those using the units of CO2E, SbE, and CFC11E are really suitable for decisions. Toxicity categories are intuitively important for small-sized consumer electronics, but their reliability is questionable. Commonly the use of secondary LCI databases falsely indicate that certain impact categories are of relatively high - or low - importance. Figure 2 shows a relative result for PEF mid-point impact categories. There is an immense discussion ahead of which categories can actually be supported by primary data. There is a vast difference between the inherent scientific soundness of an indicator and how much (regional and local) inventory data can be measured to support the calculation of the indicator.

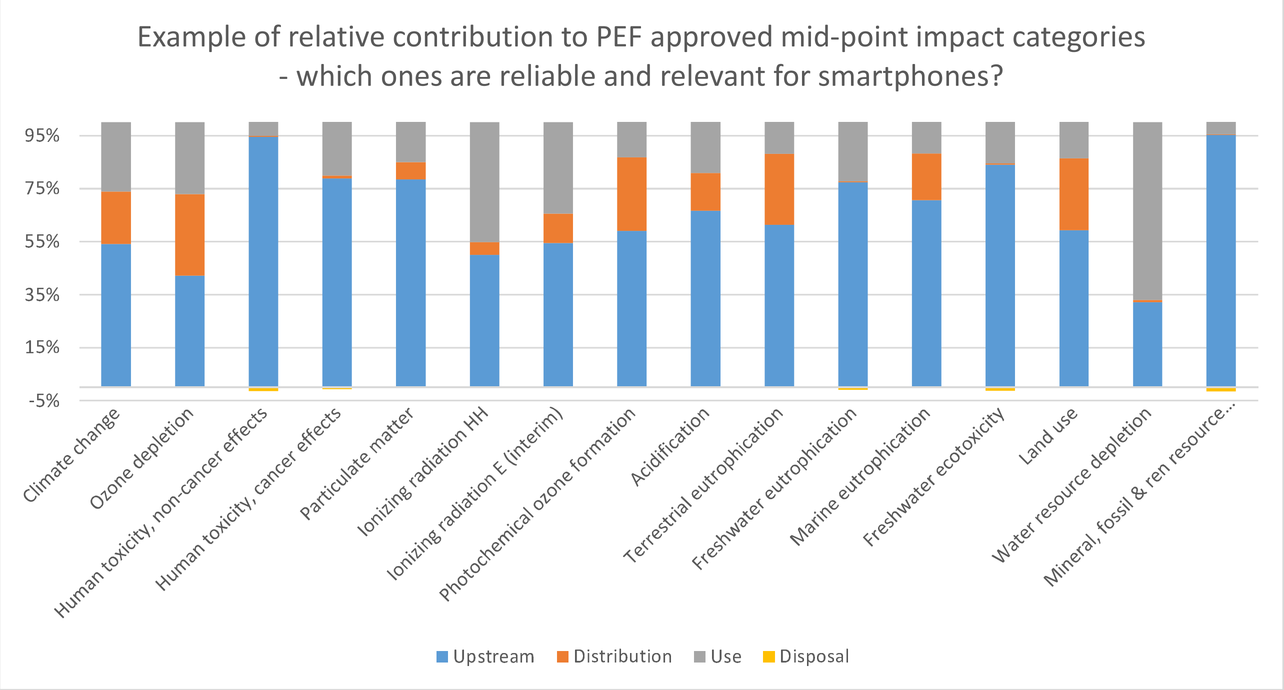

Figure 2: Examples of mid-point impact category results for a smartphone

7 Challenges associated with Full LCA of smartphones

7.0 General

This clause will explore the challenges associated with: setting the scope, defining the unit of analysis, reference flow, representative products, product classification, system boundaries, data quality requirements, data collection, benchmark and classes of environmental performance, interpretation, reporting, disclosure, communication, and verification.

7.1 Scope

7.1.0 General

The scope is currently set widely enough on product level by all manufacturers. ETSI standardized the minimum system boundaries for LCA of ICT goods and many other requirements such as silicon die area quantification [i.14].

However, the context level of the smartphones is not often analysed. That is the mutual dependence between the phones and the networks/data centres is usually not included in the scope. Some manufacturers attempted to include such effects. The consequential thinking is not as convenient to agree on as the blunt attributional LCA based on the bill-of-materials, and other product characteristics. At this stage the industry ought to focus on robust LCAs on product level before pitching into the bigger picture. In summary the scope setting is rather well understood on product level.

7.1.1 Comparisons and system boundaries for studied systems

The system boundary definition should be defined per each life cycle stage of each smartphone product system. The system boundaries of the two systems should always be clarified. Without knowing exactly what the system boundary is, there is no way of quantifying the inventory results of each smartphone product system.

7.2 Unit of analysis

Smartphones have many functions. They can replace ever more hardware units such as cameras, calendars, GPS, watches. Still, one phone of a certain model used during a certain number of years is the most commonly used Functional Unit (FU). More veridical FUs. have been proposed, but seemingly these attempts have not yet been adopted in industry.

Basically the FU should have function(s), and then a quantifiable unit that measures the performance of the function(s). If two smartphone models are compared, equivalency between the two smartphone systems should be ensured by selecting relevant function(s) and functional unit.

NOTE 1: Not all aspects are clearly countable be one exact number (e.g. mega pixel is not the only relevant figure to determine the quality of a camera). Being overly explicit with the functional unit would pretend a precision which might not exist.

Table 3: Example of Functional unit determination for smartphone

Functional unit constituents	Smartphone example
What?	Wireless access to one smartphone
When?	2018
How much?	1 hour 3G calling, 1 hour web browsing and 1 hours video watching per day
How long?	For 4 years
How well?	1440×2560 pixels resolution (499 pixels per inch as pixel density) at 3G/4G speed
Reference flow	1 Smartphone with its primary packaging and Charger One smartphone device (64 GigaByte (GB) storage, 5,9 inch screen size, 20 Mega Pixel (MP) Video Recorder, 4 GB Random Access Memory (RAM) memory, 4 000 mAh battery capacity Environmental impact/[Resolution (pixel density)×Storage (GB)×Display size (inches)×Video recorder (MP)×RAM (GB)×Battery capacity (mAh)×Lifetime (years)]
Functional unit	Enable 3G/4G access for 1 hour daily calling and enable use of a 1440×2560 pixels video player for 1 hour web browsing and 1 hour video watching daily for 4 years

A FU (e.g.) that can be used is 3G/4G access for 1 hour daily calling and enable use of a (e.g. 1440×2560) pixels video player for 1 hours web browsing and 1 hour video watching daily for (e.g. 4) years. This quantified performance can be achieved by many smartphones.

Other FU examples are:

- "one smartphone". This is obviously a too simplistic FU. It may be a so called declared unit though. Smartphones are intermediate products in Network and Service LCAs.

The following FU examples do not contain a function:

- "life time usage (3 years) of the smartphone device and its accessories for a representative usage scenario".
- "one smartphone for a three year use".

The FUs of published smartphone LCAs are usually quite simplistic and not confirmed to be in line with the PEF Guidance [i.10]. An example of this practice is from He et al. [i.20].

In summary the FU setting will requires extensive discussion between manufacturers.

NOTE 2: The FU in table 3 does not address availability, gaming, number/quality of sensors, taking photos, listening to music, data (photos, videos, music, etc.) storage and/or availability.

7.3 Reference flow

The reference flow is the amount of product needed to fulfil the defined FU [i.7]. Based on the FU chosen, the reference flow should reflect the FU. A clear definition of the reference flow is preferable in the case of comparative LCA. In case two smartphone product systems are to be compared, the two systems should be stated clearly. One manufacturer used the following reference flow: *One smartphone with its primary packaging and Charger. One smartphone device possessing certain GigaByte (GB) storage, inch screen size, Mega Pixel (MP) Video Recorder, GB Random Access Memory (RAM) memory, and mAh battery capacity*. Clearly this is a correct reference flow as that smartphone will be able to fulfil the FU.

NOTE: In a comparison between two phones the reference flow will be different and such e.g. the amount of battery used might differ [i.26]. Depending on the use pattern/assumed load pattern, usually one battery cannot fulfil the FU (e.g. 4 years and daily loading would be almost 1 500 loading cycles).

Section 2.3 in EPCR [i.18] has 10 aspects to be given for the technical description of the smartphone. Other reference flows used in smartphone FLCAs:

"*one smartphone used during three years", "the FU", "the phone as delivered to the customer including sales packaging and manual without charger*". In summary the concepts of FU and reference flow need more study.

7.4 Representative products

The representative smartphone forms the basis for the PEF screening. Several RPs might need to be defined for smartphones containing different technologies. Otherwise the PEFCR will not cover the data collection for all technologies and smartphones. Probably the adequate option for smartphones is setting up a virtual (non-existing) product made up of different technologies/materials. The virtual product should be calculated based on average sales weighted characteristics of all existing technologies/materials covered by the scope of the PEFCR.

The purposes of defining the RP for smartphones are:

1) Identifying the most relevant impact categories, life cycle stages, processes and direct elementary flows
2) Comparison between smartphones that fall within the same RP
3) Compare the EF-profile benchmark of RP
4) Define the classes of smartphone performance

7.5 Product classification

Smartphones having similar functions and applications should be grouped under one product category. Smartphone batteries might have their own classification in the PEF system to be used by smartphones PEFCR.

7.6 System boundaries

The system diagram - showing included and excluded unit processes and the data quality of each - should be designed. Before the attributable life cycle stages and unit processes should be listed. Certain unit processes can be excluded based on the cut-off rule (e.g. 1 % per unit process). The system diagram will help immensely with defining the data quality issues. Hitherto capital goods (including infrastructures) and their waste management are rarely explored in smartphone FLCA. In summary the manufacturers need to agree on which unit processes to leave out for the RP smartphone.

7.7 Data quality requirements

Not much thought is usually given to data quality if the latest LCA software and secondary data are used. One example of data quality estimation for smartphones is found [i.24]. Here the PEFCR Guidance has big role to play, as the requirement of primary data will increase.

To sum up, the manufacturers have to agree on which processes - and elementary flows - are mostly contributing to the most important impact assessment categories for the RP smartphone in a certain smartphone segment.

7.8 Data collection

Existing LCAs make up an important step for help focusing the data collection on representative plants.

The data collection is currently too unsystematic in smartphone LCAs. A high frequency of measuring in plants is not common Validation of data collected is rare.

7.9 Benchmark and classes of environmental performance

The PEFCR Guidance has started to outline the procedure for determining the benchmark product in a certain product group. The benchmark refers to the average environmental performance of the representative product sold in the EU market.

7.10 Interpretation

It is a fact that current smartphone LCA level of uncertainty is missing from most case studies presented by manufacturers.

7.11 Reporting

The PEF LCA report [i.7] should contain:

- Definition of the functional unit and reference flow.
- Flow diagram for each life cycle stage with a clear link between all processes involved and one global system boundary diagram.
- Identification of the foreground and background data.
- For each life cycle stage, a table with all processes involved with a clear identification of the source of the Life Cycle Inventory and calculation of the reference flow for each process.
- Assumption about the use, re-use (if appropriate) and end-of-life scenario including the way the EoLT formula is applied. The RC should be reported according to the CFF.
- Treatment of any multi-functionality issues encountered in the PEF modelling activity.
- Results of the sensitivity analysis with a clear identification of the minimum-maximum values used to perform it.
- Results for each EF impact category with a split per life cycle stage.

Current LCA report for smartphone contains bits and pieces of these items.

7.12 Disclosure

The PEF method requires a fair share of primary data as specified by the PEFCR Guidance. This fact prevent manufacturers from presenting PEF LCA studies which are based only on secondary data.

7.13 Communication

The proper communication format of PEF Study results of a smartphone should be tested at least by the companies carrying out the PEFCR.

7.14 Verification

Studies supporting the PEFCR for smartphones cannot be released until they have been verified by reviewers approved by the European Commission.

8 Challenges with PEF Screening

8.0 General

This clause will discuss the challenges with PEF Screening (impact assessment, interpretation and conclusion, report). A PEF Screening is a preliminary study carried out on the RPs intended to identify the most relevant life cycle stages, processes, elementary flows, impact categories and data quality needs to derive the preliminary indication about the definition of the benchmark for the product category/sub-categories in scope, and any other major requirement to be part of the final PEFCR. As shown by the present report, screening LCA based on PEF principles is the least challenging task for smartphones manufacturers. Several have already prepared for - as good as - PEF compliant LCAs. An initial challenge is to decide which smartphone should be considered the RP in each market segment. However, the rules for identifying the RP smartphone are clear. The PEF screening is done on the RP. The purpose of the PEF Screening is to simplify the development of PEFCR. As an example certain impact categories might be excluded. The PEF screening also requires a "fair" data quality rating. Storage room, final assembly allocation, marketing activities and allocation of networks and data centres are further - small - challenges.

8.1 Data challenges in general

There is a huge debate on what would be the best option if not primary data are available. It might be that no LCA should be conducted as no/not enough primary data are available. Or it could be that available secondary data are enough but it has to be mentioned/marked whether the process at hand is under the smartphone manufacturer's control. The difference between primary and secondary data is not always clear despite defined in the ETSI LCA standard [i.14].

NOTE 1: For example regarding PCB production - material content, number of layers and produced area/yield can be based on primary data from a supplier, whereas the environmental impact data per produced area are secondary. It is then not evident if this mixture of data would be regarded as primary or secondary data as a whole for the PCB model. If the data used are considered secondary, they would not fulfil the PEF requirements should the PCB production be one of the significant unit processes.

NOTE 2: It is not impossible to conduct sensitivity analyses to understand which datum need to be primary when contributing more than 80 % of an impact category.

NOTE 3: A clear process diagram (see clause 7.11) - including energy and material flows - would define which data comes from which source and what is under the direct control of the smartphone manufacturer.

9 Insights and conclusions

The maturity is quite high - regarding the knowledge of FLCA methodologies - among several smartphone manufacturers. The preparedness for PEF studies is quite high among most leading manufacturers. However, the modelling disparities are evident for all life cycle stages, components and product parts. Developing and agreeing on appropriate assessment scopes for important components would therefore be useful and not insurmountable. Something more than what the ETSI LCA standard [i.14] prescribes is probably useful. However, it is doubtful if a full adherence to the PEFCR Guidance is necessary for smartphones.

10 Suggestions for future standardization activities

Depending on what will happen with the PEF and PEFCR Guidance in the future, several smartphones manufacturers are ready for its requirements. Anyway, for the time being the best available approach is to apply - and try to be as compliant as possible with - the ETSI LCA standard on FLCA [i.14]. However, that standard [i.14] is not prescriptive enough and too flexible. Therefore, the smartphone industry could agree on which parameters and which assessment scope FLCAs for smartphones should contain. For example the 20 most important unit processes in the smartphone life cycle can be identified and their assessment scope justified and harmonized. This is especially useful for the main components - and underlying unit processes - such as ICs and PCBs, and the main product parts, such as display, charger and battery. This work might include the most appropriate intensity values for these components and parts. The PEFCR standard idea can be abandoned presently. Consequently, there is currently no need to investigate if parameter data collection is enough for PEFCR Guidance compliance or if primary LCI data for each component/part is mandatory. It is suggested that another TR is developed which agrees on the assessment scope for FLCA - inspired by the pluses of the PEFCR Guidance [i.7] - for the smartphone industry.

History

Document history		
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