Collection rate and reliability are the main sustainability determinants of current fast-paced, small, and short-lived ICT products

ANDERS S. G. ANDRAE [1]
[1]Huawei Technologies Sweden AB
Skalholtsgatan 9, 16494 Kista
SWEDEN
[1] anders.andrae@huawei.com

Abstract: Improved material efficiency as a means of improving product sustainability scoring is of large interest. Here a theoretical idea of how collection rate, reliability and simple refurbishing affect the life cycle score is presented. There is some misconception that repair, refurbishment and remanufacturing would bring huge benefits in bringing down the environmental impact and amounts of electrical and electronic waste. Here is suggested that longevity of the first new product is superior to other operations such as repair, reuse, and upgrade strategies under the present low collection rates. However, refurbishing a product with spare parts might be interesting environmentally if the collection rate is very high. The ideas are demonstrated for a typical smartphone via simplified attributional Life Cycle Assessment. It seems like massively increasing the collection rate - and designing resilient smartphones - would systemically be very effective and efficient for reaching a high material efficiency. The answer is not to refurbish, repair or replace, instead the answer is to use the first new product as long as technically possible.

Key-Words: Circular economy; life cycle assessment; collection rate; refurbish; reliability; smartphone.

1 Introduction

Improved material efficiency – raw materials related resource efficiency - as a means of improving sustainability scoring of products is of large interest. Especially in the European Union (EU) a large trust is put in forthcoming standardization of assessment methods for product material efficiency [1]. The EU assumes that the largest barrier of improved material efficiency is lack of a large numbers of product metrics which then can be used for regulation and legislation. This paper argues that reliability in itself - and subsequently the reliability metrics - is most important for smartphones.

Kasulaitis et al. argued that circular economy approaches aimed at closing the loop on consumer electronic material still face several critical barriers particularly related to design and efficient recycling infrastructure [2].

It is still an open issue, however, how improved societal and product material efficiency is best achieved [3]. Some argue more recycling, some more repair, some more refurbish, and some more leasing or even remanufacturing. Making products more reliable and durable in the first place, i.e. minimizing the need for some of the other circular strategies, seem to have fewer proponents.
Hence, there is a need for an overarching study on the advantages and drawbacks associated with different options. Reliability could - for certain product groups and situations - be more important for improved material efficiency than reparability and (hardware) upgradeability.

A reliable product has high resistance to wear and tear without breaking down and also operates throughout a specified period without failure [4]. The durability can for instance be increased - beyond the reliability of the first new product - by repair, refurbish, upgrade and re-manufacturing.

Tasaki et al. performed Life Cycle Assessments (LCAs) and argued that there are optimum replacement times for TVs, air conditioners and refrigerators, depending on manufacturing cost and energy efficiency of new and old products [5].

Bracquené et al. performed LCAs of laptops and concluded that durability should be the priority over repair and recycling for laptops [6].

Slowly it seems like an awareness is coming that repair, refurbish and re-manufacture may not be as beneficial as believed. However, each energy using product is unique and needs its own analysis.

No publication could be found describing how the collection rate and lifetime of smartphones is related to the environmental impact when compared to other circular economy strategies.

The existing literature contains some LCAs and similar studies with variable assumptions. The effect of collection rate on the final score is usually neglected. Moreover, very commonly, there is no way to be certain that fair functional units and system boundaries have been set. Reuse focused LCAs are also rare. The following briefly describes a quick attributional LCA study comparing reliability with refurbishment for improving the longevity of smartphones.

2 Problem Formulation

In the present research the hypothesis is that ensuring a high reliability of the first new product (here smartphones) is superior to a refurbish strategy seen form an environmental standpoint, unless the collection rate is close to 100%.

3 Problem Solution

Below follow the results of three simplified attributional LCAs investigating the potential environmental impact related to reliability, refurbishment and collection rate as far as end-of-life strategies of new generic smartphones.

For ultimate transparency, Section 3 contains detailed descriptions of the practical simulation done within SimaPro 8.5.2.0 of each life cycle stage. Such details are not common as it is expected that simulation practice in LCA tools is well-known to SimaPro users in this case. However, it is assumed that variations in model set up could have an impact of the final result. Notably the end-of-life treatment model is important in this regard.

The *first* scenario (S1) assumes that the user buys one phone ("big" battery) and uses it 4 years after which it is kept at the buyer's home or collected for metal and energy recovery. Software upgrades are done during these 4 years without impacting "the speed" of the phone. S1 is video intense and there will be 39 hours between full charges of the relatively "big" battery of 4 Ah. 5% or 100% of the phones are collected, then recovered and recycled.

The *second* scenario (S2) assumes that the user buys one phone with a "small" battery of 2 Ah and uses it for one year after which it is collected and refurbished with a new battery, or kept at the buyer's home. Likely the small battery is of need of replacement sooner than a bigger one, if the phone is used heavily. All batteries in the collected phones can be replaced. The refurbished phone is used three years and then collected for metal and energy recovery. Whenever the phone is not collected in S2 it is replaced by a new phone. So when the collection rate is 100% the difference between the first and second scenarios is the extra battery needed in the second. However, when the collection rate is 5%, 3×0.95=2.85 extra life cycles are added. In those life cycles neither metal recycling nor a second refurbishment is included, only hoarding after one year use. S2 is video intense and therefore the small 2 Ah battery only lasts 31 hours between full charges. For both 5% and 100% collection rate, the battery is replaced with a new one, and the refurbished phone is reused 3 years.

The *third* scenario (S3) assumes that the user buys one phone ("big" battery) and uses it for one year after which it is hoarded and the user buys a new one three times. The phone is not collected, reused or recycled. S3 is video intense and the 4 Ah battery lasts 39 hours between full charges. 0% of the phones are collected and 100% are hoarded at home.

3.1 Major Assumptions

Table 1 shows some of the major assumptions done in the simplified LCAs.

Table 1**.** Scenarios for the smartphone headset lifecycle.

Scenario 1 (S1)	**Scenario 2 (S2)**	**Scenario 3 (S3)**
"Typical smartphone" production cradle-to-gate, 183 ELU/piece	"Typical smartphone" production cradle-to-gate, ~170 ELU/piece.	"Typical smartphone" production cradle-to-gate, 183 ELU/piece
Battery impact ~24 ELU/piece.	Battery impact ~11 ELU/piece	Battery impact, ~24 ELU/piece.
Airplane distribution	Airplane distribution	Airplane distribution
European average impact electric	EAIEP for Use and Reuse	EAIEP for Use

power (EAIEP) {~0.36 ELU/kWh} for Use		
No reuse. 5% or 100% collection. Then recycling of Al, Au, Ag, Cu, Co. Incineration of packaging materials and plastics.	5% or 100% collection. 5% or 100% disassembly and battery change. 5% or 100% reuse 3 years. Then, according to S1, recycling of Al, Au, Ag, Cu, Co. Incineration of packaging materials and plastics.	Neither collection nor reuse or recycling

3.1.1 Functional unit

The functional unit chosen here is rather simplistic: *"3G/4G access for 1 hour daily calling and enable use of a 1440×2560 pixels video player for 2 hours web browsing and 4 hours video watching daily for 4 years."* The reference lifetime is four years. This simplicity fits the objective of screening attributional LCA of smartphones in order to indicate which end-of-life strategy could be better than others.

Table 2 shows how the functional unit is determined.

Table 2. Functional unit determination for smartphone.

Functional unit constituents	**"Big" battery smartphone**	**"Small" battery smartphone**
What?	Provide wireless access to one smartphone.	Provide wireless access to one smartphone.
When?	2018	2018
How much?	1 hours 3G calling, 2 hours web browsing and 4 hours video watching per day.	1 hours 3G calling, 2 hours web browsing and 4 hours video watching per day.
How long?	For 4 years.	For 4 years.
How well?	1440 × 2560 pixels resolution (499 pixels per inch as pixel density) at 3G/4G speed.	1440 × 2560 pixels resolution (499 pixels per inch as pixel density) at 3G/4G speed.
Reference flow	1 Smartphone with its primary packaging and Charger. One smartphone device (64 GigaByte (GB) storage, 5.9 inch screen size, 20 Mega Pixel (MP) Video Recorder, 4 GB Random Access Memory (RAM) memory, 4,000 mAh battery capacity Environmental impact/[Resolution (pixel density)×Storage (GB)×Display size (inches)×Video recorder (MP)×RAM (GB)×Battery capacity (mAh)×Lifetime (years)]	1 Smartphone with its primary packaging and Charger. One smartphone device (64 GigaByte (GB) storage, 5.9 inch screen size, 20 Mega Pixel (MP) Video Recorder, 4 GB Random Access Memory (RAM) memory, 2,000 mAh battery capacity Environmental impact/[Resolution (pixel density)×Storage (GB)×Display size (inches)×Video recorder (MP)×RAM (GB)×Battery capacity (mAh)×Lifetime (years)]
Functional unit	*3G/4G access for 1 hour daily calling and enable use of a 1440×2560 pixels video player for 2 hours web browsing and 4 hours video watching daily for 4 years.*	*3G/4G access for 1 hour daily calling and enable use of a 1440×2560 pixels video player for 2 hours web browsing and 4 hours video watching daily for 4 years.*

The difference between the phones is the size and capacity of the batteries within. The smaller sized battery is assumed to lead to a faster replacement of the battery and/or the entire phone, compared to the phone with the bigger battery (S1).

System boundaries

The studied product system only considers the smartphone share of the hardware needed to provide the functions expressed in Table 2. Networks and data centers – that are necessary to fulfil the function of the smartphones - are excluded.

Within SimaPro, known to its many users, the overall level – the LifeCycle level – consists of 1 piece of Assembly, one input process for Electricity for the first user and a Disposal scenario. Of course many more processes (e.g. other energy carriers and transports) could be added, however in the present simplified attributional LCA no others are necessary. In the Assembly in SimaPro LCA software, the Pre—Final Assembly – Raw Material Acquisition & Part Production - and Final Assembly (FA) and the Distribution are modeled.

SimaPro details

The LifeCycle Level of S1 has “Big Battery Smartphone”-Assembly, one Electricity input flow, and “Disposal scenario for Big Battery Smartphone”.

The LifeCycle Level of S2 has an additional lifecycle called “Small Battery Smartphone 1 year + hoarding”. The amount of that life cycle is 3×(1-CR_SF), where CR_SF means collection rate for smartphones, 0.05 (5%) or 1 (100%). CR_SF is added to “Inventory” and “Parameters” at the LCA Explorer level in SimaPro. “Small Battery Smartphone 1 year + hoarding” life cycle consists of “Small Battery Smartphone”-Assembly, Electricity, and “Small Battery Smartphone Hoarding”.

The LifeCycle Level of S3 has “Big Battery Smartphone”-Assembly, Electricity, and “Big Battery Smartphone Hoarding”. Four life cycles are required in S3 in order to be comparable to S1 and S2.

3.1.2 Pre—Final Assembly – Raw Material Acquisition & Part Production - and Final Assembly (FA)

The pre—final assembly considers mechanical parts (plastics and screws etc.) and electronics seen from a cradle-to-gate viewpoint. For screening LCAs and the purpose of this research, secondary LCI data are enough. The masses and material contents of each part are identified from bill-of-materials lists. The total mass of the generic smartphone and its packaging materials are ≈340 grams and ≈260 grams, respectively. The “small” battery phone has a smaller total mass than the “big” battery phone. FA impacts are assumed equal for all phones. No support activities - such as product development and marketing - are included.

3.1.2.1 Description of the life cycle impact assessment method EPS2015

The bearing idea of EPS2015 [6] is the cost per LCI flow of reaching sustainability in 2100. As such, EPS2015 addresses long-term costs, but not the long-term market effects. The cost is the one for protecting so-called safeguard subjects of which abiotic resources is one example and ecosystem services is another.

EPS2015 is chosen as it results in a single score which is enough for the precision of the present study.

3.1.2.2 Description of the modelling in SimaPro

Here follows a more or less exact account of how section 3.1.2 is set up in SimaPro.

The Assembly level consists of Materials/Assemblies and Processes.

The Assembly refers to 1 piece of Big Battery Smartphone. It is called “Big Battery Smartphone Assembly”. In turn it consists of different pieces of Assemblies – added to Materials/Assemblies - of Universal Serial Bus (USB), Aluminium components, Battery, Camera, Charger, Documentation, Integrated Circuits (IC), Capacitors, Resistors, Gold components, Indium components, Displays, Packaging, Printed Circuit Boards (PCBs), Plastics, Silver components, Tin components, Final Assembly (FA) and Others components. Each amount of the Assemblies within “Big Battery Smartphone Assembly” are expressed in pieces, however, the units are grams or cm^2 where appropriate. For example, 50 pieces of “Battery” refers to 50 grams of “Battery” and 3 pieces of “Integrated Circuits (IC)” refers to 3 cm^2 of Integrated Circuits (IC)”. As an example the “IC assembly, expressed in pieces in “Big Battery Smartphone” - but referring to cm^2 die inside the IC - consists of a *Material* called “IC without Gold and Silver components”, expressed in kg. Here 1/400 kg of “IC without Gold and Silver components” per cm^2.

All in all, 1 piece of Big Battery Smartphone renders around 183 Environmental Load Units (ELU) by EPS2015 evaluation. The largest contributors are USB 42%, Gold components 18%, Battery 13%, Charger 11%. Gold is the dominating inventory flow.

Table 3 shows the ELU scores for each piece commonly expressed per gram.

Table 3. Environmental Load Unit (ELU) impacts for assemblies used in the smartphones.

Assembly	**“Big” battery smartphone**	**“Small” battery smartphone**
Universal Serial Bus (USB)	40 ELU/gram(g)	
Aluminium	0.0013 ELU/g	
Battery	0.43 ELU/g	
Camera	0.13 ELU/g	
Charger	0.2 ELU/g	
Documentation	0.001 ELU/g	
Integrated Circuits (ICs)	0.076 ELU/cm^2	
Capacitors	2.26 ELU/g	
Resistors	0.0069 ELU/g	
Gold	2000 ELU/g	
Indium	77 ELU/g	
Display	0.19 ELU/cm^2	
Packaging	~0 ELU/g	
Printed Circuit Boards (10 layers)	0.034 ELU/cm^2	
Printed Circuit Boards (6 layers)	0.025 ELU/cm^2	
Plastics	0.0028 ELU/g	
Silver	58 ELU/g	
Tin	0.59 ELU/g	
Final assembly	0.02 ELU/cm^2	

There might be differences - except for the Battery - between the phones, however, these differences have been disregarded. There exist many variants of each Assembly in Table 3 (e.g. plastics), but this study is only indicative, and it is judged that the simplicity offered is enough to draw conclusions.

3.1.3 Distribution

For S1—S3 the distribution assumes 1000 km transportation by truck from FA to the airport, and then 9500 km by air, and then 1000 km by truck from the airport to final use.

3.1.3.1 Description of the modelling in SimaPro

The transportation processes are added in the “Processes” field in the Big Battery Smartphone Assembly – below Materials/Assemblies as truck and air transports. The sum of the mass of the phone and its packaging materials - and documentation - is multiplied with the distances and values of ton×km are obtained, 5.72 for aircraft freight and 0.602 for Lorry freight.

Table 4 shows the ELU scores used for transportation.

Table 4. Environmental Load Unit (ELU) impacts for transport used in the smartphones

Process	**“Big” battery smartphone**	**“Small” battery smartphone**
Aircraft freight	0.2 ELU/[ton×km]	
Lorry freight	0.059 ELU/[ton×km]	

3.1.4 Use

The direct electricity use of a smartphone is generally related to the power use of different viewing modes. This implies that the range for the power consumption could be wide.

Lifetime electricity use calculation is done according to Equations 1-3.

$$USE = ABCD \times \frac{1}{E} \times \frac{F}{G} \qquad (1)$$

Where

USE = Lifetime Wh electricity use of a smartphone

A = Battery capacity [Ah], 4 for S1 and 2 for S2

B = Voltage [V]

C = Lifetime of smartphone [years]

D = 365 [days per year]

E = energy efficiency of the power adapter [%]

F = 24 [hours per day]

G = time between having to fully charge the battery if doing 1 hour 3G calls, 2 hours web browsing and 4 hour video playing [hours]. G is measured by 3rd party organization.

Inserting values into Equation 1 {A=4 Ah, B=3.82 V, C=4 years, E=78%, G=39 for S1 or 31 hours for S2} →

{for S1}

$$USE = 4 \times 3.82 \times 4 \times 365 \times \frac{1}{78\%} \times \frac{24}{39} \sim 17600Wh \quad (2)$$

{for S2}:

$$USE = 2 \times 3.82 \times 1 \times 365 \times \frac{1}{78\%} \times \frac{24}{31} \sim 2770Wh + \{\text{reuse}\} \quad 2 \times 3.82 \times 3 \times 365 \times \frac{1}{78\%} \times \frac{24}{31} \sim 8300Wh \quad (3)$$

{for S3}:

$$USE = 4 \times 3.82 \times 1 \times 365 \times \frac{1}{78\%} \times \frac{24}{39} \sim 4400Wh \quad (4)$$

The proposed approach - for estimating lifetime electricity in the use stage - seems fair as all factors are measurable including G which is obtained from GSM Arena battery life tests [8]. The difficulty might lie in deciding the normal behaviour scenario. Still G will scale equal for all smartphones independent of G settings.

No maintenance is included.

3.1.4.1 Description of the modelling in SimaPro

The appropriate mix for European average impact electric power (EAIEP) is added to "Processes" at the LifeCycle Level. The numerical values of Eq. 1 are inserted in the Amount cell. The unit is set as Wh. When evaluating and comparing in SimaPro, S3 requires four lifecycles compared to one each for S1 and S2.

Table 5 shows the approximate ELU score per kWh.

Table 5. Environmental Load Unit (ELU) impacts for use stage electricity used by the smartphones

Process	**"Big" battery smartphone**	**"Small" battery smartphone**
European average impact electric power (EAIEP)	0.36 ELU/kWh	

3.1.5 End-of-life treatment (EoLT)

For EoLT simplified disposal scenarios are setup featuring shares for a waste scenario and reuse, respectively.

Here follows a short description of the end-of-life scenarios.

S1: The disposal scenario refers to one assembly of the smartphone. The waste scenarios are Metal and Energy Recovery (5% or 100%) or Hoarding (95% or 0%). Metal and Energy Recovery assumes that the entire product is transported 1000 km by truck to metal recovery and/or incineration. Recycling of some valuable metals, e.g. Au, is modelled by the 50/50 allocation approach. EAIEP is assumed to be avoided as electric power could be recovered as a by—product of plastics waste incineration.

S2: The disposal scenario refers to one assembly of the smartphone. Process used is "Reuse of smartphone 3 years" (Eq.3), the waste scenario is Hoarding, and the Disassembly is Smartphone disassembly.

S3: The disposal scenario refers to one assembly of the smartphone. The waste scenario is Hoarding.

3.1.5.1 Description of the modelling of waste management of smartphones in SimaPro

S1 after use modeling

At the Life Cycle level the Waste/Disposal scenario, a Disposal Scenario is created. It is called “Disposal scenario for Big Battery Smartphone”. In the field “Referring to assembly” the Assembly created in section 3.1.2.2 “Big Battery Smartphone Assembly” is chosen. In the field “Waste scenarios” a waste scenario called “Big Battery Smartphone recovery” is chosen as well as “Big Battery Smartphone hoarding”. As “Percentage” CR_SF×100 and (1-CR_SF×100) are chosen, respectively.

The waste scenario “Big Battery Smartphone recovery” is the name of the “Waste specification”, the Amount is the total mass of the smartphone and its packaging materials in grams, and the “Category” is “Smartphones”. In “Inputs from technosphere: materials/fuels” a transport is added for the transport of the phone to material and energy recovery. Next the field “Materials and/or waste types separated from the waste stream” is populated. “Waste scenarios/waste treatments are added”. First a waste treatment called “Energy recovery of plastics in smartphones” is created. It has Material/Waste type “Plastic casing in smartphones” which is used by the Assembly called “Plastics” (Table 3). The “Percentage” is 100% as that is the mass share of plastics of “Plastic casing in smartphones”. “Default material/waste type” for “Energy recovery of plastics in smartphones” is “All waste types” with Amount 1 kg. To the field “Outputs to technosphere. Avoided products.” EAIEP electricity is added and the Amount is 0.92 (proportion of the plastic which is used for energy recovery) × 0.51 (Quality of secondary plastics/Quality of primary plastics) × 4 (Lower heating value of plastics and efficiency of the process for electricity) MJ/kg = 1.88 MJ/kg. These data are from the Product Environmental Footprint (PEF) Guide from 2016.

Second a waste treatment called “Incineration of cardboard” is created. It has Material/Waste type “Packaging materials” which is used by the Assembly called “Packaging” (Table 3).

As far as material recovery and recycling two examples are provided. A waste treatment process is created called “Recycling of cobalt in LiCo batteries in smartphones” which has Material/Waste type “Battery (LiCo) in smartphones” which is used by the Assembly called “Battery” (Table 3). The “Percentage” is 30% as that is the mass share of cobalt of “Battery (LiCo) in smartphones”. The “Default material/waste type” for “Recycling of cobalt in LiCo batteries in smartphones” is “All waste types” with Amount 1 kg. To the field “Outputs to technosphere. Avoided products.” Cobalt primary production is added and the Amount is 0.5 (Allocation factor of burdens and credits between supplier and user of recycled materials) × 0.933 (The proportion of the material in the product that will actually be recycled (or reused) in a subsequent system, here smelter recycling efficiency) = 0.467 kg. These data are from the Product Environmental Footprint (PEF) Guide from 2016.

Another example is gold recovery from Printed Circuit Board Assemblies (PCBAs) and USB Cables. Two waste treatment processes are created called “Recycling of gold in smartphone PCBAs” which has Material/Waste type “Primary gold production”, and “Recycling of gold in USB Cables” which has Material/Waste type “USB for smartphone charger”. The “Percentage” is 100% for “Recycling of gold in smartphone PCBAs” as that is the mass share of gold in “Primary gold production”. For “Recycling of gold in USB Cables” the “Percentage” is 1.8% as that is the share of gold in “USB for smartphone charger”.

Similarly, the parts containing aluminium and silver are modelled completing the waste scenario “Big Battery Smartphone recovery”.

S2 after use simulation

S2 is different from S1 as disassembly is used. The scenario is called “Disposal scenario for Small Battery Smartphone”. In the field “Referring to assembly”, the 1 piece of the Assembly created in section 3.1.2.2 “Big Battery Smartphone Assembly” is chosen. In the Processes field a new process called “Reuse of Small Battery Smartphones 3 years” is created and the Amount is CR_SF pieces. In the Waste scenarios field “Small Battery Smartphone Hoarding” is added and the Percentage is (1-CR_SF)×100%. In the Disassemblies field a new disassembly is created called “Small Battery Smart phone disassembly” with Percentage CF_SF×100%. This means that only the refurbished phones are reused 3 years and those which are not refurbished will be replaced by new phones.

“Reuse of Small Battery Smartphones 3 years” has Reuse of Small Battery Smartphones 1 piece output and EAIEP input according to the second term of Eq.3.

In the field “Referring to assembly”, within “Small Battery Smart phone disassembly”, 1 piece of “Big Battery Smartphone Assembly” is chosen. In the field “Separation of sub-assemblies. Disposal scenarios.”, a list of sub-assemblies are shown according to Table 3. For one of them, “Battery”, a disposal scenario is created, “Disposal scenario of smartphone batteries”, and 100% is added. This means that it is assumed that all of the batteries within the collected phones can be replaced. For the field “Treatment of remaining waste. Waste scenarios.” the waste scenario “Big Battery Smartphone recovery” is chosen, and Percentage 100%. This means that every part of the phone - except the battery - is treated according to that waste scenario. “Disposal scenario of smartphone batteries” consist of the referred assembly “Battery”, 1 piece, the Processes EAIEP (kWh used per phone per battery replacement) and “Battery production” 1 gram, and the waste scenario “Landfill of smartphone batteries”. “Battery production” consists of “Battery production” 1 gram output and 3.61 gram input of “Battery (LiCo) in smartphones”.

S3 after use simulation

In S3 the waste scenario is “Big Battery Smartphone Hoarding”.

Table 6 shows the ELU scores used for end-of-life treatment.

Table 6. Environmental Load Unit (ELU) impacts for End-of-Life treatment waste scenarios used in the smartphones.

Assembly	**“Big” battery smartphone**	**“Small” battery smartphone**
Lorry freight	0.0072 ELU/[ton×km]	
Primary aluminium production avoided	1.68 ELU/kg	
Primary gold production avoided	2000000 ELU/kg	
Primary cobalt production avoided	245 ELU/kg	
Primary silver production avoided	58000 ELU/kg	
Battery production	430 ELU/kg	
European average impact electric power (EAIEP)	0.36 ELU/kWh	

4 Results

As shown in Figs. 1-3, the most effective way of reducing the overall environmental impact – at least as far as EPS2015 for current relatively low collection rate - of a new mobile phone is to strive for maximum hardware and software quality - and reliability - and therefore reach a high durability at a low cost (S1). However, as shown in Fig.2, if the collection rate is 100%, refurbishing (S2) might be equal to S1 for EPS2015. For collection rates (Fig.3) below 100% it is more doubtful even though EPS2015 scores are tremendously uncertain.

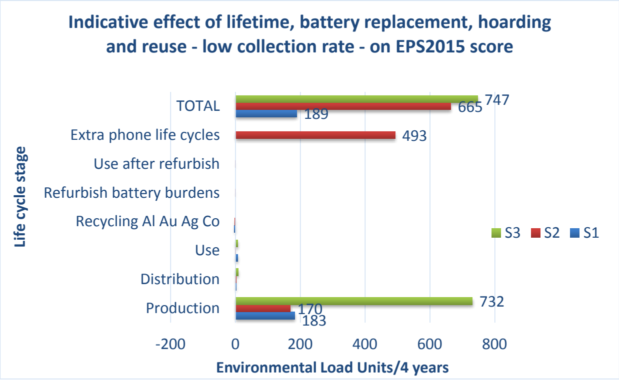

Fig.1 Indicative effect on EPS2015 score of durability strategies of mobile phones for a low collection rate (5%).

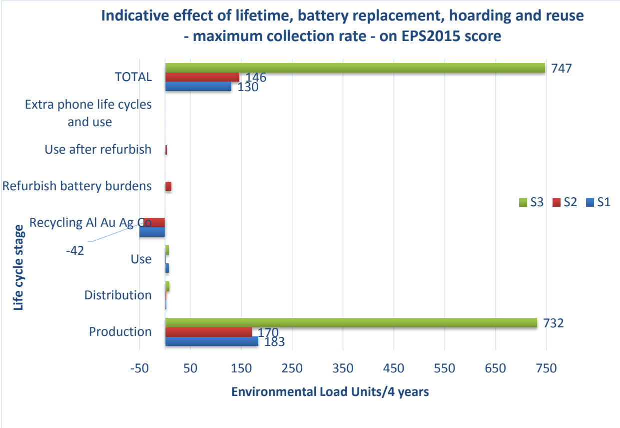

Fig.2 Indicative effect on EPS2015 score of durability strategies of mobile phones for a maximum collection rate.

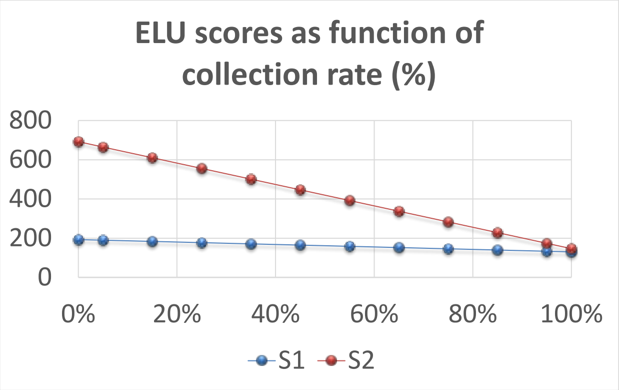

Fig.3 Relative EPS2015 scores as a function of collection rate for Scenario 1 (S1) and Scenario 2 (S2).

5 Discussion

Any environmental assessment - such as LCA - involves plenty of assumptions, major and minor ones. It is of huge importance get the major assumptions right. The latest developments in standardization have helped in this regard. Hence, it is nowadays difficult for LCA practitioners to “show whatever they want”, even with a simplistic LCA such as the present study.

The key message from this paper is the substantially better score for reliable and durable phones - compared to replacing the battery - under low collection rates. However, at high/maximum collection rates, refurbishing (S2) is seemingly as good as S1, as fewer extra phones need to be produced.

Anyway, the collection rate (CR_SF) of smartphones is globally far from 100% suggesting that a reliable smartphone product which is kept 4 years by the first user (Scenario 1) is currently the best option for the environment. The collection rate for smartphones is perhaps around 10% globally and increasing, e.g. 15% in the EU. The collection rate will probably increase if refurbished phones become more popular [9].

There is no reason to believe that refurbished phones eventually will have a much higher recycling rate than durable phones. However, those phones collected in S2 – under the control of professional repair services - for which the battery cannot be replaced after 1 year, might have a higher probability of being recycled than durable phones, under the control of the first buyer (S1).

Environmental impact is just one of three pillars of sustainability. However here the damage cost weighting method EPS2015 is used, which captures social and economic aspects too. The discussion on which impact assessment methods are preferable, for which LCA, is ongoing.

This research does not speculate about which business model overall is the best for a supply chain. It focuses entirely on environmental aspects of a limited case study. In the end it will always be the business case with the highest profit margin which will prevail [10]. For smartphones a high reliability and durability might not at all be the best business case. On the other hand, durable products likely have a higher “second-hand” value than less durable products which have to be refurbished - or repaired - to become durable. Reliable products might have a higher share of unimpaired spare parts which can be reused in second hand smartphones.

Naturally the environmental damage cost of new spare parts will determine the outcome. Here only one part, the LiCo battery, is chosen. Smartphones might have several other so called priority parts, e.g. the display.

In summary one might speculate that the entire material efficiency standardization efforts – in their current form as applied to smartphones and beyond - will miss the intended target: an increased material efficiency. The standardization focuses currently on matters which are more or less irrelevant to the end-users. It could be much more effective for society to regulate the maximum repair cost within the warranty, to regulate an increased warranty time without introducing costly service agreements, and, not the least, to ensure the achievement of the collection rate targets.

6 Conclusion

Based on a collection rate of 5%, a high reliability of the smartphone - preventing refurbishing and repair, is the best option environmentally for smartphones.
Refurbishing can be as good as reliability if the collection rate would be 100%. This is a reflection of assumed equal recycling rate of the used phones.

7 Next steps

It would be a good idea to add - and compare - more scenarios including more priority parts such as displays, collection rates, repair, upgrades, remanufacturing, reused parts, and recycled content of critical raw materials. Other LCAs of energy related products - estimating material efficiency and environmental impacts - should carefully investigate the reliability, durability extension and collection rate.

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