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Effect of modeling approach on climate change focused life cycle assessments for a contemporary smartphone device

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Highlights of the report:

- Two extensive smartphone LCAs are presented by two different organizations
- The spread of CO₂e results confirmed for one smartphone model
- Effect of modeling approach on result variability is presented
- ICT LCA standardization reduces need for smartphone product category rules
- CO₂e reduction potential for smartphones suggested

1. Abstract

Life cycle assessments (LCA) of consumer electronics and beyond are usually performed and reported very differently. As a result it is often difficult to assess the robustness, variability and transparency of reported LCA case studies. The value of LCA for policy makers is in doubt if the present situation cannot be clarified and improved. As a part of the solution here for the first time state-of-the art LCAs for the same smartphone model are presented by two different organizations (Orange, OGE and Huawei, HuW) and the effect of different modeling approach is scrutinized. The system boundary, the studied product system and the cut-off were agreed beforehand. Still a difference of around 32% (29.6 kg and 39.2 kg) for CO₂e baseline scores was found using same study object and Information and Communication Technology (ICT) Life Cycle Assessment (LCA) standard (ETSI TS 103 199, ETSI LCA), but different metrics, emission intensities, and LCA tools (software programs). However, the CO₂e difference was reduced to 12% (29.9kg and 33.5kg) when OGE used HuW metrics for use phase power consumption and total mass, and when HuW used OGE metrics for gold mass and silicon die area. The 1% difference for these OGE scores (29.9kg and 29.6kg) implies that product category rules (PCR) would lead to comparable external results for full LCAs of smartphones when same background LCI database is used. However, a probability test confirmed that the present baseline CC results for one specific study object modeled with two largely different and independent LCA modeling approaches are comparable if both use ETSI LCA. The general conclusion is that the ETSI LCA strongly facilitates comparable CC results for technically comparable smartphone models. Moreover, thanks to the reporting requirements of ETSI LCA, a clear understanding of the differences between LCA modeling approaches is obtained. The research also discusses the magnitude of the CO₂e reduction potential in the life cycle of smartphones.

Key words: climate change; life cycle assessment; modeling; smartphone; standardization

2. Table of Contents

Effect of modeling approach on climate change focused life cycle assessments for a contemporary smartphone device.....	1
1. Abstract	1
2. Table of Contents	2
3. Introduction	6
4. Materials and methods	8
1.1 Goal and scope.....	8
4.1.1 Functional unit	8
4.2 System boundaries	8
4.3 Inventory.....	9
4.3.1 Data collection	9
4.3.2 Data calculation	19
4.3.3 Allocation	21
4.4 Data quality.....	23
5. Results	24
6. Discussion	25
6.1 Uncertainty analyses	25
6.2 Sensitivity analyses.....	26
6.3 Potential for reduction of CO ₂ e emissions	26
6.4 Marginal electricity.....	27
7. Conclusions	29
8. Looking ahead.....	30
9. Acknowledgements	30
10. References	31
11. Supplementary material	34
12. Goal&Scope definition and setting the system boundary and functional unit	35
12.1 Goal	35
12.2 Lifetime	35
12.3 Functional unit	35
12.4 Studied Product System and Scope.....	35
13. Life Cycle Inventory	40
13.1 Data collection.....	40
13.1.1 OGE (Orange) Equipment Raw material acquisition	40

13.1.2	OGE Production	40
13.1.3	OGE Materials and parts	41
13.1.4	OGE Use stage.....	47
13.1.5	OGE End-of-life carbon footprint used by Orange with EIME	47
13.1.6	OGE Distribution Transport	49
13.1.7	HuW Raw Material Aquisition	49
13.1.8	HuW Part Production.....	49
13.1.9	HuW Use	49
13.1.10	HuW End-of-life treatment	49
13.1.11	HuW Transport	49
13.2	Data calculation	49
13.2.1	OGE B1.1.1 Batteries	49
13.2.2	OGE B1.1.2 Cables.....	49
13.2.3	OGE B1.1.4 ICs	50
13.2.4	OGE B1.1.5 Mechanics / Materials	50
13.2.5	OGE B1.1.6 Displays	50
13.2.6	OGE B1.1.7 PCBs	50
13.2.7	OGE B1.1.8 Other PCBA Components (Parts)	50
13.2.8	OGE B1.1.9 Packaging materials	50
13.2.9	OGE B1.1.10 Black box modules.....	50
13.2.10	OGE B1.1.11 Software	50
13.2.11	OGE B1.2 Assembly	50
13.2.12	OGE G1 transport and travel	50
13.2.13	OGE Secondary packaging.....	51
13.2.14	OGE Energy consumption for warehouses and shops	51
13.2.15	OGE Transports between B1.2 and C1 location (France).....	51
13.2.16	OGE End of life D1D3	52
13.2.17	Examples of HuW data calculations	52
13.3	Allocation of data	52
13.3.1	OGE Equipment raw material acquisition	52
13.3.2	OGE Production (PP+ Assembly)	52
13.3.3	OGE Use.....	53
13.3.4	OGE End-of-life	53
13.3.5	OGE Generic processes, G1-G7	53
13.3.6	OGE Cut-off	53
13.3.7	HuW Equipment raw material acquisition.....	53
13.3.8	HuW Production (PP+ Assembly)	53
13.3.9	HuW Use	53
13.3.10	HuW End of Life Treatment including Recycling	53
13.3.11	HuW Upgrades during the lifetime of the U8350.....	53
13.3.12	HuW Cut-off.....	53
13.4	Data quality.....	54
13.4.1	OGE Completeness.....	54

13.4.2	OGE Uncertainty	55
13.4.3	OGE Acquisition method	55
13.4.4	OGE supplier independence	55
13.4.5	OGE data representativeness	55
13.4.6	OGE Data Age	55
13.4.7	OGE Geographical correlation	56
13.4.8	OGE technological correlation	56
13.4.9	OGE Rule of inclusion / exclusion	56
13.4.10	OGE example of data quality for B1.1.4 “Integrated circuits”	57
13.4.11	HuW Methodological appropriateness and consistency (MC)	58
13.4.12	HuW Completeness (total LCA level) (C).....	58
13.4.13	HuW Uncertainty (U)	58
13.4.14	HuW Acquisition method (AM)	59
13.4.15	HuW Supplier independence (SI)	59
13.4.16	HuW Data representativeness (DR).....	59
13.4.17	HuW Data age (timeliness) (T).....	59
13.4.18	HuW Geographical correlation (GC).....	59
13.4.19	HuW Technological correlation (TC).....	59
13.4.20	HuW Cut-off rules (rules of inclusion/exclusion) (RIE).....	59
13.4.21	HuW Summary of data quality for each life cycle stage	59
14.	Life Cycle Impact Assessment.....	63
15.	Life cycle interpretation	64
15.1	Initial Conclusions	64
15.2	Uncertainty estimation.....	64
15.3	Sensitivity analyses.....	64
15.3.1	OGE Eco-Rating.....	65
16.	Reporting.....	69
16.1	OGE results.....	69
16.2	HuW results	70
16.2.1	Environmental impact category indicator result diagram	70
16.2.2	Environmental impact category indicator result: distribution between sub-unit processes within each life cycle stage	71
16.2.3	Environmental impact category indicator overview	71
16.2.4	Sensitivity analysis results	72
16.3	Cover page.....	74
16.4	Included life cycle stages, activities and generic processes	77
16.5	Generic processes	79
16.6	Transportation/travel.....	81
16.7	Raw materials	82
16.8	Part production	85

16.9	Energy consumption use stage.....	89
16.10	End-of-life treatment	89
16.11	LCI results	90
16.12	LCIA results	91
16.13	Check of fulfillment of mandatory requirements.....	92
17.	References.....	103

3. Introduction

Information and Communication Technology (ICT) and the Entertainment & Media (E&M) are two of the fastest growing industries and a future is foreseen where almost all electronic devices are network connected. The annual shipped number of mobile devices can be counted in billions. As such the smartphone sales are currently around one billion units per annum. However, the share of the production of ICT and E&M Equipment, its use and end-of-life treatment of the global annual electricity usage and CO₂e emissions are currently relatively low at around 8% and 4% (Tucker et al., 2012; Sloma, 2013; Corcoran and Andrae, 2013; Mills, 2013). Moreover certain ICT Services (such as virtual meetings in enterprise offices) could help reduce the global CO₂ emissions and environmental impacts (Global Sustainability Initiative, 2012; Coroama et al. 2012). Still the amount of ICT and E&M Equipment in use is increasing, especially end-user equipment such as mobile phones and tablets driven by a surge in cloud computing applications (Cisco, 2012). Mobile phones usually have a relatively short operating lifetime of 1 to 3 years which negatively influences eco-environmental impacts. As shown in Figure 1 three previous non-comparable smartphone Life Cycle Assessments (LCAs) suggest that the total CO₂e per lifetime is around 16-70 kgCO₂e with the Raw Material Acquisition (RMA)+Part Production (PP)+Assembly+Distribution dominating the score. (Apple, 2011; Nokia, 2012; Huawei, 2013).

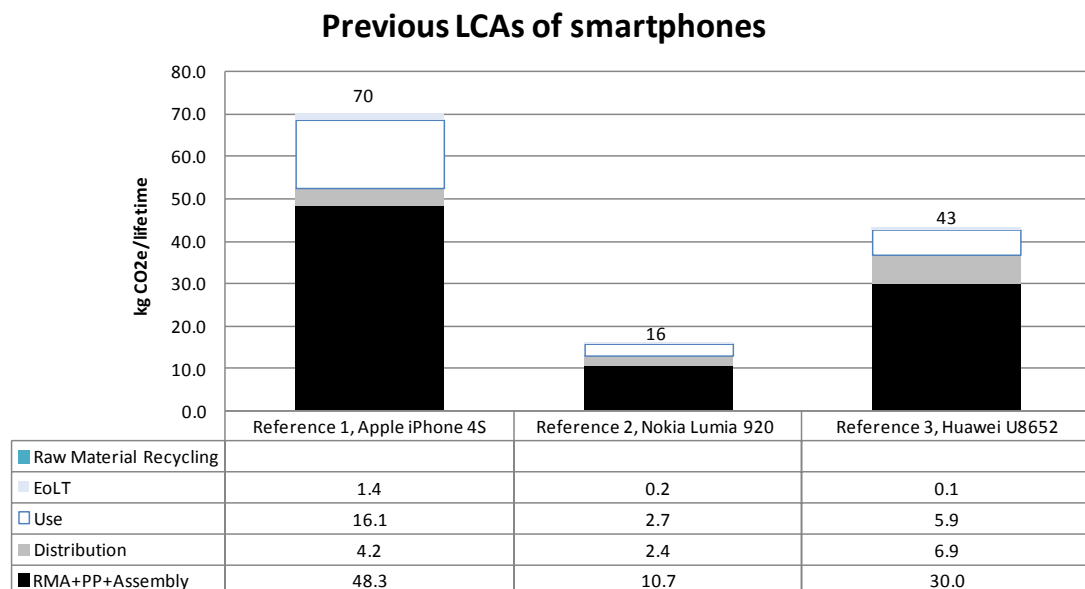


Figure 1. Results of previous LCAs (Climate Change, CC) of several smartphones with 3 year lifetime.

Several environmental impact studies of mobile phones show similar relative ranking in between life cycle stages however still these and other electronics LCA studies often raise questions due to lack of transparency (Andrae and Andersen, 2010; Hertwich and Roux, 2011; Teehan and Kandlikar, 2012). I.e. recently three different mobile phone LCA studies came to these astonishing conclusions for CC; the charger is the main driver (Sangprasert and Pharino, 2013), the use stage is the dominating life-cycle stage (Hoffmann, 2013), and the smartphone has a better absolute eco-environmental performance than the simpler entry phone (Siu, 2013). These mobile phone LCAs are unfortunately not isolated occurrences as far as electronics LCAs studies. Hirschier et al. identified for LCA comparisons of media consumption via tablet or printed versions that differences can be explained by different methodological approaches used for LCI modeling. (Hirschier et al, 2014).

Hence without proper sector standardization beyond ISO the robustness of LCA results in general and ICT Equipment LCA results and ICT Sector footprint in particular will be in doubt. In 2009 and 2010 the European Commission (EC) addressed this problem (European Commission, 2009; European Commission, 2010) and result several standards/guides have emerged. The most detailed requirement specification for LCA of ICT Equipment is from ETSI (European Telecommunications Standards Institute, ETSI, 2011). In 2012 Orange (OGE) and Huawei (HuW) were among the organizations that volunteered to participate in an EC project pilot testing ICT LCA methodologies. A report about the outcome of the pilot test concluded that the tested LCA methodologies are in

principle compatible and workable however allow considerable freedom regarding LCA modeling decisions that influence the calculation outcomes (European Commission, 2012a).

This research will for the first time shed light on these conclusions by presenting two LCAs of one smartphone, one by HuW and the other by OGE. The additional goals were to understand the effect on Climate Change (CC) impact category results in LCA of using different LCA tools, databases and methodological choices. We want to understand if the difference and uncertainty of electronics LCA scores is bearable for policy makers if the LCA studies are based on ETSI TS 103 199 (ETSI LCA) (ETSI, 2011).

In summary the problems addressed in the present report are:

- What is the difference in absolute CC GWP100 score for smartphone LCAs induced by different modeling approach?
- Does the ETSI TS 103 199 LCA standard lead to comparable results for technically comparable smartphones?
- What is the potential for reducing the absolute CC GWP 100 score for smartphones?

4. Materials and methods

1.1 Goal and scope

The goal of the study is to estimate the CC mid-point impact category result of a Smartphone (U8350) during its lifetime using attributional process-sum LCA.

The study object (product system) was the U8350 (ICT Equipment) smartphone manufactured in China and shipped to France for use in Wireless Networks, and later end-of-life treatment.

HuW and OGE both strived for full compliance with ETSI LCA, i.e. fulfilling all of its 83 mandatory requirements (Table S35).

Except the operating system software program, U8350 physically consists of these building blocks: smartphone, Li-ion battery, complete packaging (cardboard, plastic bags, manual, USB/μUSB cable, headset, charger).

These building blocks can be categorized according to Parts defined in Table B.1 in ETSI LCA. In this LCA the impact of eventual spare parts production was not included.

4.1.1 Functional unit

The mandatory basic functional unit (f.u) as required by ETSI LCA is total lifetime use. More specifically the f.u. was defined as *two years of U8350 usage charging the battery from 0% to 100% once every 24 hour*. The reference flow is one U8350 smartphone with its packaging and accessories.

4.2 System boundaries

OGE advocated a cradle-to-grave approach using the EIME 5.0 LCA tool database version 11.4. (Bureau Veritas, 2013). EIME 5.0 uses a database specifically designed for electrical and electronic products based on data compiled from the Federation of Electric and Electronic Industries and Communication (FIEEC). The current software database represents some 160 Parts, 470 Raw Materials and 190 processes called "modules".

HuW on the other hand used the SimaPro 7.3.2 LCA tool and an approach separating all life cycle stages such as RMA and PP.

Table 1 of ETSI LCA (ETSI, 2011) specifies the mandatory, recommended, and optional life cycle stages/unit processes for ICT Equipment. A1, A2, B1.1, B1.2, C1, D2.1, D2.2, D3 (Figure 2) life cycle stages were included in this LCA.

The activities, B1.3, B2, B.3, C2-C4 and D1 were not part of the studied product system.

Support activities are not considered for any unit processes because of lack of data and models.

In Figure 2 below the underlined processes are included in the studied product system whereas the italic marked are not.

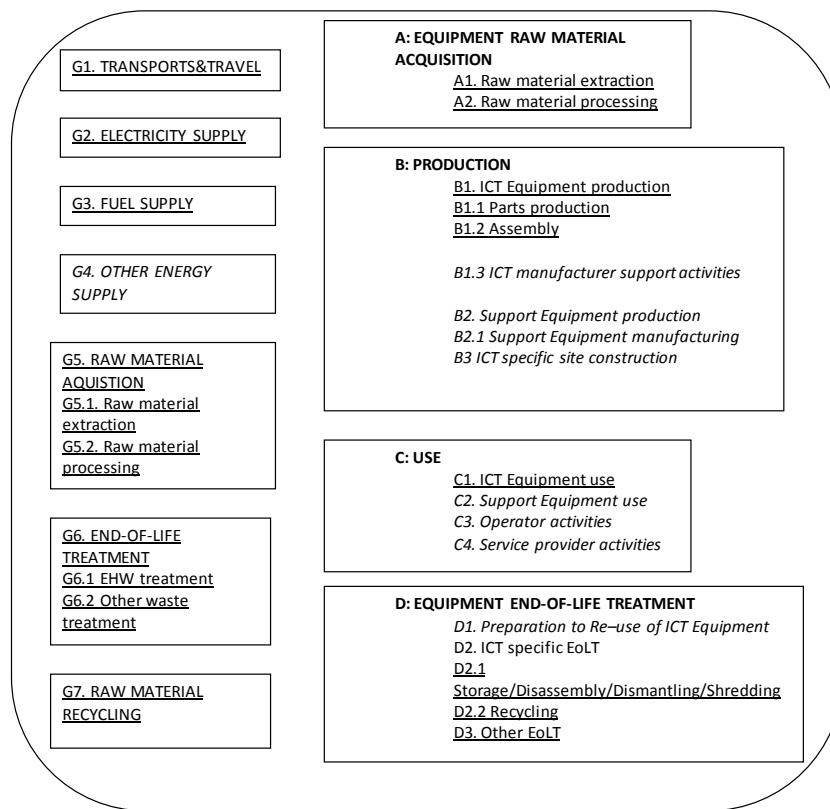


Figure 2. The system boundary of the product system for OGE and HuW LCA of the U8350

The geographical and temporal coordinates vary dynamically for the RMA and Production of the ICT Equipment. The presented results for RMA and Production will therefore represent a global average for the U8350.

OGE used a laboratory weighing machine (Milligram scale) to establish the mass of each part. HuW mass numbers for Parts are originally provided by as material content declarations by Part producers. U8350 is manufactured in China and sent to France by plane.

4.3 Inventory

4.3.1 Data collection

4.3.1.1 Raw Material Acquisition, Part Production, Assembly

Regarding data collection in the EIME 5.0 software RMA and PP are linked, i.e. it is not possible to show separate results for RMA (A). For raw material extraction (A1) and raw material processing (A2) databases contained within the LCA tool/LCI databases were used representing a mix of primary and secondary content for world production. The transports occurring in RMA are modeled inside these LCI data.

The specific data, which constitutes measurements of material constituents and power consumption, were gathered at OGE Labs Grenoble laboratory as well as ICT specific (ETSI, 2011), either primary or secondary, from manufacturers. For the secondary specific data from EIME, the data quality requirements are established by Bureau Veritas. ETSI LCA clearly allows secondary specific data for electronic PP. Geographical areas, date of creation as well as the source of the 10 most impacting modules in this study are listed in Table S2. Empirical measurement techniques such as densitometry and flame tests were performed to identify plastic contents. For metal parts identification was carried out using tests such as magnetization, color or presence of surface treatment. Feedback from plastic & metal Part manufacturers was also used to identify these parts as well as ISO 1043 markings.

Passive Parts (B1.1.8 Other PCBA components) were classified by function and dimension and divided into six categories; resistors, capacitors, inductors, filters, quartz. Small light emitting diodes (LED) for backlight were also considered in this category, even if they are actually active components. The material composition of passive parts appears relatively homogeneous among different Part manufacturers. Therefore, it was not motivated to request material composition and LCI data for the manufacturing of each Part.

Active Parts (B1.1.4 Integrated Circuits, IC) mainly include ICs, transistors and diodes. LCAs of mobile phones tend to show that these Parts have a relatively high eco-environmental impact. Therefore it was decided to analyze IC in greater detail than other Parts. Importantly, there are a many different types of IC package types whose architecture directly influences the eco-environmental impact of the IC Parts (Andrae and Andersen, 2011). For each IC with more than 12 connections the good silicon (Si) die area inside the IC chip was identified. Supplementary Material Section 13.1.2 describes further the OGE data collection for Parts.

Below in Table 1 is shown OGE detailed modeling for the μ USB cable. While this approach was also used for the other U8350 building blocks it will not be outlined in detail.

Table 1 Summary of OGE CO₂e scores for A+B for μ USB cable.

USB A connector			
Part	Unit	Amount	Module in EIME database
<u>Solder</u>	g	4.000	PWB (Soldering, Wave SnAgCu)
<u>Overmoulding</u>	g	2.811	PVC (Polyvinyl Chloride, Moulded by Injection)
Connector insulant			
<i>Polybutylene terephthalate</i>	g	0.454	PBT (Polybutylene Terephthalate)
<i>Glass Fiber</i>	g	0.136	Glass Fibers
<i>Injection process</i>	g	0.648	Plastics (Molding by Injection, Thermoplastic)
<u>Lower casing</u>	g	2.048	Steel (Stainless)
<i>Deep drawing process</i>	g	2.048	Ferrous metals (Deep drawing, Steel)
<u>Upper casing</u>	g	0.808	Steel (Stainless)
<i>Deep drawing process</i>	g	0.808	Ferrous metals (Deep drawing, Steel)
<u>EVA sealing</u>	g	0.492	EVA (Polyethylene-co-Vinyl Acetate)
<i>Injection process</i>	g	0.492	Plastics (Molding by Injection, Thermoplastic)
Wire			
<i>Inner jacket</i>	g	0.078	PE (High Density, HDPE)
<i>Extrusion process</i>	g	0.078	Cable process (Thermoplastic, Extrusion)
<i>Copper Wire</i>	g	0.075	Copper (Wire, 0.6mm)
<i>Wire stranding process</i>	mm	927.500	Core stranding of copper wire; FR
	mm ²	0.283	
<i>Tin plating</i>	mm ²	1750.000	Ferrous metals (Coating, Tin plating)
Contact pins			
<i>Brass</i>	g	0.290	Brass (CuZn)
<i>Sheet rolling process</i>	g	0.290	Non ferrous metals (Sheet rolling, Cu)
<i>Deep drawing process</i>	g	0.290	Ferrous metals (Deep drawing, Steel)
<i>Tin plating</i>	mm ²	310.000	Ferrous metals (Coating, Tin plating)
<i>Gold plating</i>	mm ²	80.000	PWB (Finish, Gold)
<u>Aluminium foil shielding</u>	g	0.012	Aluminium (Al, Foil)

<i>Armoring process</i>	g	0.012	Armouring of cable; wrapping of steel or aluminium; FR
<i>Outer jacket</i>	g	0.162	PVC (Polyvinyl Chloride, polymerized by suspension)
<i>Extrusion process</i>	g	0.162	Cable process (Thermoplastic, Extrusion)
<i>Printed Label</i>	mm ²	112.000	Label (Pre-printed adhesive paper)
Micro USB B connector			
Part	Unit	Amount	Model in EIME database
<i>Contact pins casing</i>	g	0.209	Steel (Stainless)
<i>Deep drawing process</i>	g	0.209	Ferrous metals (Deep drawing, Steel)
<i>Lower casing</i>	g	0.555	Steel (Stainless)
<i>Deep drawing process</i>	g	0.555	Ferrous metals (Deep drawing, Steel)
<i>Upper casing</i>	g	0.328	Steel (Stainless)
<i>Deep drawing process</i>	g	0.328	Ferrous metals (Deep drawing, Steel)
<i>EVA</i>	g	0.121	EVA (Polyethylene-co-Vinyl Acetate)
<i>Injection process</i>	g	0.121	Plastics (Molding by Injection, Thermoplastic)
<i>Bare Copper Wire</i>	g	0.016	Copper (Wire, 0.6mm)
<i>Wire stranding process</i>	mm	161.000	Core stranding of copper wire; FR
	mm ²	0.283	
<i>Tin plating</i>	mm ²	300.000	Ferrous metals (Coating, Tin plating)
Wire			
<i>Inner Jacket</i>	g	0.048	PE (High Density, HDPE)
<i>Extrusion process</i>	g	0.048	Plastics (Extrusion, thermoplastics)
<i>Copper Wire</i>	g	0.056	Copper (Wire, 0.6mm)
<i>Wire stranding process</i>	mm	644.000	Core stranding of copper wire; FR
	mm ²	0.283	
<i>Tin plating</i>	mm ²	1215.000	Ferrous metals (Coating, Tin plating)
Wire insulant			
<i>EPDM rubber</i>	g	0.038	EPDM (Ethylene Propylene Diene copolymer)
<i>Carbon Black</i>	g	0.013	Carbon Black
<i>Injection process</i>	g	0.051	Plastics (Molding by Injection, Thermoplastic)
<i>Tape</i>	g	0.009	Swelling tape (Acrylate)
<i>Tape wrapping process</i>	g	0.009	Wrapping process; FR
<i>Outer jacket</i>	g	0.159	PVC (Polyvinyl Chloride, polymerized by suspension)
<i>Extrusion process</i>	g	0.159	Cable process (Thermoplastic, Extrusion)
<i>Aluminium foil shielding</i>	g	0.022	Aluminium (Al, Foil)
<i>Armoring process</i>	g	0.022	Armouring of cable; wrapping of steel or aluminium; FR
Casing - front part			
<i>Liquid crystal polymer</i>	g	0.075	LCP (Liquid Crystal Polymer)
<i>Glass Fiber</i>	g	0.032	Glass Fibers
<i>Injection process</i>	g	0.107	Plastics (Molding by Injection, Thermoplastic)
Contact pins			
<i>Copper</i>	g	0.080	Copper (Cu, Ingot)
<i>Zinc</i>	g	0.009	Zinc (Zn)
<i>Phosphorus</i>	g	0.001	Chemicals (inorganic unspecified)
<i>Sheet rolling process</i>	g	0.090	Non ferrous metals (Sheet rolling, Cu)

<i>Tin plating</i>	mm ²	135.000	Ferrous metals (Coating, Tin plating)
<i>Gold plating</i>	mm ²	20.000	PWB (Finish, Gold)
Contact pins insulant			
<i>Liquid crystal polymer</i>	g	0.036	LCP (Liquid Crystal Polymer)
<i>Glass Fiber</i>	g	0.016	Glass Fibers
<i>Injection process</i>	g	0.052	Plastics (Molding by Injection, Thermoplastic)
<i>EVA sealing</i>	g	0.014	EVA (Polyethylene-co-Vinyl Acetate)
<i>Injection process</i>	g	0.014	Plastics (Molding by Injection, Thermoplastic)
Casing - rear part			
<i>Liquid crystal polymer</i>	g	0.074	LCP (Liquid Crystal Polymer)
<i>Glass Fiber</i>	g	0.032	Glass Fibers
<i>Injection process</i>	g	0.106	Plastics (Molding by Injection, Thermoplastic)
<i>Rear contact pin</i>	g	0.052	Steel (Stainless)
Cable			
Part	Unit	Amount	Model in EIME database
<i>Extrusion process</i>	g	13.222	Cable process (Thermoplastic, Extrusion)
Aluminium foil shielding			
<i>Aluminium</i>	g	0.925	Aluminium (Al, Foil)
<i>Armoring process</i>	g	0.925	Armouring of cable; wrapping of steel or aluminium; FR
Bare Copper Wire			
<i>Copper</i>	g	0.835	Copper (Wire, 0.6mm)
<i>Wire stranding process</i>	cm	805.000	Core stranding of copper wire; FR
	mm ²	0.283	
<i>Tin plating</i>	mm ²	1520.000	Ferrous metals (Coating, Tin plating)
Copper Wire			
<i>Copper</i>	g	4.129	Copper (Wire, 0.6mm)
<i>Wire stranding process</i>	cm	3220.000	Core stranding of copper wire; FR
	mm ²	0.283	
<i>Tin plating</i>	mm ²	6070.000	Ferrous metals (Coating, Tin plating)
Inner jacket			
<i>High-density polyethylene</i>	g	2.053	PE (High Density, HDPE)
<i>Extrusion process</i>	g	2.053	Cable process (Thermoplastic, Extrusion)

Below in Table 2 is shown OGE measured values for Parts and important examples of respective EIME models used for each Part. For B1.1.3 Electro–mechanics and B1.1.5 Mechanics / materials the value in “Measured mass” corresponds only to the mass of parts described in “Noticeable EIME module(s) used”. Moreover OGE’s approach with EIME makes use of other metrics than mass, for e.g. PWBs and Displays, explaining why the total mass is not 326g as given below in Table 5.

Table 2 Summary of OGE data sources for A+B

	Part categories included	Part Unit processes included	Measured mass	Noticeable EIME module(s) used
B1.1.1 Batteries	Lithium Battery	Raw Material Acquisition, Battery cell assembly, Battery module (pack) assembly	24.526g	Li-ions battery; RER
B1.1.2 Cables	Charger cable	Raw Material Acquisition, Cable final assembly	31.823g	See Table 1 above
B1.1.3 Electro-mechanics	CEM1 1 layer : 1921 mm ² Switch Mode Transformer, SMT, low voltage; RER : 7.2 g Polycarbonate (PC); moulded by injection; RER : 26.4 g	Raw Material Acquisition, Part final assembly	33.4g	Charger : PWB, CEM1 preg, 1 layer; RER Switch Mode Transformer, SMT, low voltage; RER Polycarbonate (PC); moulded by injection; RER
B1.1.4 Integrated circuits (ICs)	Processors, DSPs	Front-end: Special IC Raw Materials Acquisition, Wafer production, Chip production (“the wafer fab”) Back-end: Raw Material	ICs 1.211 g Diodes 0.701 g Transistors 0.016 g Additional Silicon dies are expressed in mm ² in EIME, no available mass	Integrated circuits (silicon die and packaging) : Flip chip semiconductor, CSP FLIP CHIP; France, FR Low profile fine pitch ball grid array packages semiconductor, LFBGA; France, FR Very thin fine pitch quad flat semiconductor, VFQFPN; France, FR Shrink small outline plastic packages, SSOP; France, FR Additional wafer for silicon die : Wafer, from silicon; before dies slicing; France, FR
	ASICs			
	Memories			
	Microprocessors			
	Transistors and diodes			

		Acquisition, IC encapsulation		Transistors and diodes : Small outline transistor, Low power, SOT23 - SOT89 - SOT223; France, FR Small outline diode semiconductor, Low power, SOT23 - SOT89 - SOT223; France, FR Plastic body diode; SP
B1.1.5 Mechanics / materials	Housing : Polycarbonate (PC); moulded by injection; RER : 20.3 g Steel, stainless; RER : 24.9 g	Raw Material Acquisition, Part final assembly	45.2g	Housing : Polycarbonate (PC); moulded by injection; RER Steel, stainless; RER
B1.1.6 Displays	LCD Screen	G2 for Display module assembly, Display panel assembly	34.22 cm ² (EIME uses a surface for screens not a mass)	Capacitive touchscreen display, based on LCD color technology, production mix, CN
B1.1.7 Printed circuit boards (PCBs)	FR4 8 layers : 2556 mm ² FR4 4 layers : 2825 mm ² FR4 1 layer : 42.25 mm ² Flex 2 layers : 1047 mm ² CEM1 1 layer : 1921 mm ² (EIME requires a surface for PWBs not a mass)	Raw Materials Acquisition, Raw materials Acquisition for special PCB materials, Raw materials Acquisition for PCB semi-produced composite materials, PCB final assembly	83.91 cm ²	Main PCB : PWB, FR4 preg, 8 layers; RER Keyboard PCB : PWB, FR4 preg, 4 layers; RER Keyboard flex PCB : PWB, Polyimide copper flexible, 2 layers; RER Link flex PCB : PWB, Polyimide copper flexible, 2 layers; RER Camera Image sensor PCB : PWB, FR4 preg, 1 layer; RER Camera flex PCB : PWB, Polyimide copper flexible, 2 layers; RER

B1.1.8 Other PBA components	<p>EIME requires a surface for ceramic capacitors and a volume for electrolytic capacitors</p> <p>Inductors : 0.21 g Varistor : 1.3 g Resistors : 0.59 g Quartz crystal oscillators : 0.07 g</p>	Raw Material Acquisition, Part final assembly	2.17g	<p>Mobile phone : Axial ferrite inductor, SMD, RoHS compliant; Singapore Ceramic capacitor, RoHS compliant; BR Flat ship resistor, SMD, RoHS compliant; GLO Metal body quartz oscillator; CN Generic surface mounted device, SMD, RoHS compliant; GLO</p> <p>Charger : Electrolytic capacitor, aluminium package; RER Zinc oxide battery; FR Resistor, 5 - 20W; PT</p>
B1.1.9 Packaging materials	<p>Duplex-triplex cardboard; primary production; RER : 90.6 g Paper; from virgin fiber; RER : 7.9 g Polyethylene low density (PE-LD) resin; RER : 4.2 g</p>	Raw Material Acquisition, Part final assembly	102.7g	<p>Duplex-triplex cardboard; primary production; RER Paper; from virgin fiber; RER Polyethylene low density (PE-LD) resin; RER</p>
B1.1.10 Black box modules	<p>Camera: Wafer, from silicon; before dies slicing; France, FR : 25 mm² PWB, Polyimide copper flexible, 2 layers; RER : 170 mm²</p>	“Cradle-to-gate” LCA from supplier	1.67g	<p>Camera sensor : Wafer, from silicon; before dies slicing; France, FR Camera flex : PWB, Polyimide copper flexible, 2 layers; RER</p>

B1.1.11 Software	Purchased SW	<p>Development: e.g. daily way to work for programmer, business trips for programmer, electricity usage of ICT equipment used by programmer, office lighting.</p> <p>Production: e.g. manuals production, Data medium production, Download size if software is available as download.</p>	Cut-off	
B1.2 Assembly				<p>Re-flow soldering: used to fix the surface mount components assembled (SMC) onto the printed circuits.</p> <p>Wave soldering: used for mixed components to be fixed on the printed circuit: SMC and through-holes</p>

HuW's approach (Zhu and Andrae, 2014) is based on supplier data from Product Data Management (PDM) systems and the RMA and PP are modeled separately in SimaPro LCA tool and associated LCI databases (See Section 2.3.2). RMA includes the total use of Raw Materials, losses and connection to EoLT metal recycling.

HuW estimated the Si die area according to Eq. 1:

$$Siarea = ChO \times \frac{CdW}{WO} + ChS \times \frac{CdW}{WS} + PO \times \frac{PdW}{WO} + PS \times \frac{PdW}{WS} = 7.26 \text{ cm}^2 \quad (1)$$

Where

ChO = share ordinary dies in Charger, 100%

ChS = share stacked dies in Charger, 0%

PO = share ordinary dies in Phone, 53.5%

PS = share stacked dies in Phone, 46.5%

CdW = mg Si dies in Charger, 47.25 mg

PdW = mg Si dies in Phone, 85.7 mg

WO = mg/cm² for ordinary Si dies, 150

WS = mg/cm² for stacked Si dies, 6

The measured value from OGE is 4.85 cm².

4.3.1.2 Transports

Transport of U8350 to Use stage, Trp_{U8350} , was modeled by both companies on assumptions of share of Air, Truck and Van Transports (See Eq. 2).

HuW LCA used the following values

A = % of transports from B1.2 to France by Air. 1 (100% Air transport)

B = Average air distance from near B1.2 Airport to near France Airport [km]. 9 600 km

C = Average emission factor for air freight [kg CO₂e/tonkm, 1.07].

D = Average Distance B1.2 to near B1.2 Airport [km]. 100 km

E = Average emission factor for lorry in B1.2 [kg CO₂e/tonkm, 0.279].

F = Average Distance France Airport to France warehouse [km]. 230 km

G = Average emission factor for lorry in France [kg CO₂e/tonkm, 0.279].

H = Average Distance France warehouse (shop) to C1 use location site [km]. 150 km

I = Average emission factor for van [kg CO₂e/tonkm, 1.51].

W = weight of U8350, 357 g

$$Trp_{U8350} = A \times W(B \times C + D \times E + F \times G + H \times I) = 3.78 \text{ kgCO}_2\text{e} \quad (2)$$

OGE did not consider the H transport due to high variability (mean of transport, distance...).

4.3.1.3 Use stage power

Use phase electricity energy usage was measured by OGE in its laboratory (uncertainty 2.6σ, 99% confidence interval around the mean value) using Software Labview and National Instruments for the capture card. A complete charge of the battery 0 to 100% was measured at the mains.

HuW used measurements of charger efficiency and battery capacity and one assumed one charge of the battery 0 to 100% per day.

Huawei estimated the electricity usage for the studied U8350, Use_{U8350} , according to Eq. 3

$$Use_{U8350} = \frac{BC}{1000} \times V \times Y \times \frac{DY}{CE} = 4\,754\,Wh \quad (3)$$

Where

BC = [mAh] Battery capacity = 1 200

V = [Voltage, V] = 3.7

Y = [years] lifetime = 2

DY = [days per year], charging = 365

CE = [%], charger efficiency = 0.6817

A French average electricity mix for low voltage was applied ("Electricity, low voltage, at grid/FR U" from ecoinvent db, 0.108 kgCO₂e/kWh) as the U8350 was operating in France market and the purpose of the study was to estimate CC impact of the smartphone in French Networks.

4.3.1.4 End-of-life

For its end-of-life management, the U8350 follows the European WEEE directive requiring more than 85wt% recyclability (European Parliament, 2012).

For end-of-life, OGE used EIME database for specific EoLT for Storage/Disassembly/Dismantling/Shredding and Recycling. The EoLT is assumed to be done in France and EoL transport distances are set accordingly (Table S4).

HuW focused the EoLT modeling on the metal recycling and used the 50/50 allocation method, however, no primary data were collected as EoLT for CC has shown to be of low importance in previous LCAs. Supplementary Materials Section 13.1.10 describes further the HuW data collection for EoLT.

4.3.2 Data calculation

As far as data calculation OGE LCA value for CC is expressed as the total of A (all raw materials) + B (production) for all Part types according to Table 2 above. HuW separates these life cycle stages for all Parts as shown in Tables 3 and 4.

Table 3 Summary of HuW CO₂e scores for Equipment Raw Material Total Usage (A1-A2)

Raw Material	Amount per piece U8350	Unit	Mean g CO ₂ e per unit and uncertainty $\pm 2\sigma$	Mean g CO ₂ e per piece U8350
Iron/Steel alloys (primary)	$13 \times 1.25 = 16.3$	g	6.13, 10%	100
Aluminum alloys (primary)	$7.9 \times 1.10 = 8.69$	g	12.2, 15%	106
Copper alloys (primary)	$28.8 \times 1.25 = 36$	g	3.34, 15%	120
Gold (primary)	$0.123 \times 1.01 = 0.124$	g	18 800, 32%	2 336
Silver (primary)	$0.179 \times 1.01 = 0.181$	g	145, 24%	26
Nickel	$1.2 \times 1.25 = 1.5$	g	7.18, 25%	11
Tin	$1.56 \times 1.25 = 1.95$	g	17.1, 46%	33
Palladium	$0.0336 \times 1.01 = 0.034$	g	10 500, 22%	356
Zinc	$0.972 \times 1.25 = 1.215$	g	4.29, 31%	5
Acrylonitrile butadiene styrene (ABS)	$18.4 \times 1.25 = 23$	g	4.39, 7%	101
Polyester (e.g. PET)	$2.29 \times 1.25 = 2.86$	g	2.7, 13%	8
PMMA	$1.53 \times 1.25 = 1.91$	g	8.38, 6%	16
PA (Nylone)	$1.3 \times 1.25 = 1.62$	g	8.5, 5%	14
PVC	$14.5 \times 1.25 = 18.1$	g	2.01, 11%	36
Polyethylene (PE) — HD	$6.9 \times 1.25 = 8.62$	g	2.02, 7%	17
Polycarbonate (PC)	$2.15 \times 1.25 = 2.69$	g	7.78, 7%	21
Polypropylene	$1.05 \times 1.25 = 1.31$	g	1.97, 10%	3
Polyurethane (PUR)	$1.26 \times 1.25 = 1.58$	g	4.83, 22%	8
Epoxy	$16 \times 1.25 = 20$	g	1.1, 11%	22
Glassfibre	$34.6 \times 1.25 = 43.3$	g	2.79, 18%	121
SiO ₂	$5.7 \times 1.25 = 7.13$	g	0.021, 10%	0.15
Glass	$26.7 \times 1.25 = 33.4$	g	1.09, 32%	36
SUM of B1.1 and B1.2 including Ancillary Raw Material Acquisition.				3 496, $2\sigma = 782$

For Assembly OGE used pre-made LCA modules whereas electricity was measured by HuW in the assembly factory.

**Table 4 Summary of HuW CO₂e scores for Part Production including Auxiliary Raw Materials
B1.1-B1.2 + G5 in ETSI LCA**

Part category	Amount per piece U8350	Unit	Mean g CO ₂ e per unit and $\pm 2\sigma$	Mean g CO ₂ e per piece U8350
B1.1 Batteries, Lithium	24.06	g	5.62, 18%	135
B1.1.2 Cables	<i>μUSB-cable included in B1.1.3</i>			
B1.1.3 Electro-Mechanics	42	g	5.64, 56%	237
B1.1.3 Chargers	56.3	g	35.6, 28%	2 004
B1.1.4 ICs, Si die area (front-end)	7.26	cm ²	2170, 56%	15 754
B1.1.4 ICs, all types (back-end)	0.984	g	182, 14%	179
B1.1.4 Transistors	0.0737	g	141, 24%	10
B1.1.4 Diodes (Light Emitting, Transient Voltage Suppression, Metal–oxide–semiconductor field-effect transistor)	0.886	g	250, 20%	221
B1.1.5 Mechanics/Materials, Aluminum alloys	7.9	g	4.6, 14%	36
B1.1.5 Mechanics/Materials, Iron/Steel alloys	13	g	1.16, 11%	15
B1.1.5 Mechanics/Materials, Copper alloys	28.8	g	1.23, 15%	35
B1.1.5 Mechanics/Materials, Polymers	72.4	g	1.85, 16%	134
B1.1.6 Touch Screen+LCD module	20.16	cm ²	487, 68%	9 818
B1.1.7 PCB, Plastic multilayer boards (FR4)	35.6 (6 layers, 49 cm ²)	g	33.8, 12%	1 203
B1.1.8 Filters	0.057	g	537, 11%	31
B1.1.8 Inductors (chip type)	0.169	g	38.4, 30%	6
B1.1.8 Resistors (Thick film chip)	2.04	g	30.6, 35%	62
B1.1.8 Capacitors (SMD ceramic)	0.675	g	40.7, 33%	27
B1.1.8 Quartz crystal oscillators (Crystal resonator, Temperature Compensated)	0.054	g	56.7, 11%	3
B1.1.9 Packaging materials, Cardboard box	132	g	0.445, 9%	59
B1.1.10 Electronic components, unspecified (Fuses, Speaker,	1.34	g	282, 105%	378

Microphone)				
B1.2 Assembly, PCBAs	1	p	680, 21%	680
G1. Transport, air scenario for Distribution	357	g	10.5, 11%	3 770
-Air	357	g	10.2, 8%	3 641
-Lorry	357	g	0.092, 60%	32
-Van	357	g	0.23, 56%	81
SUM of B1.1 and B1.2 including Ancillary Raw Material Acquisition.				34 779, 2σ=14 600

4.3.3 Allocation

Regarding allocation of data, due to limitations of the EIME 5.0 LCA tool, OGE was bound to use the 100/0 allocation method for Raw Material Acquisition with recycled content ratios for each Raw Material fixed by the EIME tool. No Raw Material Recycling discount is therefore included in the calculation model.

Moreover the EIME LCA tool is not able to handle metal, paper, cardboard or plastic recycling.

HuW's modeling approach within SimaPro is flexible regarding allocation and recycled content. 100/0 allocation and no recycled content was used for RMA and 50/50 allocation and 50wt% material recovery for steel, aluminium, copper, gold, silver, and palladium for RM recycling of the metals within the Phone Device .

All Raw Materials used are assumed to be 100% primary, i.e., no recycled content (Eq. 4). At G7 (Raw Material Recycling), according to the 50/50 allocation method, 50% of the Secondary Raw Material Acquisition was allocated to the present life cycle. 50% metal recovery efficiency was assumed not to overestimate the recycling benefit. The impact of metal production, I_{metals} , per mass according to 100/0+50/50 and 50/50 allocation methods is given by Eqs. 4 and 5, respectively.

$$I_{metals} = 1.0 \times P \times I_P + 0.0 \times S \times I_S + 0.5 \times (S + R_P) \times I_S - 0.5 \times (S + R_P) \times I_P \quad (4)$$

$$I_{metals} = 0.5 \times P \times I_P + 0.5 \times S \times I_S + 0.5 \times R_P \times S + 0.5 \times L_P \times P \quad (5)$$

P = share primary, %, 100

S = share secondary, %, 0

I_P = Impact primary production

I_S = Impact secondary production

R_P = Recovered material, %, 50

L_P = Lost material, %, 50

The share of the U8350 (smartphone+charger+Li-ion battery+packaging materials) which goes to metal recycling is 33.3g of 357 g, i.e. 9.3%. The remaining 324.7 g is cardboard box (smartphone packaging materials), charger packaging materials, Li-ion battery, charger, mechanical polymers in smartphone, and residuals.

For gold the 100/0+50/50 allocation method according to Eq. 4 results in $14\,311 \text{ gCO}_2\text{e/g gold}$, $1.0 \times 1.0 \times 18\,800$ (burden upstream) + $0.0 \times 0.0 \times 846$ (burden upstream) + $0.5 \times (0 + 0.5)$ (burden downstream) $\times 846 - 0.5 \times (0 + 0.5)$ (credit downstream) $\times 18\,800$.

The 50/50 allocation method according to Eq. 5 gives the same result as 100/0+50/50 method, $0.5 \times 1.0 \times 18\,800 + 0.5 \times 0.0 \times 846 + 0.5 \times 0.5 \times 846 + 0.5 \times 0.5 \times 18\,800$.

For Gold per piece U8350 (-)556 g CO₂e, $0.5 \times 0.5 \times 0.124\text{g} \times 846\text{g/g} - 0.124\text{g} \times 0.5$ (allocation) $\times 0.5$ (recovery efficiency) $\times 18\,800\text{g/g}$, is avoided.

Hence, the CC impact for Gold per U8350 life cycle is 1 774 g CO₂e ($0.124 \times 14\,311$), where 2 331 ($0.124 \times 18\,800$) is from Raw Material Acquisition, and (-)556 from Metal Recycling.

These effects are shown below in Figures 3 and 4 and more details in Table S29.

4.4 Data quality

OGE sought high quality of LCI data for the most impacting flows (e.g., area of good Si dies, area of Display LCD screen, and the CO₂e intensities for these Parts).

Both companies did a qualitative evaluation of the data quality based on criteria listed in ETSI LCA Section 5.2.4 and found the quality “good” according to the Product Environmental Footprint guide (European Commission, 2012b).

OGE made a Data Quality Rating (DQR) according to Eq. 6

$$DQR = (Completeness\ score, C + Acquisition\ method\ score, AM + Data\ Representativeness\ score, DR + Data\ Age\ score, T + Geographical\ correlation\ score, GC + Technological\ correlation\ score, TC + (weakest\ quality\ obtained) \times 4) / (6 + 4) \quad (6)$$

Due to lack of time only IC data quality was estimated as $(1.4 + 1 + 1 + 2 + 3 + 2 + 4 \times 3) / (10) = 2.24$.

HuW estimated the overall data quality by Eq. 7:

$$DQR = (Methodological\ consistency, MC + C + Uncertainty, U + AM + Supplier\ Independence, SI + DR + T + GC + TC + Cut - off\ rules, RIE + (weakest\ quality\ obtained) \times 4) / (10 + 4) \quad (7)$$

$$= 1.75 + 1.5 + 2.75 + 2.25 + 2.25 + 2 + 2 + 2 + 2.25 + 1.25 + 2.75 (weakest\ quality\ obtained) \times 4 / (10 + 4) = 2.21.$$

Details can be found in Supplementary Materials Section 13.4.

5. Results

Below in Figures 3 and 4 we summarize the key results of the present paper.

GWP100 comparison of different LCA modelling

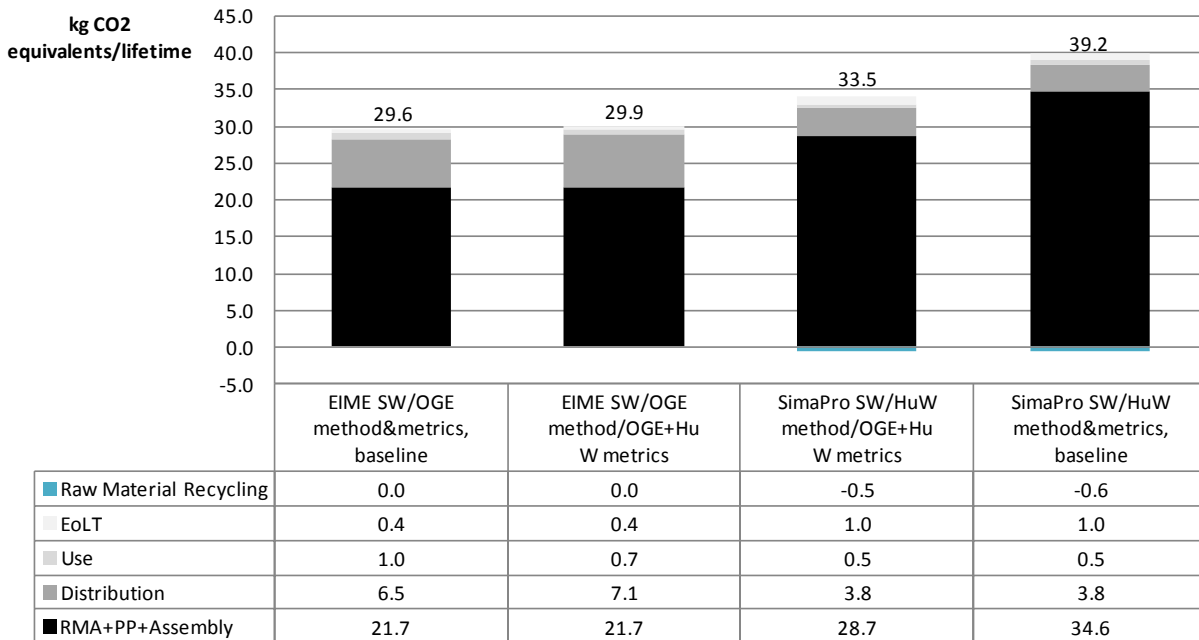


Figure 3. The effect of different LCA modeling approach on CC impact category.

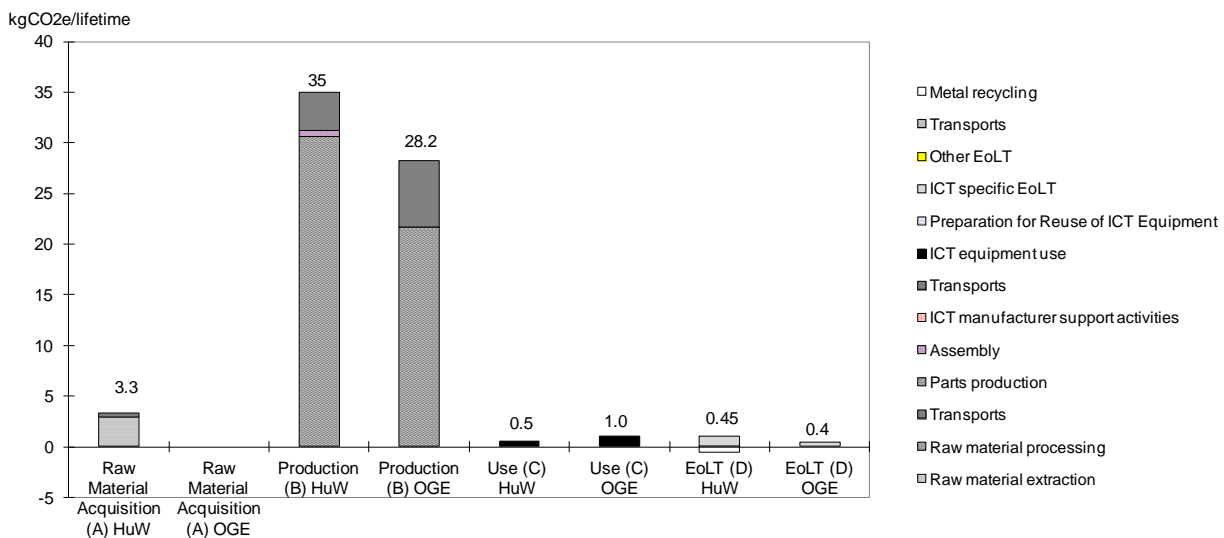


Figure 4. Partition of baseline HuW and OGE U8350 CC scores according to ETSI LCA Figure 10.

OGE's LCA method has a higher precision (mainly due to measurement of Part masses) than HuW's but both lead to the same conclusions for CC impact category. Different inventory databases could lead to diverse results because of vague system boundary definitions and incomplete data quality (Andrae and Andersen, 2010). However, as shown in Figure 4, thanks to the reporting requirements of the ETSI LCA, a clear understanding of the differences between LCA modeling approaches is obtained. For smartphone LCAs the differences between two different practitioners modeling choice are apparently not crucial for understanding the main drivers of CC.

6. Discussion

Different LCA approaches are allowed by the current LCA ICT standards that do lead to different absolute scores but hopefully not different conclusions for eco-design. As an example, an LCA standard will not normally prescribe which databases to use or which algorithms to employ. Therefore the ETSI LCA standard specifically denies comparisons of LCAs whose modeling choices and assumptions are not equal. A key question is thus, how consistent are the results derived from ETSI LCA requirements and can we occasionally justify a direct comparison?

This has to be judged case by case. In Table 5 the most important metrics used by OGE and HuW are shown. These can partly explain the CC score differences.

Table 5. Important metrics used by OGE and HuW for LCA of U8350

	EIME - SW/OGE method&metrics	EIME - SW/OGE method/OGE&HuW metrics	SimaPro - SW/HuW method/OGE&HuW metrics	SimaPro - W/HuW method&metrics
Si die area (cm²)	4.85	4.85	4.85	7.26
Au mass (mg)	119	119	119	123
Use electricity (kWh)	6.57	4.75	4.75	4.75
Total mass (g)	326	357	357	357
kg CO₂e	29.6	29.9	33.5	39.2

Table 1 shows that if OGE and HuW would have been able to obtain the same metrics values the differences induced by the LCA tools (allocation, databases, algorithms) would be significantly reduced. Rules for measurement and calculation defined in product category rules (PCR) can solve this problem and two different smartphone models from different companies could then theoretically be compared should they be technically comparable. Anyway, a clearly achievable improvement compared to the present situation is that the relative change within product groups such as smartphones can be measured more consistently and credibly. With a high likelihood the strictness of ETSI LCA indicates that PCR might be unnecessary for comparing smartphone LCAs.

6.1 Uncertainty analyses

The uncertainty analysis by OGE was made by estimation as EIME LCA tool incapable of uncertainty analysis, however, EIME claim that their modules have less than 20% uncertainty range.

Nonetheless, as OGE made numerous measurements for masses and areas of Si die and screens, the largest uncertainty is found in the intensity measures from the LCI database, e.g. kg CO₂e/cm² Si die area. However, EIME's LCI database is updated systematically so OGE estimated the 95% confidence interval to 23.7-35.5 kg CO₂e.

Table 6: HuW t-test of baseline LCA scores

		Coefficient of Variation %	
OGE U8350 basic CO₂e (kg)	29.6	0.1	20% 2σ
HuW U8350 basic CO₂e (kg)	39.2	0.178	35.6% 2σ
			-0.69243 = =LOG(29.6/39.2)/(SQRT(0.0866^2+0.153^2))
	t-test	0.49	0.692011 = TINV(0.49, 150)
σ ln x	0.0997	0.177	=SQRT(LN(0.1^2+1)), OGE
e(σ)	1.105	1.193	=e0.099751, OGE
(e(σ))^2	1.220	1.423	=1.10489, OGE

log10	0.086	0.153	=log10 (1.2208), OGE
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HuW used SimaPro uncertainty calculation which is based on Monte Carlo simulation resulting in a 95% confidence interval of 24.5-53.9 kg CO₂e.

Based on the above data HuW made a *t-test* (Andrae et al., 2008) in which here a high probability of mistakenly favoring one score before other is desired.

The *t-test* showed (Table 6) that it is a 49% probability that OGE baseline score 29.6 kg could be higher than HuW baseline score 39.2 kg and vice versa.

This means that the CC results for one study object, at least smartphones, modeled with two largely different and independent LCA modeling approaches are likely robust if both use ETSI LCA. Nevertheless, comparisons between ICT LCAs performed by different organizations were agreed to be beyond the scope of ETSI LCA, as such comparisons would require that the assumptions and context of each study are exactly equivalent. Here the context was the same whereas several assumptions were different.

6.2 Sensitivity analyses

OGE evaluated the robustness of the results based on sensitivity analysis including four parameters (*electricity consumption* in the Use stage, *area* of display LCD touch screen, *distance* of Air transportation and *area* of good Si dies).

A change of $\pm 1\%$ in the input values for these four drivers gives a change of $\pm 0.84\%$ for the outcomes. HuW sensitivity analysis is founded in cut-off analyses and changing of flows for lifetime, electricity mix and metal recovery (Figure 5).

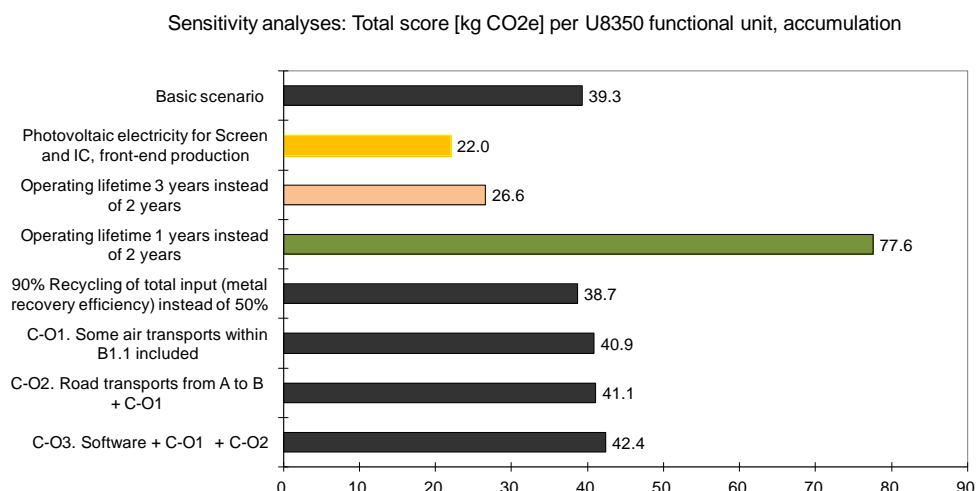


Figure 5: Results of HuW Sensitivity analyses

Moreover this research is associated with the Eco-Rating (ER) schemes proposed by telecom operators for mobile phones (Rice et al., 2012). The reason is that these schemes include a Basic LCA section in which several metrics based criteria are defined. Here two sensitivity checks were also made with OGE ER Basic LCA (Orange, 2013), and a linear model for RMA+PP+Assembly+Distribution using display screen mass, battery mass, and printed circuit board assembly (PCBA) mass as inputs (Teehan and Kandlikar, 2013).

For OGE ER 27.44 kg CO₂e was obtained using 7.26 cm² as Si die area (Supplementary Materials Section 15.3.1), and with Teehan/Kandlikar linear model $0.18 \times 100\text{g (mass PCBA)} + 0.3 \times 24\text{g (mass battery)} + 0.065 \times 28.3\text{g (mass display screen)} = 27.0\text{kg}$. The result for OGE's ER is not surprising as the carbon footprint indicator algorithms are based on the information of hundreds of mobile phone models. The simplified method from Teehan and Kandlikar for RMA+PP+Assembly+Distribution with 27.0 kg shows a good precision compared to OGE's full LCA value for RMA+PP+Assembly+Distribution, 28.2kg.

6.3 Potential for reduction of CO₂e emissions

The upstream and the display LCD screen is the most important Part and it has to be determined if it is the direct CO₂e emissions or the grid power which is the source of the problem. In 2012 research showed that NF₃ is a marginal contributor in LCD flat-screen manufacturing (Thomas et al., 2012). This suggests that production chemical related gases

contributing to global warming is not the main issue for screen production.

Then, if the main reason for CO₂e emissions in Display LCD screen production is global average electricity production (Table S27) and if it could be replaced by renewable electricity, the reduction potential for U8350 life cycle is 22%. As shown in Figure 5 another 21% is possible if also the global average power used in IC wafer fabs could also be replaced.

Actually the consequential LCA (CLCA) approach (Ekvall and Andrae, 2006; Andrae, 2009) is necessary for a more precise understanding of the reduction potentials. Here the main identified drivers for CC can be regarded as the processes which should be further analyzed with CLCA techniques.

Valkering compared five different OLED lighting technologies to LED and fluorescent lighting and showed that at the moment, OLED lighting has higher environmental impacts than the other technologies. This is explained by the dominance of the use phase in the life cycle impacts of all lighting technologies. In order to compete with current LED and fluorescent lighting, the luminous efficacy of the OLEDs should be comparable to those of the other lighting technologies. However, it is not straight-forward to translate Valkering's results to smartphone application. Anyway, the CO₂e emissions for the manufacturing and end-of-life of OLED foils were estimated to 0.6-1.2 gCO₂e/cm² (0.099-0.2 kg/Mega Lumen-hour) (Valkering, 2012). However, Valkering's scope was basically only the light emitting foil itself without electronics such as ICs with gallium arsenide/Si dies inside. According to OGE ER, mobile phone LCD manufacturing cradle-to-gate including these dies, emits around 480 gCO₂e/cm². Seen from a CC manufacturing point of view OLED screen technologies will likely be preferable to LCD if the OLED screen design requires fewer semiconductors than LCD or LED. OGE is currently investigating the issue of next screen technology eco-environmental impacts.

Distribution of U8350 by Ship ought to be more CO₂e efficient than air transport. OGE estimated from EIME that Ship transport emit 100 times less CO₂e per kg×km than Air transport opening an opportunity to reduce the total CC score by 22% (HuW 9%). The difference between OGE and HuW is due to LCI data used generating different CO₂e for Air transport.

6.4 Marginal electricity

Marginal electricity mixes can be used instead of average ones reflecting the difference in time and season when the present smartphone is charged. As shown in Tables 7 and 8 the marginal electricity in France is a mix of thermal power (≈56%) and renewable (≈44%) and can be estimated by electricity statistics (Andrae, 2013), in this case between 2008 and 2009.

Table 7: French electricity production sources 2008-2010 and 2020, TWh

Source of electricity	Gross generation (g.g.) in 2008 (Wikipedia, 2014)	G.g. in 2009 (IEA, 2009)	G.g. in 2010 (Global Energy Network Institute, GENI 2011)	Expected in 2020, (GENI, 2011)
Thermal, all			59.4	90
Thermal, Coal	27	28.7		
Thermal, Oil	6	6.17		
Thermal, Gas	22	21.0		
Nuclear	439	409.7	407.9	385
Hydro	68	61.9	68	79
Other renewables	12.9	14.5	15	96
TOTAL	575	542	550	650

Table 8: HuW estimation of French marginal electricity mixes 2009 and 2020

Source of electricity	Change 2008-2009 (TWh)	Applied mix	Expected change 2010-2020 (TWh)	Applied mix
Thermal, all	-		30.6	25%
Thermal, Coal	1.7	46.3%	-	-
Thermal, Oil	0.2	10.1%	-	-
Thermal, Gas	0	0%	-	-
Nuclear	0	0%	0%	0%
Hydro	0	0%	11	9%
Other renewables	1.6	43.6%	81	66%
TOTAL	3.7	100%	122.6	100%

The 2008-2009 French marginal mix, being some 0.6 kgCO₂e/kWh, is assumed to be used at night when demand is lower than at day.

The 2010-2020 French marginal mix is expected to be thermal ($\approx 25\%$), hydro ($\approx 9\%$), and other renewables ($\approx 66\%$) which would render around 0.3 kgCO₂e/kWh.

Therefore nighttime charging of smartphones with French marginal mix suggests higher use stage emissions than the average French electricity mix around 0.1 kgCO₂e/kWh dominated by nuclear. All in all however, also in France, the use stage electricity usage for smartphones will still be relatively small.

Moreover, the smart mobile devices are used in a larger context of wireless networks which in 2012 used around 10% of the annual ICT Sector electricity globally (appr. 1 100 TWh) whereas the smartphone RMA+PP+Assembly+Distribution (appr. 23 TWh) and charging (appr. 5 TWh) only used 2.5% (Corcoran and Andrae, 2013).

In this context the relation between the receiver sensitivity of the mobile phones and the radio base station power usage has been highlighted (Pedersen, 2013). Possibly this relation could be an extension of the mobile phone LCA or ER schemes.

7. Conclusions

In conclusion the attributional LCAs showed that the most significant activity in terms of the CC category impact is the *Production Stage* of the smartphone life-cycle. This is primarily due to the short life-cycle of smartphones and also the poor reparability of some models (Wiens & Corcoran 2013, 2014). Nevertheless, as the use stage is a rather small contributor for smartphones and tablets, and these to some degree are replacing PCs and TV sets having a larger impact from the use stage, the overall impact from consumer electronics is actually decreasing (Corcoran & Andrae, 2014).

Energy costs of the production stage are driven mainly by the area of screen and the amount of Si die area (good Si die area) used by the U8350.

As far as transports are concerned the CO₂e emissions are significant from a life cycle perspective. However, the consequential LCA approach needs to be applied to understand more about the actual reduction potentials.

Differences in smartphone LCA results arise mainly due to modeling choices. Secondary emission intensity data from upstream processes and LCA tools have a less significant effect.

Thanks to the reporting requirements of the ETSI LCA, a clear understanding of the differences between LCA modeling approaches is obtained. For smartphone LCAs the differences between two different practitioners modeling choices are apparently not crucial for understanding the main drivers of CC.

A linear simplistic model for the pre-use life cycle stages, using display screen mass, battery mass, and printed circuit board assembly (PCBA) mass as inputs, shows a good precision compared to OGE's full LCA value.

This research report shows clearly that the results of two different LCAs of smartphones are comparable if both LCAs used ETSI LCA and the study objects have comparable technical function and physical characteristics such as battery capacity, display screen size and type, memory capacity, and chipset. Whenever necessary, Product Category Rules based on ETSI LCA would definitely lead to comparable results for smartphones.

Nevertheless there is scope for improvement in some aspects of testing of how LCA standards are used in practice.

8. Looking ahead

The present research described in detail in this report has meticulously confirmed the basic CC footprint of smartphones confirmed by independent research methodologies implemented by researchers in two distinct organizations. HuW methodology has fulfilled all requirements of ETSI TS 103 199 but two, whereas OGE could not fulfill the requirements to this degree due to LCA tool limitations.

Note that less skilled LCA practitioners might not be able to choose intensity data carefully enough. As an example, consider the need to use an LCI data model for production of 1 m² of Si die. In EIME one LCA practitioner would choose “Wafer, from silicon; before dies slicing; France, FR” or “Wafer, from silicon; before dies slicing; China, CN”. In Simapro another would pickecoinvent’s “Wafer, fabricated, for integrated circuit, at plant/GLO”. The ratio between these EIME and Simapro LCI data is 1:2.4 and 1:5, respectively, and could therefore be significant for the whole smartphone LCA. It is evident that the LCA practitioner needs to possess the necessary skills to assess the data quality and representativeness and test it against the requirements of ETSI LCA.

The subjective choices made by an individual LCA analyst are seemingly unavoidable and it could be challenging to establish calculation rules for all situations.

This underlines the need for more public data sets for upstream processes such as those listed in Annex B of ETSI LCA (ETSI, 2011). The comparability and data issues aside, this report shows clearly that the ETSI LCA standard ensures a very high quality of electronics LCAs and will provide excellent studies/reports which are more useful to policy makers than previous attempts. Moreover, in 2014 ETSI and the International Telecommunication Union (ITU) fully aligned their LCA standards, ETSI ES 203 199 and ITU L.1410, in practice making the requirements of ETSI LCA globally applicable for any ICT device.

9. Acknowledgements

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Supplementary Materials Available

The supplementary materials contain extensive details about the LCAs.

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11. Supplementary material

This Supplementary Material shows details of the life cycle assessment (LCA) of U8350 performed separately but simultaneously by Orange (OGE) and Huawei Technologies (HuW). These details could not fit into the main article “Effect of modeling approach on climate change focused life cycle assessments for a contemporary smartphone device”.

12. Goal & Scope definition and setting the system boundary and functional unit

12.1 Goal

The goal of the study is to estimate indicators for Climate Change (CC) mid-point impact categories of a U8350 during its lifetime.

The purpose of the study is to find understand the effect of modeling approach on CC result.

The studied product system is one U8350 used in Wireless Networks.

Except the operation system software program, U8350 physically consists of general building blocks such as:

Phone Device, USB Cable, Charger, Head-set, Battery.

These building blocks can in turn be categorised according to Parts defined in Table B.1 in ETSI TS 103 199 (ETSI LCA).

Packaging materials, installation Guides and labels are also part of the studied product system.

12.2 Lifetime

The operating lifetime is estimated to be 2 years based on the studied type of *U8350*.

12.3 Functional unit

The applicable functional unit is 2 years of use of a U8350 smartphone in France charging the battery once from 0% to 100% every 24 hour. The reference flow is one U8350 smartphone with its packaging and accessories. All results below will therefore be expressed total lifetime use.

12.4 Studied Product System and Scope

Table 1 in ETSI TS 103 199 specifies the mandatory and optional life cycle stages/unit processes for ICT Equipment. Listed below are the life cycle stages included in this LCA.

A1

A2

B1.1

B1.2

C1

D2.1

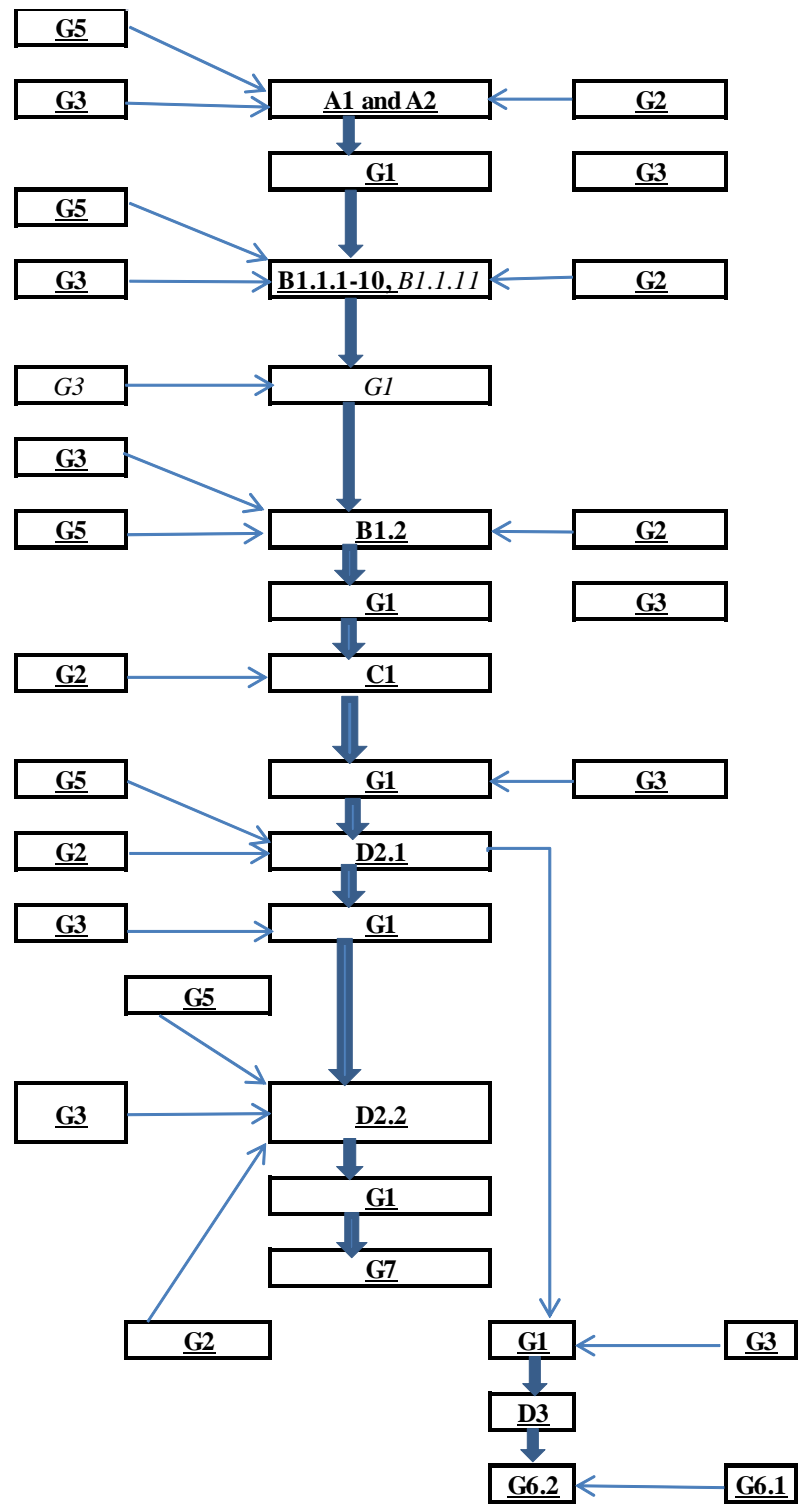
D2.2

D3

The activities B1.3, B2, C2-C4, B.3, and D1, are left out as not part of the studied product system.

Support activities including B1.3 are not considered for any unit processes because of lack of data and models. These will be included when the models are developed further. The geographical and temporal coordinates vary dynamically for the Raw Material Acquisition and Production of the ICT Equipment. The presented results for Raw Material Acquisition and Production will therefore represent a global average for the U8350.

Figure S1 below shows a product system flowchart showing where the generic re-occurring processes are used. Boxes in which the text is marked **underlined and bold** type style **are modeled** whereas boxes marked with *italic style are cut-off*. These *italic* processes are within the studied product system but are cut-off. E.g. the transports G1 from B.1 and the fuel productions for these transports, G3, are cut-off but tested in sensitivity analyses (See Figure S13 Below).



**Figure S1: The system boundary of the product system for HuW LCA of
U8350 showing connections with generic processes**

Figure S2 shows OGE's view of the U8350 product system at hand.

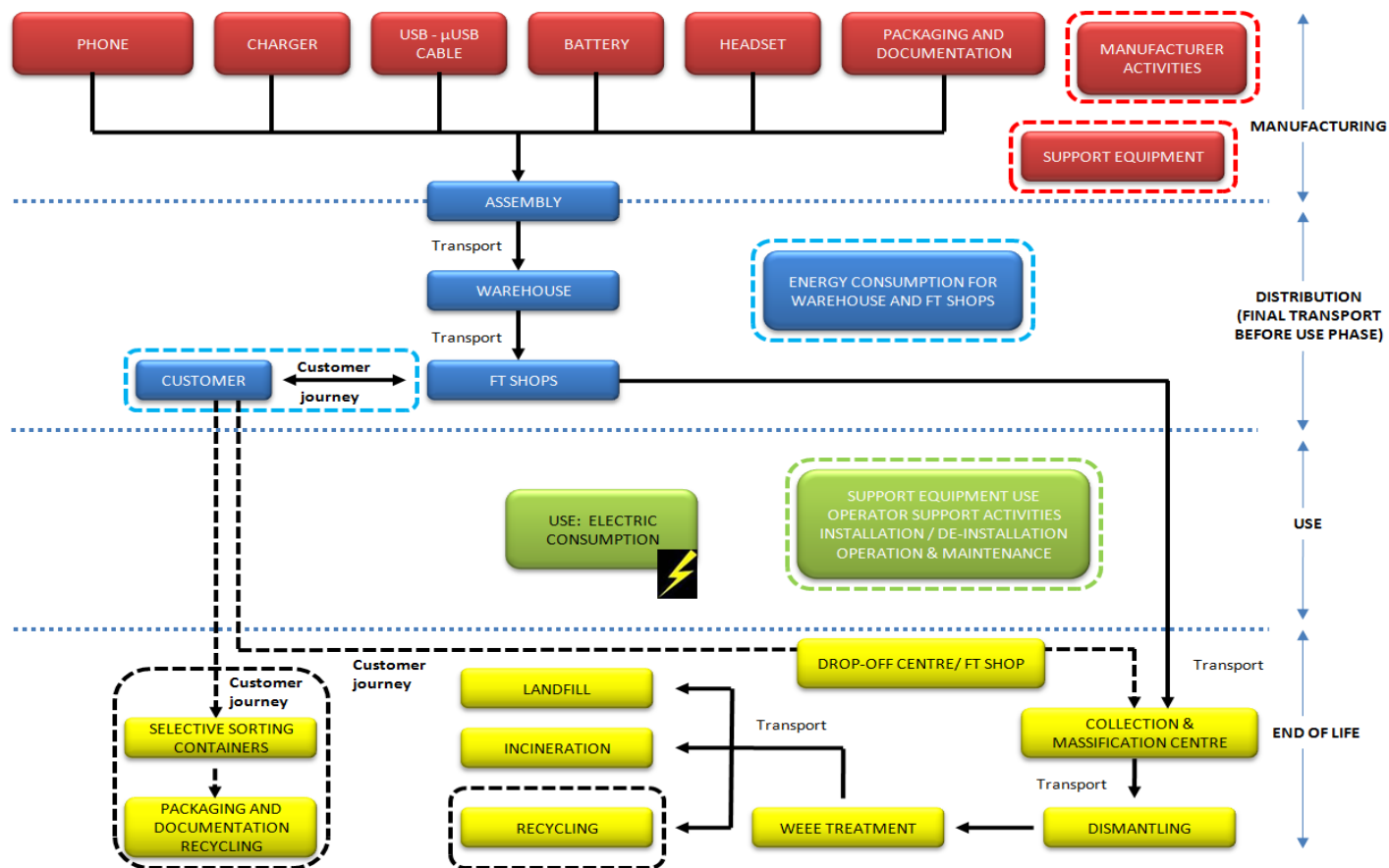


Figure S2: OGE cradle-to-grave approach for U8350 LCA

13. Life Cycle Inventory

13.1 Data collection

13.1.1 OGE (Orange) Equipment Raw material acquisition

In EIME 5.0 software Raw material acquisition and Production are linked and it is not possible to show separate results for Raw material acquisition (A).

For raw material extraction (A1) and raw material processing (A2) databases contained within the LCA tool/LCI databases were used representing a mix of primary and secondary content for world production. The transports occurring in raw material acquisition are modeled inside these LCI data.'

For example, "Steel cold rolled; without surface treatment; 47% recycled ; GLO" module in EIME was used for parts made with un-alloyed steel sheets. Table S1 shows OGE quality types for the data collected.

13.1.2 OGE Production

Table S1: OGE application of Table 2 in ETSI TS 103 199

Tag	Life cycle stage		Unit process	Type of data
				Equipment
A	Equipment Raw Material Acquisition			
A1		Raw material extraction		Generic data
A2		Raw material processing		Generic data
B	Production			
B1	ICT equipment production			
B1.1			Parts production	Specific data
B1.2			Assembly	Specific data
C	Use			
C1		ICT equipment use		Specific data
D	Equipment End of Life Treatment			
D1		FFF Re-use		Specific data
D2		ICT specific EoLT		Specific data
D2.1			Storage/Disassembly/Dismantling/Shredding	Specific data
D2.2			Recycling	Specific data
D3		Other EoLT		Generic data

The primary specific data, which constitutes most of the inventory, were gathered at the OGE Labs Grenoble laboratory or from manufacturers. On one hand LCI data is specific because, for example, for integrated circuits the most accurate package were identified and matched with the corresponding package in the EIME database. The components were also weighed and the Si die areas specified.

On the other hand the data for air and water emissions were not collected in the factory which manufactured the specific integrated circuits. This data is secondary ICT specific and according to the ETSI TS 103 199 definition specific.

For the secondary specific data from EIME, the requirements are those established by CODDE Bureau Veritas. Geographical areas, date of creation as well as the source of the 10 most impacting modules in this study are listed in the Table S2 below.

Table S2: The 10 most impacting processes for CC in OGE LCA

The 10 most impacting models for Global Warning	Source	Year	Geographic zone
Capacitive LCD touch screen display, CN	CODDE study based on literature data and on 1 Asian manufacturer	2011	CN
ELCD - Plane transport; cargo; 68 t capacity; RER	ELCD	2005	RER
Silicon wafer, without package; ; FR	CODDE study - SITELESC (5 manufacturers)	2007	FR
ELCD - Electricity Mix; 230V; France, FR	ELCD	2002	FR
Li-ions battery; RER	Ecobilan study	1997	RER
Polycarbonate (PC); molded by injection; RER	Boustead ; plastics Europe	2005	RER
Low profile fine pitch ball grid array packages semiconductor, LFBGA; FR	CODDE study - SITELESC (5 manufacturers)	2007	FR
PWB, FRx preg, x layers; RER	CODDE study - GIXEL (3 manufacturers)	2006	RER
Waste incineration of WEEE; after dismantling; GLO	CODDE study from Ecoinvent and DEAM	2005	GLO
Very thin fine pitch quad flat, VFQFPN; FR	CODDE study - SITELESC (5 manufacturers)	2007	FR

CN = China, RER = Europe, FR = France, GLO = Global.

13.1.3 OGE Materials and parts

Plastics

The international standard ISO 11469: 2000 stipulates a labeling system for plastic parts whose weight is greater than 25g. This system means that most heavy parts can be identified directly; PC casing is the best example. The labeling allows only identification of the basic polymer. It does not give any information on the fillers, plasticizers or the additives used.

Small plastic parts, such as the loudspeaker plastic casing, for example, are not always labeled. Tests have been carried out in order to identify these materials as accurately as possible:

- **Densitometry test.** First of all it is used for separating PE and PP components¹, which float in water, from other thermoplastics. It can also assess the density of a material. To do this, a sample is weighed using precision scales of the laboratory and then placed in a graduated test tube to determine its volume. Despite

¹ Polyethylene and polypropylene

using an analytical balance accurate to the milligram and a graduated test tube at 0.2ml, this method introduces a non-negligible margin of measurement error. In addition, the obtained density is compared with the pure polymer density (for example 1.2 for PC). The presence of fillers, unknown densities, introduces a wide margin of error.

- **Flame test:** various tables are available to identify a plastic material depending on the color of the flame, odor and fumes as well as the speed of burning. The table produced by Vishu Shah in 2008 was used for this study.

In addition to these tests, manufacturers (such as Molex for connectors) were also contacted directly to obtain information about the used materials. Through Materials Declarations / Material Declaration Sheets such as IPC-1752 were used in this correspondence.

Metals

Metals can also be difficult to identify because of the many existing alloys. Unlike plastics, they are not labeled, which complicates the process.

Identification was carried out using tests such as magnetization, color or presence of surface treatment. Density measurements, carried out by dividing the mass of a sample by its estimated volume, were used to identify light alloys such as aluminum (density ≈ 2.7) from steel (density ≈ 7.8). The technical documentation for certain specific parts, such as electromagnetic shielding elements, also provide interesting information. Indeed, these parts are frequently designed in tinned steel (or tin-plate) or stainless steel.

Manufacturer feedback was also used to identify these parts.

Electronics

Passive components

These components are classified, first of all, by function. Overall, they are divided into six categories, resistors, capacitors, inductors, filters, quartz and Small light emitting diodes LED). LED for backlight are also considered in this category, even if they are actually active components. Visual identification requires a certain experience, yet can rapidly classify the components. Figure S3 shows a ceramic capacitor on the left and a resistor on the right.

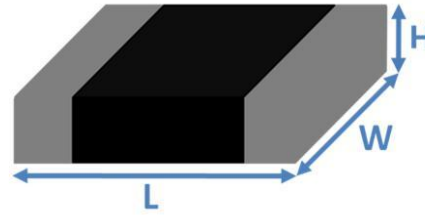


Figure S3: Detail of passive components (Source: Orange Labs)

Passive components are also classified in accordance with their dimensions, using standards. For resistors or ceramic capacitors, such as those shown above, the IPC-7351B standard is applied. This standard classifies the components according to a 4- or 5-number code. The length of the component, converted to tenths of an inch, gives the first two numbers of the code, and its width the remaining numbers. Thus a 1206 component, such as the one shown in Figure S5 and Table S3, has a length of 0.126 inches and a width of 0.063 inches, that is 3.2 x 1.6mm.

TableS3: Dimensions of passive components (Source: Samuli Vaija, OGE)

Case size	L : length (mm)	W : width (mm)	H : height (mm)
1005	0.40	0.20	0.13
201	0.60	0.30	0.23
402	1.00	0.50	0.35
603	1.60	0.80	0.45
805	2.00	1.25	0.60
1206	3.20	1.60	0.60
1210	3.20	2.50	0.60
1812	4.50	3.20	0.60
2010	5.00	2.50	0.60
2512	6.40	3.20	0.60



The impact of these components was noted as not significant in the various studies previously conducted. (Nokia, 2005 ; Janin, 2008). Moreover, the composition of these elements appears relatively homogeneous among the different manufacturers. Therefore, it is unnecessary to look for the manufacturer for each component.

Active components

This category mainly includes the integrated circuits, transistors and diodes. Life cycle analyses of mobile phones tend to show that these components have a high impact. Therefore they must be studied in minute detail within the framework of this analysis.

The identification of these components begins with a distinction of the three above-mentioned categories. Transistors and diodes have specified dimensions in IPC-7351B (SOT cases for transistors and SOD cases for diodes). These components are easily identified by their number of connections and their specific shape.

Data collection for integrated circuits is much more complex. First of all, there are a many different types of cases currently on the market, and their architecture directly influences the impacts of the component. Figure S4 provides an overview of the development of the case types. Certain case types appeared in the 80s, such as SOPs, and are still used in current electronic cards. The range of existing cases is thus extremely wide.

For these components, visual identification firstly enables four major families of integrated circuits to be created:

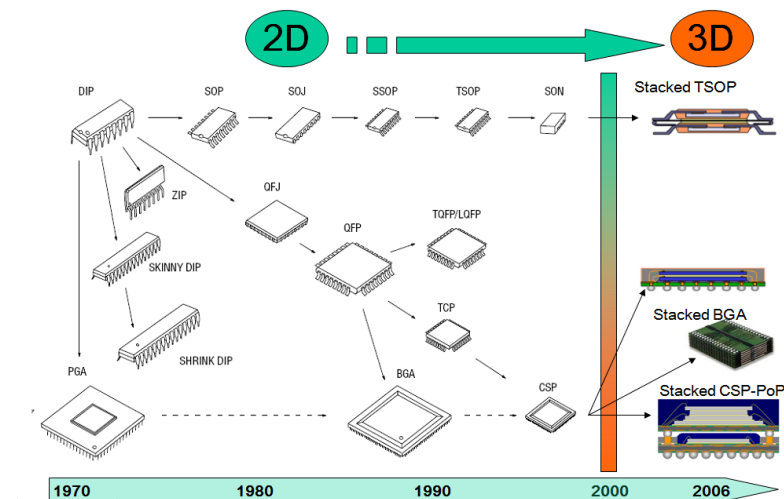


Figure S4: Development of case types (Source: Orange Labs)

The first family incorporates all the integrated circuits with SOP cases type ("Small Outline Package") shown in Figure S5a.

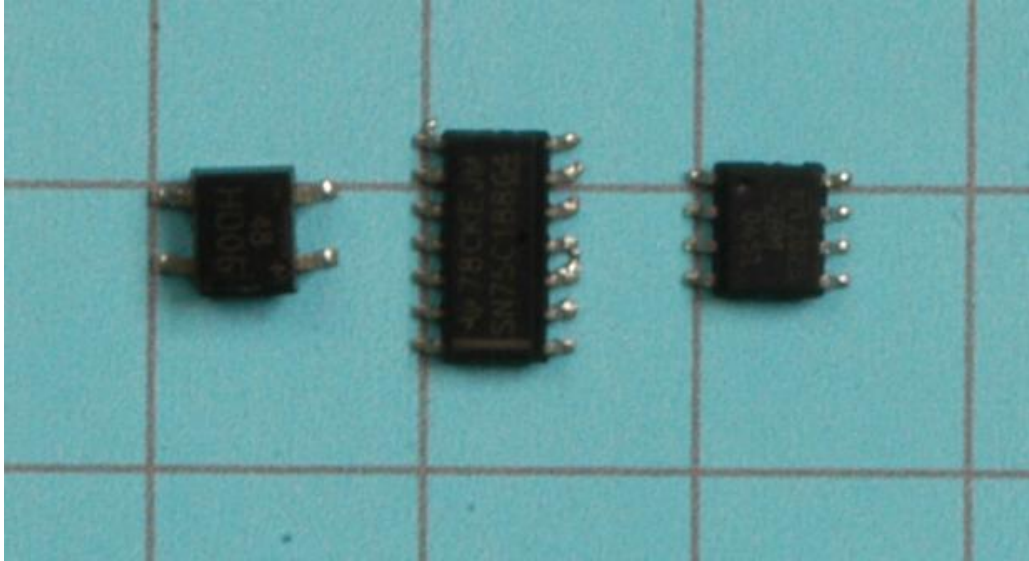


Figure S5a: SOP case

These cases feature connection pins that extend significantly from the epoxy case template. The SOP type includes several subcategories (SSOP, TSOP, TSSOP, etc.) in accordance with the shape and size of the case or the spacing between two pins.

The second family incorporates all the components for which the case is of the BGA type ("Ball Grid Array") shown in Figure S5b.

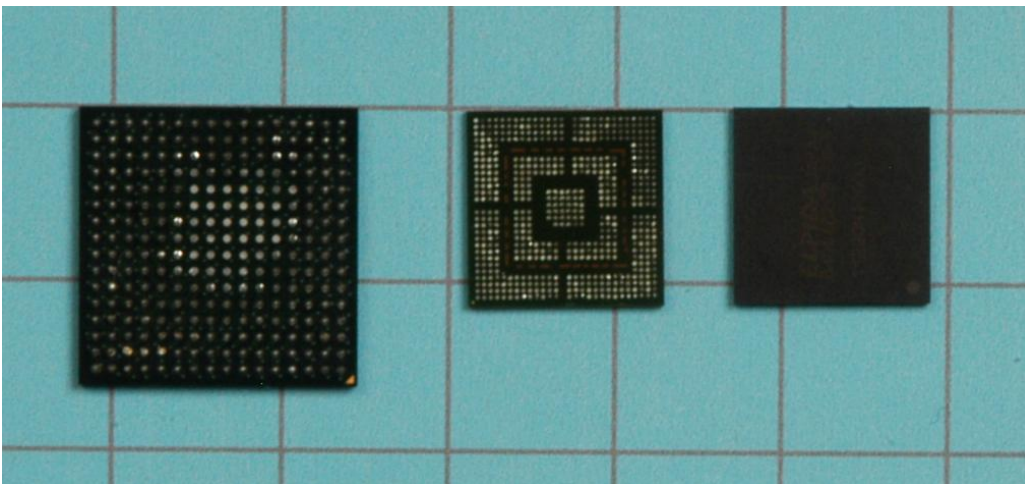


Figure S5b: BGA case

These cases are recognizable by the fact that they are assembled on a grid of balls, which serve as connection points. The name varies depending on the material from which the box is made: PBGA for a plastic case or a CBGA for a ceramic case. The height of the case, as well as the spacing between the ball grids are also factors taken into account in the name (e.g. TBGA, or "Thin Ball Grid Array", for a thinner case).

The third family includes all the integrated circuits of the QFP type ("Quad Flat Pack") shown in Figure S5c. These packaging's have short connection pins on all four sides. Like the BGAs, there are variants (TQFP, or "Thin Quad Flat Pack No Leads" for a thinner QFP).

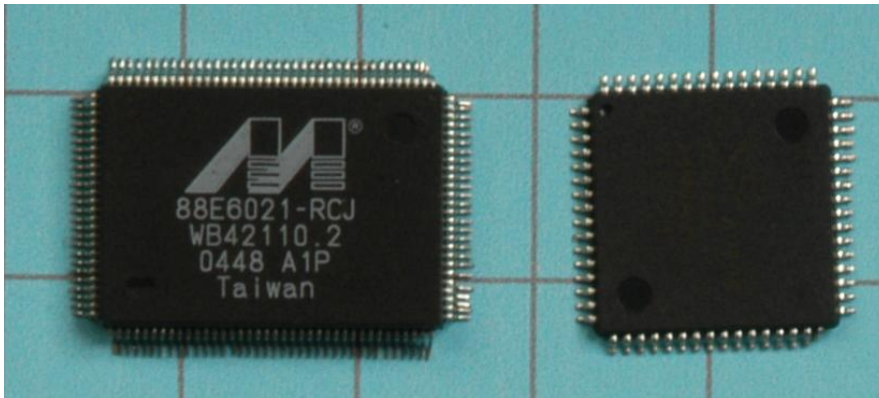


Figure S5c: QFP case

The fourth family (see Figure S5d) includes "Flip Chip" component.

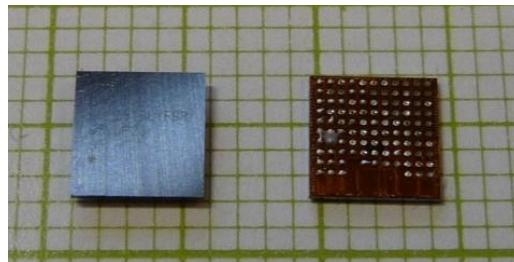


Figure S5d: Flip Chip case

Source for Figure S5a-d: OGE Labs

The silicon (Si) chips of these integrated circuits are not encapsulated. The back face of the Si chip, which is turned over (hence the name "Flip Chip"), gives a metallic aspect to these circuits. Like the other families, variants exist (WL-CSP, or "Wafer Level - Chip Scale Package", for a thinner Flip Chip).

For all these families, the dimensions of the case are used for identification purposes. On QFP or SOP integrated circuits, the number of connections also provides additional information.

Finally, the manufacturer labeling can be used to find, the exact reference of a component relatively quickly.

Figure S6 below gives an example of manufacturer labeling. This component is marked "Texas Instruments" and the manufacturer name is clearly readable. Labeling is not present on all components and it does not systematically correspond to the manufacturer name.



Figure S6: Manufacturer labeling (Source: Orange Labs)

For each integrated circuit with more than 12 connections (balls, pins...) good Si die area was identified. Technical and economic analyses were used to assess the good Si area according to each integrated circuit specific part number.

Miscellaneous components

This category generally includes the connectors and complex parts such as microphones or loudspeakers. Connectors are used either to link accessories (e.g. headphone) or to link the mobile phone to the power supply. These connectors have been modeled according to Materials Declarations retrieved from several manufacturers such as Molex or TE Connectivity. Microphones and loudspeakers have been modeled by a similar approach.

Printed circuits boards

Printed circuit boards, rigid and flexible, are detailed in this category. For each rigid printed circuit board, it is necessary to determine the number of conductive copper layers. The main printed circuit of the handset is considered as being of FR-4 type². Indeed, this is the most common type in this scope. That of the charger is of the CEM-1 type. This less expensive type is sufficient to manage electronics simpler than the charger.

The LCD and touch-screen are connected to the electronic card via flexible printed circuit. Unlike rigid printed circuits, it is not possible to determine the number of copper layers of the studied element. For this reason, it is considered that the number of copper layers equals 2, which corresponds to the flexible module dedicated in EIME.

Soldering

The electronic components are fixed on the printed circuits by a soldering process. Soldering is an assembly process that establishes a metallic continuity between connected parts. There are 2 types of soldering:

Reflow soldering: used to fix the surface mount components assembled (SMC) onto the printed circuits.

Wave soldering: used for mixed components to be fixed on the printed circuit: SMC and through-holes

Results modeling analysis of the reflow soldering technique showed an overestimation of paste weight to be soldered per soldering point. Corrections were made as this over-valuation impacted on the silver and tin weights.

Cables

USB - micro USB cable was modeled according to Materials Declarations retrieved from manufacturers such as ATTEND Technology Inc.

Packaging

The primary packaging consists of a duplex/triplex cardboard box and plastic bags.

² The FR-4, or Flame Resistant 4 is a composite of epoxy resin reinforced with glass-fibre.

13.1.4 OGE Use stage

Use phase energy consumption (electricity) was measured by OGE in its laboratory (primary data) uncertainty +/- 1% Software Labview and National Instruments for the capture card. A complete charge of the battery 0 to 100% measured at the mains.

A French average energy mix (electricity) for low voltage was applied as the U8350 was operating on a French market and the purpose of the study was to estimate impact share in French Networks.

13.1.5 OGE End-of-life carbon footprint used by Orange with EIME

At the end of its life the U8350 follows the European WEEE directive. (European Commission, 2012).

For end-of-life, data was based on EIME database for specific EoLT for Storage / Disassembly / Dismantling / Shredding and Recycling.

The EoLT is assumed to be done in France and a French average energy mix (electricity) for high voltage was applied.

► Primary data

Masses of Device, battery and charger.

► Semi-specific data: End-of-life scenario

The End-of-life scenario is based on the assumption that the consumer brings back the mobile phone to an OGE store.

Once a mobile phone is taken back to an OGE store by the consumer, the following average scenario is considered to estimate the End-of-life impacts

Mobile phones are shipped to the “Ateliers du Bocage”, where some of them are repaired and sold on second-hand markets. This second hand market is considered out of the scope of the evaluation, only those devices that are dismantled and sent to material or energy recovery are considered. Once the devices are dismantled, there are three main destinations:

- The devices (without their batteries) are incinerated at UMICORE in Belgium (where precious metals are recovered)

- Batteries are treated separately in France.

- Chargers, cables and accessories are treated together in France

Benefits from recycling or energy recovery are not accounted for in this scenario (Figure S7), which only takes into account direct impact from transportation and treatment processes.

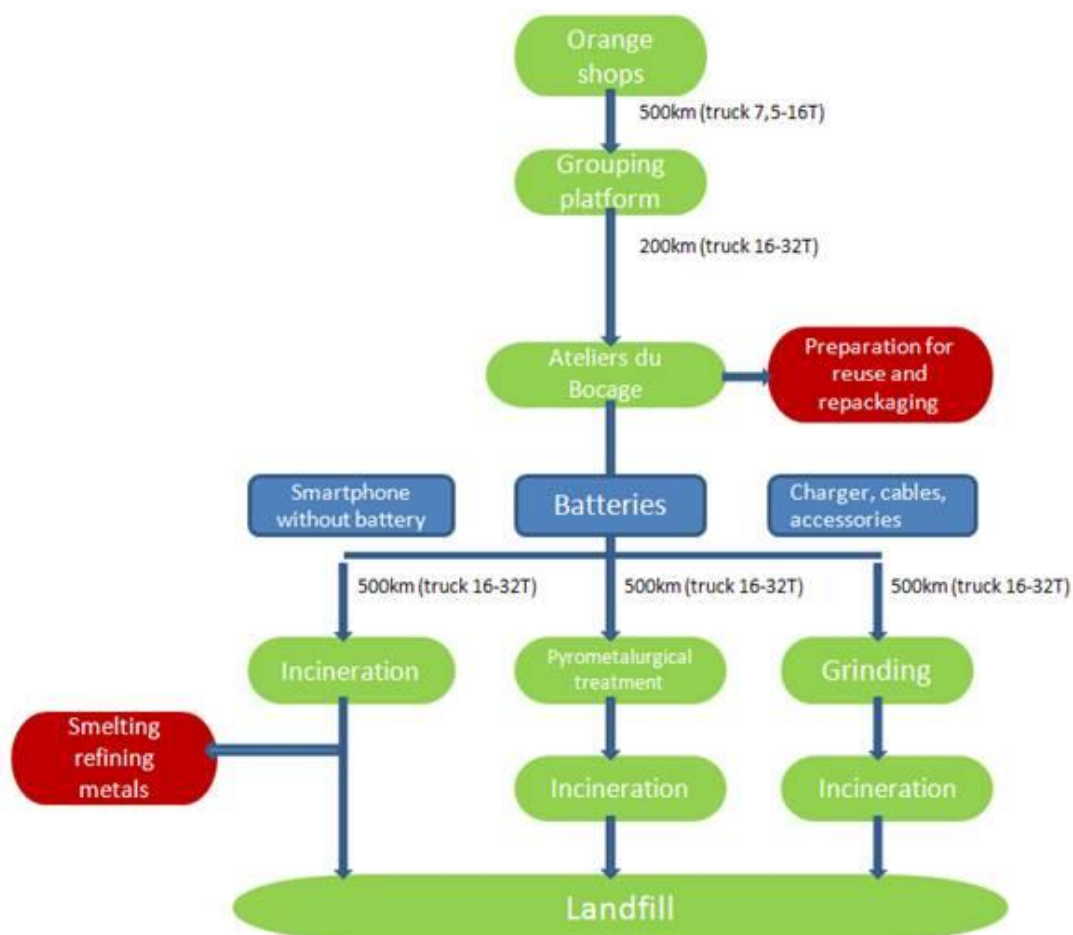


Figure S7: OGE End of life scenario

The data used by OGE for the scenario depicted in Figure S7 is shown in Table S4.

Table S4: OGE Secondary data used for end of life

Data	Value	Source	Year
Lorry transport; for freight transport; 7,5-16t; RER	0.11835 g CO ₂ eq. per kg.km	CODDE Study form Ecoinvent and DEAM	2005
ELCD - Lorry Transport; articulated lorry, 27t capacity; RER	0.04989 g CO ₂ eq. per kg.km	ELCD	2005
Waste pretreatment of WEEE; including dismantling and material separation; GLO	38.651 g CO ₂ eq per kg	CODDE Study form Ecoinvent and DEAM	2005
Waste treatment of Lithium-ion battery; by pyrometallurgy; RER	278.19 g CO ₂ eq per kg	CODDE Study form Ecoinvent and DEAM	2004
Waste treatment of Cable; GLO	884.1 g CO ₂ eq per kg	CODDE Study form Ecoinvent and DEAM	2005
Waste treatment of Printed Wiring Board (PWB); GLO	80.23 g CO ₂ eq per kg	CODDE Study form Ecoinvent and DEAM	2005
Waste incineration of WEEE; after dismantling; GLO	3024.7 g CO ₂ eq per kg	CODDE Study form Ecoinvent and DEAM	2005
ELCD - Waste incineration of paper fraction in municipal solid waste (MSW); without energy recovery; EU-27	36.332 g CO ₂ eq per kg	ELCD	2006
ELCD - Waste incineration of plastics (PE, PP, PS, PB); without energy recovery; EU-27	3262.2 g CO ₂ eq per kg	ELCD	2006
Landfill of WEEE; after dismantling; GLO	2.848 g CO ₂ eq per kg	CODDE Study form Ecoinvent and DEAM	2005
ELCD - Waste incineration of municipal solid waste (MSW); without energy recovery; EU-27	365.53 g CO ₂ eq per kg	ELCD	2006

13.1.6 OGE Distribution Transport

Transport of U8350 to Use stage was modeled based on assumptions of share of Air, Truck and Van Transports. Air China Cargo operates from three different airports (Beijing Capital Airport; Hangzhou Xiaoshan Airport and Tianjin Binhai International Airport). The smartphone is sent to the French airport Charles de Gaulle, near Paris. The distance by plane is around 8 185 km from Beijing Capital Airport; 9 252 km from Hangzhou Xiaoshan Airport and 8 297 km from Tianjin Binhai International Airport.

13.1.7 HuW Raw Material Acquisition

For raw material extraction and raw material processing databases contained within the LCA tool/LCI databases are used.

13.1.8 HuW Part Production

For unit processes within B1.1 data are mainly collected from literature reflecting a global average supply chain but also samples from own suppliers of ICs and PCBs.

For B1.2 Assembly data are collected as annual consumption data from the U8350 assembly plant.

For data collection from suppliers clause 5.2.2.1.1 in ETSI TS 103 199 is considered as well as the Annexes A to G.

For manufacturing process share (e.g. electricity used per Part unit processes) of the impact of applicable

Parts B1.1.1-10 data are reused from a previous Huawei LCA case studies.

B1.1.9 Packaging materials are modeled per piece and mass/piece.

B1.1.10 Black box modules are modeled per piece based on estimation of mass/pieces of sub-Parts inside the black boxes.

B1.1.11 Software is based on annual data collected internally.

For material content share of the impact, primary data are collected. E.g. amount of steel for a certain part.

Whenever B1.3 is included in the studied product system, data are collected as annual data for applicable offices.

13.1.9 HuW Use

Use phase energy consumption (electricity) is usually measured by the operator as the annual average consumption.

More common as starting point for LCA is measurements of the actual power usage.

Global average energy mixes (electricity) are applied as the product is operating on a Global market and the purpose of LCA case studies is commonly to find design improvements. The electricity footprint is always estimated for all life cycle stages in order to understand the impact in different regions.

13.1.10 HuW End-of-life treatment

For end-of-life data are based on assumptions and literature on global average ICT specific EoLT for Storage/Disassembly/Dismantling/Shredding and Recycling.

For data collection for generic processes the databases which came with the LCA tool/LCI database are used.

13.1.11 HuW Transport

For Raw Material Acquisition no transparent data on transports are available, thus impacts from these transports are embedded (if included) and cannot be reported separately.

Transport of U8350 to Use stage is modeled based on assumptions of share of Rail, Air, Truck and Ship Transports.

13.2 Data calculation

OGE carried out a complete reverse engineering process, therefore data acquisition for parts such as connectors or good Si die area can be considered highly accurate. On the other hand OGE was not able to estimate B1.2 assembly steps in such detail.

13.2.1 OGE B1.1.1 Batteries

Orange value is expressed as the total of A (all raw materials for Li-ion battery) + B (production) for Lithium batteries.

13.2.2 OGE B1.1.2 Cables

Orange disassembles the USB – micro USB cable and identifies the different materials according to expert knowledge and manufacturers Materials Declarations. Assembly processes, such as copper wire core stranding or PVC sheath extrusion, are also taken into account.

13.2.3 OGE B1.1.4 ICs

The package types (e.g., FBGA-676) for each IC, transistor and diode inside the U8350 Phone device including Screen and Charger were identified.

The mass of each package type was measured.

For each integrated circuit with more than 12 connections (balls, pins...) the good Si die area was identified. Technical and economic analyses were used to assess the good Si die area according to each integrated circuit specific part number, when not possible the packaging is dissolved in acid and the the good Si die area measured. This is especially true for stacked circuits or multichip modules.

EIME 5.0 specific integrated circuits models (LFBGA, VFQFPN...) are used and wafer area is added to match with real good die area.

13.2.4 OGE B1.1.5 Mechanics / Materials

Orange classifies in ETSI B1.1.5 all Raw Materials which are not part of other subsets (e.g. copper is included in B1.1.10 so it is not included in B1.1.5). All Raw Materials are identified as well as shaping or surface finishing.

13.2.5 OGE B1.1.6 Displays

LCD TFT model and a specific mobile phone touch-screen model (developed by Orange and CODDE) are used.

13.2.6 OGE B1.1.7 PCBs

Orange identifies each rigid board area and amount of layers. Boards are considered as FR-4 grade. According to grade and amount of layers a specific model is chosen in EIME database. Surface finishing processes, such as HASL or ENIG, are also considered by Orange. For flexible boards, Orange uses a specific 2-layers model developed in collaboration with CODDE.

13.2.7 OGE B1.1.8 Other PCBA Components (Parts)

This category consists of passive components (Parts). Parts are classified by functionality (resistor, capacitor...) and size (0402, 0603...). Mass or area of each component functionality/size set is established according to manufacturer datasheets. For example, a 0402 resistor mass is equal to 0.8 mg and a 0603 ceramic capacitor area is equal to 1.28 mm². Four different LCI dataset are used according to each feature of the Part.

13.2.8 OGE B1.1.9 Packaging materials

Packaging boxes consist mainly of Cardboard. Orange identifies all material (for ex. duplex-triplex type cardboard for external packaging) and inking/varnishing process.

For each secondary packaging allocated impacts per smart phone are not significant for CC and ED. Therefore secondary packaging was considered as cut-off.

13.2.9 OGE B1.1.10 Black box modules

Orange considers connectors and charger as black-boxes (see B1.1.10). For each connector type a specific model has been design, according to identified material and assembly processes.

13.2.10 OGE B1.1.11 Software

Due to lack of data software is a cut-off.

13.2.11 OGE B1.2 Assembly

Orange did not have access to direct assembly line data, further assembly process are taken into account:

- PWB (Soldering, Reflow SnAgCu)
- PWB (Soldering, Wave SnAgCu)
- PWB (Gluing of Surface Mounted Devices)

13.2.12 OGE G1 transport and travel

For this step the ETSI standard requires explaining of transports allocation. In other words whether the allocation is based on chargeable weight or volume, whichever limits the transport capacity.

In order to assess the limiting factor OGE carried out estimations with the load calculator tool available on Sea-rates website. (Sea-rate, 2013).

The procedure for a transport step with a 40 t (gross vehicle weight rating) truck is detailed below:

First two operations are meant to select container type (container or truck) and cargo type (boxes, bigbags, barrels or sacks). For this example we chose a truck and boxes.

Cargo parameters are determined in step three.

Pallets parameters are set in step four. For this example maximum loading height is limited to 1150 mm, in order to be able to fill the truck with to two levels of pallets.

Truck characteristics are specified in step five. For this example we gathered information from trailer manufacturers (e.g. Schmitz Cargobull) and tractor unit manufacturers (e.g. Renault), in order to create a model of 40 t semi-trailer.

Spacing settings of cargo in container are determined in step six. For this example we chose to maximize the loading capacity, therefore all loading positions are accepted.

Final loading for 9999 units of U8350 smartphones is detailed below. The maximum amount of cargos is 9999 and unfortunately it was not enough to fill the trailer.

Therefore we had to assess loading rates with pallets. According to the software it is possible to load up to 895 U8350 smartphones on a EUR-pallet.

Thus a fully loaded U8350 pallet weighs:

$$0.326 \times 895 + 25 \text{ kg (approximate EUR-pallet weight)} + 0.250 \text{ kg (approximate LLDPE wrap film weight)} = 317.02 \text{ kg}$$

It is possible to put up to 66 EUR-pallets in this type of truck. Therefore a full load weights:

$$317.02 \times 66 = 20\,923 \text{ kg.}$$

Our truck maximum capacity is 24 400 kg. Therefore weight loading rate is equal to:

$$20\,923 / 24\,400 = 85.75 \%$$

This loading rate, 85.75%, was used in EIME software for transport steps.

Similar calculations were carried out other means of transports, such as delivery service van (truck with a gross vehicle weight rating inferior to 3.5 t).

13.2.13 OGE Secondary packaging

Orange did not include any modeling of the impact of the secondary packaging. Instead HuW numbers were used when studying the effect of using same metrics.

Orange carries out estimations for secondary packaging: EUR pallet, Unit load device for plane transport, LLDPE stretch wrap.

For each secondary packaging allocated impacts per smart phone are non significant for Global Warming Potential and Energy Depletion.

13.2.14 OGE Energy consumption for warehouses and shops

Orange carries out energy consumption estimations for warehouses and shops. Energy consumption impact, assessed with an average warehouse consumption value, was allocated according to smart phone packaging area. For shops, a WWF report on Orange shops energy consumptions was used. For both, storage impacts per smart phone are non significant.

13.2.15 OGE Transports between B1.2 and C1 location (France)

For first transport step, from assembly plant to airport, Orange used distance provided by Huawei. As Orange warehouse in France is located near Paris, Roissy Charles-de-Gaulle was selected as plane destination. Orange assumed that the mobile phone is transported by Air China cargo from one of the 3 airline cargo terminal in China: Beijing, Hangzhou or Tianjin. From warehouse to shop Orange used internal data from previous life cycle assessments.

13.2.16 OGE End of life D1D3

Due to LCA tool limitations Orange is bound to use the 100/0 allocation method for Raw Material Acquisition with recycled content ratios for each Raw Material fixed by the EIME 5.0 LCA tool. No Raw Material Recycling discount is therefore included in the calculation model.

Moreover the EIME 5.0 LCA tool is not able to handle metal, paper, cardboard or plastic recycling.

13.2.17 Examples of HuW data calculations

For ICs the mass of each IC, transistor, and diode package is estimated and summed. One package type based LCI data set (e.g. BGA packages) is applied to the total mass of the IC, transistor, and diode packages.

The mass and type of each Si die is identified. From the mass of Si and type of die, the good die area in the U8350 is estimated. One Si area based LCI data set is applied to this good die area. See Table S29 below.

For PCBs the area and number of layers for each PCB piece are identified. LCI data expressed per area of a specific type of PCB (e.g. 6-layer PCB) is used for each PCB.

For Other PCBA Components the process environmental data per mass are estimated from databases. Mass based LCI modules are created for a set of Parts in this group. The mass and material content of each Part is identified. The mass based LCI modules are applied to appropriate Parts.

For the *U8350* packaging materials consisting mainly of cardboard with mass 0.132 kg is used.

Software development is modeled as a Part of which the *U8350* is made. A simplified estimation/calculation is enough which uses the number of programmers involved in software development per year, the number of hours annual work per programmer, salary in USD per programmer per hour, the output of CO₂ per USD estimated by an EIO-LCA tool, and the number of *U8350s* supported by the annually produced software. These metrics give the CO₂ emissions, water, energy, land use for B1.1.11 software per *U8350*. Results obtained with EIO-LCA databases and tools are sometimes of large variance. The output of CO₂ per USD 541511 (Custom computer programming services) is 0.183 kg CO₂ (EIOLCA, 2013).

For 1 USD of R&D with USA Input-Output database 0.304 kg eq. CO₂ and for 1 USD of R&D with NL Input-Output database 0.699 kg eq. CO₂ are obtained, respectively.

For assembly of the *U8350* the amount of solder paste used per day for an assembly line is measured and divided by a certain number of PCBAs produced daily by an assembly line. This gives the solder used per PCBA.

For the above assembly line the following metrics are measured and monitored:

- the power usage for a number of Assembly steps;
- the number of boards produced per day;
- the hours of usage.

By the above data the electricity per PCBA is calculated.

Transports

Transport is a generic activity according to ETSI TS 103 199 and not a separate life cycle stage. However, the distribution of the *U8350* is the most important transport. An approach where the distance in km per transported ton is used. The procedure is that from B1.2 to C1 the share of different transport mode (Air, Ship and Rail) are estimated. Different Lorry and Van distances are connected to either transport mode. The mass of the *U8350*+Packaging material is multiplied with the distances for each transport mode and emission factors from LCI databases for each transport mode is applied. In this way the transport from B1.2 to C1 is estimated.

13.3 Allocation of data

13.3.1 OGE Equipment raw material acquisition

The allocations performed for the database data used were not transparently reported by the database.

13.3.2 OGE Production (PP+ Assembly)

Facility data for production facilities shall preferably be allocated to product systems based on relevant physical data (i.e., area and number of layers for printed circuit boards, good Si die area for ICs, weight for other Parts according to Table B1 in ETSI TS 103 199 v1)

13.3.3 OGE Use

There was no need for allocations in use stage in this study.

13.3.4 OGE End-of-life

Due to limitations of the EIME 5.0 LCA tool Orange is bound to use the 100/0 allocation method for Raw Material Acquisition with recycled content ratios for each Raw Material fixed by the EIME 5.0 LCA tool. No Raw Material Recycling discount is therefore included in the calculation model.

Moreover the EIME 5.0 LCA tool is not able to handle metal, paper, cardboard or plastic recycling.

13.3.5 OGE Generic processes, G1-G7

The transports were allocated based on mass.

13.3.6 OGE Cut-off

Pallet, unit load device, stretch rap film, storage and shop energy consumption were cut-off.

Data gaps were additives in plastics and software.

13.3.7 HuW Equipment raw material acquisition

For raw material acquisition the allocations performed for the database data used are not transparently reported by the database.

13.3.8 HuW Production (PP+ Assembly)

For the Part Production data used it could be confirmed that data had been allocated by the practitioner based on the relative proportion of relevant physical characteristics (such as pieces, mass and area) compared to totally produced amount, as preferred by ETSI TS 103 199.

13.3.9 HuW Use

No allocation was done for use. Huawei estimated the typical average power consumption for the studied *U8350* by its battery capacity, voltage, chargings per day, and charger efficiency (See Table S31) to get the annual and lifetime electricity usage. This simplification was judged to be enough for the goal and scope of the LCA study.

13.3.10 HuW End of Life Treatment including Recycling

After two years use the *U8350* go for average PCBA (D2.2.2), Cable (D2.2.3) and Mechanics (D2.2.4) Recycling and then to Raw Material Recycling (G7) and Landfill (G6.2). After these EoLT processes 70wt% of the *U8350* materials (including packaging materials) goes to Landfill and Incineration (G6.2).

The *100/0+50/50 method* is applied for *Raw Material Production* and *Raw Material Recycling* applied to Iron/Steel alloys, Aluminium alloys, Copper alloys, Silver, and Gold.

All Raw Materials used are assumed to be 100% primary, i.e., no recycled content. At G7 (Raw Material Recycling), according to the 50/50 allocation method, we allocated 50% of the *Secondary Raw Material Acquisition* to the present life cycle. 50% metal recovery efficiency is assumed not to overestimate the recycling benefit. The *U8350* cardboard packaging box is not credited neither for material nor energy recycling.

13.3.11 HuW Upgrades during the lifetime of the U8350

Upgrades would be handled as extra impacts for the non-use life cycle stages during the two years life cycle.

As for HuW Generic Processes transports are allocated based on mass.

13.3.12 HuW Cut-off

One cut-off criterion is set: 5 % addition to the first iteration LCA score for CC. That is, if the excluded activities/processes do not increase the total CC score with more than 5 %, respectively, the cut-off criterion is justified. See Section 16.2.4 for details on the quantitative handling of the cut-off.

Based on this criterion several cut-offs are done from the studied product system:

Transports between A and B1.1, some Air transports within B1.1, B1.1.11.

From a total environmental impact point of view these excluded processes are not assessed to be associated with

any specific concerns, thus the cut-off is made.

13.4 Data quality

OGE data quality system is described below. However, due to lack of time within the EU pilot test OGE did not apply the data quality system for all sections of the LCA study. Therefore no final data quality score is detailed, only one example for B1.1.4 “Integrated circuits”.

13.4.1 OGE Completeness

Two indicators are used by OGE to estimate the completeness: one for LCA software (EIME) database models and one for inventory (data collected by Orange). Tables S5-S8 shows how the completeness is evaluated in a semi-quantitative manner.

Table S5: OGE Data completeness levels as used in EIME LCA SW

EIME Software	SCORE	EIME DATA COMPLETENESS (EC)
	3	High
	2	Medium
	1	Low

High: Inventory field is complete (taking into account all the significant stages of the process, the composition in weight is determined to be 98%)

Medium: Inventory field is incomplete (some significant stages of the process not taken into account, composition in weight is determined to be less than 98%)

Low: Only composition in weight is indicated.

Table S6: OGE Data completeness data quality indicators

Inventory	SCORE	INVENTORY DATA COMPLETENESS (InvCo)
	4	83% < Data completeness ≤ 100%
	3	67% < Data completeness ≤ 83%
	2	51% < Data completeness ≤ 67%
	1	Data completeness ≤ 50%

OGE Completeness (C) = EIME DATA COMPLETENESS (EC) × INVENTORY DATA COMPLETENESS (InvCo)

Table S7: OGE Inventory data completeness

		INVENTORY DATA COMPLETENESS (InvCo)			
		1	2	3	4
EIME DATA COMPLETENESS	1	1	2	3	4
	2	2	4	6	8
	3	3	6	9	12

Color scale indicates OGE Completeness (C) score:

Table S8: OGE Color scale for completeness

Good	1	Poor	3
Fair	2	Very Poor	4

13.4.2 OGE Uncertainty

Global uncertainty is a combination of several factors such as data completeness, so it cannot be assessed. Monte-Carlo analyses are not available in EIME, so Orange was not able to assess uncertainty with this method.

13.4.3 OGE Acquisition method

Directly measured data as acquisition method (AM) means that OGE carry out length, mass or area measurements in its own laboratory (Table S9).

No environmental data, such as carbon dioxide emissions were directly measured.

Table S9: OGE Acquisition methods data quality indicators

SCORE	ACQUISITION METHOD
1	Directly measured data or specific manufacturer data
2	Calculated data based on measurements or generic manufacturer data
3	Calculated data based on assumptions
4	Estimated data

13.4.4 OGE supplier independence

Orange do not manufacture the product and was not able to identify all suppliers. For example for the USB - micro USB cable there is no manufacturer marking, so Orange asked major manufacturers for information.

Therefore in the U8350 LCA context supplier independence data quality evaluation is challenging for OGE.

For EIME database models it is challenging to find out links between information provider and CODDE Bureau Veritas for each LCI module.

13.4.5 OGE data representativeness

Data representativeness (DR) is ranked according to information provided by CODDE Bureau Veritas (EIME software developer) in models descriptions (Table S10).

Table S10: OGE data representativeness data quality indicators

SCORE	DATA REPRESENTATIVENESS
1	Data originating from at least three industrial sites
2	Data originating from one or two industrial sites
3	Bibliographic data
4	Representativeness unknown

13.4.6 OGE Data Age

Data age (Y) is ranked according to information provided by CODDE Bureau Veritas (EIME software developer) in models descriptions (Table S11).

Table S11: OGE data age data quality indicators

SCORE	DATA AGE (Réf. 2012)
1	< 3 years
2	< 6 years

3	< 10 years
4	> 10 years

13.4.7 OGE Geographical correlation

Geographical correlation (GC) is ranked according to information provided by CODDE Bureau Veritas (EIME software developer) in models descriptions (FR/RER/GLO/... tags in models names) and most plausible real location (Table S12).

Table S12: OGE geographical correlation data quality indicators

SCORE	GEOGRAPHICAL CORRELATION
1	Exact Area
2	Larger area (same continent for ex.)
3	Different large area (France instead of China for ex.)
4	Unknown area

13.4.8 OGE technological correlation

Technological correlation (TC) is ranked according to information provided by CODDE Bureau Veritas (EIME software developer) in models descriptions and most plausible real technologies used (Table S13).

Table S13: OGE technological correlation data quality indicators

SCORE	TECHNOLOGICAL CORRELATION
1	Data from the exact process/material
2	Data from process/material with similar technology
3	Related process/material data
4	Unknown technology

For example, if a generic thermoplastic injection process is used for a “Polycarbonate injection process” the TC score will be 3 for the data quality evaluation of “Polycarbonate injection process”.

13.4.9 OGE Rule of inclusion / exclusion

Full documentation is still not available for all EIME models. Those based on European Life Cycle Data Network (ELCD) models are relatively well described, including rules of inclusion and exclusion.

OGE sought to obtain the highest quality of LCI data for the most impacting parameters/Parts e.g., good Si die area, and area of screen. Significant efforts were also made to check that the consequences of Parts with the lowest ratings were not significant for the entire study.

An extensive check and scoring of 10 different data quality criteria (such as Completeness and Uncertainty and Data age) is done.

13.4.10 OGE example of data quality for B1.1.4 “Integrated circuits”

Below in Tables 14a-f the application of the data quality system on B1.1.4 Parts is shown.

Table S14a: OGE data quality analysis for C for Integrated Circuits

COMPLETENESS	EIME Models	E C	Inv Co	C	Sc ore
	Semiconductor (Low profile fine pitch ball grid array packages, LFBGA)	3	4	3×4 =12	1
	Semiconductor (Very thin fine pitch quad flat, VFQFPN)	3	4	12	1
	Semiconductor (Flip chip, CSP FLIP CHIP)	3	4	12	1
	Diode (Small outline diode, Low power, SOT23 - SOT89 - SOT223)	3	2	6	2
	Transistor (Small outline transistor, low power, SOT23 - SOT89 - SOT223)	3	2	6	2
	For B1.1.4 Completeness is equal to	1 .4			

Table S14b: OGE data quality analysis for AM for Integrated Circuits

ACQUISITION METHOD	EIME Models	Sco re
	Semiconductor (Low profile fine pitch ball grid array packages, LFBGA)	1
	Semiconductor (Very thin fine pitch quad flat, VFQFPN)	1
	Semiconductor (Flip chip, CSP FLIP CHIP)	1
	Diode (Small outline diode, Low power, SOT23 - SOT89 - SOT223)	1
	Transistor (Small outline transistor, low power, SOT23 - SOT89 - SOT223)	1
	For B1.1.4 Acquisition method is equal to	1

Table S14c: OGE data quality analysis for DR for Integrated Circuits

DATA REPRESENTATI.	EIME Models	Sco re
	Semiconductor (Low profile fine pitch ball grid array packages, LFBGA)	1
	Semiconductor (Very thin fine pitch quad flat, VFQFPN)	1
	Semiconductor (Flip chip, CSP FLIP CHIP)	1
	Diode (Small outline diode, Low power, SOT23 - SOT89 - SOT223)	1
	Transistor (Small outline transistor, low power, SOT23 - SOT89 - SOT223)	1
	For B1.1.4 Data representativeness is equal to	1

Table S14d: OGE data quality analysis for Y for Integrated Circuits

DATA AGE (Ref 2012)	EIME Models	Sco re
	Semiconductor (Low profile fine pitch ball grid array packages, LFBGA)	2
	Semiconductor (Very thin fine pitch quad flat, VFQFPN)	2
	Semiconductor (Flip chip, CSP FLIP CHIP)	2
	Diode (Small outline diode, Low power, SOT23 - SOT89 - SOT223)	2
	Transistor (Small outline transistor, low power, SOT23 - SOT89 - SOT223)	2
	For B1.1.4 Data Age is equal to	2

Table S14e: OGE data quality analysis for GC for Integrated Circuits

GEOGRAPHICAL CORRELATION	EIME Models	Score
	Semiconductor (Low profile fine pitch ball grid array packages, LFBGA)	3
	Semiconductor (Very thin fine pitch quad flat, VFQFPN)	3
	Semiconductor (Flip chip, CSP FLIP CHIP)	3
	Diode (Small outline diode, Low power, SOT23 - SOT89 - SOT223)	3
	Transistor (Small outline transistor, low power, SOT23 - SOT89 - SOT223)	3
	For B1.1.4 Geographical correlation is equal to	3

Table S14f: OGE data quality analysis for TC for Integrated Circuits

	EIME Models	Score
	Semiconductor (Low profile fine pitch ball grid array packages, LFBGA)	2
	Semiconductor (Very thin fine pitch quad flat, VFQFPN)	2
	Semiconductor (Flip chip, CSP FLIP CHIP)	2
	Diode (Small outline diode, Low power, SOT23 - SOT89 - SOT223)	2
	Transistor (Small outline transistor, low power, SOT23 - SOT89 - SOT223)	2
	For B1.1.4 Technological correlation is equal to	2

Data Quality Rating is equal to: (Completeness score + Acquisition method score + Data Representativeness score + Data Age score + Geographical correlation score + Technological correlation score + 4* weakest rated score) / (6+4)

= (1.4 + 1 + 1 + 2 + 3 + 2 + 3×4)/(10) For B1.1.4 Data Quality Rating is equal to **2.24**.

13.4.11 HuW Methodological appropriateness and consistency (MC)

The applied LCI methods and methodological choices are in line with the goal and scope of the data. The methods have been applied consistently across all data. The average grade is “very good (5)” for this data quality indicator.

13.4.12 HuW Completeness (total LCA level) (C)

>99% of the number of applicable LCI flows in Table E.1 is included in the LCI. The applicable LCI flows are those that could contribute to CC. The degree of coverage of the CC Table F.10 is close to 100 % based on mass. Completeness is very good as far as included applicable unit processes which emit greenhouse gases. The average grade is “very good (5)” for this data quality indicator.

13.4.13 HuW Uncertainty (U)

For CC the variability of the data elements used in the LCA is low enough to separate the Use stage from Raw Material Acquisition + Production + EoLT stages when the *U8350* is used 2 years in France.

For CC the combined Raw Material Acquisition, Part Production and EoLT stages total variability lead via Monte Carlo simulation to the uncertainty range 25 – 53 kg CO₂e/lifetime³, i.e. confidence interval 2σ = 14 around the mean value 38.7. For CC for the Use stage the uncertainty range is 0.26 – 0.74 kg CO₂e/lifetime, i.e. confidence interval 2σ = 0.24 kg around the mean value 0.51 kg. These ranges imply that the probability is very high (3σ) that the Use stage is lower than the other stages combined.

I.e. for CC the probability is close to 100% that the *The Raw Material Acquisition* and *Part Production* stages combined is more important than the *Use Stage*.

³ The range has included the estimation of Si die area and uncertainty of impact per Si die area.

The amount of Si die area, the amount of CO₂e per Si die area, and the amount of CO₂e per screen area, and the amount of gold are the most important data elements for which the variability shall be as low as possible low for the present *U8350* LCA.ⁱ

The average grade is “good (2)” for this data quality indicator.

13.4.14 HuW Acquisition method (AM)

Some of the data used have been directly measured such as the number of Parts. Si die areas were estimated based on functionality of ICs. None of the data used are “nonqualified estimations”.

13.4.15 HuW Supplier independence (SI)

Most of the data used are “Independent source but based on unverified Information”. “Verified data from independent source” to “Unverified information from industry” have been used”. The average grade is “fair (3)” for this data quality indicator.

13.4.16 HuW Data representativeness (DR)

None of the data used have unknown representativeness, however, most of the data for the *Raw Material Acquisition* and *Part Production* stages can be characterized as “Representative data from a smaller number of sites and shorter periods, or “incomplete data from an adequate number of sites and periods”. The average grade is “fair (3)” for this data quality indicator.

13.4.17 HuW Data age (timeliness) (T)

No data have an unknown age. The average grade is “fair (3)” for this data quality indicator.

13.4.18 HuW Geographical correlation (GC)

"Average data from a larger area" has been used for *Raw Material Acquisition* and *Production* and *Transports*, and *EoLT*. "Data from an area with similar production conditions" is used for Electricity used in the the Use stage. World average electricity is considered optimal for *Raw Material Acquisition* and *Production*. The grade is “good (4)” for this data quality indicator.

13.4.19 HuW Technological correlation (TC)

"Data from process studied of the exact company" is used for *Assembly* and amount of *Use* stage electricity. "Data from process studied of company with similar technology" is used for Parts production. The grade is “fair (3)” for this data quality indicator.

13.4.20 HuW Cut-off rules (rules of inclusion/exclusion) (RIE)

The cut-off criteria were homogeneously and transparently applied.

13.4.21 HuW Summary of data quality for each life cycle stage

In Tables S15-S16 is shown HuW data quality indicators and their application the whole LCA.

Table S15: HuW data quality indicators

Indicator score	1	2	3	4	5
Indicator					
<i>Methodological appropriateness and consistency (MC)</i>	Very good	Good	Fair	Poor	Very poor
<i>Completeness (total LCA analysis level) (C)</i>	Very good	Good	Fair	Poor	Very poor
<i>Uncertainty (U)</i>	Very good	Good	Fair	Poor	Very poor
<i>Acquisition method (AM)</i>	Directly measured data	Calculated data based on measurements	Calculated data based on assumptions	Qualified estimation (by experts)	Nonqualified estimation
<i>Supplier independence (SI)</i>	Verified data from independent source	Verified data from enterprise with interest in the study	Independent source but based on unverified information	Unverified information from industry	Unverified information from enterprise interested in the study
<i>Data representativeness (DR)</i>	Representative data from a sufficient sample of sites over an adequate period to even out normal fluctuations	Representative data from a smaller number of sites but for adequate periods	Representative data from an adequate number of sites but for shorter periods	Representative data from a smaller number of sites and shorter periods, or incomplete data from an adequate number of sites and periods	Representativeness unknown or incomplete data from a smaller number of sites and/or from shorter periods
<i>Data age (T)</i>	<3 years	<6 years	<10 years	<15 years	age unknown
<i>Geographical correlation (GC)</i>	Data from the exact area	Average data from a larger area	Data from an area with similar	Data from an area with slightly similar	Unknown area

			production conditions	production conditions	
<i>Technological correlation (TC)</i>	Data from process studied of the exact company	Data from process studied of company with similar technology	Data from process studied of company with different technology	Data from process related to company with similar technology	Data from process related to company with different technology
<i>Rule of inclusion/exclusion (Elements/Flows/Process) (RIE)</i>	Transparent, justified, homogeneous application	Transparent, justified, Nonhomogeneous application	Transparent, non-justified, Nonhomogeneous application	Not transparent on exclusion but specification of inclusion	Unknown

Table S16: HuW application of data quality indicators per life cycle stage

[illegible]

Total Data Quality Rating formula in Table S16 is adapted from European Commission Joint Research Center. (European Commission, 2012b)

$$\text{Formula 1} \quad DQR = \frac{TeR + GR + TiR + C + P + M + X_w * 4}{i + 4}$$

- *DQR* : Data Quality Rating of the data set; see Table 5
- *TeR*: *Technological Representativeness*
- *GR*: *Geographical Representativeness*
- *TiR*: *Time-related Representativeness*
- *C*: *Completeness*;
- *P*: *Precision/uncertainty*;
- *M*: *Methodological Appropriateness and Consistency*
- *Xw* : weakest quality level obtained (i.e. highest numeric value) among the data quality indicators
- *i* : number of applicable (i.e. not equal "0") data quality indicators

14. Life Cycle Impact Assessment

The following impact category is included: Climate Change (CC).

The impact assessment method applied by HuW was "Climate change" from ReCiPe Midpoint (H) V1.05. OGE used 'IPCC 2007 – 100 years' methodology within EIME Version 4.1 PEP Eco-passport impact indicator set.

15. Life cycle interpretation

The typical approach for life cycle interpretations is to run scenario calculations using different bases for the underlying calculations.

15.1 Initial Conclusions

The LCA showed that the most significant activity for the CC category is the *Production Stage* driven by the area of screen and the amount of Si die area (good Si die area) used by the *U8350*. As far as transports are concerned the impact is significant from a life cycle perspective for CC and ED. The assessment also indicates that *Gold and Palladium* dominate Raw Material Acquisition stage.

15.2 Uncertainty estimation

OGE evaluated the robustness of their LCA methodology with a sensitivity analysis tuning four drivers: *electricity consumption* in the Use stage, *area* of display touch screen, *distance* of Air transportation and *area* of good Si dies.

A change of $\pm 1\%$ in the input values for these four drivers gives a change of $\pm 0.84\%$ for the outcomes. For HuW see Section 16.2.4.

t-test

The *t-test* by HuW below in Table S17 shows that it is a 49% probability that OGE baseline score 29.6 kg could be higher than HuW baseline score 39.23 kg and vice versa. This means that the results are equal statistically suggesting that the ETSI LCA standard have lead to robust results.

Table S17: HuW t-test of baseline LCA scores

		Coefficient of Variation %	
OGE U8350 basic CO₂e (kg)	29.6	0.1	20% 2σ
HuW U8350 basic CO₂e (kg)	39.2	0.178	35.6% 2σ
			$-0.69243 = \text{=LOG}(29.6/39.2)/(\text{SQRT}(0.0866^2 + 0.153^2))$
	t-test	0.49	$0.692011 = \text{TINV}(0.49, 150)$
$\sigma \ln x$	0.099751	0.176614	$\text{=SQRT}(\text{LN}(0.1^2 + 1)), \text{ OGE}$
$e(\sigma)$	1.104896	1.19317	$\text{=e}^{0.099751}, \text{ OGE}$
$(e(\sigma))^2$	1.220795	1.423655	$\text{=1.104896}^2, \text{ OGE}$
\log_{10}	0.086643	0.153405	$\text{=log}_{10}(1.220795), \text{ OGE}$

15.3 Sensitivity analyses

OGE did not perform sensitivity analyses. For HuW see Section 16.2.4.

15.3.1 OGE Eco-Rating

Tables S18-S22 below provide the outline of and which metrics are needed within OGE Eco-Rating Methodology.

Manufacturing

Table S18: Outline of OGE ER for Manufacturing with HuW U8350 metrics

CO2LCD	Intensity value	g/cm2	
Area LCD	20.155	cm2	
CO2 main PCB	Intensity value	g/cm2	
Area main PCB	49	cm2	
CO2 flex PCB	Intensity value	g/cm2	
Area flex PCB	8	cm2	
CO2 Si	Intensity value		
Area Silicon dies	726	mm2	
CO2 battery	Intensity value	g/g	
Mass of battery	24	g	
CO2 charger	Intensity value	g/g	
Mass of charger	56.3		
CO2 Al casing	Intensity value	g/g	
Mass of Al casing	7.9	g	
CO2 steel casing	Intensity value	g/g	
Mass of steel casing	13		
CO2 plastic casing	Intensity value	g/g	
Mass of plastic casing	18.4		
CO2 rest	Intensity value	g/g	
mass rest	79.9	Steel, Rubber, different plastics	
CO2 pack	Intensity value	g/g	
Mass of packaging	132.7	g	
TOTAL		(g)	23223.2706

Distribution

Table S19: Outline of OGE ER for Distribution with HuW U8350 metrics

CO2 plane	Intensity value	g/kgkm	
distance plane	9800	km	
CO2 truck	Intensity value	g/kgkm	
distance truck	480	km	

CO2 ship	Intensity value	g/kgkm	
distance ship	0	km	
CO2 train	Intensity value	g/kgkm	
distance train	0		
Mass of product	0.358	kg	
TOTAL		(g)	3655.039664

Use

Table S20: Outline of OGE ER for Use with HuW U8350 metrics

t com		Communication time per month
a com	14.5	Autonomy in talking time mode (Autonomy during calls)
t stby		Time in stand-by per month
a sby	628	Autonomy in standby mode (Autonomy during standby)
t charge	3	Time necessary to charge the battery from 0% to 100%
t c+m		Time spent after each charge, charger connected
E charge	13500	Absorbed energy to charge the battery (Mains electricity consumed to charge the battery from 0% to 100% in mWh)
P c+m	290	Absorbed power with full battery (Power used by the charger from the mains, when the mobile phone is connected and 100% charged)
P cs	30	Absorbed power by the charger alone (Power used by the charger alone)
t cs		Time spent after each charge with only the charger connected
N charges per month		OGE formulae
E tot per month mWh		OGE formulae
2 year kWh		
El France		
TOTAL		62.14 g

EoLT**Table S21: Outline of OGE ER for end-of-life with HuW U8350 metrics**

mass mobile+charger	201.3	g	Mass mobile device + charger
Mass battery	24	g	Mass battery
Mass mobile	145	g	Mass mobile device
Area main PCBA	49	cm2	area of main PCBA
TOTAL			500.1737 g

Summary OGE ER**Table S22: Summary results of OGE ER with HuW U8350 metrics**

Manufacturing (kg)	23.23
Distribution (kg)	3.655
Use, FRANCE (kg)	0.062
EoLT (kg)	0.500
TOTAL (kg)	27.44

16. Reporting

16.1 OGE results

Results for smart phone *U8350* with EIME software and OGE method and metrics are shown below in Table S23 and Figure S8.

Table S23: CC LCA results from OGE

Complete LCA cradle to grave	Indicators	Unit	Manufacturing	Distribution	Use	End of life
Global Warming Potential (GWP for PEP)	GW P	kg CO ₂ e	21.7	6.53		0.38

Figure S8: GWP100 result diagram for U8350 for Mandatory processes/activities (diagram for Global Warming Potential (GWP100) (CO₂e).

"This LCA result cannot be compared to the result of another LCA unless all assumptions and modeling choices are equal"

Figures S9a-c show OGE CC impact values by sub-assembly:

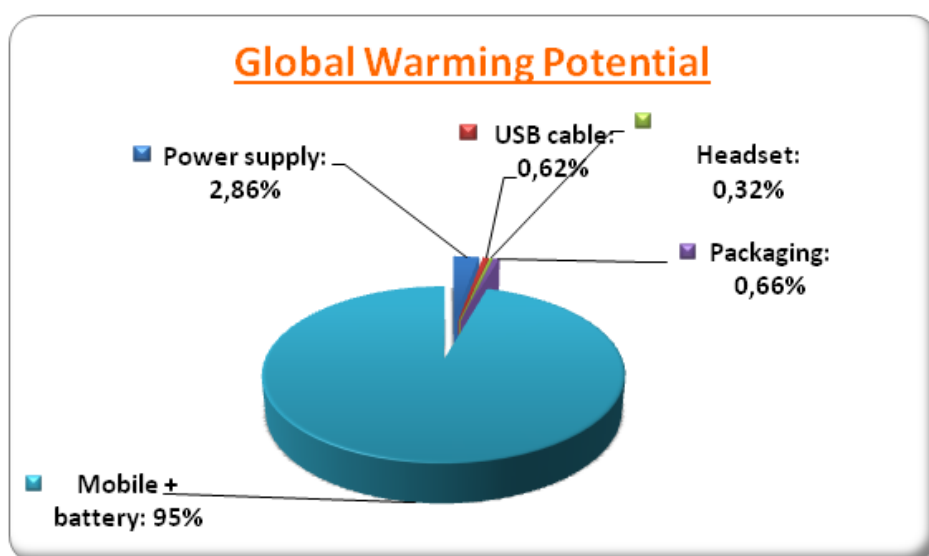


Figure S9a: GWP100 result for distribution between sub-unit processes within each life cycle stage.

"This LCA result cannot be compared to the result of another LCA unless all assumptions and modeling choices are equal."

Smartphone: Global Warming Potential

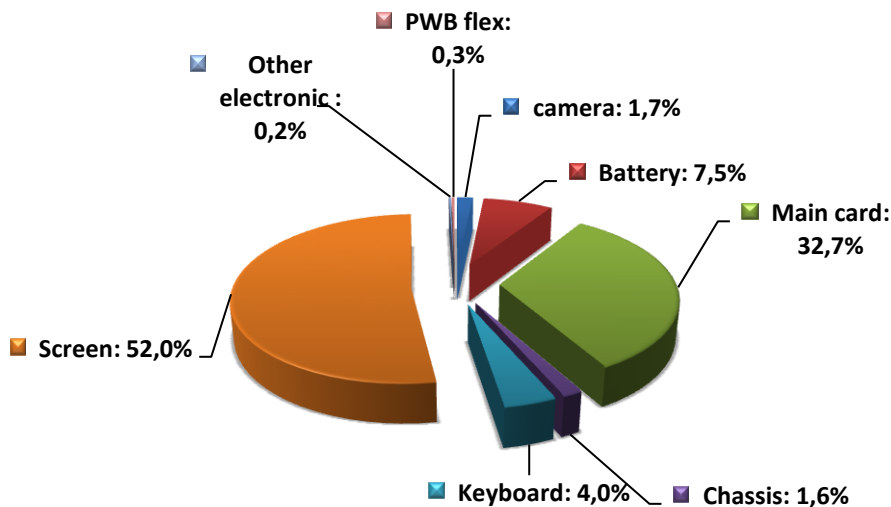


Figure S9b: GWP100 result for distribution between sub-unit processes within each life cycle stage. "This LCA result cannot be compared to the result of another LCA unless all assumptions and modeling choices are equal."

Main card: Global Warming Potential

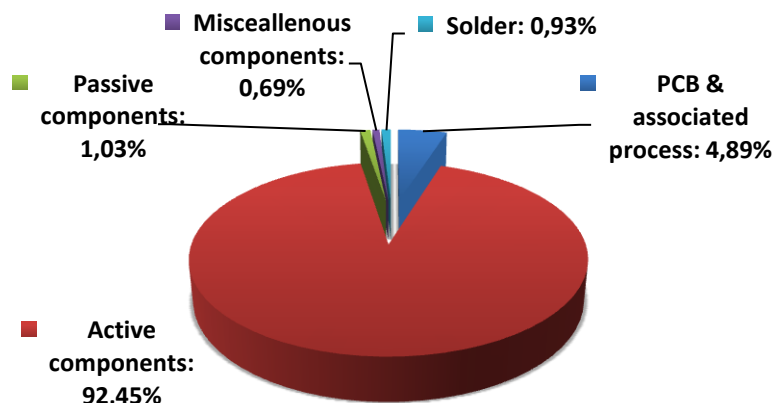


Figure S9c: GWP100 result for distribution between sub-unit processes within each life cycle stage.

"This LCA result cannot be compared to the result of another LCA unless all assumptions and modeling choices are equal."

16.2 HuW results

The LCA shows (Figures S10-S11 and Table S33 below) that the most significant activity for CC impact category, CED indicator, electricity usage, and water usage is the *Production Stage* driven by the amount of electricity used by the *Display (LCD Screen)* and *IC, front-end processes*.

16.2.1 Environmental impact category indicator result diagram

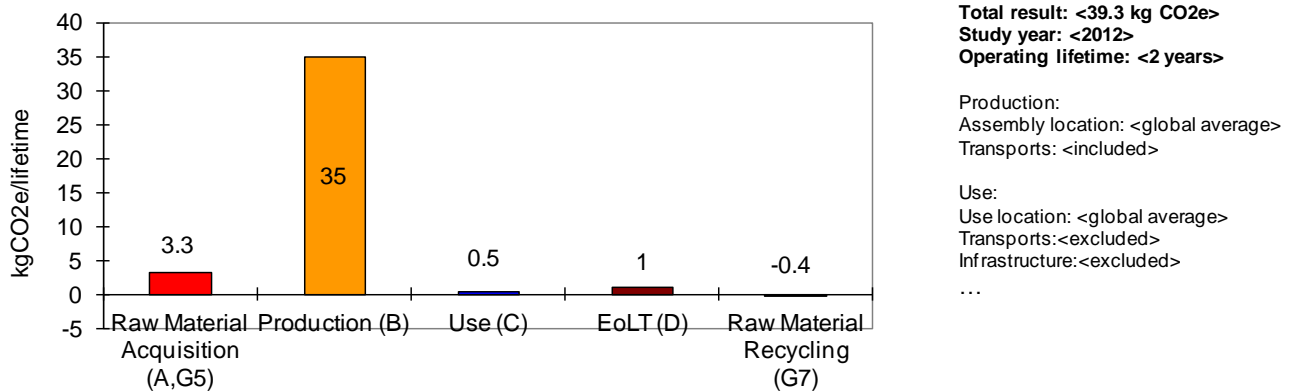


Figure S10: HuW application of Figure 9a in ETSI TS 103 199

The transports are responsible for around 5 kg CO₂e. "This LCA result cannot be compared to the result of another LCA unless all assumptions and modelling choices are equal"

16.2.2 Environmental impact category indicator result: distribution between sub-unit processes within each life cycle stage

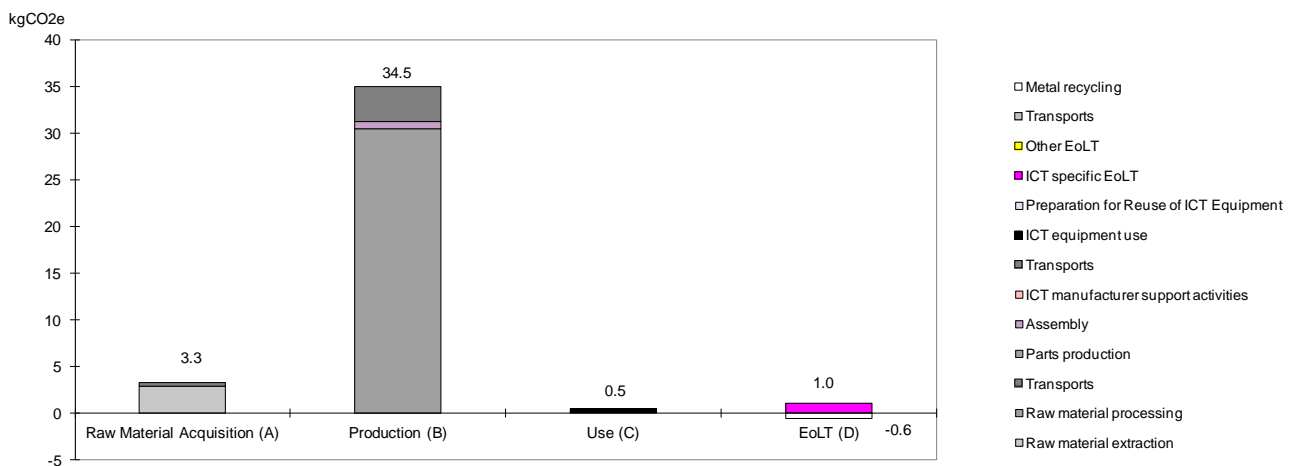


Figure S11: HuW application of Figure 10 in ETSI TS 103 199

"This LCA result cannot be compared to the result of another LCA unless all assumptions and modelling choices are equal".

16.2.3 Environmental impact category indicator overview

Figure S12 shows the CC indicator life cycle stage distribution from HuW.

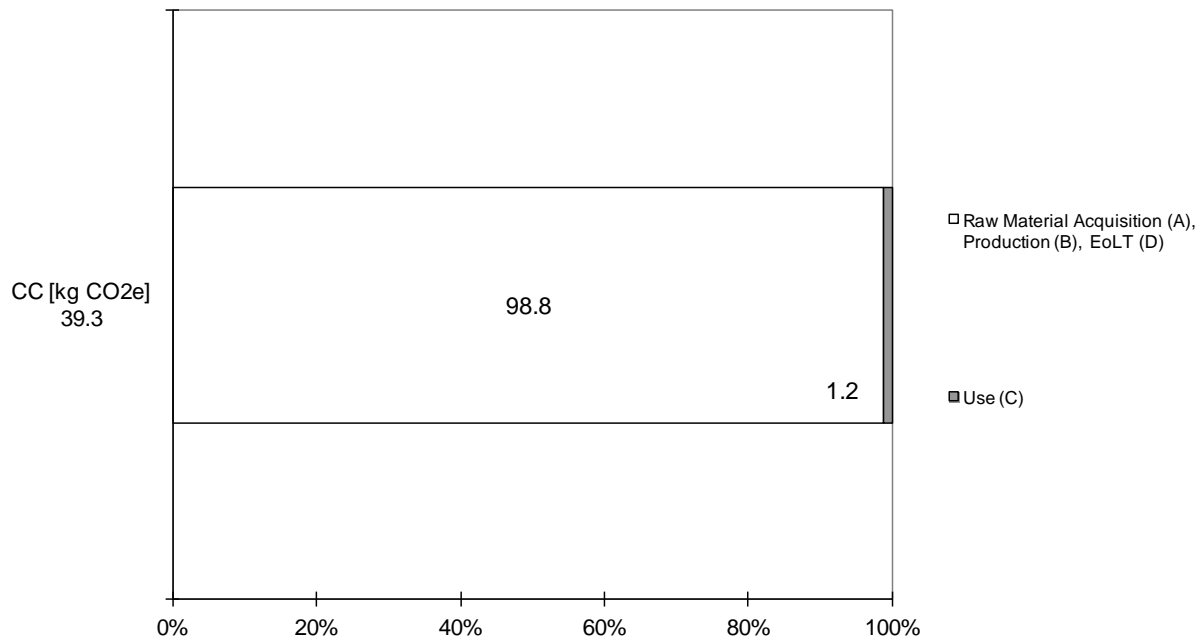


Figure S12: HuW application of Figure 11 in ETSI TS 103 199

16.2.4 Sensitivity analysis results

Figure S13 shows the sensitivity analysis from HuW on U8350.

Sensitivity analyses: Total score [kg CO2e] per U8350 functional unit, accumulation

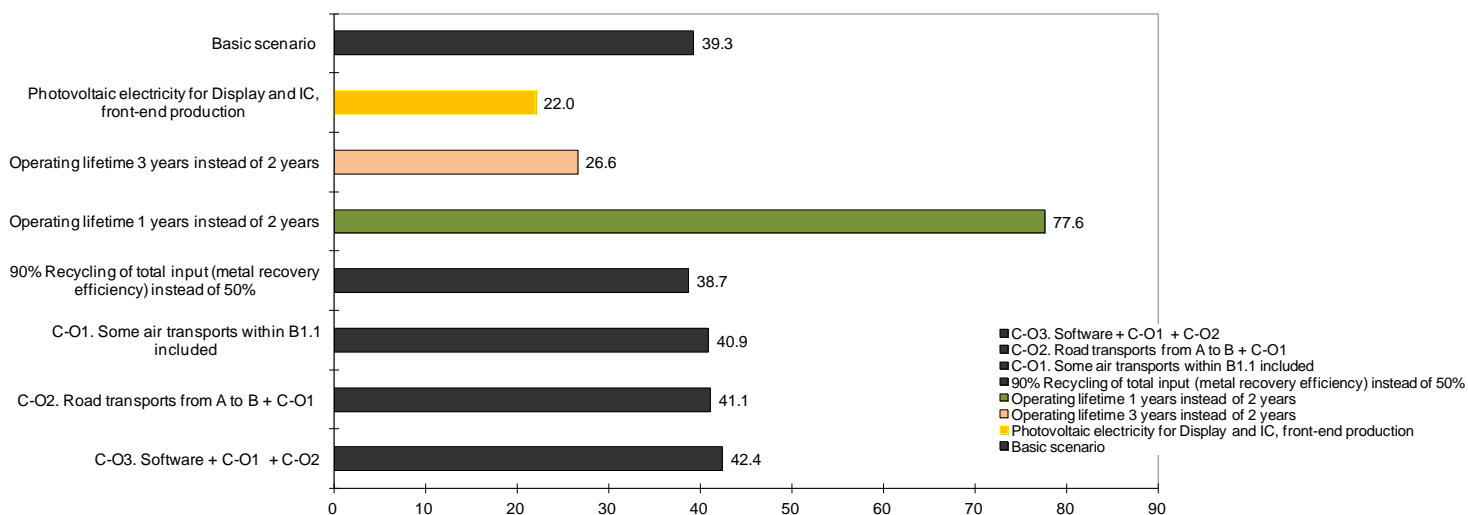


Figure S13: Results of HuW Sensitivity analyses

As far as transports are concerned the impact is limited from a life cycle perspective for the included impact category.

Uncertainty Calculation is done according to the Monte Carlo procedure provided by the LCA tool. The uncertainty range for total CC given as two standard deviations is around 14 kg (39.2kg ($2\sigma = 14\text{kg}$)). Uncertainty of LCIA characterization factors is currently not possible to estimate in a reliable manner.

The following steps are taken to reduce the uncertainties: verification of the reasonableness of the Si die area electricity usage of the U8350.

By contribution analysis the most contributing elementary LCI flows and unit processes are identified for the environmental impact category CC. Subsequently models applied and the data used are assessed with respect to

accuracy and a list of candidates bound for sensitivity analysis is identified, e.g.:

- operating life time;
- overall recovery rates for metals;
- production region for Parts;

Moreover, the sensitivity of the cut-off processes:

- Transports between A and B1.1
- Some Air transports within B1.1
- B1.1.11 transports within EoLT
- Raw Material consumptions, Electricity, and Fuel consumptions within EoLT,
- EoLT activities (D3) G6.1-2)

were tested by inserting a range of Raw Material consumptions, electricity consumptions and Road transport distances. These sensitivity analyses revealed that the conclusions were stable. See Figure S24.

Sections 16.3-16.12 below is an application by HuW of the ETSI LCA reporting format to the U8350 LCA.

16.3 Cover page

Table S24: HuW application of Table F.1 in ETSI TS 103 199 Cover page

REPORTING			
	Yes	No	Description / references to page
General information			
Company name and contact information	X		Huawei Technologies CO., Ltd.
Project name			
Product System	X		No infrastructure. No support activities. ICT Equipment mass excluding packaging material, 226 g
Product System related information		X	Packaging material (cardboard box) 95 g (Phone Device) 36,7 g (Charger)
Product System function	X		
Product system description	X		U8350 (Smartphone)
Product picture (optional)		X	
Date of completion of assessment (3/4/2012)			
Compliant with ETSI TS103199		X	5.3.3.1.4 and 6.2.2.5. Distribution transport and Use stage need more details for full compliance
Software tool used	X		SimaPro 7.3.2
External Review (yes/ no)		X	
Reviewers			
Goal definition			
Reason for carrying the study	X		LCA standards road test
Target audience(s)	X		EU DG CONNECT pilot test report of ICT LCA standards

Comparative assessment		X	
Scope definition			
Functional unit	X		Total ICT Equipment lifetime use = Two years of U8350 usage charging the battery from 0% to 100% once every 24 hour
Reference flow	X		One U8350 smartphone with its packaging and accessories
Define system boundary	X		According to rules in ETSI TS 103 199 standard Table 1
Environmental impact categories	X		CC according to "Climate change from ReCiPe Midpoint (H) V1.05 and Cumulative Energy Demand
List of Optional and recommended stages considered	X		No optional or recommended stages considered
Cut off criteria	X		Less than 5% addition to the Baseline (first iteration) LCA score for CC
Resource used and emission profile			
Generic data sources			
Data collection procedure	X		
Technical process flow diagram	X		
Unit process description	X		
Calculation procedure	X		
Allocation procedure for environmental footprint	X		
Data quality	X		
Handling multi functionality		X	Not applicable to the goal&scope
Data gap	X		Insignificant for LCIA category presented
Environmental impact assessment			
Assessment results	X		for CC

Normalization		X	
Weighting		X	
Interpretation			
Identify hot spot	X		Production stage
Conclusion	X		Production stage excluding Final transport is 90% of CC

16.4 Included life cycle stages, activities and generic processes

Table S25: HuW application of Table F.2 in ETSI TS 103 199

Tag	Life cycle stage	Unit process	Included (Yes/No)	Electricity mix (specific/country/world average)	Support activities included (Yes/No)	Transport activities included (Yes/No)	Other generic activities included (Yes/No)	Motivation/Comment
A	Equipment Raw Material Acquisition							
A1	Raw material extraction		Yes	World	No	Yes	Yes	Mandatory. LCI databases used. Global average is assumed as the supply chain is flexible.
A2	Raw material processing		Yes	World	No	Yes	Yes	Mandatory. LCI databases used. Global average is assumed as the supply chain is flexible.
B	Production							
B1	ICT equipment production							

B1. 1		Parts production	Yes	World	No	Yes	No	Mandatory. "Electricity for World" according to IEA as a global average electricity mix is used for all processes.
B1. 2		Assembly	Yes	World	No	Yes	No	Mandatory. "Electricity for World" according to IEA is used.
B1. 3		ICT manufacturer support activities	No	World	Yes	Yes	No	Optional.
B2	Support equipment production							
B2. 1		Support manufacturing Equipment	N.A.					Not included in studied product system
B 3		ICT specific Site construction	N.A.					Not included in studied product system
C	Use							
C1	ICT equipment use		Yes	France	No	No	No	Mandatory. Only electricity usage (G2) is included. French low voltage electricity used (Electricity, low voltage, at grid/FR U, .
C2	Support equipment use		N.A.					Not included in studied product system

C3	Operator activities		N.A.					Not included in studied product system
C4	Service provider activities		N.A.					Not included in studied product system
D	Equipment End of Life Treatment							
D1	Preparation of ICT Equipment for Re-use		N.A.					Not included in studied product system
D2	ICT specific EoLT							
D2.1		Storage/Disassembly/Dismantling/ Shredding	Yes	World	No	Yes	Yes	Mandatory.
D2.2		Recycling	Yes	World	No	Yes	Yes	Mandatory.
D3	Other EoLT		Yes	World	No	Yes	Yes	Mandatory.

16.5 Generic processes

Table S26: HuW application of Table F.3 in ETSI TS 103 199

Generic process	Generic process categories included	Unit processes included (for each generic process category)	Important issues
G1. Transports&Travel	Air	Fuel supply chain + Direct (during transport) emissions	No other transports considered than Air and Road.
	Road	Fuel supply chain + Direct (during transport) emissions	

G2. Electricity	World electricity mixes, French electricity mixes	Fuel supply chain + Direct emissions (during electricity production)	
G3. Fuels	Oil	Fuel supply chain	These fuels are used for heating, to produce electricity, and for transports.
	Diesel	Fuel supply chain	
	Petrol	Fuel supply chain	
	Coal	Fuel supply chain	
	Gas	Fuel supply chain	
G4. Other energy	N.A		Not included in studied product system
G5. Raw material acquisition	Nitrogen gas (N2) used in B1.1.4, solder paste used in B1.2.	Extraction + Processing	
G6. End – of – life treatment	EHW (destruction and energy recovery) Special EHW landfill AND Diverse recycling Energy recovery (e.g., incineration, see note) Landfill	Recovery/treatment AND Recycling/recovery/treatment, respectively	
G7. Raw material recycling	Metal recycling	Smelting	
		Refining	

Table S27: Electricity world average used in A and B

Name	G2		Uncertainty
------	----	--	-------------

<i>Inflows</i>	<i>Flow</i>	<i>Unit</i>	
Coal	0.44	kg CO2 eq	Lognormal 2σ (LGN 1.1)
Natural gas	0.136	kg CO2 eq	LGN 1.1
Oil	0.0485	kg CO2 eq	LGN 1.1
Nuclear	0.00105	kg CO2 eq	LGN 1.1
Hydro	0.00063 5	kg CO2 eq	LGN 1.1
Wind	0.00015 4	kg CO2 eq	LGN 1.1
<i>Outflows</i>	<i>Flow</i>	<i>Unit</i>	
Electricity (World)	1	kWh	
CO2e	0.627	kg CO2 eq	2σ = 0.06

16.6 Transportation/travel

Table S28: HuW application of Table F.4 in ETSI TS 103 199

Mode	CO2 emission factor (see note 4)	Raw material acquisition transports		Production stage transports excluding final transport		Final transport (see note 1) (Production to use stage)		Use stage transports		EoLT transports		Total travels	
		Transport work (see note 2)	GWP 100	Transport work	GWP 100	Transport work	GWP 100	Transport work	GWP 100	Transport work	GWP 100	Transport distance (see note 3)	GWP 100
		{ton × km}	{kg CO2e}	{ton×km}	{kg CO2e}	{ton × km}	{kg CO2e}	{ton×km}	{kg CO2e}	{ton × km}	{kg CO2e}	{km}	{kg CO2e}

Air	Air: (Transport, aircraft, freight, intercontinental/ RER S) 1.07 kg CO ₂ e/(ton×km).	Occasionally included in LCI modules in database		Cut-off. Tested in sensitivity analysis. 10 000 km Air transport per kg Part (B1.1.3-4,7-8, 10)		0.000358 ton×9 600 km = 3.4368 tkm.	3.68						N.A	
Road	Road: Lorry (Transport, lorry 3.5-20t, fleet average/CH U) 0.279 kg CO ₂ e/[ton × km], Van (Transport, van <3.5t/CH U) 1.51 kg CO ₂ e/[ton×km],	Occasionally included in LCI modules in database		Cut-off. Tested in sensitivity analysis. 1 000 km Lorry per weight of Raw Material.		Lorry, 0.000358 ton × 330 km = 0.118 tkm. Van, 0.000358 ton × 150 km = 0.0537 tkm.	0.114							
Ship	N.A			N.A			N.A						N.A	
NOTE 1: The final transport of ICT Equipment from assembly to operator, including pre– and post transports connected to the main transport														
NOTE 2: average in terms of distance, transport mode, load factor, chargeable weight etc.														
NOTE 3: average in terms of distance, transport mode, load factor, chargeable weight etc														
NOTE4: this include direct fuel consumption and also fuel supply chain														

16.7 Raw materials

Table S29: HuW application of Table F.5 in ETSI TS 103 199

	Total input (g) per piece U8350	Content in product (%) (see note 1)	Recycled raw material used (see note 2) (%)	Recycling of total input(see note 3) (%)	Reference	Material content per piece U8350 358 (g)	Material recovery of total input per piece U8350 (g)	PHONE DEVICE piece U8350 145 (g)	CHARGER piece U8350 56.3 (g)	BATTERY piece U8350 24 (g)
Iron/Steel alloys	16.25	80	0	50	The loss of steel has been estimated from previous LCAs. 50wt% Steel recovery efficiency. "Steel high alloy ETH U" with Electricity for World was used to model all kinds of primary Steel.	13.0	8.1	6.9	6.1	
Aluminium alloys	8.69	90	0	50	The loss of Aluminium has been estimated from previous LCAs. 50wt% Aluminium recovery efficiency. "Aluminium, primary, at plant/RER U", with Electricity for World used for primary Al.	7.90	4.3	4.5	3.4	
Copper alloys	35.98	80	0	50	The loss of Copper has been estimated from previous LCAs. 50wt% Copper recovery efficiency. "Copper, primary, at refinery/GLO" with Electricity for World used for primary Cu.	28.8	18.0	17.9	10.9	
Silver	0.18	99	0	50	The loss of Silver has been estimated from previous LCAs. 50wt% Silver recovery efficiency. "Silver, at regional storage/RER U" with "Silver, secondary, at precious metal refinery/SE U" set to ZERO used for primary Ag.	0.179	0.1	0.175	0.004	

Gold	0.12	99	0	50	The loss of Gold has been estimated from previous LCAs. 50wt% Gold recovery efficiency. "Gold, at regional storage/RER U" with "Gold, primary, at refinery/GLO U" set to ONE used for primary Au.	0.123	0.06	0.105	0.018	
ICT product system Raw materials (optional)										
Plastics	18.13	80.00	0.00	0.00	LCI modules predominately from ecoinvent for Primary production (no recycled input) were used for below Raw Materials. In the basic scenario the electricity mix used by ecoinvent was not changed to World average (see Table F7).	72.0		52.0	20.0	
Palladium	0.03	99.00	0.00	0.00	The loss of Pd has been estimated from previous LCAs. 50wt% Pd recovery efficiency. "Palladium, primary, at refinery/RU U" with Electricity for World	0.0336	0.0168	0.0335	0.00006	
Silicon dies								0.0857	0.0473	
Other materials (see note 4)						79.0		62.0	16.0	
Battery materials (see note 5)						24.0				24.0
Packaging materials(optional)										

Cardboard box	13 1.70	10 0.00	0. 00	0. 00		132		95.0	36.7	
Auxiliary Raw Materials (production materials etc.) (optional)										
TOTAL						358		241	93.0	24.0
Note 1: Percentage of total input material present in the product after the production process, i.e. total input minus the related production waste.										
Note 2: The amount of recycled raw material used in the production process, this include the raw material contained in the product and the related production waste.										
Note 3: Total recycling of all input materials, i.e., recycling of manufacturing waste and recycling of total content in final product during EOL. 50% for the basic scenario is a low estimate avoiding overestimation of recycling benefits										
Note 4: Includes e.g. Nickel for surface treatment. Double counting with high-alloy steel models with nickel is avoided.										
Note 5: Lithium compounds make up around 30wt% of battery materials. Battery contains also silicon dies, copper alloys, silver and plastics however the quantification was beyond the scope of the LCA.										

HuW estimated the Si die area as: $ChO * CdW / WO + ChS * CdW / WS + PO * PdW / WO + PS * PdW / WS = 7.26 \text{ cm}^2$

Where

ChO = share ordinary dies in Charger, 100%

ChS = share stacked dies in Charger, 0 %

PO = share ordinary dies in Phone, 53.5%

PS = share stacked dies in Phone, 46.5%

CdW = mg Si dies in Charger, 47.25 mg

PdW = mg Si dies in Phone, 85.7 mg

WO = mg/cm² for ordinary Si dies, 150

WS = mg/cm² for stacked Si dies, 6

The measured value from OGE is 4.85 cm².

16.8 Part production

Table S30: HuW application of Table F.6 in ETSI TS 103 199

	Part categories included	Part Unit processes included	Handling of special issues		Phone Device	Charger	Battery
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B1.1.1 Batteries	Lithium Battery	Raw Material Acquisition, Battery cell assembly, Battery module (pack) assembly	24g	24	0	0	24
B1.1.2 Cables	Charger cable	Raw Material Acquisition, Cable final assembly	<i>Included in charger</i>				
B1.1.3 Electro- mechanics	Connectors (2g), Micro USB (30.88g), Headset (10g), Charger (56.3g)	Raw Material Acquisition, Part final assembly	99.2g				
				99.2	42.9	56.3	0
B1.1.4 Integrated circuits (ICs)	Processors, DSPs	Front-end: Special IC Raw Materials Acquisition, Wafer production, Chip production ("the wafer fab") Back-end: Raw Material Acquisition, IC encapsulation	0.984g ICs, Diodes 0.886g, Transistors 0.0734g. Si dies and GaAs dies weigh 0.133g				
	ASICs			0.984	0.984		
	Memories			0.886	0.886		
	Microprocessor s			0.073 4	0.0734		
	Transistors and diodes						
B1.1.5 Mechanics / materials		Raw Material Acquisition, Part final	30g. The impact of B1.1.5 is from a larger mass.				
	Mechanical Parts (154g) is the sum of <i>main</i>						

	<i>mechanical Parts</i> (30g) such as housing, and <i>smaller sub-parts</i> such as alloyed leadframe within ICs or glass within B1.1.6 Screens (124g).	assembly					
				30	30		
B1.1.6 Displays	LCD Screen	G2 for Display module assembly, Display panel assembly	28.3g	28.3	28.3		
B1.1.7 Printed circuit boards (PCBs)	Plastic, FR4	Raw Materials Acquisition, Raw materials Acquisition for special PCB materials, Raw materials Acquisition for PCB semi-produced composite materials, PCB final	36.2g				
				36.2	36.2		

		assembly					
B1.1.8 Other PBA components	Resistors (2 g)	Raw Material Acquisition, Part final assembly	3g				
	Capacitors (0.67g)						
	Inductors (0.17g)			3	3		
	Quartz crystal oscillators (0.054g)						
B1.1.9 Packaging materials		Raw Material Acquisition, Part final assembly	95+36.7=131.7 g				
				131.7			
	Cardboard (131.7g)						
B1.1.10 Black box modules	Camera (1.67g)	"Cradle-to- gate" LCA from supplier	1.67	1.67	1.67		
B1.1.11 Software	Purchased SW	Developmen t: e.g. daily way to work for programmer, business trips for programmer, electricity usage of ICT equipment used by programmer, office lighting. Production:	Cut-off. Tested in sensitivity analysis. Some 1.3 kg CO2e/U8350 according to previous LCAs.				

		e.g. manuals production, Data medium production, Download size if software is available as download.					
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16.9 Energy consumption use stage

Table S31: HuW application of (Table F.7 in ETSI TS 103 199)

	Energy consumption {kWh/year}	Source {long term average/standardized measurement/ modeled	Motivation/ comment
ICT equipment	2.38 (2.2 – 2.5)	<p>Huawei estimated the typical average power consumption for the studied U8350.</p> <p>BC = [mAh] Battery capacity = 1 200 V = [Voltage,V] = 3.7 Y = [years] lifetime = 2 DY = [days per year], charging = 365 CE = [%], charger efficiency = 0.6817</p> <p>Wh used per lifetime:</p> <p>$BC/1000 \times V \times Y \times DY / CE = 4\,754 \text{Wh}$</p>	Simplified purpose of LCA study. "Electricity, low voltage, at grid/FR U" from ecoinvent db. (0.108 kg CO2e/kWh)
<i>Support equipment</i>	<i>N.A.</i>		<i>Not included in studied product system</i>

16.10 End-of-life treatment

Table S32: HuW application of (Table F.8 in ETSI TS 103 199)

	Process categories included	Process Unit processes included	Handling of special issues
G6.1 EHW treatment	<i>EHW (destruction and energy recovery) Special EHW landfill</i>	<i>N.A</i>	<i>N.A.</i>
G6.2 Other Waste treatment	Incineration Landfill	Recycling/recovery/treatment	"Disposal, plastic, consumer electronics, 15.3% water, to municipal incineration/CH U"
D2. ICT specific EoLT	D2.1 Storage/Disassembly/Dismantling/Shredding D2.2 Recycling D2.2.1 Battery recycling ICT specific metal/mechanical parts/fractions EoLT D2.2.2 PCBA recycling D2.2.3 Cable recycling D2.2.4 Mechanics recycling D2.2.5 Other ICT recycling D3. Other EoLT	Recycling, recovery and treatment	"Disposal, treatment of printed wiring boards/GLO U", "Disposal, Li-ions batteries, pyrometallurgical/GLO U", Shredding, electrical and electronic scrap/GLO U".

16.11 LCI results

Table S33: HuW application of (Table F.9 in ETSI TS 103 199)

	TOTAL	Raw materials acquisition, Production, and EoLT	Use
Primary energy use[1]	698 MJ	633 MJ (41 RMA, 600 P, -8EoLT)	65 MJ
Total electricity use [2]	51 kWh	46.3 kWh	4.75 kWh
Land use [3]	1.084 m ² a	1.067 m ² a	0.018 m ² a

Fresh water use [4]	0.26 m ³	0.229 m ³	0.031 m ³
[1] Based upon ecoinvent's Cumulative Energy Demand method			
[2] 633 MJ is obtained as 698 MJ minus 65 MJ. 65 is obtained by analyzing 4754 kWh "Electricity, low voltage, at grid/FR U" for ecoinvent's Cumulative Energy Demand. 3.6 is conversion between MJ and kWh. 2.96 MJ primary energy/MJ electricity is based upon the amount of MJ primary energy/MJ electricity according to IEA (http://www.iea.org/stats/electricitydata.asp?COUNTRY_CODE=29) and ecoinvent processes "Electricity, hard coal, at power plant/UCTE S", "Electricity, nuclear, at power plant/UCTE S", "Electricity, oil, at power plant/UCTE S", "Electricity, natural gas, at power plant/UCTE S", "Electricity hydropower in UCPTE S", and "Electricity, at wind power plant 2MW, offshore/OCE S".			
[3] Based upon Agricultural land occupation + Urban land occupation from ReCiPe Midpoint (H) V1.05 / World ReCiPe H			
[4] Based upon Water depletion from ReCiPe Midpoint (H) V1.05 / World ReCiPe H			
"This LCA result cannot be compared to the result of another LCA unless all assumptions and modelling choices are equal"			

16.12 LCIA results

Table S34: HuW application of (Table F.10 in ETSI TS 103 199)

Mid-point Impact Assessment Categories included	Impact category indicator value	LCIA methodology reference
Climate change(CC) (mandatory)	39.2 kg CO ₂ e	Mid – point Category indicator: Infrared forcing as GWP100, IPCC as used by ReCiPe MidPoint (H) V1.05 "climate change"

"This LCA result cannot be compared to the result of another LCA unless all assumptions and modelling choices are equal"		

16.13 Check of fulfillment of mandatory requirements

Table S35: Checklist of fulfillment of mandatory requirements of ETSI TS 103 199

Section in ETSI TS 103 199	Requirement	OGE	HuW	OGE comment	HuW comment
4.1	Full compliance towards the present document can be claimed if all mandatory requirements are fulfilled.	No	No	See below	5.3.3.1.4 and 6.2.2.5
4.2	A third-party review is also needed if the comparison result is to be externally communicated.	Yes	Yes	U8350 is not compared to another phone	U8350 is not compared to another phone
4.2	In case of comparative assessment between ICT Equipment LCAs the operational lifetime shall be set equal.	Yes	Yes		
5.1	ISO 14040 , ISO 14044 and ETSI TS 103 199 have to be taken into account.	Yes	Yes		
5.1.1	Four high-level life cycle stages shall be assessed	Yes	Yes		
5.1.1	Transports and energy supplies shall be included in all life cycle stages.				
5.1.1	Transports of equipment between production and use stages shall be taken into account.	Yes	Yes		

5.1.1	The data collected shall be structured in such a way that the GHG emissions and energy consumption/ environmental impact arising from the transport processes could be reported transparently	No	Yes	EIME 5.0 LCA SW is incapable of reporting transports which are inside "A: Equipment Raw Material Acquisition" and "B: Production", because their impact is aggregated inside EIME model. Possible to report transports from the assembly factory to OGE shops.	
5.1.2	Software shall be considered as well as hardware	No	Yes		SW considered with alternate data and cut-off
5.1.3	Operating lifetime shall always be reported when presenting LCA results	Yes	Yes	2 years	2 years
5.1.3	Operating lifetime estimates and assumptions shall also be clearly described in the reporting	Yes	Yes		
5.2	The building blocks of the ICT Equipments shall be identified	Yes	Yes	Phone Device, Charger, Accessories and Packaging	See OGE
5.2.1.1	The functional unit requires inclusion of the relevant quantifiable properties and the technical/functional performance of the system.	Yes	Yes	Typical Use of phone functions	
5.2.1.1	The operational lifetime of all included ICT Equipment shall be specified	Yes	Yes		
5.2.1.2	The functional unit shall be chosen in the context of goal and scope of the LCA and shall be further clarified by system boundary and cut-off rules				
5.2.1.2	Annual ICT Equipment use or Total ICT Equipment use per lifetime of ICT Equipment shall be applied as	Yes	Yes	Total ICT Equipment use per lifetime of ICT Equipment	Total ICT Equipment use per lifetime of ICT Equipment

	functional unit				
5.2.2.1	Table 1 life cycle stages for ICT Equipment shall be included.	Yes	Yes		
5.2.2.1	Mandatory life cycle stages or unit processes shall not be cut-off before considered for inclusion by using alternate data	Yes	Yes		For B1.1.11 SW etc
5.2.2.1.1	Facility data shall be allocated to the targeted product system according to clause 5.3.3.1.3.	Yes	Yes		
5.2.2.1.1	Emissions (elementary flows) shall be included according to Annex E	Yes	Yes		
5.2.2.1.1	Resource objects (elementary flows) shall be included according to Annex E	Yes	Yes		
5.2.2.1.1	Energy, product and services inputs shall be included	Yes	Yes		
5.2.2.1.1	Product, water and waste outputs shall be included	Yes	Yes		
5.2.2.2.2	Raw Materials shall be included in the LCA of ICT equipment according to Annex D (Table D.1)	Yes	Yes		
5.2.2.2.3	Parts and Part unit processes shall be included where applicable to the studied ICT product system according to Annex B	Yes	Yes		
5.2.2.2.3	The Assembly (B1.2) shall include as minimum PCBA Module Assembly, Final Assembly, Warehousing, and Packaging.	No	Yes	Warehousing, Packaging, + Soldering, PCBA finish processes and SMD components gluing	Whole factory included
5.2.3	Cut-offs shall be avoided as	Yes	Yes		

	far as possible.				
5.2.3	ISO 14044 section 4.2.3.3 recommendations for cut-off shall be used as closely as possible.	Yes	Yes		
5.2.3	The cut-off criteria used within a study shall be clearly understood and described.	Yes	Yes		
5.2.3	Cut-offs from Table 1 shall be clearly motivated.	Yes	Yes		
5.2.3	All cut-offs shall be listed and motivated in the final report.	Yes	Yes		
5.2.3	Activities/processes/flows that have been cut-off shall be included in the sensitivity analysis.	No	Yes	OGE did not perform sensitivity analyses.	
5.2.4.1	The practitioner used shall reduce bias and uncertainty as far as practicable by using the best quality data achievable	Yes	Yes		
5.2.4.1	A qualitative description of the data quality and any efforts taken to improve it shall be disclosed	Yes	Yes		
5.3.1.1	The LCA practitioner shall report for which processes transports/energy supplies have been added separately and for which they are "hidden".	Yes	Yes		
5.3.1.1	Data shall be collected for all mandatory processes outlined in Table 1.	Yes	Yes		
5.3.1.2	Periods of idling and power off are important to model the usage profile and shall be included if applicable.	Yes	Yes	Charging every day	Charging every day

5.3.1.2	The LCA practitioner shall use the applicable electricity mix to calculate the potential environmental impact from the use stage more exactly.	Yes	Yes	OK for ALCA	OK for ALCA
5.3.2	All calculation procedures shall be explicitly documented and the assumptions made shall be clearly stated and explained.	Yes	Yes		
5.3.2	The same calculation procedures shall be consistently applied throughout the study.	Yes	Yes		
5.3.2	A check on data validity shall be conducted during the process of data collection to confirm that the data quality requirements for the intended application have been fulfilled	Yes	Yes		
5.3.3.1.1	Data for generic processes (G1 to G7) shall be allocated as a whole (i.e. for the full lifecycle for the generic process) to the associated life cycle stage of the product system.				
5.3.3.1.1	All Raw Material Acquisition (G5) shall be allocated to the life cycle stage Raw Material Acquisition (A).	No	Yes	EIME 5.0 LCA SW incapable	
5.3.3.1.3	Facility data for production facilities shall preferably be allocated to product systems based on relevant physical data according to Table B.1 for Parts	Yes	Yes		
5.3.3.1.4	Transports shall be allocated	No	No	Allocation procedure re-used from a previous internal	Simplified mass based

	based on chargeable weight or volume whichever limits the transport capacity			Set-top box LCA	calculation
5.3.3.1.5	Landfill shall be fully allocated to the life cycle that puts the material on a landfill, or other types of rest waste storage	Yes	Yes		
5.3.3.1.5	The material resource depletion impact and related elementary flow shall be fully allocated to the life cycle that depletes the material resource	No	Yes	EIME LCI modules cannot be modified	No allocations made, e.g. of the CO2 emissions, in gold production, to other life cycles than U8350
5.3.3.1.5	The 100/0 allocation method shall be used for calculating primary Raw Material Acquisition impact	Yes	Yes		
5.3.3.1.5	The 50/50 allocation method shall be applied when possible to allocate both the use of recycled input material in the raw material acquisition stage and the recycling of materials in the EoLT stage	No	Yes	EIME 5.0 LCA SW incapable	
5.4	In the LCA it shall be ensured that the inventory elementary flows (see Annex E) are correctly linked with appropriate LCIA characterization factors	Yes	Yes		
5.4	The mid-point category Climate change is mandatory.	Yes	Yes		
5.4	For climate change mid-point impact assessment category, the recent global warming characterization factors from the Intergovernmental Panel on Climate Change (IPCC) for	Yes	Yes		

	each greenhouse gas shall be used				
5.4	All impact categories and category indicators included shall be disclosed and justified.	Yes	Yes		
5.4	Primary energy usage = Cumulative Energy Demand (CED) and Fresh water usage are to be reported as LCI results	Yes	Yes	EIME indicator which provides total water depletion (cooling, ground, river, sea, surface and unspecified)	
5.5.1	The steps of the interpretation shall ensure the robustness of the conclusions from the LCA.	Yes	Yes		
5.5.1	The life cycle interpretation shall include an analysis of the results and the consistency, a completeness check, and a sensitivity check of the significant issues and methodological choices as to understand the uncertainty of the results.	Yes	Yes	OGE data quality method.	
5.5.2	The uncertainty of the results of an LCA shall be assessed in accordance with ISO 14044 to the extent needed to understand the results.	Yes	Yes		
5.5.2	The sources of uncertainty and methodological choices made shall be assessed and disclosed.	Yes	Yes		
6.1	The reporting of ICT product systems shall fulfil the reporting rules as defined by ISO 14040 and ISO 14044	Yes	Yes		
6.1	Annex F shall be followed for	No	Yes		

	reporting of studies claiming compliance with the present document.				
6.1	The report shall contain a compliance statement saying either that the LCA fully complies with the present document (in case of full compliance) or that the LCA partially complies with the present document with the exception of transparently listed and justified requirements (partial compliance).	Yes	Yes		
6.1	The extent in which Support activities and other optional/recommended activities are excluded for different parts of the life cycle shall be clearly described	Yes	Yes		
6.1	Operating lifetime: All lifetime assumptions shall be stated and motivated.	Yes	Yes		
6.1	Cut-off: Any cut-off made shall be clearly stated and motivated	Yes	Yes		
6.1	Allocations: Basis for allocations made shall be described, especially for recycling, use of recycled materials, distribution of facility data and support activities.	No	Yes	EIME 5.0 LCA SW incapable	
6.1	Data sources: Data sources (i.e. specific/generic) shall be clearly stated, and deviations towards Table 2 shall be motivated	Yes	Yes		

6.2.1	Figures 9a shall be reported	No	Yes	EIME 5.0 LCA SW incapable	
6.2.1	Operating Lifetime: number shall always be present in the graph	Yes	Yes		
6.2.1	Figure 9a shall be accompanied by the disclaimer "This LCA result cannot be compared to the result of another LCA unless all assumptions and modelling choices are equal".	Yes	Yes		
6.2.1	For transports, the total result including all transports throughout the life cycle (Annex F, Table F.4) shall be stated in the immediate proximity of Figure 9a	No	Yes	EIME 5.0 LCA SW incapable	
6.2.1	A graph summarizing distribution of environmental impact category indicators between life cycle stages according to Figure 11 shall also be presented together with absolute figures	Yes	Yes		
6.2.1	Figure 11 shall be accompanied by the disclaimer "This LCA result cannot be compared to the result of another LCA unless all assumptions and modelling choices are equal".	Yes	Yes		
6.2.2	Any deviation to Table 1 and clause 5.2.2 with respect to mandatory life cycle stages/unit processes shall be clearly stated and motivated.	Yes	Yes		
6.2.2	Also handling of optional stages/activities shall be clearly reported as well as	Yes	Yes		

	electricity mix applied, and handling of support activities and transports.				
6.2.2	Especially for transports, lack of transparent data are common for many unit processes, which shall be considered for the reporting.	Yes	Yes		
6.2.2	Additionally, inclusion of generic processes shall be clearly stated in a flow diagram combined with the main life cycle stages/unit processes.	Yes	Yes		
6.2.2.1	Generic processes deviations shall be reported according to Annex F, Table F.3.	Yes	Yes		
6.2.2.1	For reporting of transports and travel refer to Annex F, Table F.4	No	Yes	EIME 5.0 LCA SW incapable	
6.2.2.3	The use of raw materials shall be transparently reported according to Annex F, Table F.5.	No	Yes	EIME 5.0 LCA SW incapable	
6.2.2.4	Compliance to Annex B, Table B.1 shall be reported according to Annex F, Table F.6.	Yes	Yes		
6.2.2.5	The basis for the energy consumption figures for the ICT equipment use stage shall be reported together with the annual value of the energy consumption.	Yes	Yes		
6.2.2.5	Transparently report distribution over time for different usage modes including power off and idle	No	No	The use stage was not modeled on the basis of different use modes.	The use stage was not modeled on the basis of different use modes.

	and the basis for those.				
6.2.2.6	Any deviations towards Annex C shall be transparently reported and motivated.	Yes	Yes		
6.2.3	For LCI the following items shall be reported transparently: total use of primary energy, electricity, land use, and fresh water according to Annex F, Table F.9	Yes	Yes		

17. References

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