Ecodesign preparatory study on mobile phones, smartphones and tablets

Final Task 6 Report

Design options

Written by Fraunhofer IZM, Fraunhofer ISI, VITO
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CONTENT

FIGURES

TABLES

1 GLOSSARY

Term	Definition
ABS	Acrylonitrile Butadiene Styrene
AMOLED	Active Matrix Organic Light Emitting Diode
BAT	Best Available Technologies
BGA	Ball Grid Array
BNAT	Best Not yet Available Technologies
BOM	Bill-of-Materials
CNC	Computerized Numerical Control
CO2	Carbon Dioxide
CPU	Central Processing Unit
DECT	Digital Enhanced Cordless Telecommunications
DO	Design option
DRAM	Dynamic Random Access Memory
EN	European Norm
EoL	End of Life
EPS	Expanded Polystyrene
eSIM	embedded SIM
EU	European Union
GaAs	Gallium Arsenide
GB	Gigabyte
GF	Glass Fibre
GPU	Graphics Processing Unit
Hz	Hertz
IC	Integrated Circuit
ICT	Information and Communications Technology
IP	Internet Protocol
IPS	In-Plane Switching
ISO	International Organization for Standardization
ITO	Indium-Tin-Oxide
JRC	Joint Research Centre
kWh	Kilowatt Hour
LCA	Life Cycle Assessment
LCD	Liquid Crystal Display
LCO	Lithium-Cobalt-Oxid
LDPE	Low Density Polyethylen
LED	Light Emitting Diode
LGA	Land Grid Array
LIB	Lithium-Ion Battery
LLCC	Least Life Cycle Cost
mAh	Milliampere Hour
MCU	Microcontroller Unit
MEErP	Methodology for the Ecodesign of Energy-related Products
MLCC	Multi-Layer Ceramic Capacitors
NAND	Not And
NiMH	Nickel-Metal Hydride

Term	Definition
OEM	Original Equipment Manufacturer
OLED	Organic Light Emitting Diode
PA	Polyamide
PC	Polycarbonate
PCB	Printed Circuit Board
PCR	Post Consumer Recycled
PCT	Projected Capacitive Touch
PIR	Post Industrial Recycled
PMMA	Poly(methyl methacrylate)
PoP	Package-on-Package
PSU	Power-Supply Unit
PVC	Polyvinyl Chloride
QFN	Quad Flat No-Lead
rABS	recycled Acrylonitrile Butadiene Styrene
RAM	Random-Access Memory
RF	Radio Frequency
RJ	Registered Jack
SD	Secure Digital
SDHC	Secure Digital High Capacity
SDRAM	Synchronous Dynamic Random Access Memory
SDXC	Secure Digital Extended Capacity
SIM	Subscriber Identity Module
SMD	Surface Mounted Devices
SoC	System-on-Chip
SOC	State Of Charge
SOT	Small Outline Transistor
SSD	Solid State Drive
TB	Terrabyte
TEP	Triethyl Phosphate
TPU	Thermoplastic Polyurethane
TWh	Terrawatt Hour
US	United States
USB	Universal Serial Bus
V	Volt
W	Watt
WEEE	Waste Electrical and Electronic Equipment

2 INTRODUCTION

Preparatory studies aim to assess and specify generic or specific ecodesign measures for improving the environmental performance of a defined product group, sometimes in combination with energy label criteria. The ecodesign preparatory studies therefore provide the scientific foundation for defining these generic and/or specific ecodesign requirements as well as energy labelling criteria. The overall objective is to clearly define the product scope, analyse the current environmental impacts of these products and related systems (extended product scope) and assess the existing improvement potential of any measures. The central element of the MEErP (Kemna 2011; Mudgal et al. 2013), being the underlying assessment methodology, is to prioritise today's possible improvement options from a Least Life Cycle Cost (LLCC) perspective. Identification of the improvement options are based on possible design innovations, Best Available Technologies (BAT) for the short term and Best Not yet Available Technologies (BNAT) for long term, which can help in mitigating the impacts of these products.

Objective: Task 6 identifies the most relevant design improvement options, and quantifies their influence on environmental impacts and LCC for the consumer compared to the results of Task 5 for the Base Cases. One or more solutions of BAT and LLCC need(s) to be identified. The LLCC is the designated target level for Ecodesign measures, as indicated in the Ecodesign directive. Further environmental improvements beyond the point of Least Life Cycle Costs up to "Best Available Technologies" can qualify as mid- or long-term targets. The cumulative effects of combining multiple design options will be assessed.

3 SUBTASK 6.1 – IDENTIFICATION OF DESIGN OPTIONS AND ASSESSMENT OF THEIR IMPACTS

Design options and underlying data are derived mainly from prior tasks as described in the following sub-chapters. Options are grouped under the following sub-chapters:

- Reliability
- Operating system, software and firmware
- Reparability
- Use of materials
- Readiness for second use and recycling
- Ability to recycle devices and parts
- Packaging
- Manufacturing
- Energy
- Other features

The individual design options are derived from prior work by DG JRC (Cordella et al. 2020; Tecchio et al. 2018b), implemented criteria in rating and labelling schemes, and further options identified in the technical analysis in Task 4.

Data on costs is integrated in this chapter to ease reflection on the interplay of design options, likely effects on environmental aspects and on costs. Some design options can be dropped at this stage already due to issues with associated costs.

3.1 Lifetime model

Many of the design options affect the lifetime. Therefore, estimations of the effect of design options on the lifetime of base case devices are needed. Further, products exit the active use phase and enter end-of-life distributed over time rather than all at the same point in time. Therefore, a lifetime model was set up that takes account of the identified reasons for products reaching their end of life and how this changes over time.

The assumed average lifetime is a statistical value. The products exit the active use phase and enter end-of-life distributed over time rather than all at the same point in time. The lifetime model takes account of the identified reasons for products reaching their end of life and how this changes over time. To build the lifetime model and calculate the number of products retired per year and per reason, a maximum lifetime was defined:

- Smartphones and feature phones (BC 1-4) :
  - Average lifetime: 2.5 – 3.5 years
  - Maximum lifetime: 7 years
- DECT phones and tablets (BC 5+6)
  - Average lifetime: 5 years
  - Maximum lifetime: 9 years

It is assumed that from a stock sold in year 0, the first products are retired in year 1 and the last products are retired in 7 / 9. For the simplified lifetime model, no product is used longer than the maximum lifetime.

Products leave the use phase due to hardware defects and non-hardware reasons:

- Hardware defects:
  - Display damage
  - Damage of glass back cover
  - Battery failure and/or loss of capacity
  - Damages through water & dust ingress
  - Other defects
- Non-hardware reasons:
  - Performance-related product retirement
  - Software-related product retirement
  - Non-technical reasons ("psychological obsolescence", context-related reasons, etc.)

For the hardware-related defects, a yearly failure rate and yearly repair rate are calculated as percentages of the remaining stock based on assumption from Task 5. Battery-related issues are treated differently with a failure rate of batteries increasing over time. The non-hardware reasons are then adjusted to meet the average lifetime of each base case.

The individual design options are plotted on these lifetime models to account for e.g. additional repairs and defects in later years when options extend product lifetime. Thereby, the reduction of one failure rate (e.g. more resistant display) will reduce the number of products leaving the stock due to this specific defect, leading to the increase in absolute numbers of other defects and repairs in the following years as the number of products in the remaining stock changes and the percentaged failure rates stay the same.

Depending on the design option, the failure rate and/or the repair rate is affected.

Within the lifetime model, repair costs are calculated in parallel. Thereby, as for the failure rate, the repair regarding all defects change with each option as the percentaged failure and repair rates stay the same. As an example, the longer provision of OS updates (see section 3.3.2) would lead to higher absolute hardware defects and higher repair costs as less products leave the stock early for software reasons. The costs per active use time however would decrease.

The lifetime model for Base Case 1 is depicted in Figure 1: On average, the product lifetime is 2,5 years, but some units will leave the stock of products sold in a given year earlier than others, and there is a tail of products reaching much longer lifetimes. Maximum lifetime for the purpose of this modelling is assumed to be 7 years. The bars show the number of products leaving the stock (left scale) per reason. The blue line shows the remaining stock from year 0 (right scale).

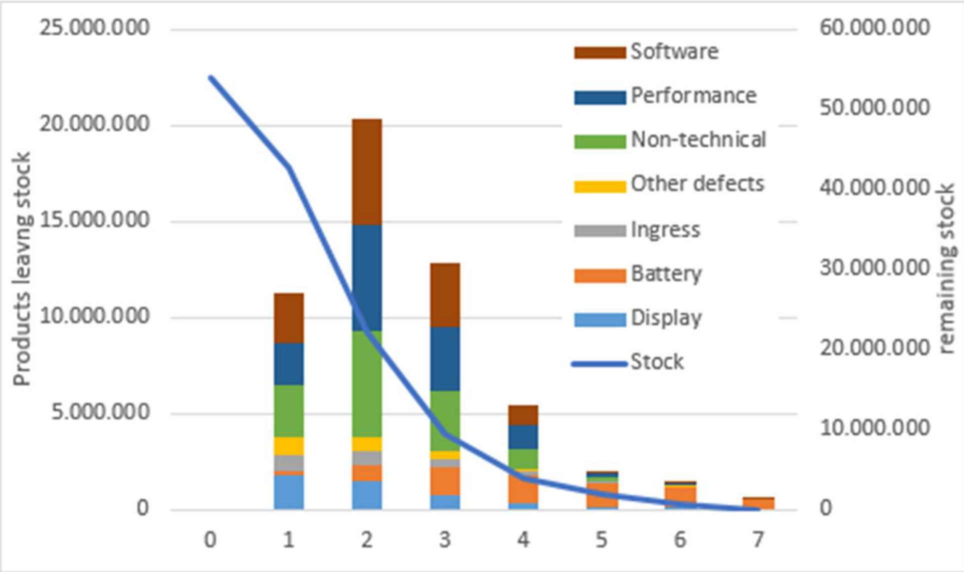

Figure 1 : BC 1 - Lifetime model

For comparison, the lifetime models of the other Base Cases are shown below.

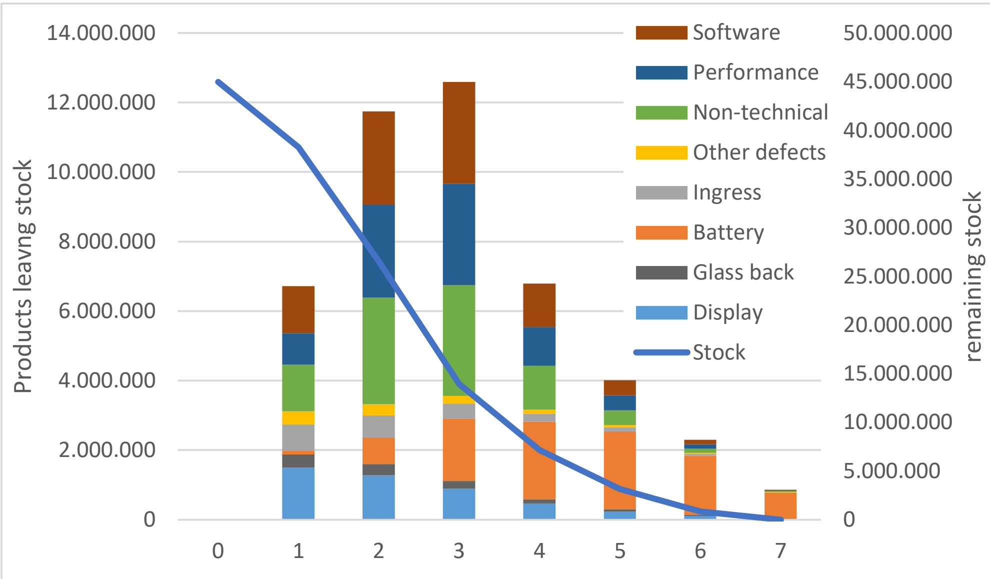

Figure 2 : BC 2 - Lifetime model

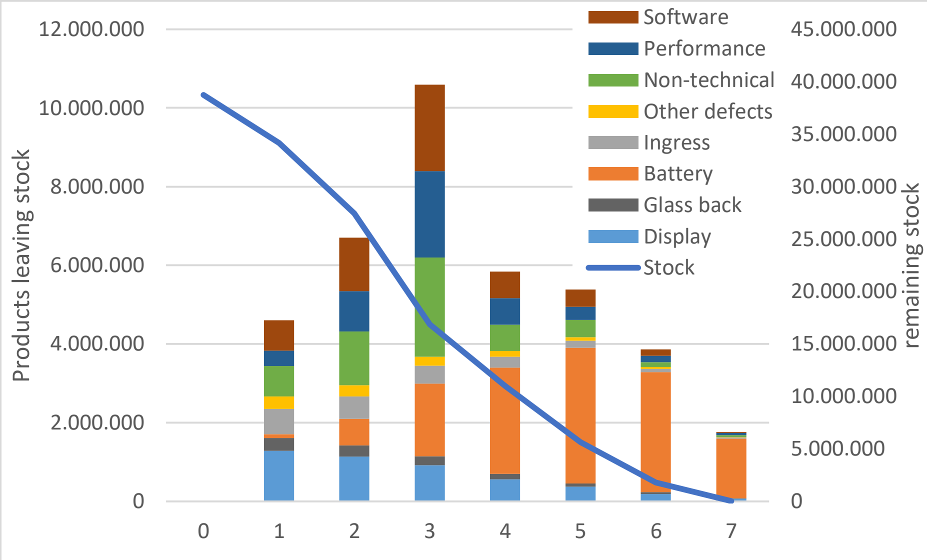

Figure 3 : BC 3 - Lifetime model

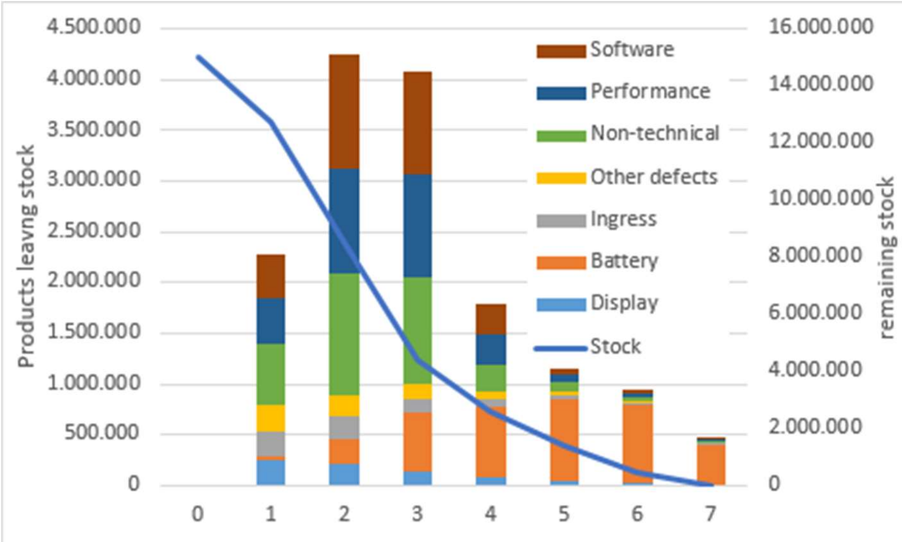

Figure 4 : BC 4 - Lifetime model

The lifetime model for cordless phones in Figure 5 is simpler than the other ones as there are not so many triggers for end of life than for the more complex smartphones and tablets.

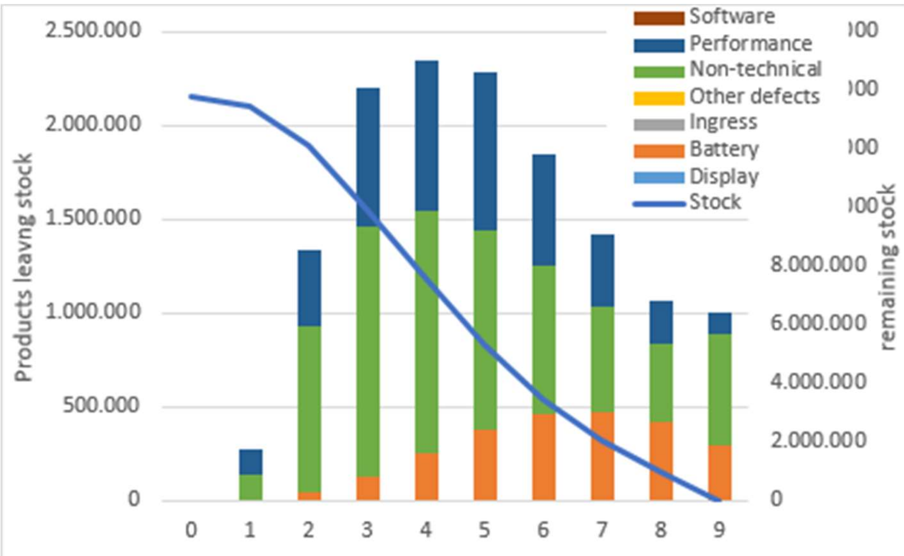

Figure 5 : BC 5 - Lifetime model

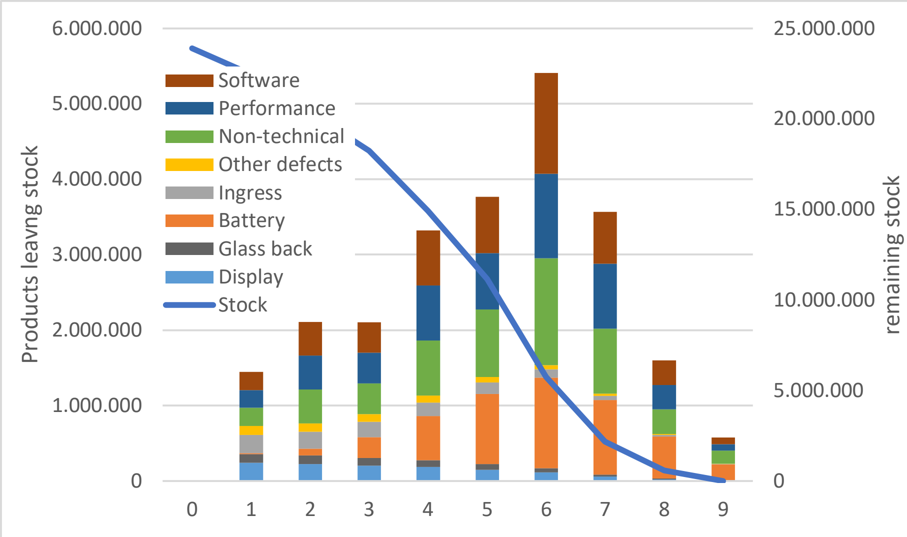

Figure 6 : BC 6 - Lifetime model

3.2 Reliability

3.2.1 DO1 Robustness of display and glass back-cover against accidental drops

Task 3 Report established that the most frequent defect in smartphones and tablets are damages of the display. It can be assumed that a large share of the defects is broken glass due to drops of the device. Therefore, design measures to increase the glass withstand used to cover the display and the back of the device appear appropriate to mitigate the relatively high failure rates[1].

The use of display glass BAT as outlined in Task 4 Report has the potential to decrease the probability of display and back cover glass shattering when a drop of the device occurs. For instance, the reported fracture toughness of the BAT (Corning® Gorilla® Glass Victus™) is increased by more than 10 % over one of the previous iterations of hardened glass for mobile devices (Corning®Gorilla® Glass 5).

Table 1 shows the expected effect and share of devices in each base case.

[1] Note: The toughness of the display can have also other influence factors than just the variety of the glass. It depends on how the display it is integrated into the device, e. g. if the display is tightly integrated under tension it is more likely to break. The alternative is to build it in a flexible way on a rubber seal or the like which dampens shock forces transmitted from other housing components to the display.

Table 1 : Design Option DO1 – display robustness - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Estimated cost effect
BC1: Smartphone, low-end	15 % increase fracture toughness (currently use subpar glass)	100 % (no devices currently use BAT)	3€
BC2: Smartphone, mid-range	10 % increase fracture toughness (currently use typical glass)	100 % (no devices currently use BAT)	1€
BC3: Smartphone, high-end	10 % increase fracture toughness (currently use typical glass)	50 % (50% devices currently use BAT)	1€
BC4: Feature phone	No effect (plastic is used rather than glass)	0 % (plastic is used rather than of glass)	
BC5: DECT phone	No effect (display damage no relevant failure)	0 % (plastic is used rather than of glass)	
BC6: Tablet	10 % increase fracture toughness (currently use typical glass)	70 % (30 % currently already use BAT)	2€

Costs:

- 2-3€ for BC1 according to several press coverage on gorilla glass (e.g. https://www.forbes.com/sites/timworstall/2013/03/21/could-sapphire-replace-gorilla-glass-in-smartphones/ https://www.autonews.com/article/20150829/OEM10/308319972/will-automakers-go-for-gorilla-glass)
- 1 € for BC2, BC3, 2€ for BC6 (bigger) as Victus seem to have the same production costs as earlier gorilla glass generations (e.g. https://www.androidauthority.com/corning-gorilla-glass-victus-1140743/)

Improvement:

- Lifetime extension through less retired devices
- Cost reduction through less repairs and extended lifetime
- Cost increase through different cover glass

Another display related aspect is the way front glass and display unit are assembled: Current smartphone designs are characterised by front glass and display unit being fused or glued together by an adhesive. This has some advantages as outlined in task 4, but makes repairs more costly, as in case of a defect the whole assembly of screen glass and display unit has to be exchanged. For tablets it has been more common to keep display unit and cover glass separated, thus both being replaceable individually. This design can be considered best practice in terms of reparability. As it does not relate to a design improvement, but rather represents a “design freeze” of what was common practice until few years ago, no calculation of an improvement potential is provided here.

3.2.2 DO2 Display scratch-resistance

Design measures to increase the withstand of the glass used to cover the display do not only prevent breaks in case of accidents, but also scratches of the display, which might lead to hard to read displays and may also weaken the glass in case of accidents. Improved scratch resistance can also contribute to reducing replacement of phones for aesthetic reasons. New display glass generations are not only hardened to prevent breaks, but are also more scratch-resistant and both aspects can be addressed by the same design change. Additionally, scratches are not defined as failures in the base case. Therefore, scratch-resistance is not calculated as an individual design option, but relevance for product lifetime has to be acknowledged.

Besides the scratch resistance of the display also those of others surfaces matter: Scratches make devices not desirable anymore and as such also limit the reuse value of used devices even if full functionality is still given.

3.2.3 DO3 Provision of additional screen and glass back-cover protection

Damages of the display and of the back cover glass through accidental drops could be reduced by smartphone covers/bumpers and display protection foils. According to clickrepair (clickrepair 2019) 20% of the smartphones without protective covers showed damages throughout their live, but only 10% of the smartphones with protective cover, see Task 3. This would mean that covers would reduce the probability of damages by 50%. The difference is even higher for tablets according to clickrepair (WERTGARANTIE 2018).

Assumption: 80% already use bumpers and/or foil, more people use bumpers than foil (clickrepair 2019), half of the other users could be reached through bumpers and foil included in delivery. The additional costs will affect all 20% which were not already using a cover.

From material perspective, this design option would require additional bumpers and foils for 20% of the users (of which half of them will actually use them). Bumpers and display protection foils can be made from different materials: plastics, leather, textiles for phone covers and PET or glass for the display protection. This design options assumes bumpers made of TPU / silicone and display foils made of PET.

Table 2 : Design Option DO3 – protection - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Estimated cost effect
BC1: Smartphone, low-end	50 % increase fracture toughness	10% of devices	4€
BC2: Smartphone, mid-range	50 % increase fracture toughness	10% of devices	4€
BC3: Smartphone, high-end	50 % increase fracture toughness	10% of devices	4€
BC4: Feature phone	50 % increase fracture toughness	10% of devices	4€
BC5: DECT phone	No effect (display damage no relevant damage)	0 %	

Base Case	Expected effect on affected devices	Share of devices affected in base case	Estimated cost effect
BC6: Tablet	60 % increase fracture toughness (protective effect seems to be higher for tablets than for smartphones according to click repair)	15% of devices (70% already use bumpers)	5€

Costs:

- 4/5€ for bumper and display foil together
- costs within smartphone package are expected to be lower than end-user prices for individual bumpers and foils

Improvement:

- Lifetime extension through less retired devices
- Cost reduction through less repairs and extended lifetime
- Cost increase through additional screen foil and bumper

3.2.4 DO4 Water and dust resistance

The Task 4 report established that close to 50 % of smartphones sold in Europe in 2019 had an IP-rating to indicate a level of ingress protection from dust and water. However, as this estimation is based on market data on the 25 best-selling smartphone models in Europe, and therefore it can be assumed that the market share of phones with an IP-rating is overestimated, as the lower-end devices with a lower individual market share, but a high combined market share, are likely not to feature an IP-rating.

The failure rate of the devices in scope of this study that are associated with ingress of water and particles is not known. However, the Task 3 report established that "dropped into water" was among the most common accidental smartphone damages in a U.S. survey in 2018 (39 % of respondents reported this damage).

The Task 5 report does not assign a specific failure rate related to water and particle ingress to the Base Cases. Instead, it falls under the collective category "other defects". Therefore, the assumed failure rate due to water ingress was estimated to be half of all defects in the category "other defects", which results in an annual failure rate of 0,84 % for bases cases 1-4, 0 % for BC5 and 0,5% for BC6.

Improvement

- Due to a lack of data on the improvement rate between a device with and without IP-rating, it is assumed that the probability of failure due to ingress is reduced by 50 %.

Cost

- Ingress protection needs to be accounted for in the design phase of devices. Effort and material is needed to implement it, sealing any points of entry to the phone with gaskets and adhesives, possibly applying water-resistant coatings. This may also result in increased manufacturing costs over devices without an IP-rating. Testing and verification of ingress protection according to testing standards may also be an additional cost factor.
- As no data on the cost associated with the implementation of ingress protection could be identified, we assume that it adds 3 Euros to manufacturing costs as a proxy.

It can be argued, that dust and water ingress protection also have an effect on repair costs and lead to more complex repairs. The actual parts replacement time, which is likely to increase by 2 – 3 minutes, plus the additional time for testing water tightness after repair (which is done in a vacuum chamber or similar within seconds) is only one aspect of overall repair labour costs. Thus, repair costs per individual repair case is likely to increase slightly, but this considered marginal across all devices compared to the purchase price increase for all devices.

Table 3: Design Option DO4 – water and dust resistance - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Estimated cost effect on affected devices per unit
BC1: Smartphone, low-end	50 % decreased failure from ingress	100 %	+3 Euros purchase price
BC2: Smartphone, mid-range	50 % decreased failure from ingress	100 %	+3 Euros purchase price
BC3: Smartphone, high-end	50 % decreased failure from ingress	0 % (assumed to have a high IP-rating)	none
BC4: Feature phone	50 % decreased failure from ingress	100 %	+3 Euros purchase price
BC5: DECT phone	Not relevant	0 %	none
BC6: Tablet	50 % decreased failure from ingress	100 %	+3 Euros purchase price

Material

- Yu et al. provided insights into the materials used to achieve ingress protection in smartphones in three smartphone models. The methods and associated materials include adhesive strips, glue, rubber gaskets, ePTFE membranes (Yu et al. 2019).

3.2.5 DO5 Battery endurance (cycle stability)

The Task 4 report established that smartphones with user-replaceable batteries no longer play a major role on the market, while tablets have always had embedded rather than user-replaceable batteries. As batteries can therefore not easily be replaced, the inevitable ageing of the embedded batteries will likely lead to a limiting state at some point during the use phase. On the contrary, the batteries of feature phones and DECT phones can commonly be accessed and replaced easily.

The Task 5 report establishes battery-related defect rates of the base cases over their lifetime between 8,3 % (BC1) and 50 % (BC5).

The endurance of device batteries can be defined over time or over use. Some OEMs specify the number of charge/discharge cycles device batteries are expected to withstand before their capacity drops to 80 % relative to the nominal or initial capacity. For instance, Apple Inc. states that smartphone batteries are designed to retain up to 80 % of their initial capacity after 500 full charge cycles, and 1000 full charge cycles in case of tablets[2].

[2] https://www.apple.com/batteries/service-and-recycling/

The endurance of batteries may either be increased by specifying a minimum state of health after a defined period of use time or after a defined number of charge/discharge cycles. Such a design option can be verified by battery endurance testing in accordance with the international standard IEC/EN 61960. The standard specifies a testing procedure to continuously charge and discharge batteries and measure the capacity fade up to a threshold to be specified or over a specified number of charge/discharge cycles. However, such tests can be time-consuming. Depending on the battery capacity and the charging profile defined by the OEM, one cycle may take 5 hours or more. Therefore, testing over 500 cycles may take more than 100 days. This potential burden on OEMs needs to be taken into account if a design measure was to be defined.

The design option to be assessed here is: Device batteries shall retain at least 90% of their initial capacity after 300 full charge/discharge cycles, measured in accordance with IEC/EN 61960.

No data is available regarding the average performance of batteries for the different base cases. Data presented in the Task 4 report (section "Battery durability") indicates the endurance of batteries in smartphones and tablets from one specific OEM. The majority, but not all, of those smartphone and tablet batteries appear to retain more than 90 % of their initial capacity after 300 cycles.

Assumptions:

- If batteries are technically able to retain more than 90 % of their initial capacity during use in the field, their performance in laboratory testing according to IEC/EN 61960 will not be worse, given that calendar ageing plays a much smaller factor in accelerated laboratory testing and that environmental factors (particularly ambient temperature) can be held constant.

Improvement

- Assuming linear capacity loss as a function of the number of charge/discharge cycles, smartphone batteries may improve by 20 % (SOH 80 % after 600 cycles instead of 500 cycles) as illustrated in Figure 7.
- Batteries of feature phones (BC4) are also assumed to be improved by 20 %.
- Batteries of DECT phones are not expected to improve, as their ageing is assumed to not be influenced as much by cycle withstand and more by calendar ageing.
- Tablet batteries may not be affected by the design option when they were designed to withstand 1000 cycles while retaining 80 % SOH. However, not all tablet batteries may be designed this way.

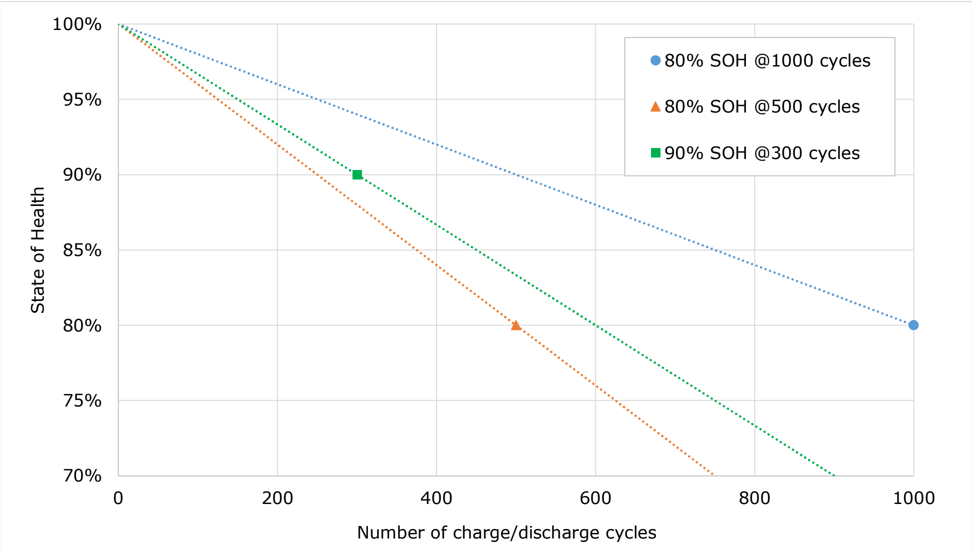

Figure 7: Extrapolated battery degradation assuming a linear progression from 100 % SOH to defined reference points

Cost

- A lithium-ion battery cell for a smartphone costs the device OEM somewhere between $2 to $4 depending on its capacity and other design attributes. It constitutes about 1 to 2% of the entire cost of the mobile device. https://www.beroeinc.com/article/lithium-ion-batteries-price-trend-cost-structure/
- It is therefore assumed that a high-endurance battery costs the OEM $4, which is assumed to equal 4 Euros for reasons of simplicity. This results in an increase by 0 to 2 Euros, depending on the assumed quality and capacity of the base case without this design option. Tablet batteries are assumed to cost double due to their higher capacity.

Table 4: Design Option DO5 – battery endurance (cycles) - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Estimated cost effect
BC1: Smartphone, low-end	20 % longer lifetime of battery	100% of devices (estimate)	+2 Euro production cost
BC2: Smartphone, mid-range	20 % longer lifetime of battery	50% of devices (estimate)	+1 Euro production cost
BC3: Smartphone, high-end	No effect (devices assumedly already have high-endurance batteries)	0% of devices (estimate)	No effect
BC4: Feature phone	20 % longer lifetime of battery	100% of devices (estimate)	+1 Euro production cost
BC5: DECT phone	No effect (cycle withstand is assumed not as relevant to battery ageing in DECT phones)	0 % of devices (estimate)	+1 Euro production cost
BC6: Tablet	20 % longer lifetime of battery	50 % of devices (estimate)	+2 Euro production cost

Material

- There is no significant effect on the material consumption during the manufacturing of higher endurance batteries. Rather it is assumed that the manufacturing processes are improved to yield higher quality batteries.

3.2.6 DO6 Higher battery capacities to reduce number of charging cycles and states of very low state of charge

The Task 3 report established that long battery life is the most important feature in smartphones for prospective buyers. Battery life denotes the time the device can be used before the battery needs to be recharged. As batteries inevitably age over time and with use, the available capacity decreases, leading to a decrease in battery life. Installing batteries with higher capacity results in increased battery life and therefore, even as the batteries age, the battery life may remain to be acceptable to the user for a longer period of time. Higher battery capacity therefore may postpone a limiting state in which the decreased battery life is insufficient to the user and results in a repair (battery replacement) or replacing the device with a new unit. It can be assumed that the same logic applies to feature phones, DECT phones and tablets.

Higher battery capacity may also decrease the charging frequency and therefore the number of charging cycles is stretched out over a longer period of time, which enhances product lifetime.

This design option has not been elaborated on for the following reasons:

- It is assumed that OEMs strive to implement high battery capacity due to the demand on user-side for longer battery life, even without this design option.
- Battery life results from a combination of battery capacity and power draw from the device, i.e. the same battery life may be achieved by a smaller battery in a device with a lower power draw compared to a larger battery in a device with a higher power draw. Therefore, "higher battery capacity" is relative and cannot be specified across the board for all devices in a product group.

3.2.7 DO7 Pre-installed battery management software

Some manufacturers of smartphones have started implementing features that aim at extending the battery lifespan. Some of these include:

- Smart charging that aims to prevent the battery to remain in trickle charge mode for extended periods of time after the charging process is complete (e.g. via timed overnight charging). A high state of charge tends to accelerate battery ageing.
- User-selectable charging rate to prevent fast charging when it is not needed. High charging rates tend to accelerate battery ageing.
- Dynamic performance management of the device to prevent random shutdowns in cases where an aged battery can no longer meet the required power draw from high-performance applications. Unexpected shutdowns may lead to users replacing their battery or device.

Improvement

- Task 5 report establishes that trickle charging (or another mode, which keeps the battery close to full charge) takes place for up to 9,5 hours per day after the charging process is complete[3]. De Vroey et al. indicated decreased calendar ageing of approximately 5 % for Li-Ion batteries stored at 50 % SOC at room temperature compared to Li-Ion batteries stored at 100 % SOC over the course of 40 weeks (De Vroey et al. 2015). The improvement potential is therefore estimated to be 5 % reduced battery capacity degradation per year for software that implements smart charging.
- Current smartphones commonly employ fast charging and may fully charge the battery from 0 to 100 % SOC within 1 hour. This translates to an average charging rate of 1C during the charging process. In the typical CC-CV (constant current, constant voltage) charging processes, it is therefore likely, that charging rates higher than 1C are employed during the CC phase, while the charging rate is decreased during the CV phase. In one study, the capacity degradation per cycle was shown double from around 5*10^-4 Ah to around 10*10^-4 Ah when increasing the charging rate from 0,67C to 1C (Clemm et al. 2020b). These findings are supported by more fundamental research in the field (Choi and Lim 2002).
- It is assumed that the around half of the charging processes benefit from the functionality of this smart charging software. Therefore, the overall benefit for

[3] Note that the term trickle charge is sometimes also used differently, referring to either the initial charging phase Huawei 2021 or the final phase, where charging current is reduced for a more gentle charging process Apple 2021.

affected device batteries is assumed to be roughly 25 % increase lifespan (roughly half a year).

Cost

- The development and maintenance of such software incurs costs. A generic cost-estimation of developing an app amounts to around 30k Euros. The cost of hiring an app developer in the U.S. was estimated at around 100k Euros per year. https://www.businessofapps.com/app-developers/research/app-development-cost/
- Given the considerable sales data on smartphones in particular, and considering that OEMs constantly develop new software features for their handsets, it is assumed that the additional cost to develop and maintain a pre-installed battery management software is negligible on a per-device basis, with the exception of the low-end smartphone, where the profit margins are comparatively smaller.
- Considering neither feature phones nor DECT phones have such software in place and it would need to be fully developed by OEMs, and given the assumedly comparatively smaller profit margins in these products, a minor cost increase is expected in case of BC4 and 5.

Material consumption

- No changes to the material composition

Energy consumption

- The energy consumption is only increased due to the extended lifetime of devices.

Table 5: Design Option DO7 – battery management - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Estimated cost effect
BC1: Smartphone, low-end	25 % longer lifetime of battery	100 % of devices (none currently have such software)	+1 Euro production cost
BC2: Smartphone, mid-range	25 % longer lifetime of battery	75 % of devices	No effect
BC3: Smartphone, high-end	25 % longer lifetime of battery	50 % of devices	No effect
BC4: Feature phone	25 % longer lifetime of battery	100 % of devices	+2 Euro production cost
BC5: DECT phone	25 % longer lifetime of battery	100 % of devices (estimate)	+1 Euro production cost
BC6: Tablet	25 % longer lifetime of battery	50 % of devices (estimate)	No effect

3.2.8 DO8 Battery status (SOH, age, cycles, peak performance) reporting

As has been established in the Task 4 report, some ICT device batteries employ specialized hardware and software to store, estimate and report the battery status to the host device's OS. Making this information accessible to stakeholders including the user as well as the repair and refurbishment practitioners may come with a range of potential advantages, including the possibility for continued use of a battery based on specific information on its health. (Clemm et al. 2019) listed some potential benefits and drawbacks of making such data available for different stakeholders.

Relevant state of health information includes: battery type, date of manufacture, nominal battery capacity, remaining battery capacity, number of charging cycles performed.

Potential benefits may include, among others:

- Incentive for users to adopt behaviour that slows down battery degradation
- Consumer empowerment with regard to in-warranty battery failures
- Users may benefit from a "race to the top" as manufacturers are incentivized to optimize battery endurance
- Continued use of batteries that may otherwise be disposed of due to unknown health status
- Increased trust in used devices by potential buyers due to known battery health status

Potential pitfalls may include, among others:

- Observable degradation of battery may elicit "psychological obsolescence" (e.g. "My device is not perfect anymore, I want to replace it")
- Conservative SOH-based decision-making during repair or refurbishment may lead to premature disposal of used batteries
- Second-hand market buyers may not be willing to buy devices with battery health below a certain threshold

Clemm et al. (2019) further reported that iOS devices commonly provide such information while Android devices do not. No feature phones or DECT phones could be identified that provide such a functionality.

Cost

- A lithium-ion battery cell for a smartphone costs the device OEM somewhere between $2 to $4 depending on its capacity and other design attributes. It constitutes about 1 to 2% of the entire cost of the mobile device (Venkatasamy 2019).
- It is assumed that a battery with advanced functionality on battery SOH estimation will increase the price to the OEM by no more than 1 Euro, in practice most likely rather in the range of a few cents.

Improvement

- It is estimated that the lifespan of 10 % of the smartphone and tablet batteries is increased by 20 % through the potential benefits of this design option listed above, effectively reducing the failure rate caused by batteries.
  It is assumed that due to battery health information being available, the confidence in second-hand devices increases slightly. On the other hand, devices with relatively lower SOH may no longer sell on second-hand markets for the same reason. It can well be assumed that reliable information about the actual value of second hand smartphones will increase the average price consumers are willing to pay for them. In general, uncertainty leads buyers to base their bidding price on the worst case scenario, decreasing the resale value of second hand products which are actually in good condition (Akerlof 1970).

Table 6: Design Option DO8 – battery status - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Estimated cost effect
BC1: Smartphone, low-end	20 % longer lifetime of battery	10% of devices	minimal
BC2: Smartphone, mid-range	20 % longer lifetime of battery	10% of devices	minimal
BC3: Smartphone, high-end	20 % longer lifetime of battery	10% of devices	minimal
BC4: Feature phone	n.a.	n.a.	n.a.
BC5: DECT phone	n.a.	n.a.	n.a.
BC6: Tablet	20 % longer lifetime of battery	10 % of devices	minimal

3.2.9 DO9 Information provision (correct use; whether it is embedded and therefore not replaceable)

Assumption:

- An informed user who is aware of the influence of their behaviour on the lifespan of their device battery is more likely to favour behaviour that is beneficial for the lifespan.
- A share of 10 % of the device batteries benefits from more aware users. Their lifespan increases by 10 %. This is applicable to all base cases.

Cost

- This design option does not lead to increased purchase prices for the devices.

Table 7: Design Option DO9 – battery information - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Estimated cost effect
BC1: Smartphone, low-end	10 % longer lifetime of battery	10% of devices (estimate)	none
BC2: Smartphone, mid-range	10 % longer lifetime of battery	10% of devices (estimate)	none
BC3: Smartphone, high-end	10 % longer lifetime of battery	10% of devices (estimate)	none
BC4: Feature phone	10 % longer lifetime of battery	10% of devices (estimate)	none
BC5: DECT phone	10 % longer lifetime of battery	10% of devices (estimate)	none
BC6: Tablet	10 % longer lifetime of battery	10% of devices (estimate)	none

Materials

- The information can be provided to the user digitally or via the manual, if any. In the latter case, an additional page of paper is needed in the manual.

3.3 Operating system, software and firmware

3.3.1 DO10 New models on the market should always be equipped with the most recent OS

According to the findings in Task 3, 3.1, 20% of devices reach end-of-life due to software issues, and an OS not further supported is a major issue here. New devices on the market are always equipped with the most recent operating system (OS) version are potentially supported longer with up-to-date software. The effect could be 1 to 2 years longer product life as approximately every year a new OS version (Android and iOS) is introduced. However, hardware in the market is not always compatible with latest OS versions nor does the intended use require all latest OS features. Such an option therefore might also lead to the non-intended effect, that models are discontinued earlier than needed or devices are increasingly "oversized" in terms of the specification. Due to these side effects, this option is not analyzed any further. Instead, supporting the OS, with which a model is shipped, for an extended period of time, regardless which actual OS version it is, is seen as the more effective option (see following option).

3.3.2 DO11 Availability of update support of OS (e.g. 5 years after the placement of the last unit of the model on the market), including information on impact of updates and reversibility of updates

Discontinued OS support is a major reason for security and performance issues. Task 4, 3.2.8.1., provides data on OS support for individual models, suggesting, that low-end devices are supported much shorter than high-end devices. Support duration is roughly in the range of the Base Case lifetimes of 2,5, 3 and 3,5 years for Base Cases 1, 2, 3 respectively. An OS support of 5 years eliminates the OS as major lifetime limiting factor for another 2,5, 2 and 1,5 years for these 3 Base Cases.

According to Task 3, 3.1, almost 20% of users bought a new device as software or applications stopped working on their device. These 20% are at stake for a prolonged lifetime through extended OS support. Although it is not certain, that third party application providers follow suit with their maintenance strategy it is much more likely as they are at risk to lose part of their user base.

As with increasing lifetime other obsolescence factors will become more important (defects, performance other than OS), continued OS support will not extend the lifetime of all 20% of the devices at stake to full 5 years. It seems plausible, that in average for these 20% the lifetime is extended by ¼ of the time span between Base Case end of life and OS support duration of 5 years.

Assumption on additional costs per device is based on approximately 1000 different smartphone models being on the EU market, with on average 150.000 sold units, and updates being in the cost range of "several hundred thousand US dollars per model" (Clark 2016), i.e. calculating with 2 Euros per device for this option. For comparison: Stated software development costs for the Fairphone 2 are 4,62 € at 140.000 sold phones per year (Fairphone 2015)

Table 8: Design Option DO11 – operating system support - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Estimated cost effect
BC1: Smartphone, low-end	2,5 years longer lifetime	5%	+2 Euros purchase price
BC2: Smartphone, mid-range	2 years longer lifetime	5%	+2 Euros purchase price
BC3: Smartphone, high-end	1,5 years longer lifetime	5%	+2 Euros purchase price
BC4: Feature phone	Not relevant	n.a.	none

Base Case	Expected effect on affected devices	Share of devices affected in base case	Estimated cost effect
BC5: DECT phone	Not relevant	n.a.	none
BC6: Tablet	1 year longer lifetime	5%	+2 Euros purchase price

It is worthwhile noticing, that offering the option of upgrades and updates does not mean, the user will make use of this option: As one telecommunication provider points pout, making use of updates over-the-air (OTA) depends also on user acceptance, and user acceptance is legally required. For high-end Smartphones the acceptance quota is roughly 80-90%, for other categories it is still around 60%.

3.3.3 DO12 Possible use of open source OS or open source Virtual Machine software

The use of open source OS or open source Virtual Machine software has been mentioned by the JRC material efficiency study (Cordella 2020) as an option. Actually, also Android is an open source project and OEMs are adapting Android according to their specific interests (features, user experience etc.). The possibility to change over from a pre-installed OS to (another) open source OS is motivated by, e.g. keeping a device running with a less phone-resource intensive operating system when the pre-installed / market-leading OS slows down the device or does not support the device anymore. Data privacy concerns are also a motivation for some users to rely on alternative open source software. The latter is not directly related to any lifetime extension. In general, deviating from a pre-installed OS or one of the market-dominating OS requires some technical skills. It is therefore questionable, how many users would really make use of alternative open source OS. Most likely the effect would be minimal, but there is no data to underpin this judgement.

3.3.4 DO13 Security patches latest 2 months after the release of the new update

Getting security patches rolled out rapidly is important to reduce data security risks. In case of Android, such a provision of security patches requires some time due to e.g. OEM specific OS variants, which need to be updated as well. 1 month for providing such security patches after the initial update is considered hardly feasible. 2 months delay is still ambitious but feasible (Mobile & SecurityLab 2019). While this option enhances data security for the user, there is no specific improvement potential in terms of lifetime extension. In conjunction with an overall long-term support of the OS, such timely provision of security patches is considered a relevant sub-aspect.

3.3.5 DO14 The capacity of the device allows the installation of next OS versions and future functionalities (e.g. min. 4 GB for the RAM and 64 GB for the Flash could be considered reasonable for current models on the market)

A higher kind of "future-proof" hardware in terms of memory (RAM) and storage (Flash) has been mentioned by the JRC material efficiency study (Cordella 2020) as an option. The minimum requirement for Android 10 and 11 is 2GB of RAM and there are several smartphone models on the market with 32 GB Flash supporting Android 10. Android 11 has been released only on September 8, 2020, and there are few devices at all on the market, apparently none with 32 GB. Technically, Android 10 and 11 require 4 GB flash memory for application private data, thus a 32 GB storage capacity leaves room for additional software and data. Just providing more memory and storage does not guarantee an upwards compatibility with future OS versions, as also the SoC and other hardware components need to be compatible.

The environmental assessment in Task 5, confirmed by LCA data published by OEMs, indicates the high environmental impact of flash memory in particular and incentivizing an oversizing of storage capacity should be avoided. Also from a cost perspective there is a significant difference between a model with 32 and the same model with 64 GB (in the range of 20,- Euros purchase price difference), which will not be compensated LCC-wise through longer product lifetime.

Due to these consideration the option of more memory and storage to support future OS versions is not considered for the further analysis.

3.4 Reparability

3.4.1 DO15 Battery removability/replacement: Joining techniques

The Task 4 report established that all of the 25 best-selling smartphones of 2019 had an embedded battery that cannot be easily removed and replaced without the use of tools. The majority of embedded batteries are fixed in the devices using adhesives. This is a potential barrier to the removal and replacement of the battery, as thermal energy, solvent, and/or prying force need to be applied in order to dissolve the joint. This may also increase the risk of physical damage to the battery and other components during the removal process, as thermal energy, solvents and/or tools may need to be applied. The semi-soft battery packs may be bend or punctured, leading to short circuit and thermal runaway in the worst case. These factors can be assumed to lead to a decrease in (successful) repair attempts by users. Professional repair operators are assumed to have the skills, tools and knowledge to remove and replace batteries independently of the type of adhesive employed, but the use of strong adhesives may increase the time spent on the process and therefore the involved repair cost for the user.

This design option avoids designs that utilize adhesive joining of the battery within devices in favour of solutions that intend to ease the process of removal and replacement of batteries and make it safer. Such designs where reversible adhesive bonds are in use, include (for details see Task 4):

- Batteries are mounted into the housing with double sided pressure sensitive adhesive (PSA) tapes with stretch-release-properties;
- PSA systems with adhesion properties that are sensitive to contact with ethanol;
- battery wrapping technology with a pull tab attached to the battery wrap.

Accordingly, the design option aims at a device design where the battery is not fastened within the device using joining techniques that require tools, thermal energy, or chemicals to solve.

The Task 4 report established that solutions exist that facilitate the removal of batteries, such as stretch-release tapes with pull tabs that do not require thermal energy, solvents, tools or excessive force. Close to 50% of the best-selling smartphones sold in Europe in 2019 had a type of pull tab adhesive solution in place.

It is assumed that the implementation of such joining techniques incurs negligible additional costs during the manufacturing phase that do not result in an increased purchase price for consumers. On AliExpress, an order of 500 pull tabs ranges from USD 44 to 132, equivalent to 0,07 to 0,22 Euro[4], depending on the smartphone model. It can

[4] https://www.aliexpress.com/item/1005001600575453.html?spm=a2g0o.productlist.0.0.22f2163fOOflmJ&algo_pvid=91f8cc02-b8df-4539-b6de-fd9efe489503&algo_expid=91f8cc02-b8df-4539-b6de-fd9efe489503-

be assumed that the cost for the adhesives strips does therefore not play a role in manufacturing devices when bought in much larger quantities directly from suppliers.

Although the potential of such repair-friendly battery implementation is significant, it materialises only in conjunction with better overall accessibility of the battery (see DO17) and spare parts availability (DO21), as other barriers, such as the need to still consult professional repair services, thus still significant overall repair costs, data privacy concerns in case of third party repairs and times of non-availability of the device remain. With better removability of the battery only a small additional fraction of the devices with integrated batteries will be repaired.

Material

- It is assumed that the above-mentioned adhesive tapes with pull tabs are the preferred solution my OEMs.
- Adhesive tapes commonly consist of a carrier material (paper, plastic film, cloth, foam, foil, or similar), an adhesive coating (nitrocellulose, polyvinyl acetate, vinyl acetate-ethylene copolymer, polyethylene, polypropylene, polyamides, polyesters, acrylics, cyanoacrylics, phenol formaldehyde, urea formaldehyde, unsaturated polyesters, epoxies, or polyurethanes) and a release liner (plastic film).
- It is assumed that the adhesive strip with pull-tabs is implemented instead of other types of adhesives, such as liquid adhesive with or without carrier. Therefore, it is not assumed that additional material is required.

Table 9 : Design Option DO15 – battery joining techniques - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Cost effect on affected devices per unit
BC1: Smartphone, low-end	BC1-3: Repair rate for defect battery is increased from 33 % to 35 %	50 %	Battery repair cost reduced by 5 Euros
BC2: Smartphone, mid-range		50 %	
BC3: Smartphone, high-end		50 %	
BC4: Feature phone	Not relevant for BC4	0 %	None
BC5: DECT phone	Not relevant for BC5	0 %	None
BC6: Tablet	Repair rate for defect battery is increased from 33 % to 35 %	50 %	Battery repair cost reduced by 5 Euros

3.4.2 DO16 Battery removability/replacement: Joining battery and display unit

Professional repair operators are assumed to have the skills, tools and knowledge to remove and replace batteries in almost any type of design with respect to all six base cases. However, the probability of damaging other components in the process may be influenced by the product design choices. One design choice that may considerably increase the likeliness of damaging other components is to adhere the device battery to the backside of the display unit. This design has been documented in at least one smartphone of a major manufacturer (Clemm and Lang 2019). This design choice is likely

32&btsid=0b0a187916055554100847479eede6&ws_ab_test=searchweb0_0,searchweb201602_,searchweb201603_

to increase the cost for repair due to the increased risk of damage to the display unit, as well as increasing the material consumption due to additional display units required to replace accidentally broken units during repair. An additional impact of this design choice may be that users themselves are further discouraged from DIY repairs. Therefore, this design option aims to prevent this design choice from being implemented in future devices: Batteries may not be adhered to the display unit.

It is unknown whether any devices currently employ this design choice, therefore it is assumed that 1 % or less of devices is affected in the market for all base cases.

Due to the uncertainty with respect to market relevance of the design choice, this design option is not evaluated further.

3.4.3 DO17 Battery removability/replacement without use of tools and use of standardised batteries for cordless phones

The Task 4 report established that less than 10 % of the mobile phones sold released to the market in 2019 had a user-replaceable (non-embedded) battery, and none of the best-selling smartphone models in Europe in 2019 had a user-replaceable battery.

By definition, embedded batteries are integrated into devices and cannot be accessed without the use of tools. Devices are commonly sealed using adhesives and require thermal energy, hand-held tools, or machines to be opened. The design that was prevalent in smartphones previously allowed access to the battery by simply removing the back cover of the device. This design is still commonplace in feature phones and DECT phones, but not in smartphones and tablets.

This design option requires all devices to adopt a design where batteries can be accessed, removed, and replaced without the use of any types of tools, thermal energy, or solvents.

In case of cordless phones, user-replaceable (rechargeable) AAA batteries, or other standardized battery form factors, which are available in the market, ease not only the exchange of batteries, but also long-term availability at reasonable prices from multiple sources is given. Although most cordless phones are designed for user-replaceable AAA batteries there are some products, which feature other, non-standardized form factors and not in all cases these are user-replaceable. The exact market share of these designs is not known, but as this is a feature of some popular models, a market share of 15% is a plausible estimate.

Benefits are the ease of replacing a faulty or faded battery and the opportunity to use a secondary battery. A likely side-effect is that the back cover is easily removable with such a design as well. Another side-effect may be in the material of the back cover of devices with a user-replaceable battery. A removable back cover is less likely to be made from glass, but rather from plastic or metal, to ease damage-free separation from the device. There are only very few devices on the market with high ingress protection and a readily-removable battery. The battery is accessible without any tools after removing the back cover.

It has been pointed out by a stakeholder that back covers made of metal, as well as allowing batteries to be user replaceable (which means making the back cover detachable) might make it harder or impossible to integrate coils for wireless charging capabilities. In fact the very few smartphones with user replaceable battery on the market do have wireless charging capability, e.g. Gigaset GS4.

This design option depends on the availability of spare batteries (DO21) to unveil its full potential. The scenario outlined in Table 10 is a conservative estimate.

The repair rate is increased as a weak battery is always a trigger point, which might lead to upgrading to another device. A user-replaceable battery would lower the barrier to get a repair done, thus is assumed to increase the repair rate significantly – in particular for already somewhat older devices -, also in comparison to an established professional repair infrastructure.

The reduced battery repair costs correspond to batteries as OEM spare parts, to be acquired by the user. However, some will likely make use of the convenience of a professional battery replacement (without the need to wait for a replacement battery to be shipped), but also in these cases replacement costs are not expected to be much higher than the parts costs due to the simplicity of the process.

Table 10 : Design Option DO17 – battery removable without tools - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Estimated cost effect on affected devices per unit
BC1: Smartphone, low-end	BC1-3: Repair rate for defect battery is increased from 33 % to 50 %	95 %	Battery repair cost reduced to 30 Euros
BC2: Smartphone, mid-range		95 %	
BC3: Smartphone, high-end		100 %	
BC4: Feature phone	Assumed to already have user-replaceable battery	0 %	none
BC5: DECT phone	+2,5 years lifetime	15 %	7 Euros for one extra AAA battery set
BC6: Tablet	Repair rate for defect battery is increased from 33 % to 50 %	95 %	Battery repair cost reduced to 50 Euros

- For BC1,2,3 and 6, the share of devices damaged by ingress is expected to increase, however, at the same time, fewer devices are expected to feature glass back cover and therefore fewer devices are damaged from drops. These effects cannot properly be estimated and are therefore assumed to roughly cancel each other out.

Materials

- JRC 2020 note that device designs with user-replaceable batteries could require an increased amount of materials compared to devices with embedded batteries, such as for additional casing and protection layers. This, in turn, may lead to product designs that are thicker than the average device with an embedded battery. However, it is further noted that there are smartphones on the market with user-replaceable batteries and modular designs that seem to have weights comparable to those of fully integrated smartphones.

3.4.4 DO18 Glass back cover removability/replacement

Damage of a glass back cover is one of the main limiting states of technical nature for smartphones and tablets (Task 3). Therefore, in addition to design measures to replace the display, the ability to detach and remove a shattered glass back cover has the potential to prevent a premature limiting state and prolong the lifetime of the device.

Cost

- Easily removable glass back cover needs to be accounted for in the design phase of devices. As there is no evidence of smartphone or tablet designs with easily removable glass back cover and no data on the cost associated with the implementation of easily removable glass back could be identified, we assume that it adds 2 Euros to manufacturing costs. This amount or a part thereof may be added to the sales price.

Table 11 shows the expected effect and share of devices in each base case.

Table 11 : Design Option DO18 – glass back cover - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Estimated cost effect
BC1: Smartphone, low-end	no effect	0%	n.a.
BC2: Smartphone, mid-range	40 % more repaired	50%	+2 Euros purchase price
BC3: Smartphone, high-end	50 % more repaired	60 % (glass back-cover typical for this BC)	+2 Euros purchase price
BC4: Feature phone	No effect (glass back cover not relevant for this BC)	0% (glass back cover not relevant for this BC)	n.a.
BC5: DECT phone	No effect (glass back cover not used in this BC)	0% (glass back cover not relevant for this BC)	n.a.
BC6: Tablet	no effect	0 % (glass back-cover not typical for this BC)	n.a.

Improvement:

- Lifetime extension through higher number of repaired devices.

Making glass back covers detachable might make it harder to integrate coils for wireless charging capabilities.

3.4.5 DO19 Display removability/replacement

Task 3 established that the most frequent defect in smartphones and tablets are damages of the display. Therefore, in addition to design measures to increase the withstand of the display glass against accidental drops, the ability to detach and remove a shattered display without further damage seems appropriate to preclude a premature limiting state.

Prioritizing the display in the design and making it accessible has the potential to incentivize repair, thus prolonging the lifetime of the device.

For instance, there are examples that the display can be removed either without tools or just with the use of a regular Philips screwdriver, see Task 4.

Whereas displays can be replaced by professional repair shops with some efforts, i.e. costs, a detachable display unit mainly fosters additional DIY repair, but also simplifies and speeds up the process for professional repair shops.

This measure depends on the availability of display units (DO21) to unfold its full potential. As long as availability for consumers is not given, the effect will be limited to those cases, where displays can be sourced from third parties or through cannibalising other defect devices.

Table 12 shows the expected effect and share of devices in each base case.

Table 12 : Design Option DO19 – display replacement - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Estimated cost effect
BC1: Smartphone, low-end	10 % more display defects repaired	70 %	Costs per additional display repair: −50%
BC2: Smartphone, mid-range			
BC3: Smartphone, high-end	20 % more display defectsrepaired	70 %	Costs per additional display repair: −50%
BC4: Feature phone	30 % more display defects repaired	95 % (use of adhesives or adhesive + screws is typical for this BC)	Costs per additional display repair: −50%
BC5: DECT phone	No effect as displays in most designs are already integrated repair-friendly	0 %	n.a.
BC6: Tablet	No effect as displays in most designs are already integrated repair-friendly	0 %	n.a.

Improvement:

- Lifetime extension through higher number of repaired devices

3.4.6 DO20 Provision of repair and maintenance information

Provision of information (e.g. through user manuals) is necessary to support the repair/upgrade operation. Repair information should be both comprehensive and available to various target groups of repairers. Enabling a broad access to such information (e.g. to independent repair service providers) could contribute to create a level-playing field in the repair sector and to reduce repair costs and the effort to find suitable repair centres (Cordella et al. 2020).

For popular devices comprehensive repair guidance is available through third parties already, and additional information through OEMs would not improve the situation for these devices much. However, OEMs are able to provide information, how a device is supposed to be repaired instead of relying on the guess-work and experience of third parties. For the broad market of low-end and mid-range devices such third party repair instructions are much less common and better OEM information can make a significant difference.

Better information is of limited effect, if the repair process is still too complicated and if no spare parts are available. Therefore this option unveils its full potential only in conjunction with DO15, DO19, DO21 and DO23. Due to these other barriers this option is calculated as stand-alone with a 10% increase in repairs.

Table 13 shows the expected effect and share of devices in each base case.

Table 13 : Design Option DO20 – repair information - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Estimated cost effect
BC1: Smartphone, low-end	10 % more repaired	100 %	no effect
BC2: Smartphone, mid-range	10 % more repaired	100 %	no effect
BC3: Smartphone, high-end	10 % more repaired	100 %	no effect
BC4: Feature phone	10 % more repaired	100 %	no effect
BC5: DECT phone	not relevant		
BC6: Tablet	10 %more repaired	100 %	no effect

Costs:

- Provision of repair and maintenance information does not result in additional costs.

Improvement:

- Lifetime extension through higher number of repaired devices

3.4.7 DO21a/b Availability of spare parts (priority parts, e.g. battery, display) that can be used for repair without negative implications for functionality of the device

The availability of spare parts, especially for those parts with highest failure rate, is a paramount parameter to ensure that a repair/upgrade process can take place. Task 3 established that the lack of spare parts prevented 4% of the respondents in a study on consumer repair attitudes to repair their smartphones.

Another important aspect is the provision of information on repair costs. As established in Task 2 most of the OEM provide professional repair services in-house or through authorised independent repairers. As an example, it is possible to bring iPhones and iPads to Apple stores where they can be repaired[5]. Samsung has launched a doorstep repair service where professional repairers come to the customer. Huawei also offers customer service centres where repairs are offered. Most of the OEMs provide information on their repair services and costs on their websites.

Also, there are market platforms providing information on the costs of spare parts[6]. Some manufacturers raised the concern of counterfeit parts/products on the market, which could undermine the functionality of the device and the brand reputation, especially in case of bad repair (Cordella et al. 2020).

[5] https://support.apple.com/repair

[6] https://www.parts4repair.com/xiaomi/

Table 14 shows the expected effect and share of devices in each base case under the assumption spare parts are available for professional repairer (including independent professional repair shops).

Ensuring spare parts availability results in additional logistics costs, but it is up to the price policy of the OEM, if this results in increased product prices or increased spare parts prices. Given the very competitive market this option is calculated with no changes to purchase prices, but higher repair costs (+5%).

Table 14 : Design Option DO21a – spare parts available for professionals - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Estimated cost effect
BC1: Smartphone, low-end	10 % more repaired	30 %	+5% repair costs
BC2: Smartphone, mid-range	10 % more repaired	20 %	+5% repair costs
BC3: Smartphone, high-end	10 % more repaired	10 %	+5% repair costs
BC4: Feature phone	5 % more repaired	10 %	+5% repair costs
BC5: DECT phone			
BC6: Tablet	10 % more repaired	50 %	+5% repair costs

Table 15 shows the expected effect and share of devices in each base case under the assumption OEM spare parts are available for the end user. The availability of spare parts has a limited effect on DIY repairs as long as other reparability options are not implemented (removable and reusable fasteners, DO 23; display removability, DO 19), but is assumed to be more than the 4%, which stated in the survey, missing spare parts was the reason not to get the device repaired, as availability for the user also addresses the cost barrier and other causes of not getting a device repaired.

Again, additional logistics costs arise, but DIY repairs cost less. Given a 5% cost increase on professional repairs due to increased parts costs and that the additional 10% of repairs are DIY, both effects compensate each other.

Table 15 : Design Option DO21b – spare parts available for end-users - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Estimated cost effect
BC1: Smartphone, low-end	10 % more repaired	60 %	0 EUR
BC2: Smartphone, mid-range	10 % more repaired	75 %	0 EUR
BC3: Smartphone, high-end	10 % more repaired	90 %	0 EUR
BC4: Feature phone	10 % more repaired	10 %	0 EUR
BC5: DECT phone			
BC6: Tablet	10 % more repaired	50 %	0 EUR

Improvement:

- Lifetime extension through higher number of repaired devices

3.4.8 DO22 Provision of information on maximum costs for display & battery replacement

Another important aspect is the provision of information on repair costs. As stated above, most of the OEM provide professional repair services in-house or through authorised independent repairers and offer information on repair services and prices on their websites.

The main potential effect of this option is the informed choice by consumers for products where repair is less costly. Thus the market would shift towards better reparable devices.

This market shift depends on numerous factors, including the repair costs spread, once such information is available across the market, and how consumers would factor this in their purchase decisions. A positive effect on LCC and the environment is likely, but can be estimated hardly at this moment. Therefore this option is not calculated in this Task.

Costs:

- No evidence of increased product costs.

Improvement:

- Lifetime extension through higher number of repaired devices

3.4.9 DO23 Use of reversible and reusable fasteners (housing)

The use of removable and reusable fasteners to join the housing together is a considerable factor influencing the reparability and dismantlability of products. Commonly used fasteners for the housing are clips that require no tools to reversibly disconnect, snap-fits that do require tools for leverage, screws, adhesives, or a combination of screws and adhesives. Adhesives commonly require the application of thermal energy or chemical solvents to be dissolved, except for pull-tab solutions (Clemm et al. 2020a).

This option refers to better access to relevant parts for repair, and better re-assembly of repaired devices without the need to acquire new fasteners not provided with the spare part.

The disassembly and repair can be supported through the use of reversible and reusable fasteners, assuming, that this will simplify repairs. The full repair potential however depends also on other aspects (availability of spare parts etc., DO21). As a stand-alone option this is likely to have a limited effect, increasing repair rates by 10% (more DIY repairs, faster turnaround in repair shops etc.).

Product costs might slightly increase as the use of adhesives reduces typically assembly times, BOM changes are considered marginal. Product prices are expected to increase by 0,10 Euros. On the other hand the increased number of DIY repairs reduces repair costs. DIY repairs (spare part only) is roughly 50% of the costs of professional repairs. This option is calculated with a 50% repair costs reduction for the 10% of additional repairs. It is likely that some of the repairs now done by professional repair shops will then be done as DIY, which will decrease LCC further and is not accounted for here.

Table 16 shows the expected effect and share of devices in each base case.

Table 16 : Design Option DO23 – reversible and reusable fasteners - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Estimated cost effect
BC1: Smartphone, low-end	10 % more repaired	70 %	+0,07 EUR for all devices Costs per repair –5% (across all repairs)
BC2: Smartphone, mid-range	10 % more repaired	70 %	+0,07 EUR for all devices Costs per repair –5%
BC3: Smartphone, high-end	10 % more repaired	90 %	+0,09 EUR for all devices Costs per repair –5%
BC4: Feature phone	no effect	n.a.	0 EUR (no effect)
BC5: DECT phone	not no effect	n.a.	0 EUR (no effect)
BC6: Tablet	10 % more repaired	90 %	+0,09 EUR for all devices Costs per repair –5%

Improvement:

- Lifetime extension through increased repairability and higher number of repaired devices.

3.4.10 DORep-a, DORep-b Combined Reparability Option

As many of the reparability options as stand-alone option are of limited effect, combined options have to be calculated. These scenarios include a moderate reparability option (DORep-a) and a broad reparability option (DORep-b)

The **moderate reparability option** includes the combination of:

- Provision of repair and maintenance information (DO20)
- Battery removability / replacement: Joining techniques (DO15)
- Availability of spare parts for professionals (DO21a)

This combination of options increases repair rates, mainly at professional repair shops. Provision of repair information closes a gap mainly for low-end and mid-range devices. Availability of spare parts is relevant for all segments.

Costs of repairs in general go up as logistics costs for long-term spare parts provision has to be added, but better – and in particular faster - replaceability partly counters this effect.

This scenario should not be misinterpreted in a way, that tablet batteries fail as often as those in smartphones, but over the longer lifetime of a tablet – featuring a less intense use overall – battery issues are emerging as well.

Table 17 : Design Option DORep-a – moderate reparability - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Cost effect on affected devices per unit
BC1: Smartphone, low-end	Battery repair rate : 33% -> 50% Display repair rate : 25% -> 50% Other repair rate : 33% -> 50%	100 %	+4% repair costs
BC2: Smartphone, mid-range	Battery repair rate : 33% -> 45% Display repair rate : 25% -> 45% Other repair rate : 33% -> 45%	100 %	+4% repair costs
BC3: Smartphone, high-end	Battery repair rate : 33% -> 40% Display repair rate : 25% -> 40% Other repair rate : 33% -> 40%	100 %	+4% repair costs
BC4: Feature phone	Battery repair rate : 33% -> 50% Display repair rate : 25% -> 50% Other repair rate : 33% -> 50%	100 %	+5% repair costs
BC5: DECT phone	Not relevant		
BC6: Tablet	Battery repair rate : 33% -> 45% Display repair rate : 25% -> 45% Other repair rate : 33% -> 45%	100 %	+4% repair costs

The **broad reparability option** includes the combination of:

- Provision of repair and maintenance information (DO20) – same as above
- Use of reversible and reusable fasteners for the housing (DO23)
- Battery removability / replacement without use of tools (DO17, which actually includes DO15)
- Glass back cover removability / replacement (DO18)
- Display removability / replacement (DO19)
- Availability of spare parts for end-users (DO21b)

This combination of broader and additional options increases repair rates, now also significantly as do-it-yourself repairs. The resulting design changes are very significant. Provision of repair information closes a gap mainly for low-end and mid-range devices. Availability of spare parts is crucial for all segments. Better access to defect components is a pre-condition, that device owners can undertake repairs themselves. This is included in this option through reversible and reusable fasteners for the housing, battery replacement without tools, simplified glass back cover replacement (the only design option for which there is no example stated in the technical analysis in Task 4) and a simplified display replacement.

Increased DIY rate reduces individual repair costs significantly (unless design choices lead to additional defects caused by DIY repairs), but also for repair professionals processes are less complex, i.e. less costly. These effects reduce costs for the consumer much more than the potentially higher parts costs for spare parts availability logistics and the slightly more costly assembly process add to the LCC.

Repair rates are assumed to stay well below 100% (i.e., at maximum 70%) as the findings from Task 3 indicate, that a significant share of users see a defect device rather as an opportunity to upgrade to a new one. Furthermore, spare parts costs compared to the remaining value of the device after a certain period is for a share of the device owners not worth the investment anymore.

Table 18 : Design Option DORep-b – broad reparability - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Cost effect on affected devices per unit
BC1: Smartphone, low-end	Battery repair rate : 33% -> 70% Display repair rate : 25% -> 70% Other repair rate : 33% -> 50%	100 %	Battery repair cost reduced to 30 Euros Display repair costs (across all repairs): -30%
BC2: Smartphone, mid-range	Battery repair rate : 33% -> 70% Display repair rate : 25% -> 70% Other repair rate : 33% -> 45%	100 %	Battery repair cost reduced to 30 Euros Display repair costs (across all repairs): -30%
BC3: Smartphone, high-end	Battery repair rate : 33% -> 70% Display repair rate : 25% -> 70% Other repair rate : 33% -> 40%	100 %	Battery repair cost reduced to 30 Euros Display repair costs (across all repairs): -30%
BC4: Feature phone	Battery repair rate : 33% -> 50% Display repair rate : 25% -> 70% Other repair rate : 33% -> 50%	100 %	Display repair costs (across all repairs): -20%
BC5: DECT phone	+2,5 years lifetime	15 %	7 Euros for one extra AAA battery set
BC6: Tablet	Battery repair rate : 33% -> 70% Display repair rate : 25% -> 70% Other repair rate : 33% -> 45%	100 %	Battery repair cost reduced to 50 Euros Display repair costs (across all repairs): -30%

3.5 Use of materials

3.5.1 DO24 Use of recyclable materials

Positive effect on the the effectiveness and efficiency of recycling can be facilitated through appropriate product design targeting depollution, dismantling, recyclability and recoverability of products. Also, where the market of certain recycled materials needs to be stimulated, it could be more appropriate to set quantitative targets in terms of recyclability (Cordella et al. 2020).

EN 45555:2019 provides guidance for the assessment of the recyclability of electronic products, taking into account the fasteners and assembly techniques, compatibility of materials with current recycling techniques as well as the ability to access and remove plastics parts containing fillers or flame retardants.

In addition to positive effects on repairability, some design options (DO 15-19, DO23) have the potential to facilitate design for higher recyclability. Thus, this design option is not evaluated further.

In the later modelling the benefits of ease of disassembly through reparability measures is not taken into account as it is unlikely, that recyclers under current conditions would treat disposed devices in any way differently than they do today. Separation of individual fractions beyond "batteries" and "rest of the device towards a copper / precious metal smelter" is unlikely, but might change with OEMs putting in place dedicated recovery technologies (Chandler 2020).

3.5.2 DO25 Use of post-consumer recycled plastics

The use of post-consumer recycled (PCR) plastics in electrical and electronic equipment still poses a number of special challenges. This includes in particular diverse material-related quality requirements, e.g. the impact resistance, tensile strength, rigidity, processability or insulating properties. These requirements must also be met by recycled plastics if they are to be used within the existing device design and the established production processes. Another basic requirement for the use of plastic recyclates is compliance with defined limit values for harmful substances (e.g. RoHS, REACH). The challenges lie particularly in the reliable procurement of quality-assured raw materials that originate from appropriately optimized preparation processes.

The availability and prices for such quality-assured secondary materials are decisive factors for the replacement of primary materials.

Manufacturers of smartphones and DECT phones have already started using post-consumer recycled plastics. As established in Task 4, the technical feasibility of using 100% recycled ABS was demonstrated in DECT phone.

Fairphone has reported the use of 40% recycled plastics in the Fairphone 3 and Apple revealed 35% recycled plastics content in their smartphones (e.g. iPhone 12 and SE).

Assumption: the price of post-consumer recycled is equivalent to the price of virgin (petrochemical) plastics.

Table 19 shows the expected effect and share of devices in each base case.

Table 19 : Design Option DO25 – post-consumer recycled plastics - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Estimated cost effect
BC1: Smartphone, low-end	no effect on lifetime	60 %	0 EUR (no effect)
BC2: Smartphone, mid-range	no effect on lifetime	40 %	0 EUR (no effect)
BC3: Smartphone, high-end	no effect on lifetime	10 %	0 EUR (no effect)
BC4: Feature phone	no effect on lifetime	60 %	0 EUR (no effect)
BC5: DECT phone	no effect on lifetime	80 %	0 EUR (no effect)
BC6: Tablet	no effect on lifetime	60 %	0 EUR (no effect)

Improvement:

- An LCA performed under the H2020 PolyCE project indicates that the potential environmental impact of a plastic component produced by injection moulding with recycled feedstock can be reduced by 24 %, compared to the use of virgin plastics.

3.5.3 DO26 Use of bio-based plastics

Apple reported the use of bio-based plastics in the cover glass frame of iPhone (Apple 2018).

Several phone companies such as Nokia, Samsung and NEC have launched phones using PLA in the phone housing (Shen et al. 2009).

Production costs, technical challenges in the scale-up of production, short-term availability of bio-based feedstock as well as the need for the plastics converters to adapt to the new material are amongst the main reasons for the relatively low replacement rate of virgin (petrochemical) with bio-based plastics (Venkatasamy 2019).

Assumption: in view of the complex processing required, the market price of bio-based plastics is substantially higher (at least 70%) than the price of virgin plastics.

Table 20 shows the expected effect and share of devices in each base case.

Table 20 : Design Option DO26 – bio-based plastics - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Estimated cost effect
BC1: Smartphone, low-end	no effect on lifetime	60 %	0 EUR (no effect)
BC2: Smartphone, mid-range	no effect on lifetime	40 %	0 EUR (no effect)
BC3: Smartphone, high-end	no effect on lifetime	10 %	0 EUR (no effect)
BC4: Feature phone	no effect on lifetime	60 %	0 EUR (no effect)
BC5: DECT phone	no effect on lifetime	80 %	0 EUR (no effect)
BC6: Tablet	no effect on lifetime	60 %	0 EUR (no effect)

3.5.4 DO27 Provision of products without External Power Supplies (EPS) and other accessories

The Impact Assessment Study on Common Chargers of Portable Devices (Ipsos 2019) analysed the effect of common chargers and the option to sell mobile phones without external power supplies. Decoupling of selling a mobile device and the external power supply is an option. In case all mobile phones, smartphones and tablets are sold without external power supplies by default, given that compatible units are already widely available in households, only a limited share of users would be expected to purchase a separate external power supply. Headsets are a slightly different issue, but continued use of existing ones is definitely an option. Headset cables are to a non-negligible share subject to defects, thus replacement purchases will be required more frequently than those of EPS, but many also purchase higher quality headsets than those shipped with the phone. A rough estimate is 25% more users would buy a separate headset, if phones are shipped without by default.

Table 21 : Cost figures EPS according to common charger impact assessment study, estimated headset costs and correlation with Base Cases

Main component	Type	Production cost [€]	Wholesale price [€]	Retail price [€]	Base Case (Mobile phones, smartphones, tablet study)
Source: Common Charger Impact Assessment Study					
EPS - USB C	USB C - Standard charger	2,50	6,-	11,-	1, 4, 5
EPS - USB C	USB C - Fast charger - USB-PD	4,-	8,-	15,-	2, 3, 6
EPS - USB C	USB C - Fast charger - QuickCharge	4,-	8,-	15,-	
Headset	Mid-range quality, wired	3,50	7,-	14,-	1, 2, 3, 4

The smaller package reduces logistics costs all the way from final assembly and packaging to the shop floor. Estimated savings on packaging material savings and more importantly logistics are in the range of 0,50 € for phones and 1,- € for the larger tablets.

Table 22 shows the expected effect and share of devices in each base case of mobile phones, smartphones and tablets study.

This design option is assumed to have no effect on the lifetime of phones or tablets.

Table 22 : Design Option DO27 – unbundling - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Cost effect on affected devices per unit
BC1: Smartphone, low-end	All new products sold without EPS, headset, smaller package	100 %	-0,80€ (0,50+2,50+3,50€ saved by all; 11€ paid by 20% for extra EPS, 14€ paid by 25% for extra headset)
BC2: Smartphone, mid-range	All new products sold without EPS, headset, smaller package	100 %	-1,50€ (0,50+4+3,50€ saved by all; 15€ paid by 20% for extra EPS, 14€ paid by 25% for extra headset)
BC3: Smartphone, high-end	All new products sold without EPS, headset, smaller package	100 %	-1,50€ (0,50+4+3,50€ saved by all; 15€ paid by 20% for extra EPS, 14€ paid by 25% for extra headset)
BC4: Feature phone	All new products sold without EPS, headset, smaller package	100 %	-0,80€ (0,50+2,50+3,50€ saved by all; 11€ paid by 20% for extra EPS, 14€ paid by 25% for extra headset)
BC5: DECT phone	All new products sold without EPS, headset, smaller package	100 %	-0,80€ (0,50+2,50€ saved by all; 11€ paid by 20% for extra EPS)
BC6: Tablet	All new products sold without EPS, headset, smaller package	100 %	-2,00€ (1+4€ saved by all; 15€ paid by 20% for extra EPS)

3.5.5 DO28 Standardised interfaces for external connectors and EPS

A common charger solution eases the implementation of decoupling external power supplies from device sales, but is not essential for such an approach as shown by Apple's recent announcement to ship iPhones without external power supplies. Furthermore the widespread use of external power supplies with detachable USB Type-A to USB Type-C cables allows in many cases already a reuse of existing power supplies.

As the Impact Assessment Study on Common Chargers of Portable Devices (Ipsos 2019) has demonstrated, the harmonisation of connectors as such has little effect on consumers and the environment. The benefits of harmonised connectors and chargers materialise with the decoupling or unbundling of device and external power supply, see design option above.

For a distinct environmental and LCC assessment of a common charger solution see the Impact Assessment Study on Common Chargers of Portable Devices (Ipsos 2019).

3.6 Readiness for second use and recycling

3.6.1 DO29 Reliable data erasure through encryption combined with factory reset

There are strong indications, that data privacy concerns are a major reason for the large amount of hibernating devices. Instead of hibernation, many of these devices could be made available for the reuse market, thus replacing new devices, if the user has confidence in data erasure or encryption with deletion of the encryption key. Encryption by default leads to reliable data erasure, once a factory reset is done. This requires the encryption key to be deleted in the factory reset process. Android and iOS support this feature. Alternatively third party software can be used to overwrite data before factory reset, but given the architecture of flash memory not all data might be erased this way.

Table 23 : Design Option DO29 – data erasure - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Estimated cost effect
BC1: Smartphone, low-end	+1,5 years	5%	+2,5€ (i.e., 50 € recommerce costs/margin per device)
BC2: Smartphone, mid-range	+1,5 years	10%	+10€ (i.e., 100 € recommerce costs/margin per device)
BC3: Smartphone, high-end	+1,5 years	10%	+15€ (i.e., 150 € recommerce costs/margin per device)
BC4: Feature phone	+1,5 years	5%	+2€ (i.e., 40 € C2C shipping costs and replacement battery)
BC5: DECT phone	n.a.		
BC6: Tablet	+1,5 years	10%	+10€ (i.e., 100 € recommerce costs/margin per device)

65% of smartphones, feature phones, tablets are assumed to go into hibernation (see Task 4, 4.7).

37% are hoarding devices in Germany as they are afraid, that data might be extracted from disposed phones. In UK 40% have similar concerns when being asked why not recycle used devices – and it can be assumed a similar high rate would give the same answer, if the question would have been related to "why not reuse"? (Task 3)

This means that more than 20% of all mobile phones and tablets due to data privacy concerns are hoarded after use. A conservative estimate is, that with proper and trustworthy data erasure processes in place, 5% of low-end smartphones and feature phones (as there is a smaller reuse market for these devices) and 10% of all other mobile phones and tablets could re-enter the reuse market. Due to other limitations, second life is assumed to be shorter than first life, a plausible assumption are an additional 1,5 years. Refurbishment will likely require a battery replacement as additional material consumption. For the first user the re-sale value of the device reduces life cycle costs, the second user has to pay the higher re-sale price, if the device is traded through a recommerce company, which is frequently the case, but just selling C2C through ebay or similar is also common. Assuming at least a battery replacement and a recommerce margin for some of the devices adds additional costs - as depicted as estimated cost effect in Table 23 - throughout the significantly extended lifetime. These recommerce processing costs and margins are derived from a short analysis of leading recommerce platforms and comparing offered prices for acquiring used devices and sales prices. The found margins also indicate, that recommerce platforms can achieve better margins with flag-ship devices than with low-end devices, which likely results in less interest by the recommerce platforms to get engaged more in these market segments and reuse would need to rely rather on the C2C reuse market.

Table 23 shows the expected effect and share of devices in each base case.

3.6.2 DO30 Data transfer from an old to a new product is conveniently possible via installed or downloadable tools or cloud-based services

Complicated data transfer from one device to another one is a barrier to phone and tablet reuse and recycling as devices are rather kept as a data archive: 24% of all users in Germany hoarding devices do so as they consider data transfer too complicated. Similarly, valuable information stored on the old device turned out to be a major reason for users in the UK not to recycle old phones. These findings are presented in more detail in Task 3, 5.3.

These data points indicate, that simpler data transfer could also increase the number of hoarded devices which can be made accessible for reuse, i.e. a second life.

Data transfer through the cloud under the condition of an existing Google account is typically feasible for transfers from Android to Android devices with limited effort and if registering for a Google account is not seen as a barrier. Similarly such data transfer is conveniently provided for iPhones. However, users still state to consider this too complicated (or they are just not aware of the feature). Hence, this design option is rather about better transparency, how to transfer data technically than implementing new technical measures.

Given the figures for Germany, the maximum potential is 15% of devices which can be reused, if this option is fully exploited. A conservative estimate is, that this in the end might materialise for 5% of the low-end smartphones and 10% of other smartphones and tablets. For feature phones this option is assumed not to be a relevant option.

Similar to the data erasure option above, enhanced data transfer is assumed to yield more reuse / recommerce: Refurbishment will likely require a battery replacement as additional material consumption. For the first user the re-sale value of the device reduces life cycle costs, the second user has to pay the higher re-sale price, if the device is traded through a recommerce company, which is frequently the case, but just selling C2C through ebay or similar is also common. Assuming at least a battery replacement and a recommerce margin for some of the devices adds additional costs throughout the significantly extended lifetime.

Given that this option and the data erasure option above are calculated as conservative scenarios by far not exploiting the full potential, these two options can be considered additive. The amount of devices the reuse market can absorb however is definitely limited and these two options would already have a massive push effect on the reuse market.

Table 24 shows the expected effect and share of devices in each base case.

Table 24 : Design Option DO30 – data transfer - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Estimated cost effect
BC1: Smartphone, low-end	+1,5 years	5%	+2,5€ (i.e., 50 € recommerce costs/margin per device)
BC2: Smartphone, mid-range	+1,5 years	10%	+10€ (i.e., 100 € recommerce costs/margin per device)
BC3: Smartphone, high-end	+1,5 years	10%	+15€ (i.e., 150 € recommerce costs/margin per device)
BC4: Feature phone	n.a.		
BC5: DECT phone	n.a.		
BC6: Tablet	+1,5 years	10%	+10€ (i.e., 100 € recommerce costs/margin per device)

3.7 Ability to recycle smartphones / parts / materials

3.7.1 DO38 Collection of products / put in place take back schemes

Insufficient collection is particularly relevant for small devices such as smartphones and tablets. Lack of information about disposal of obsolete devices, hording effects and data security issues are amongst the main reasons for the low collection rates, see Task 3. Separate collection and mindful storage avoiding excessive mechanical stress also facilitates reuse.

Setting up take-back schemes offers additional positive effects, for example, devices being returned via take-back schemes and transported further for refurbishment or recycling or parts harvesting. It should be noted that anti-theft and security software installed on smartphones poses potential barrier for independent organisations and professionals since this software can only be removed by the original owner or by the manufacturer (Cordella et al. 2020).

An option to incentivise the collection of mobile devices is a deposit. This has been proposed in the past by various stakeholders and industry came forward with arguments against it, arguing among other points, that logistics and capital lockup would be issues. The German manufacturer Shift however introduced few years back a 22,- Euros deposit on smartphones (which is more than 5% of the price of their cheapest model), demonstrating the feasibility of this approach.

The option to put in place and strengthen product take-back schemes is currently subject to another study of the European Commission, which investigates this aspect more in detail. Results of this parallel study are not yet available and thus might go beyond the findings of this study. In case a separate new take-back policy is implemented, this will have an effect on impacts of a potential ecodesign regulation. Therefore we calculate such improved take back here in this study as a future scenario.

Improvement

- As reported in Task 3, 5.3, in Germany 64% of all citizens stated to have disposed or sold a mobile phone in the past, but 21% keep (all) their used phones. For 36% of those who are hoarding phones laziness is apparently the main barrier: Disposing or selling the old phone is not worth the effort for them. 19% do not know how to dispose old phones properly. Devices from these 2 groups, i.e. roughly 50% of hoarded devices could be returned potentially through a convenient take back scheme.
- Of those collected via take-back schemes, half are assumed to enter the second-hand (reuse) market: 21 % * 50 % * 50 % = 5,25 %. This high share of reused devices requires a take-back system, which incentivizes returning devices as soon as they are taken out of operation. A delayed return of devices will significantly reduce the reuse share and increase the recycled share. For cordless phones, due to lower hibernation rate, a lower reuse rate of 4% is more plausible.
- Devices that enter the reuse market remain in active use for about an additional year, however, being subject to the same failure and repair rates that are assumed in each base case.

Cost

- The study team has no insights on the costs of developing and maintaining a reverse logistics system and to set up potentially an incentives scheme. In the calculated scenario the purchase price is estimated to increase by 0,50 Euros per device sold, to cover costs of reverse logistics and/or to maintain a deposit system.

Table 25 : Design Option DO38 – collection and take back - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Estimated cost effect
BC1: Smartphone, low-end	Reuse for 1 additional year	5,25 %	+0,50 EUR (all devices in BC)
BC2: Smartphone, mid-range	Reuse for 1 additional year	5,25 %	+0,50 EUR (all devices in BC)
BC3: Smartphone, high-end	Reuse for 1 additional year	5,25 %	+0,50 EUR (all devices in BC)
BC4: Feature phone	Reuse for 1 additional year	5,25 %	+0,50 EUR (all devices in BC)

Base Case	Expected effect on affected devices	Share of devices affected in base case	Estimated cost effect
BC5: DECT phone	Reuse for 1 additional year	4 %	+0,50 EUR (all devices in BC)
BC6: Tablet	Reuse for 1 additional year	5,25 %	+0,50 EUR (all devices in BC)

3.7.2 DO39 Identification, access and removal of specific parts

The removal of certain parts at the EOL is necessary for the safe disposal of the device and an efficient recycling and recovery of materials. Identification, access and removal parts of concern according to Annex VII of WEEE (batteries and PCBs) and parts containing precious/critical raw materials is of particular relevance for the effective EOL management of discarded products. Also, there is the risk that certain components (e.g. batteries and displays) difficult to be extracted would be shredded together with other waste, with the consequent dispersion of pollutants and contamination of other recyclable fractions, the risk of explosions in the shredders, and the irreversible loss of valuable resources.

Design options enhancing reparability as outlined above would also correspond better with manual dismantling processes at end-of-life, although processes and tools are typically not the same (non-destructive versus destructive). As the major LCC and environmental benefits of this option are related to reparability not recyclability, no separate "Design for Recycling" options are proposed here.

3.7.3 DO40 Provision of additional information for recyclers

For the safe and efficient recycling, information on disassembly process and location of battery and other valuable components is essential (Maya-Drysdale et al. 2017). Information could concern:

- general information on the product (including the month and year when the products were placed on the market);
- content of dangerous components/substances used (as a minimum the ones mentioned in Annex VII of the WEEE Directive, see section 3.1): provision of a short description and photo, and the place where these are usually found in the appliance;
- dismantling instructions: these could include exploded diagrams of the device, indicating the opening mechanism and required tools; in case of clips, this should include information related to the direction the housing should be opened;
- how to recognize special models and specific dismantling instructions for them;
- advice on collection (separate/mixed) and on logistics.

Additional relevant information could include also:

- Information on batteries which cannot be removed without the use of (advanced) tools).
- personal protection equipment needed for handling,
- risks for workers when the waste is not properly dismantled,
- advice on possibilities to sort the components or substances (when different treatment is possible for different types)
- advice on available treatment techniques

Apart from all this information, providing uniform, visible and comprehensive marking has the potential to improve the sorting and recycling of device and targeted parts (Maya-Drysdale et al. 2017). The marking can be applied to:

a. Content in the product of CRM and minerals from conflict-affected and high-risk areas

b. Marking of parts containing halogenated substances or hazardous substances/SVHC

c. Marking of plastic parts > 25g in accordance to ISO 11469 (mainly relevant for cordless phones and a substantial share of tablets)

d. Marking of batteries (chemistries)

After collection, batteries at the EoL mostly appear as mixtures and are subject mostly to manual sorting and separated according to their chemistries. The identification of the chemistry type is based on the label placed on the battery packaging/casing. In practice, however, when the batteries reach the recycling facility, the labels sometimes are missing, making identification and sorting difficult. In order to release manual labour force, raise the sorting speed as well as accuracy, better marking with improved readability is required in order to realize efficient identification and sorting (Tecchio et al. 2018a).

Interviews with battery recyclers conducted within the framework of the preparatory study on the Review of Regulation 617/2013 (Lot 3) indicate that uniform battery marking will facilitate the separation of mixed batteries and therefore increase the recycling rates of Li-ion batteries (Tecchio et al. 2018a).

Except for the battery marking clearly identifying chemistries, the other measures do have a very limited effect under current recycling practice, as recyclers do not have the infrastructure to access and consult such documentation easily and to integrate this information in their workflow. Research is ongoing to improve recycling through e.g. an electronic product passport, advanced automation for dismantling7, and recycling of rare earth magnets from mobile devices8, the latter even in conjunction with proposing a marking system for the magnets and their composition.

Data and information requirements and capabilities of recyclers to make use of the data needs to be developed in parallel. Currently the effect of enhanced information provision cannot be reliably predicted, and due to these major uncertainties, this is not underpinned here with a calculation.

The only case where there is a clear mentioning of data needs by recyclers is the marking of batteries per distinct chemistry, see Task 1.

This would affect those devices with Li-ion / Li-polymer batteries, which end up in the correct recycling streams. According to Task 4 findings this is likely the case for 20% of the devices covered under BCs 1, 2, 3, 4 and 6, and for those few cordless phones among the recycled 50% with Li-ion batteries, i.e. roughly 7,5% of all cordless phones. By now, a better separation could lead to more efficient battery recycling and higher recovery rates, but this benefit cannot be quantified yet.

Marking batteries is considered cost-neutral.

7 https://www.sustainably-smart.eu/

8 https://www.susmagpro.eu/

3.8 Packaging

3.8.1 DO41 Use of fiber-based packaging materials

Most of the sales packages for this product group are already made of paper and cardboard material, which typically provides good protection against rough handling and is not in conflict with an appealing appearance at the point of sales. Occasionally plastics inlays are in use, but any further improvement in materials compared to the assessment results of the Base Case seems marginal and is not further analysed here.

3.8.2 DO42 Improvement of packaging efficiency

Occasionally sales packages are oversized and packaging material could be used more efficiently. A significant effect in terms of reducing packaging sizes and material is related to the unbundling of devices and external power supply, or other accessories. This option and effect is linked to the unbundling discussion, see DO27.

3.9 Manufacturing

3.9.1 DO45 Renewable energy used for the manufacturing of PCBs and semiconductors

Given that the manufacturing of semiconductors and printed circuit boards are particularly energy intensive processes, a shift towards renewable energy for these components is particularly relevant to reduce the carbon footprint of mobile phone, smartphone and tablet production. It should be noted however that a phone or tablet is made of one or more rigid PCBs but easily in the range of 50 or more integrated circuits. Such an approach therefore would require involvement of multiple players. For a more focused approach shifting to renewable energy for the production of the

- largest PCB (i.e. mainboard, and mainboard PCBs, which are soldered together, e.g. stacked PCBs),
- CPU / SoC,
- memory: RAM, and
- storage: Flash

would already cover a large portion of the GHG emissions. The expected effect are reduced carbon emissions from mainboard, SoC, RAM, Flash manufacturing (-60% to account roughly for the electricity related energy share of PCB production and chip front-end and back-end).

As newly installed renewable power capacity increasingly costs less than the cheapest power generation options based on fossil fuels (IRENA 2020), increasing use of renewable power in the supply chain is feasible without increasing product costs, but this assumption might be challenged by the conditions in specific regions, available power sources, and the willingness of suppliers to change to renewable sources.

Table 26 : Design Option DO45 – battery joining techniques - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Cost effect on affected devices per unit
BC1: Smartphone, low-end	Reduced carbon emissions from mainboard, SoC, RAM, Flash manufacturing (-60%)	100 %	none
BC2: Smartphone, mid-range		100 %	
BC3: Smartphone, high-end		100 %	
BC4: Feature phone		100 %	
BC5: DECT phone		100 %	
BC6: Tablet		100 %	

3.9.2 DO46 Ground or cargo vessel transports only

Avoiding air cargo reduces impacts of shipping devices to the EU significantly. This also reduces costs significantly as air cargo of smartphones roughly costs 1 € and sea transport is significantly cheaper, less than 0,10€[9]. A major drawback of this option is a delayed market introduction of new devices by several weeks and a slower reaction time, if a significant share of failures in the field are detected right after market introduction.

Table 27 : Design Option DO46 – transportation - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Cost effect on affected devices per unit
BC1: Smartphone, low-end	sea transport	20 %	-0,90 Euro
BC2: Smartphone, mid-range		100 %	-0,90 Euro
BC3: Smartphone, high-end		100 %	-0,90 Euro
BC4: Feature phone		20 %	-0,90 Euro
BC5: DECT phone		0 %	not relevant
BC6: Tablet		50 %	-1,20 Euro

The carbon emissions of sea transport are 1/10 or less of the GHG emissions resulting from air freight[10]. Distribution data is adapted accordingly in the environmental assessment.

3.9.3 DO47 Area-optimised PCB design

The design of feature phones and DECT phones frequently relies on a large PCB, which provides stability to the overall device and connects all external connectors, buttons and slots on the various edges of the device. In low-end and partly also mid-range smartphones the PCB fulfils a similar function as carrier for all connectors and button contacts, but frequently in an odd-form designed around the embedded battery, resulting in significant cut-offs and PCB losses in the manufacturing process. In high-end smartphones the size of the mainboard is typically optimized, i.e. minimized, for optimal volume use inside the device and distances are bridged by flex connector PCBs. In tablets similar odd-form PCB designs are found with significant cut-off losses.

For an option with area-optimized rigid PCB design, some other design changes are required:

- BC1, BC2, BC6: More flex PCB to bridge distances (incl. connectors)

9 https://www.worldbank.org/en/topic/transport/publication/air-freight-study#:~:text=The%20demand%20for%20air%20freight,typically%20exceeds%20%244.00%20per%20kilogram.

10 Example : https://www.dhl.com/content/dam/dhl/global/core/documents/pdf/gogreen/dhl-gogreen-carbon-calculator-062016.pdf

- BC4, BC5: More flex PCB to bridge distances (incl. connectors) and additional plastics frame / housing material to provide required stability.

Whereas additional housing material adds negligible costs in the range of few cents at maximum, flex PCBs add more costs, but on the other hand area savings of the rigid PCB in a similar range materialises. The overall design, and thus the assembly is getting more complex. In the end such design might cost 0,50 € more, reflecting on the parts and assembly costs presented in Task 2.

Table 28 shows the expected effect and share of devices in each base case.

Table 28 : Design Option DO47 – optimised PCB design - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Cost effect on affected devices per unit
BC1: Smartphone, low-end	Less rigid PCB, more flex	100 %	+0,50 Euro
BC2: Smartphone, mid-range	Less rigid PCB, more flex	100 %	+0,50 Euro
BC3: Smartphone, high-end	none	0 %	none
BC4: Feature phone	Less rigid PCB, more flex, more housing plastics	100 %	+0,50 Euro
BC5: DECT phone	Less rigid PCB, more flex, more housing plastics	100 %	+0,50 Euro
BC6: Tablet	Less rigid PCB, more flex	100 %	+0,50 Euro

3.9.4 DO33 Reduction of fluorinated gas emissions resulting from flat panel display manufacturing

Reducing fluorinated gas emissions from display manufacturing can reduce the carbon footprint of LCDs by up to 10%. Reducing GHG emissions through abatement of PFCs by 5% is a substantial improvement. As various perfluorocompounds are used and for several purposes, emission reduction can be achieved through a combination of measures, including substitution, process optimisation, abatement. These measures add costs, but there is no public data on how much achieving which abatement rate costs. As a proxy this option is calculated with an additional 0,5% LCD costs.

Table 29 : Design Option DO33 – PFC reduction display production - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Cost effect on affected devices per unit
BC1: Smartphone, low-end		100%	+0,05 €
BC2: Smartphone, mid-range		100%	+0,125 €
BC3: Smartphone, high-end	-5% GHG emissions LCD	100%	+0,25 €
BC4: Feature phone		100%	+0,03 €
BC5: DECT phone		100%	+0,02 €
BC6: Tablet		100%	+0,10 €

3.9.5 DO48 Reduction of fluorinated gas emissions resulting from IC manufacturing

Similar to the LCD case, reducing fluorinated gas emissions from IC manufacturing can reduce the carbon footprint of semiconductor packages by up to 10%. Reducing GHG emissions through abatement of PFCs by 5% is a substantial improvement. This is defined as an option for CPU/SoC, RAM, Flash components, but can be extended to other semiconductors as well. As various perfluorocompounds are used and for several purposes, emission reduction can be achieved through a combination of measures, including substitution, process optimisation, abatement. These measures add costs, but there is no public data on how much achieving which abatement rate costs. Given that there are multiple activities under way by the semiconductor industry, this option is calculated with an additional 0,5% semiconductors costs.

Table 30 : Design Option DO48 – PFC reduction semiconductor production - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Cost effect on affected devices per unit
BC1: Smartphone, low-end	-5% GHG emissions CPU/SoC, RAM, Flash	100%	+0,10 €
BC2: Smartphone, mid-range		100%	+0,25 €
BC3: Smartphone, high-end		100%	+0,50 €
BC4: Feature phone		100%	+0,05 €
BC5: DECT phone		100%	+0,04 €
BC6: Tablet		100%	+0,20 €

3.9.6 DO35 Content in the product of CRM and minerals from conflict-affected and high-risk areas, and other metals

There are significant differences in the content of critical raw materials (CRMs) found by various chemical analyses (see Task 4). This is largely related to deliberately made design decisions, where certain materials are state-of-the-art, but there are also cases where the exact material choice is up to a supplier. Most relevant CRMs according to the analysis in Task 5, 4.7.2, are tantalum, cobalt, platinum group metals, indium, gallium and rare earth elements. Given the variance of concentrations found in these devices a reduction by 10 or 20% through informed design choices seems feasible. However, reducing cobalt might be in conflict with battery capacity, rare earth elements in magnets are used for affixing modules and accessories in an easily reversible way, and gallium is essential for proper radio communication and compromises here might be hardly justifiable from a performance perspective.

Gold is another relevant material, but rather from an environmental perspective. Also gold content is varying widely among devices and progress is made to reduce gold layer thicknesses and to replace gold wire bonds with copper wire bonds. As the properties of gold add to the reliability of contacts - and a large number of connectors adds to the modularity of the design -, reducing gold might be in conflict with durability and other strategies targeting at extended product lifetime.

3.10 Energy

3.10.1 DO49 Extended battery endurance per full charge

The analysis in Task 4, 3.1.1.3, indicates relevant variations in battery endurance per full charge among smartphones. This is partly related to the battery size, but even more how energy-efficient the smartphone operates. Given the multiple functions of smartphones – and tablets -, there are numerous technical aspects, including software and hardware, which have an impact on energy efficiency of the device. Battery endurance is a major indicator for this. As the analysis shows 30% above average battery endurance is achieved by a significant share of the market, including flagship devices with a high-end specification. Therefore, an energy-efficiency related design option is a battery endurance of 30% above average for smartphones and also for tablets (the latter based on Task 4, 3.1.2.3, power consumption spread of tablets in idle and active mode).

The positive effect of longer battery endurance is two-fold:

- Energy savings through less frequent charging and
- longer battery lifetime in terms of cycles as the same number of charging cycles is stretched over a 30% longer period.

As there is some correlation of battery capacity and battery endurance in a given system, a longer battery endurance incentivizes larger batteries, which has to be taken into account as a possible side-effect of this design option.

Table 31 : Design Option DO49 – battery endurance per full charge - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Cost effect on affected devices per unit
BC1: Smartphone, low-end	• Energy consumption: 30% of the active charge time in trickle charge instead • Need for battery replacement arises 30% later in time • 10% larger batteries	100%	-0,32 € Energy savings per year of use +0,40 € battery costs extended lifetime savings
BC2: Smartphone, mid-range			-0,46 € Energy savings per year of use +0,60 € battery costs extended lifetime savings
BC3: Smartphone, high-end			-0,64 € Energy savings per year of use +0,80 € battery costs extended lifetime savings
BC4: Feature phone	Not relevant	Not relevant	
BC5: DECT phone	Not relevant	Not relevant	

Base Case	Expected effect on affected devices	Share of devices affected in base case	Cost effect on affected devices per unit
BC6: Tablet	• Energy consumption: 30% of the active charge time in trickle charge instead • Need for battery replacement arises 30% later in time • 10% larger batteries		-0,51 € Energy savings per year of use +1 € battery costs extended lifetime savings

Life cycle costs include

- cost savings in terms of electricity savings for the user
- 10% increased battery costs to account for those cases, where a larger battery is chosen to implement this option, including system (i.e., device size) changes
- indirect cost savings through extended lifetime

The implementation of a thorough energy management is also a cost issue, but there is no data available, what the cost implications of a more energy efficient design might be. It is definitely more challenging – thus also more costly - for smaller brands to achieve energy savings as they have less control over the hardware, the software and the interplay of both.

3.10.2 DO50 Reduced standby power consumption (BAT: 0,4 W base station; 0,05 W charging cradle only)

There is a spread of standby power consumption among cordless phones with base station. Several devices meet a standby power consumption of 0,4 W, even with an integrated answering machine and other typical features (see Task 4, 3.1.3.2). These particularly power-saving units are in the same price range as other cordless phones with base station, which gives no reason to assume, that low power consumption comes at a significantly increased product cost. It is very unlikely, that this likely marginal extra component cost exceeds the achievable electricity cost savings of 1,84 € on average.

Table 32 : Design Option DO50 – standby reduction - expected effects

Base Case	Expected effect on affected devices	Share of devices affected in base case	Cost effect on affected devices per unit
BC1: Smartphone, low-end	Not relevant	Not relevant	
BC2: Smartphone, mid-range	Not relevant	Not relevant	
BC3: Smartphone, high-end	Not relevant	Not relevant	
BC4: Feature phone	Not relevant	Not relevant	
BC5: DECT phone	Average standby consumption 0,4 W instead of 0,6 W	100 %	-1,84€ (electricity costs savings over lifetime)
BC6: Tablet	Not relevant	Not relevant	

This design option is assumed to have no effect on the lifetime of phones or tablets.

3.10.3 DO51 Eco-DECT

There are several measures to reduce the power consumption of DECT handsets, but more important to reduce radiation. Such features are frequently summarized with the term Eco-DECT and typically include an adaptation of radiation power of handset and/or base station depending on the distance between both and that a radio connection is actually only established once there is an incoming call or the user activates the handset. Radiation power of the handset might be switched off when the handset is placed in the base station. The power savings of the handset and base station as a combo vary and actually power consumption of the base station might be even higher, if radiation power of the handset is regulated down.

Such features to reduce overall radiation are beneficial for the user, but impacts on human health cannot be quantified in the context of this study.

According to Gigaset as one main manufacturer in this market, these Eco-DECT features do not lead to increased product prices[11].

3.11 Other features

Some design features can have a positive effect on life cycle performance.

3.11.1 DO52 Memory extension card option for smartphones and tablets with 32 GB on-board Flash or less

As storage limitations can be considered a performance issue after a while of use, additional storage through providing memory extension card options is a viable way for the user to mitigate this problem. This option however is already standard and broadly available for smartphones with up to 32 GB flash storage (more than 90% of all model variants[12]). Flash capacities above 32 GB might still constitute a limitation for some users, but in general should suffice for most.

Under these conditions the design option memory extension does not change the Base Case assessment (Base Cases 1 and 6) and is not assessed here any further.

However, it might be advisable to promote the existence of memory extension options better to motivate the user to make use of this option. Memory extension through a removable memory card also (partly) solves issues with data privacy at end of life.

3.11.2 DO53 Dual-SIM (SIM-card or eSIM)

The Dual-SIM option can make a second mobile phone obsolete as the same device can e.g. be used for private and business use, with different phone contracts and numbers. In case a second device is really replaced through this feature, the impact is very relevant on a per unit basis. However, Dual-SIM, either through a second SIM card slot or an on-board eSIM chip is already implemented in the majority of devices: Among feature phones, low-end and mid-range smartphones at least 80% of all model variants feature Dual-SIM. Among high-end smartphones roughly 50% of the model variants come with a second SIM option[13].

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[11] https://blog.gigaset.com/en/what-is-eco-dect/

[12] data for Germany, idealo.de, Nov 16, 2020

[13] data for Germany, idealo.de, Nov 16, 2020

This widespread implementation of Dual-SIM is considered to leave enough options for the user to choose a Dual-SIM option, if this feature is of interest. As there are many users for whom Dual-SIM does not matter, it is important also to have choices without Dual-SIM as either the additional SIM slot or the additional eSIM chip relates to additional environmental impacts in the production phase and additional costs for the user.

Although it might be important to make a clear reference to the Dual-SIM option at the point-of-sales to ensure decision for a Dual-SIM device is made where this makes sense, this option is not further analysed in this Task report.

4 SUBTASK 6.2 – COSTS

In many cases Life Cycle Cost changes are correlated with longer product lifetime and the less frequent need to invest in a new device. The lifetime extending effect – either for the first or a second use – is crucial in this sense.

Table 33 provides an overview of calculated average lifetime per implemented option and based on the assumptions and data from subtask 6.1. Options that do not change the lifetime are marked in red (as some design options actually do not have an effect on the product lifetime), while options that do extend the lifetime are marked with color shades from lighter red through orange and yellow to green. The larger the lifetime extending-effect is, the closer to green is the shade of the cell in the table. Design options that are not expected to have any effect on the lifetime of products are not taken into account and therefore no data or shades appear in the table.

Software updates, increased confidence in data erasure, and simpler data transfer processes appear to be highly relevant in this regard. It is also apparent that hardly any individual design option alone increases product lifetime by more than 0,1 years. More substantial lifetime extensions are likely when several options are combined.

Table 33 : Calculated product lifetimes (in years) per design option

	BC1	BC2	BC3	BC4	BC5	BC6
			lifetime			
Base Case	2,500	3,000	3,500	3,000	5,000	5,000
DO1 Resistent Display	2,522	3,019	3,512	3,000	5,000	5,010
DO2 Scratch resistent display						
DO3 Bumper + foil	2,508	3,012	3,516	3,005	5,000	5,019
DO4 Water & dust ingress	2,537	3,049	3,500	3,051	5,000	5,071
DO5 battery endurance	2,574	3,055	3,500	3,126	5,000	5,047
DO6 battery capacity						
DO7 battery management software	2,580	3,091	3,590	3,137	5,091	5,051
DO8 battery status	2,506	3,008	3,513	3,000	5,000	5,007
DO9 information	2,504	3,005	3,509	3,006	5,004	5,005
DO10 most recent OS						
DO11 availability of updates	2,779	3,219	3,597	3,000	5,000	5,157
DO12 open source OS						
DO13 security patches						
DO14 capacity for next OS						
DO15 battery removability: joining techniques	2,502	3,002	3,504	3,000	5,000	5,016
DO16 battery removability: joining battery and display unit						
DO17 Battery removability w/o tools	2,530	3,049	3,582	3,000	5,338	5,054
DO18 glass back cover removability	2,500	3,009	3,519	3,000	5,000	5,000
DO19 Display removability	2,531	3,055	3,622	3,000	5,000	5,054
DO20 repair & maintenance information	2,549	3,070	3,600	3,065	5,000	5,076
DO21a availability of spare parts (shops)	2,510	3,009	3,507	3,002	5,000	5,023
DO21b availability of spare parts (end user)	2,520	3,037	3,566	3,004	5,000	5,023
DO22 information on repair costs	2,502	3,009	3,566	3,000	5,000	5,042
DO23 reversible/reusable fasteners	2,520	3,030	3,565	3,000	5,000	5,042
DO24 recyclable materials						
DO25 PCR plastics	2,500	3,000	3,500	3,000	5,000	5,000
DO26 bio-based plastics						
DO27 un-bundling	2,500	3,000	3,500	3,000	5,000	5,000
DO28 standardized interfaces						
DO29 data erasure	2,669	3,046	3,587	3,043	5,000	5,084
DO30 data transfer	2,669	3,046	3,587	3,000	5,000	5,084
DO38 take back schemes	2,524	3,031	3,537	3,073	5,025	5,045
DO39 Identification, access and removal of specific parts	2,500	3,000	3,500	3,000	5,000	5,000
DO40 provision of recycling information	2,500	3,000	3,500	3,000	5,000	5,000
DO45 declaration of share of new electricity	2,50	3,00	3,50	3,00	5,00	5,00
DO46 ground or vessel cargo	2,500	3,000	3,500	3,000	5,000	5,000
DO47 area-optimised PCB design	2,500	3,000	3,500	3,000	5,000	5,000
DO33 reduction fluorinated gas emissions - display	2,500	3,000	3,500	3,000	5,000	5,000
DO48 reduction fluorinated gas emissions - IC	2,500	3,000	3,500	3,000	5,000	5,000
DO49 battery standby time	2,586	3,135	3,705	3,000	5,000	5,112
DO50 standby DECT	2,500	3,000	3,500	3,000	5,000	5,000
DO51 Eco-DECT						
DO52 Memory extension card option						
DO53 Dual-SIM						

Life Cycle Costs of all design options are summarized in Table 34. These Life Cycle Costs are those born by the consumer, not yet including social life cycle costs. LCCs marked in green are associated with decreased costs compared to the Base Case, whereas some options increase costs from the consumer perspective (in red). Life Cycle Costs stated are per year of use and as such already reflect the effect of an extended lifetime, where applicable.

All options are calculated as individual "stand-alone" options, i.e. as if no other options would have been implemented.

The table has been sorted from lowest LCC to highest LCC for a 2020-stock-weighted average of LCC across all six Base Case products. It is apparent that the increase in costs from top to bottom of the table does not always apply to every Base Case, as some options have different effects on the individual Base Case products, even among the three smartphone Base Cases BC1-3.

This table includes only options for which LCC have been calculated. Additional design options have not been calculated, but are considered to complement one of the calculated options. Some other options cannot be reliably assessed with this approach or given system-related uncertainty. Not listing these options in this table does not exclude these options from further consideration.

Table 34 : Life Cycle Costs per year of use of all design options («stand-alone», in Euros per year of use)

	BC1	BC2	BC3	BC4	BC5	BC6	all weighted LCC
	LCC per year of use [€]						
Base Case	87,06	176,94	301,45	36,39	11,84	73,72	132,039
DO49 battery standby time	83,37	168,23	283,25	36,39	11,84	69,74	125,126
DO11 availability of updates	80,24	166,64	294,45	36,39	11,84	72,3	126,968
DO7 battery management software	84,16	170,12	293,37	34,63	11,48	71,99	127,964
DO17 battery removability w/o tools	85,31	172,8	291,52	36,39	11,55	71,92	128,491
DO21b availability of spare parts (end user)	85,24	172,53	291,45	36,25	11,84	72,32	128,517
DO29 data erasure	82,2	174,62	294,76	35,99	11,84	72,9	129,089
DO30 data transfer	82,2	174,62	294,76	36,39	11,84	72,9	129,122
DO19 display removability	86,01	173,99	292,33	36,39	11,84	73,03	129,299
DO20 repair & maintenance information	86,24	174,16	295,14	36,26	11,84	73,42	130,007
DO5 battery endurance	84,8	172,88	301,46	35,09	11,84	72,92	130,511
DO38 take back schemes	86,42	175,31	298,51	35,91	11,88	73,11	130,842
DO23 reversible/reusable fasteners	86,8	175,76	297,08	36,39	11,84	73,58	130,862
DO8 battery status	86,82	173,02	300,24	36,39	11,84	73,42	130,914
DO9 information	86,9	173,23	300,66	36,31	11,82	73,47	131,056
DO22 information on repair costs	87,04	176,57	297,46	36,39	11,84	73,68	131,166
DO4 water & dust ingress	86,92	175,09	301,45	36,78	11,84	73,22	131,569
DO27 un-bundling	86,74	176,44	301,02	36,12	11,68	73,32	131,666
DO3 bumper + foil	87,05	176,38	300,15	36,6	11,84	73,63	131,668
DO1 resistent display	87,29	175,9	300,33	36,39	11,84	73,78	131,672
DO18 glass back cover removability	87,06	176,75	300,31	36,39	11,84	73,72	131,777
DO15 battery removability: joining techniques	86,92	176,66	300,94	36,39	11,84	73,6	131,830
DO46 ground or vessel cargo	86,99	176,64	301,2	36,33	11,837	73,6	131,885
DO50 standby DECT	87,06	176,94	301,45	36,39	11,47	73,72	132,000
DO25 PCR plastics	87,06	176,94	301,45	36,39	11,84	73,72	132,039
DO39 Identification, access and removal of specific parts	87,06	176,94	301,45	36,39	11,84	73,72	132,039
DO40 provision of recycling information	87,06	176,94	301,45	36,39	11,84	73,72	132,039
DO45 declaration of share of new electricity	87,06	176,94	301,45	36,39	11,84	73,72	132,039
DO33 reduction fluorinated gas emissions - display	87,08	176,98	301,52	36,4	11,841	73,74	132,070
DO48 reduction fluorinated gas emissions - IC	87,1	177,02	301,6	36,41	11,845	73,76	132,104
DO47 area-optimised PCB design	87,26	177,1	301,45	36,56	11,94	73,82	132,157
DO21a availability of spare parts (shops)	87,2	176,99	301,68	36,55	11,84	74,01	132,199

The design option with the highest LCC savings potential is an **optimized battery endurance per full charge** (DO49), due to the two-fold effect of energy savings and longer battery life, thus product life in those cases where the battery is the limiting factor.

Availability of **OS support** for an extended time is second in yielding significant LCC savings due to the associated expected product lifetime extension. Enhanced battery management is next to save LCC through longer lifetime.

Several design options targeting increased reparability yield savings in the range of up to few Euros, even as "stand-alone" options.

Data erasure (DO29) and **simplified data transfer** from an old to a new device (DO30) both also result in relevant LCC reductions, as more used products are assumed to be available on the reuse market through this measure.

Figure 8 presents the same data for the 2020-stock-weighted average of all Base Cases. It should be noted that the y-axis does not start from zero Euros, which at first glance might give the impression of immense savings, which is not the case: The highest-ranked option DO49 results in savings of approximately 7,- Euros compared to the baseline, and a majority of the options saves 1,- Euro or less in terms of LCC.

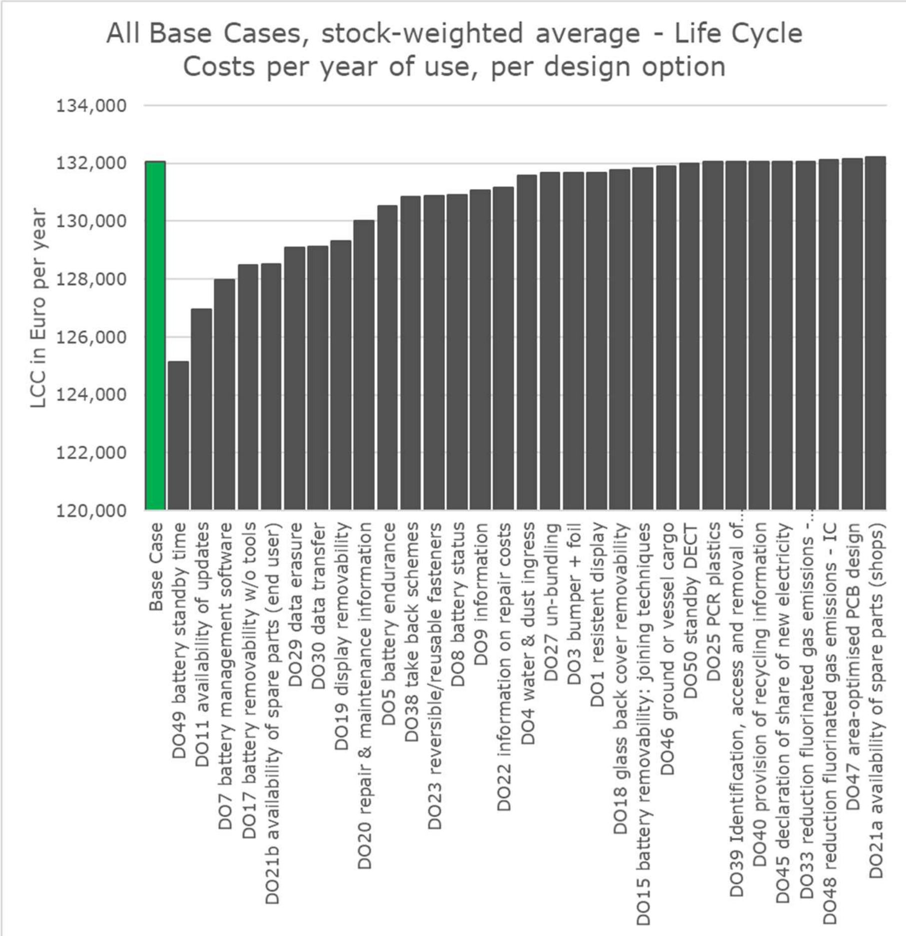


Figure 8 : All Base Cases – Life Cycle Costs for individual design options, stock-weighted average

The following chapters highlight some of the major findings and differences regarding this LCC ranking.

4.1 Base Case 1 – Comparison of Life Cycle Costs per option

Availability of OS updates is the most important individual option for Base Case 1 (low-end smartphones) to reduce LCC, which mirrors the analysis on OS support end-of-life in Task 4. Data erasure and data transfer are next to feature a significant costs savings potential (Figure 9).

Roughly two thirds of the options do not change Life Cycle Costs significantly for Base Case 1. Further, some of those options are simply not relevant for smartphones (See details on design options in subtask 6.1).

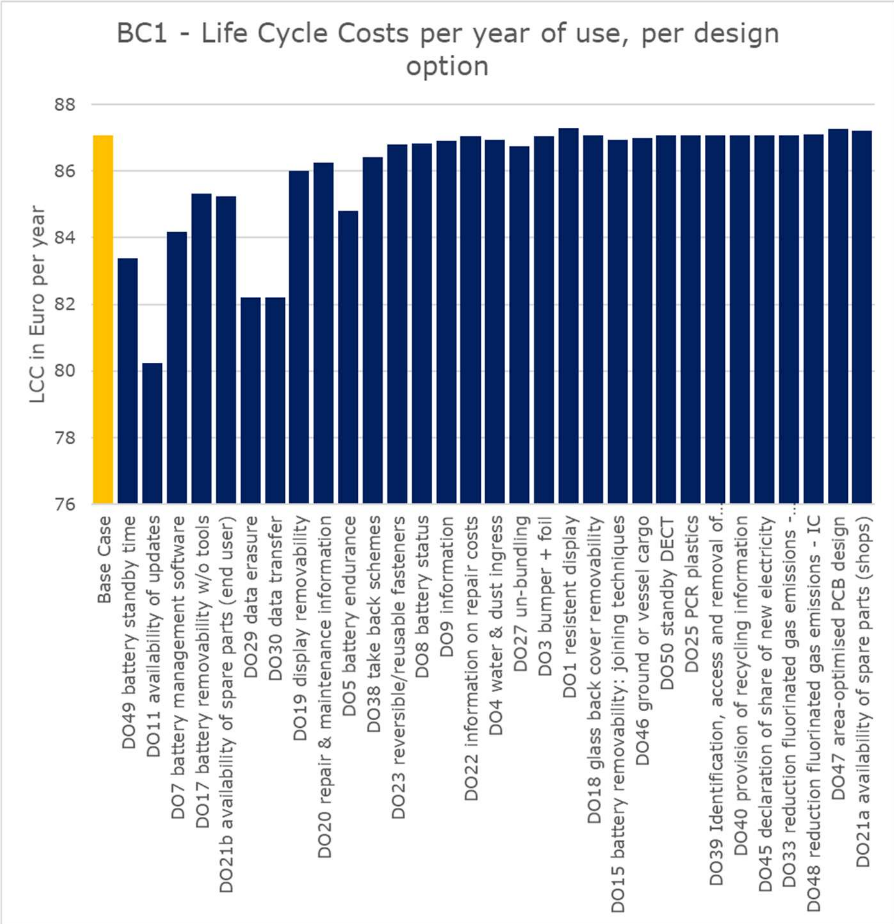


Figure 9 : Base Case 1 – Life Cycle Costs for individual design options

4.2 Base Case 2 – Comparison of Life Cycle Costs per option

Availability of OS updates is similarly important for Base Case 2 (mid-range smartphones) as it is for Base Case 1, followed by enhanced battery endurance per full battery charge (Figure 10). Battery removability and access to spare parts for device users also yield calculated savings of roughly 4,- Euros each. Other battery related options, such as overall battery lifetime in cycles, battery status, and information on how to maintain battery health are relevant as well.

Around one third of the analysed options are cost-neutral. Only the options targeting reduced manufacturing impacts are likely to increase LCC, but the difference to the Base Case without these options is miniscule.

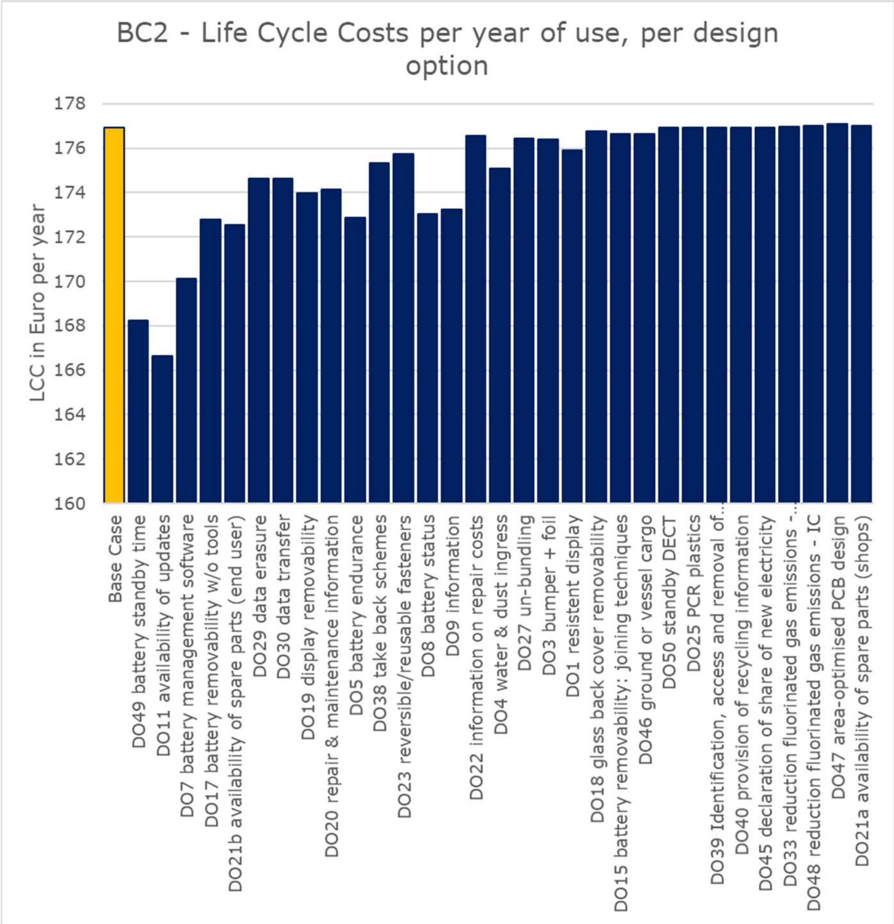


Figure 10 : Base Case 2 – Life Cycle Costs for individual design options

4.3 Base Case 3 – Comparison of Life Cycle Costs per option

For Base Case 3 (high-end smartphones), the availability of OS updates is slightly less important as for other Base Cases, as high-end smartphones are already frequently supported with OS updates for extended periods of time. According to the calculations, extended battery endurance (per charge) is the single-most relevant option to reduce LCC (Figure 11). Battery removability and access to spare parts for device users also yield calculated savings of roughly 10,- Euros each. An easily replaceable display ranks high as well.

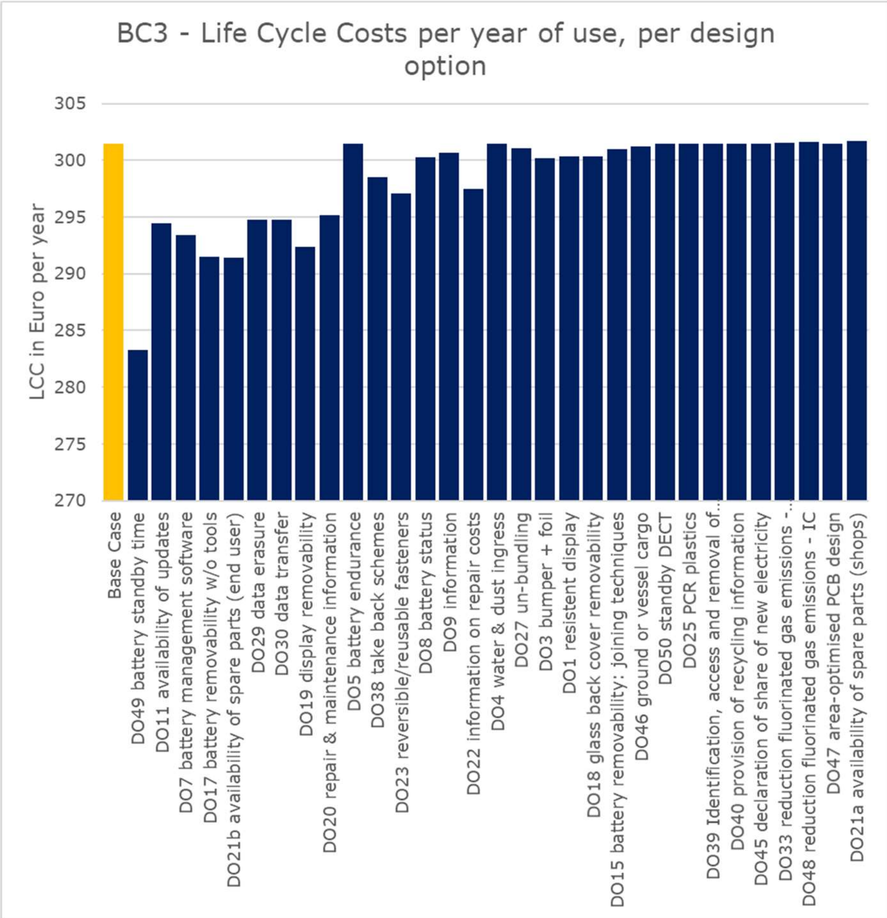


Figure 11 : Base Case 3 – Life Cycle Costs for individual design options

4.4 Base Case 4 – Comparison of Life Cycle Costs per option

For Base Case 4 (feature phones), the priority list changes significantly: Battery-related improvements are calculated to have the highest LCC savings potential, in the range of up to 1,80 Euro LCC savings per year of use. A sound collection or take-back system also results in relevant calculated savings due to the increased number of devices available for the reuse market (Figure 12).

Improved ingress protection (DO4) results in increased LCC in this calculation. The increased manufacturing costs are not outbalanced by the decreased defect rates due to ingress.

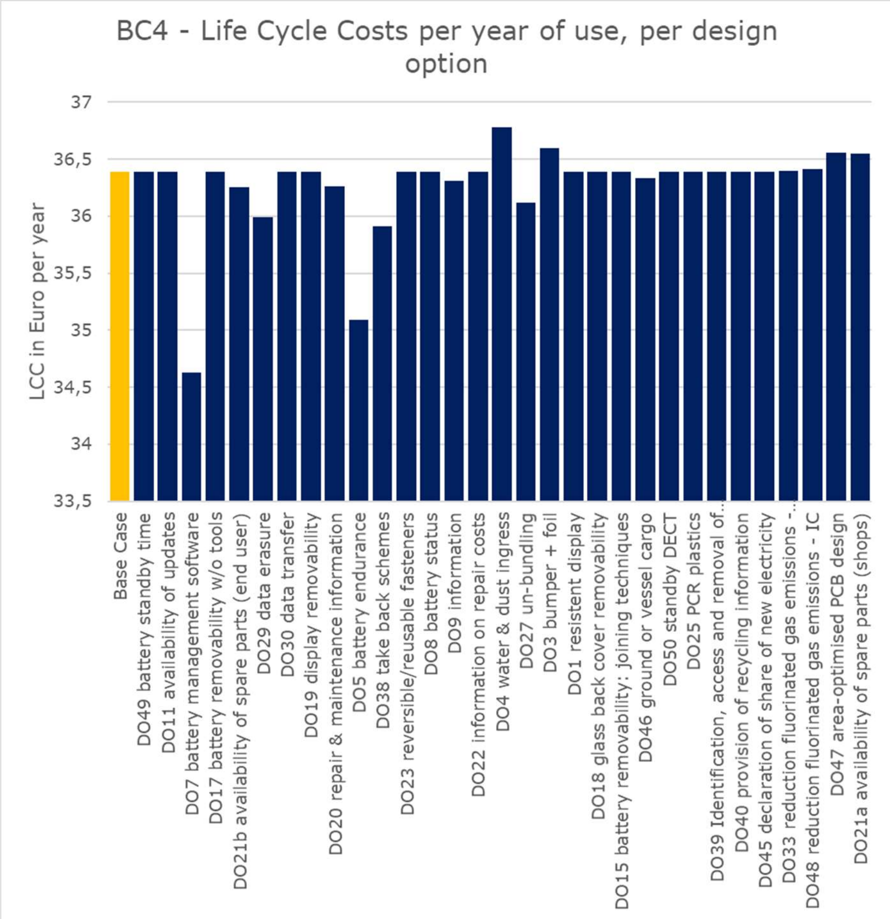


Figure 12 : Base Case 4 – Life Cycle Costs for individual design options

4.5 Base Case 5 – Comparison of Life Cycle Costs per option

Only a subset of the design options apply to Base Case 5 (cordless phones). For this reason, many options depicted in Figure 13 are cost-neutral – they simply do not have an effect on cordless phones or are not applicable.

The single most relevant option is a reduction in standby power consumption, which results in close to 0,40 Euros LCC savings per year of use. Although only relevant for a small share of the cordless phone market, the shift from integrated batteries to easily replaceable (rechargeable) AAA cells (the default in this market) also yields relevant LCC savings.

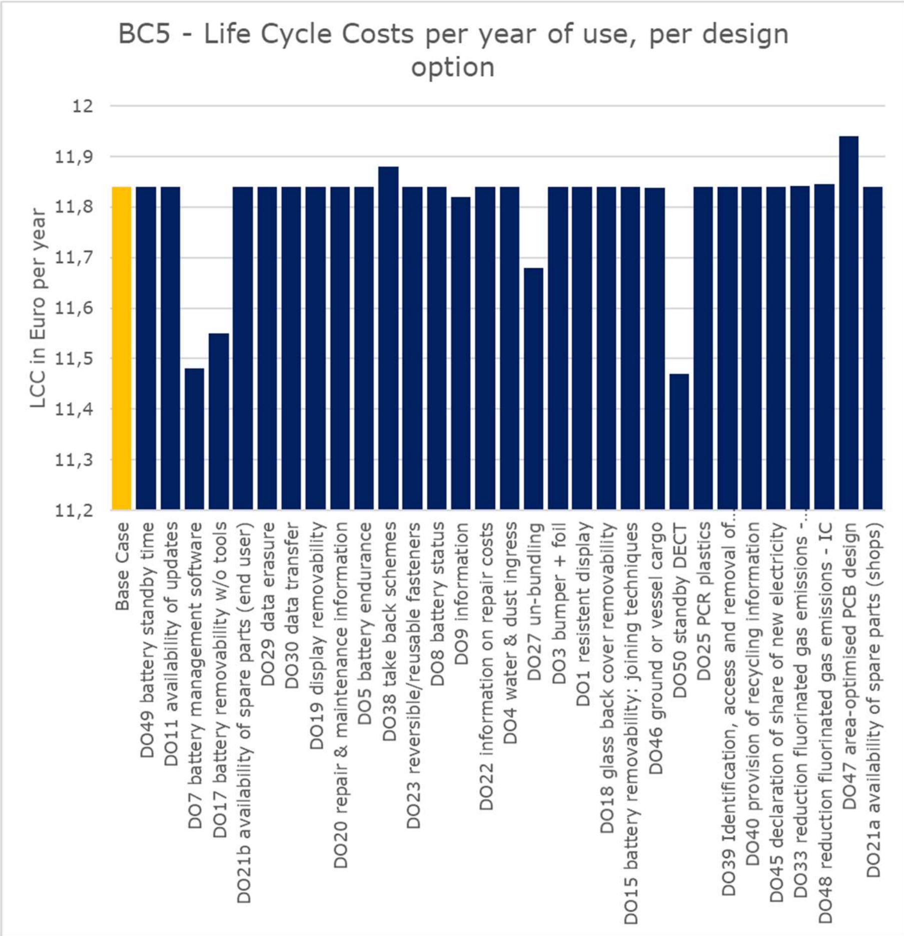


Figure 13 : Base Case 5 – Life Cycle Costs for individual design options

4.6 Base Case 6 – Comparison of Life Cycle Costs per option

For Base Case 5 (tablets), battery endurance per full charge is again the design option with the largest savings potential (4,- Euros per year of use). Several reparability criteria are relevant as well, including a user-replaceable battery and availability of spare parts. As battery health is also highly relevant for this Base Case product, options such as enhanced battery management are relevant to reduce LCC for the user (Figure 14).

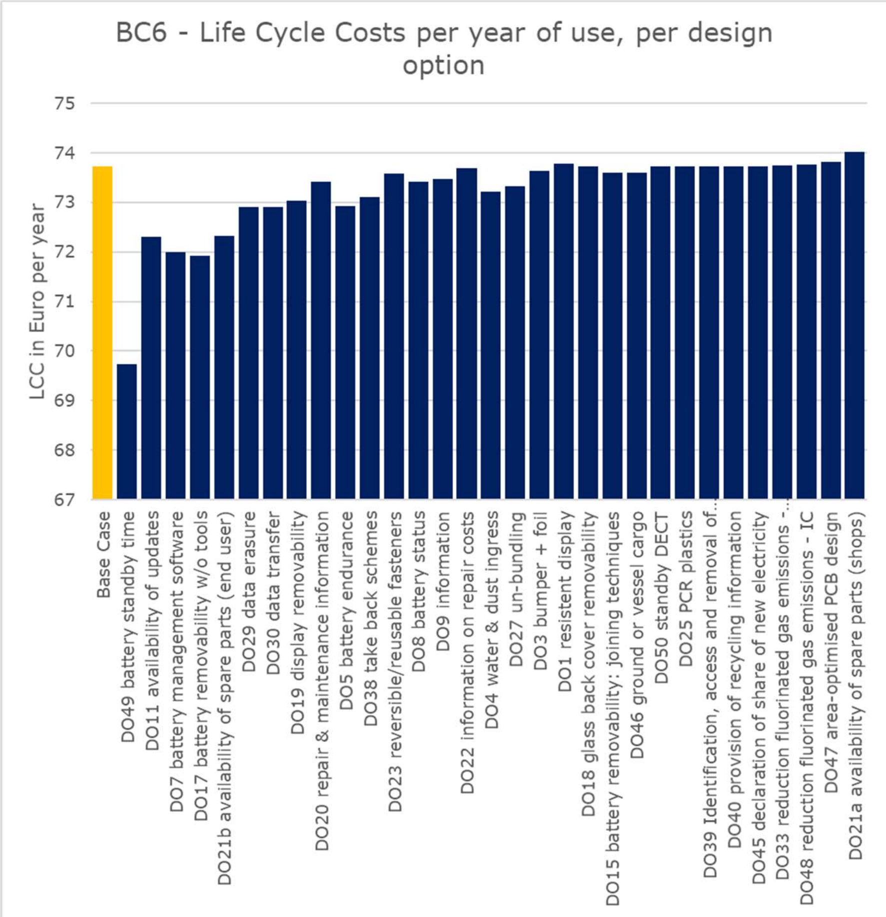


Figure 14 : Base Case 6 – Life Cycle Costs for individual design options

5 SUBTASK 6.3 - ANALYSIS OF BAT AND LLCC

For the analysis of Least Life Cycle Costs and Best Available Technology, the methodological approach as defined by MEErP is to implement design options one by one, starting with the design option with highest LCC savings potential.

Lifetime extension plays a crucial role for this product group to reduce life cycle impacts (and costs). It needs to be acknowledged that there are relevant interdependencies between various design options. Some options, implemented jointly, have a higher LCC savings potential than the addition of both individual LCC savings. In many other cases, combinations of options will yield lower effects than the addition of individual impacts as. This is because measures for lifetime extension will face limitations, as longer lifetime also means potentially more incidents that could terminate product life (e.g. accident-induced defects). Further, the reuse market cannot absorb an infinite number of reusable devices: With more devices being available for reuse this market is likely to grow significantly as there are indications, that large remanufacturers rather face a supply shortage, and are currently not limited by market demand. This statement however rather refers to the mid-range and high-end segment, not to the low-end range. For further details see Task 2.

Additionally, some aspects are in conflict with each other, such as enhanced protection against ingress of water and dust and enhanced reparability.

For these reasons, the LLCC methodology is adapted at this point to consecutively implement clusters of design options and following two separate paths:

- a reparability dominated path with ambitious reparability options (**REP path**), and

- a durability path, which also starts with some LCC reducing reparability options, but then implementing enhanced water and dust ingress, which rules out some of the reparability options (**DUR path**)

Both implementation paths are depicted in Figure 15: Most of the options are shared by both paths. Given the lower identified LCC savings potential of DO4 water & dust ingress, this option comes into play later than the second cluster of reparability options on the REP path.

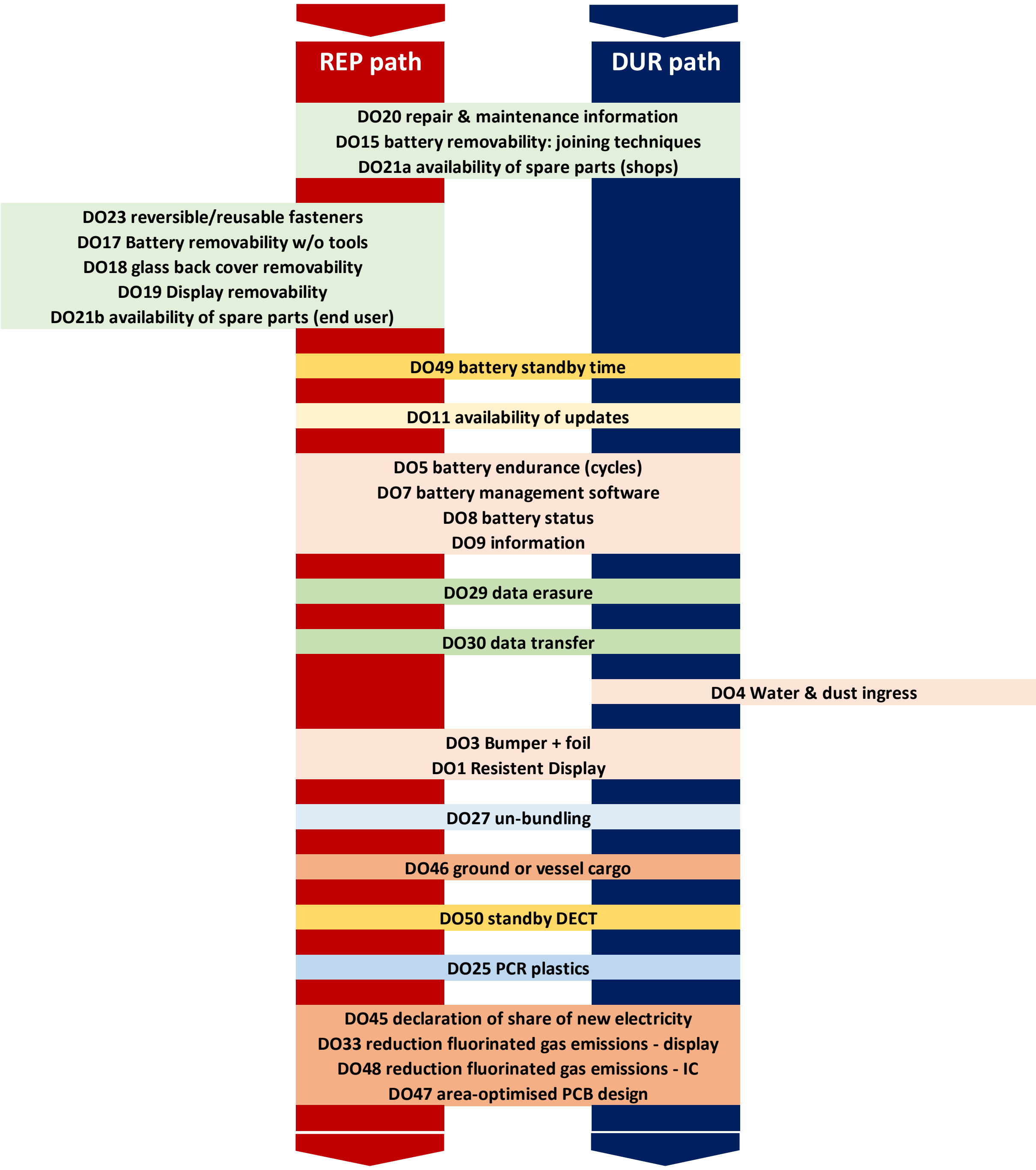


Figure 15 : LLCC and BAT approach - Design options implementation paths

The REP path represents a design path where reparability features are addressed, which target explicitly at DIY repairs and would be essential for end-users to undertake such repairs. The DUR path addresses better reparability as well, but clearly targeting at better conditions for *professional* repair – which has a positive effect on the consumer making use of repair services.

The following sub-chapters compare the analysis of Life Cycle Costs and environmental indicators per Base Case, for both the REP path and the DUR path of implementing options. The first two charts are provided with a narrower cost range on the LCC axis to show more clearly the LCC cost-reductions each additional option provides, if any. The second set of charts provides the same cost figures, but showing the full LCC axis to provide a visual impression on the overall Life Cycle Costs change.

Calculated and depicted LCC are:

- Life Cycle Costs, per year, borne by the user
- Life Cycle Costs, per year, including societal damages (as defined by MEErP with 2011 data)
- Life Cycle Costs per year, including partially updated societal costs (as introduced in Task 5)

The depicted environmental indicators are Total Energy (in MJ) and Greenhouse Gas Emissions (in kg CO_2-eq.). Similar trends can be observed for the other environmental indicators, with few anomalies. Exemplary data on these other indicators is provided in the Annex.

Total Energy and Greenhouse Gas emissions have been chosen for the following tables as these constitute the most reliable indicators with respect to background data quality and completeness. For other indicators, background data is partially incomplete, see documentation of the MEErP methodology (Kemna et al. 2005) and for the additional datasets Task 5.

The options have to be read as follows:

- DO20/15/21a: Implementation of all DO20/15/21a
- DO23/17/18/19/21b: Implementation of all DO20/15/21a and of all DO23/17/18/19/21b
- DO49: Implementation of all DO20/15/21a and of all DO23/17/18/19/21b and of DO49

…and so forth.

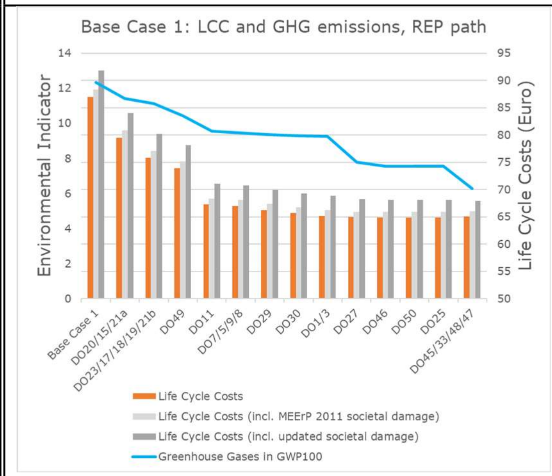
Environmental indicators have been calculated with the EcoReport tool by creating derivates from the Base Case calculations from Task 5.

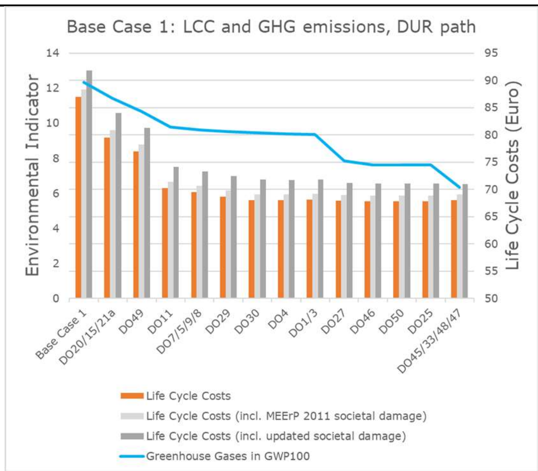
5.1 Base Case 1 – Least Life Cycle Costs and Best-Available Technology

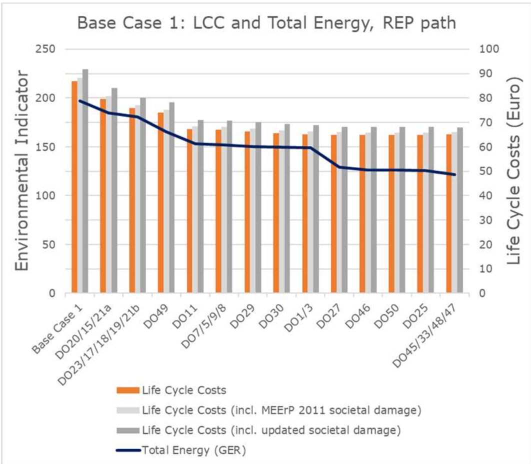
With a combination of options Life Cycle Costs for the consumer can be reduced by more than **20,- Euros per year of use**. This is mainly achieved through the options which facilitate repair by professionals and consumers. A longer battery endurance per full charge (DO49) also contributes to savings for the consumer. There are several further options, which decrease LCC slightly, and the point of **Least Life Cycle Costs** is reached on the REP path with the implementation of **DO27, DO46 and DO50 (and all options before)**. Then, with the implementation of the final manufacturing-related combination of options, LCC for the user increases slightly, but LCC including societal damages decreases further and also the environmental indicator is reduced with this final option by roughly 25%. From an environmental perspective, un-bundling (DO27) also has a significant individual effect on reducing carbon emissions, partly through material savings, but even more through more efficient distribution. The **GHG emissions savings potential at the point of LLCC is the range of 50%** (including DO45/33/48/47). According to these calculations, societal LLCC and BAT are the same and include an implementation of all calculated options.

The more durability-oriented DUR path also represents a significant overall LCC and GHG savings potential, but on a slightly higher cost level.

OVERVIEW BASE CASE 1 – LOW-END SMARTPHONE, 5”	
REP Path of option implementation	**DUR Path** of option implementation







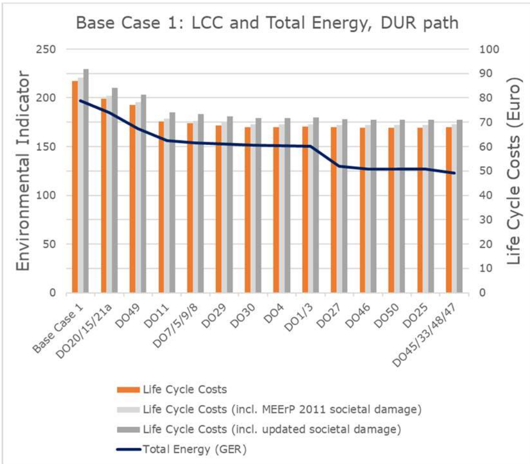


Figure 16 : Base Case 1 – LLCC, BAT Analysis, indicators Greenhouse Gas Emissions (in kg CO_2 eq.) and Total Energy (in MJ), all values per year of use

5.2 Base Case 2 – Least Life Cycle Costs and Best-Available Technology

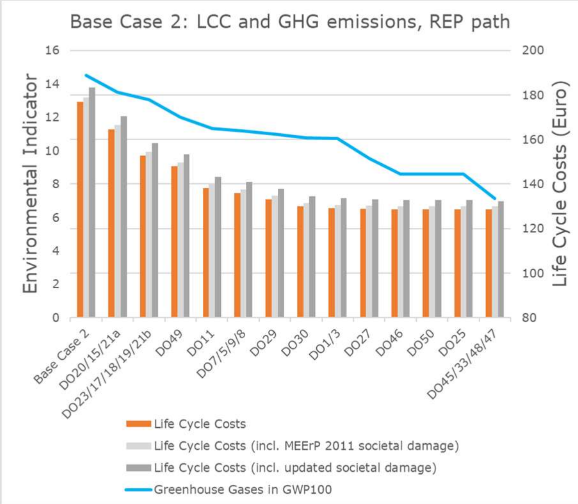
Very similarly to Base Case 1, a combination of options reduces Life Cycle Costs for the consumer significantly. The calculated potential is **close to 40,- Euros per year of use**, including extended lifetime.

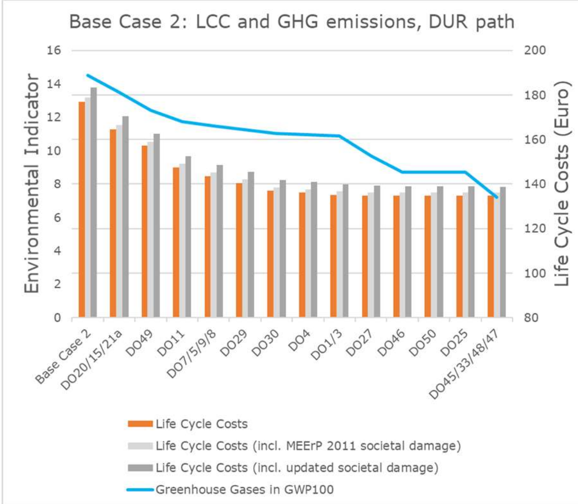
This is mainly achieved through a combination of options that facilitate repair by professionals and consumers. A longer battery endurance per full charge (DO49) also contributes to savings for the consumer, and also extended OS support (DO11) is important to bring costs down further. There are several further options, which decrease LCC slightly, and the point of **Least Life Cycle Costs** is reached on the REP path with the implementation of **DO27, DO46 and DO50 (and all options before)**. The final manufacturing-related combination of options is almost cost-neutral for the consumer, and societal damages decrease further. Again, the environmental effect of un-bundling (DO27), but also reduced air cargo (DO46) clearly contributes to overall environmental savings. The **GHG emissions-savings potential at the point of LLCC is slightly**

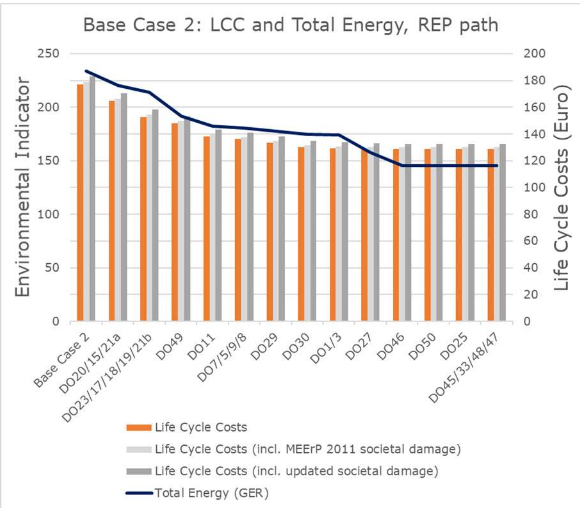
above 50% (including DO45/33/48/47). According to these calculations, societal LLCC and BAT are the same and include an implementation of all calculated options.

The more durability-oriented DUR path also represents a significant overall LCC and GHG savings potential, but on a slightly higher cost level.

OVERVIEW BASE CASE 2 – MID-RANGE SMARTPHONE, 6”	
REP Path of option implementation	**DUR Path** of option implementation







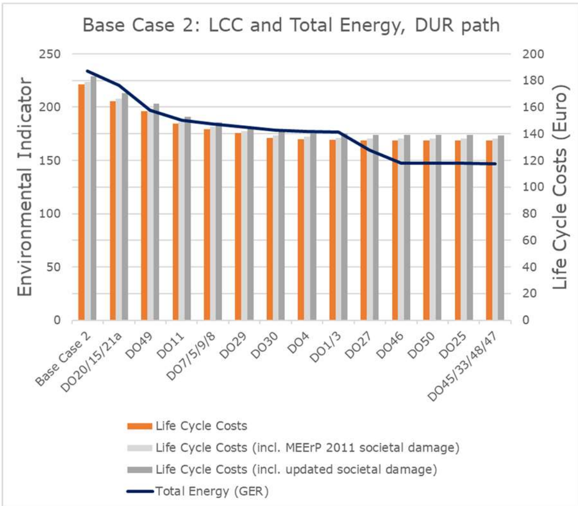


Figure 17 : Base Case 2 – LLCC, BAT Analysis, indicators Greenhouse Gas Emissions (in kg CO_2 eq.) and Total Energy (in MJ), all values per year of use

5.3 Base Case 3 – Least Life Cycle Costs and Best-Available Technology

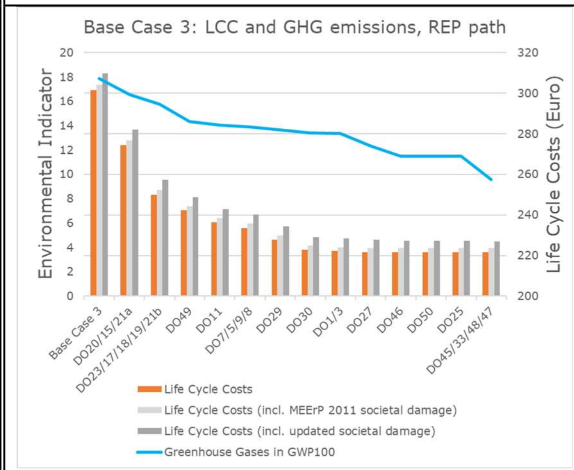
For Base Case 3 (high-end smartphones), a similar combination of options as above reduces Life Cycle Costs for the consumer considerably. The calculated potential is **close to 80,- Euros per year of use**, including extended lifetime.

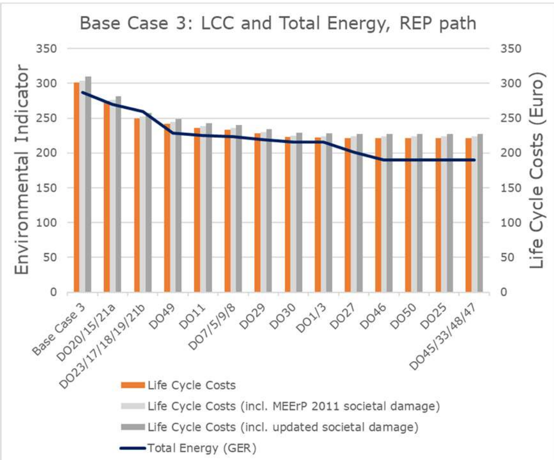
This is mainly achieved through the combined options which facilitate repair by professionals and consumers. A longer battery endurance per full charge (DO49) also contributes to savings for the consumer, and also extended OS support (DO11) is important to bring costs down further. There are several further options that decrease LCC slightly, and the point of **Least Life Cycle Costs** is reached on the REP path with the implementation of **DO27, DO46 and DO50 (in addition to the above-mentioned options)**. The final manufacturing-related combination of options is almost cost-neutral for the consumer, and societal damages decrease further. Again, the environmental effect of un-bundling (DO27), but also less air cargo (DO46), clearly contributes to overall environmental savings. The **GHG emissions-savings potential at the point of LLCC is roughly 45%** (including DO45/33/48/47). According to these calculations, LLCC and BAT are the same and include an implementation of all calculated options.

The more durability-oriented DUR path also represents a significant overall LCC and GHG savings potential, but on a 15,- Euros per year higher cost level.

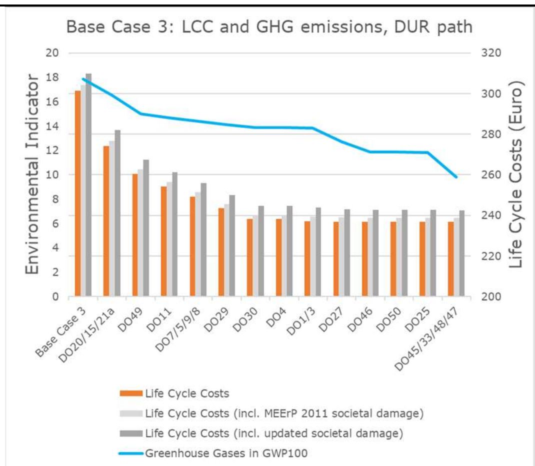
OVERVIEW BASE CASE 3 – HIGH-END SMARTPHONE, 6,5”

REP Path of option implementation





DUR Path of option implementation



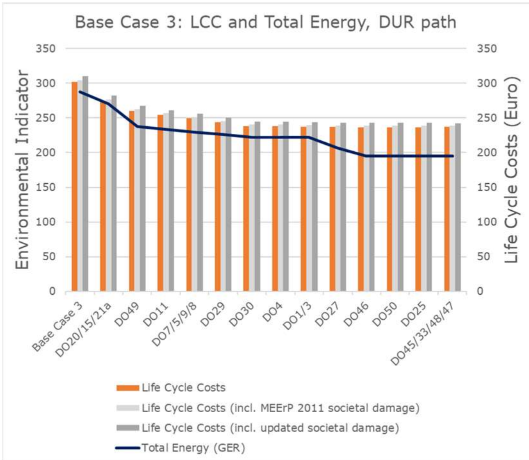


Figure 18 : Base Case 3 – LLCC, BAT Analysis, indicators Greenhouse Gas Emissions (in kg CO_2 eq.) and Total Energy (in MJ), all values per year of use

5.4 Base Case 4 – Least Life Cycle Costs and Best-Available Technology

In Base Case 4 (feature phones), Life Cycle Costs looks slightly different, and aspects such as **battery lifetime-related options (DO7/5/9/8)** and **data erasure (DO29)** have a larger effect on LCC reduction.

Several options have close to zero effect for this Base Case. Increased water and dust ingress protection (DO4) on the DUR path might even have even a cost-increasing effect for this particular Base Case, as the extra costs for implementation does not outweigh the reduction of "other defects" (all those not related to display and batteries) in the lifetime scenario.

The calculated LCC savings potential is **close to 1,50 Euros per year of use**, including extended lifetime.

Again, the environmental effect of un-bundling (DO27) clearly contributes to overall environmental savings. Sea and ground transportation to substitute air freight (DO46) has a much lower effect, as the share of air freight for this Base Case is already lower than for the other, more innovation-driven market segments. The implementation of DO46 on the REP path constitutes the point of LLCC.

The additional effect of lower GHG emissions in manufacturing (DO45/33/48/47) is clearly visible in these graphs but less relevant than for Base Cases 1-3 – for the simple reason, that there a fewer semiconductors and a smaller and less complex display involved in this Base Case. The **GHG emissions savings potential at the point of LLCC is at roughly 35%** (including DO45/33/48/47).

OVERVIEW BASE CASE 4 – FEATURE PHONE	
REP Path of option implementation	**DUR Path** of option implementation

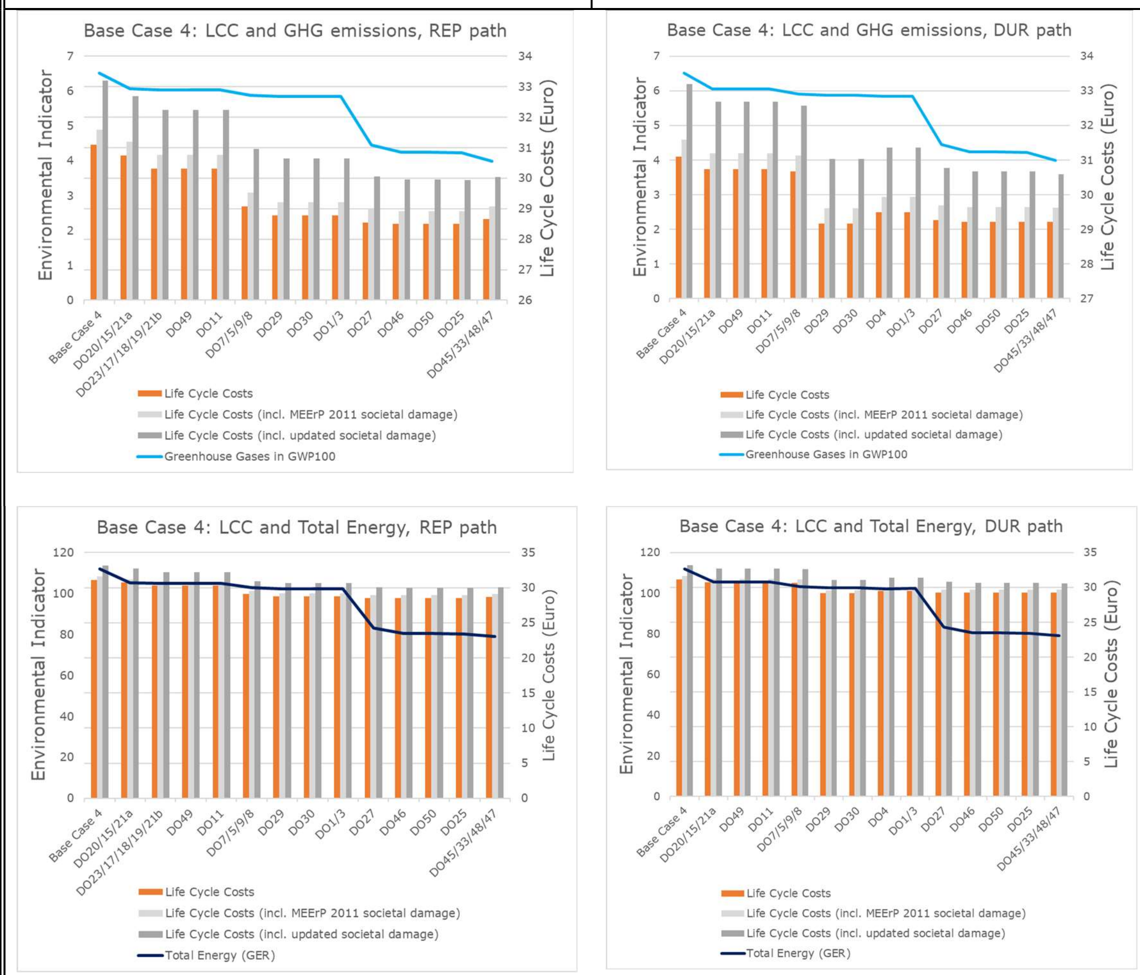


Figure 19 : Base Case 4 – LLCC, BAT Analysis, indicators Greenhouse Gas Emissions (in kg CO_2 eq.) and Total Energy (in MJ), all values per year of use

5.5 Base Case 5 – Least Life Cycle Costs and Best-Available Technology

For this Base Case, the order of options does not lead to a steady decrease in LCC. This is due to the facts that only some of the analysed design options apply to Base Case 5 (cordless phones) and that the order of implementing options is largely determined by decreasing LCC focusing on smartphones (BC1-3). In general, as can be seen in the second set of graphs in Figure 20, the relative savings in Life Cycle Costs is rather low, slightly above **0,50 Euros** per year of use.

OVERVIEW BASE CASE 5 – CORDLESS PHONE	
REP Path of option implementation	**DUR Path** of option implementation

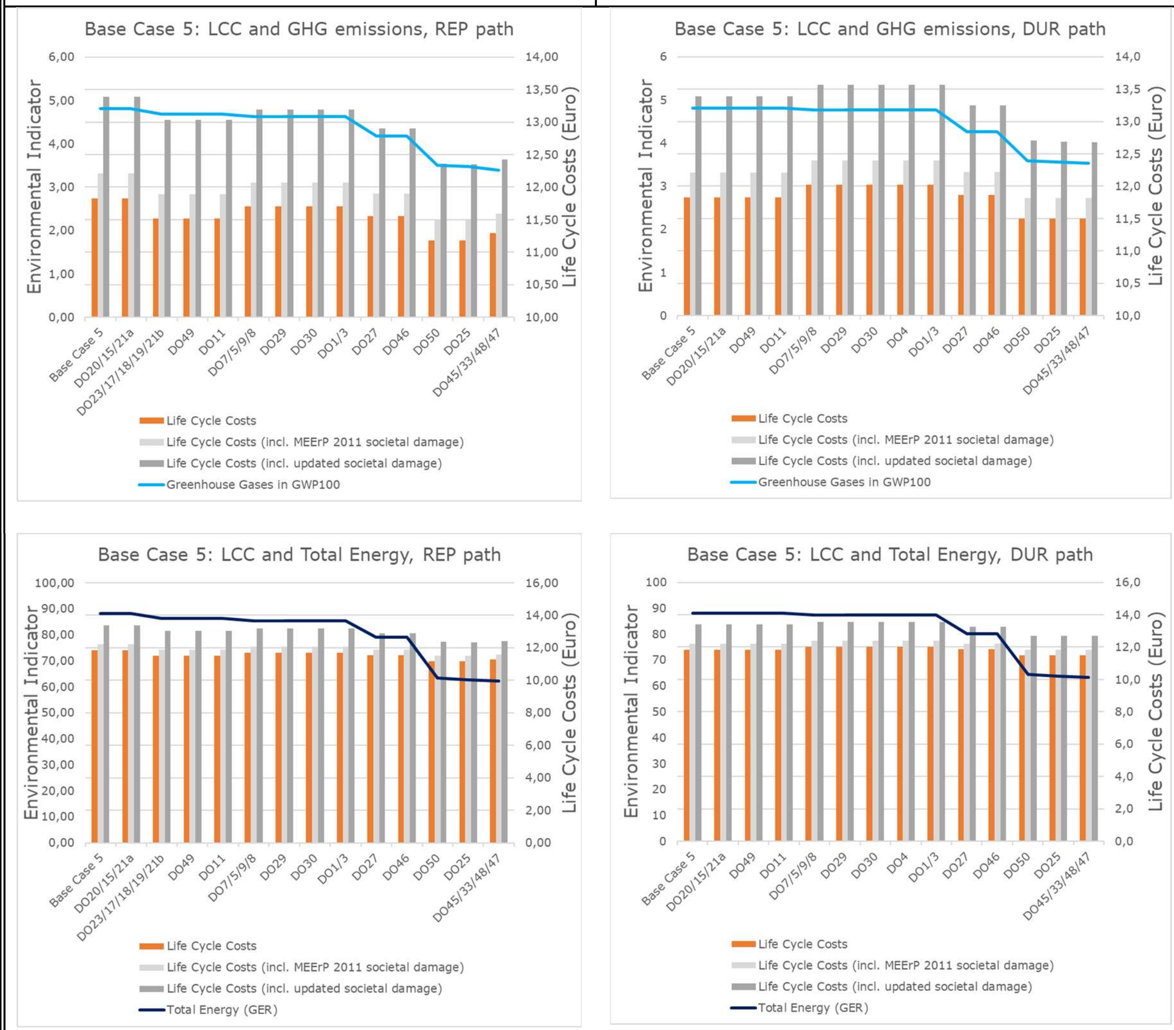


Figure 20 : Base Case 5 – LLCC, BAT Analysis, indicators Greenhouse Gas Emissions (in kg CO_2 eq.) and Total Energy (in MJ), all values per year of use

Three options are key to reduce LCC and environmental impacts:

- **DECT standby power reduction (DO50)**
- **Un-bundling of handset / base station and external power supply (DO27)** under the pre-condition, that an existing power supply unit for a base station can be used further once the base station / handset combination is replaced by a new device

- Full implementation of **replaceable AAA standard (rechargeable) batteries (DO17)** for all cordless phones

Similar as with Base Case 4 the GHG savings for manufacturing related improvements is rather low, but for other environmental indicators, such as heavy metals emissions to water, the potential to redesign PCBs (DO47) results in more significant improvements (Figure 27, p. 89).

5.6 Base Case 6 – Least Life Cycle Costs and Best-Available Technology

In Base Case 6 (tablet computers) a similar combination of options as for smartphones (Base Cases 1-3) reduces Life Cycle Costs for the consumer. The calculated potential is **above 11,- Euros per year of use**, including extended lifetime.

OVERVIEW BASE CASE 6 – TABLET	
REP Path of option implementation	**DUR Path** of option implementation

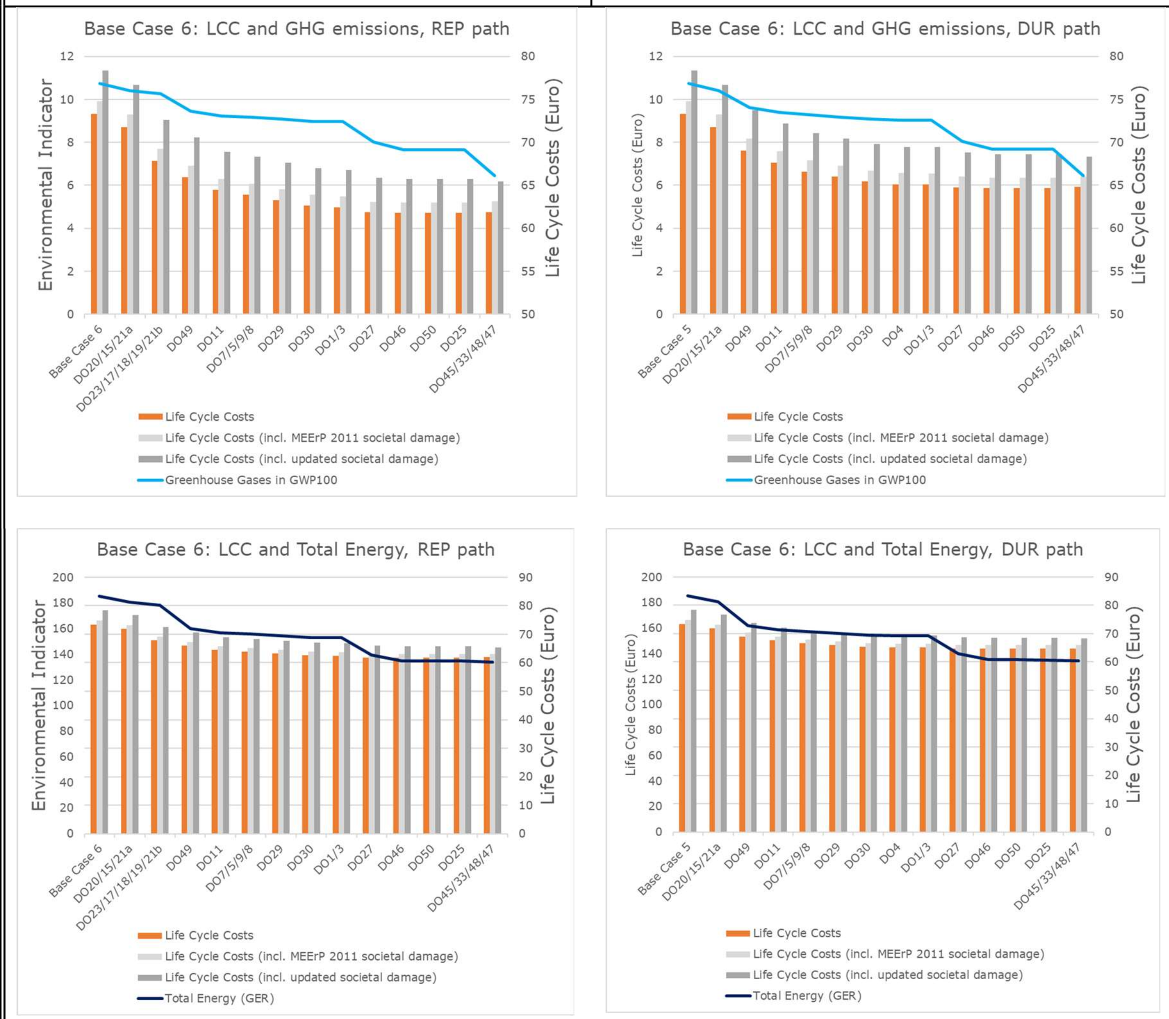


Figure 21 : Base Case 6 – LLCC, BAT Analysis, indicators Greenhouse Gas Emissions (in kg CO_2 eq.) and Total Energy (in MJ), all values per year of use

This is mainly achieved through a combination of options which facilitate repair by professionals and consumers. A longer battery endurance per full charge (DO49) and other battery related improvements (DO7/5/9/8) also contribute to savings for the consumer, mainly due to longer anticipated battery life. Extended OS support (DO11) is important to bring costs for the consumer down further. There are several further options, which decrease LCC slightly, and the point of **Least Life Cycle Costs** is reached on the REP path with the implementation of **DO27, DO46 and DO50 (and all options**

before). The final manufacturing related combination of options is almost cost-neutral for the consumer, and societal damages are decreased further. Again, the environmental effect of un-bundling (DO27), and to a minor degree also less air cargo (DO46), contributes to overall environmental savings. The **GHG emissions savings potential at the point of LLCC is at roughly 45%** (including DO45/33/48/47). According to these calculations, societal LLCC and BAT are the same and include an implementation of all calculated options.

The more durability-oriented DUR path also represents a significant overall LCC and GHG savings potential, but on a 3,- Euros per year higher cost level.

5.7 Summary BAT and LLCC analysis

As several options target an increased product lifetime, Figure 22 (REP path depicted only) provides an overview on how average lifetime changes with the consecutive implementation of options, removing barriers for continued use or reuse. The starting point is the average lifetime in the individual Base Case baseline scenarios. Lifetime increases particularly with the first set of options. These options in total are assumed to increase lifetime of products represented by

- Base Case 1 (low-end smartphones, 5”) from 2,5 to 3,42 years (DUR path: 3,38 years),
- Base Case 2 (mid-range smartphones, 6”) from 3 to 4,2 years (DUR path: 4,10 years),
- Base Case 3 (high-end smartphones, 6,5”) from 3,5 to 4,81 years (DUR path: 4,55 years),
- Base Case 4 (feature phones) from 3 to 3,55 years (DUR path: 3,56 years),
- Base Case 5 (cordless phones) from 5 to 5,35 years (DUR path: 5,09 years),
- Base Case 6 (tablets) from 5 to 5,98 years (DUR path: 5,93 years).

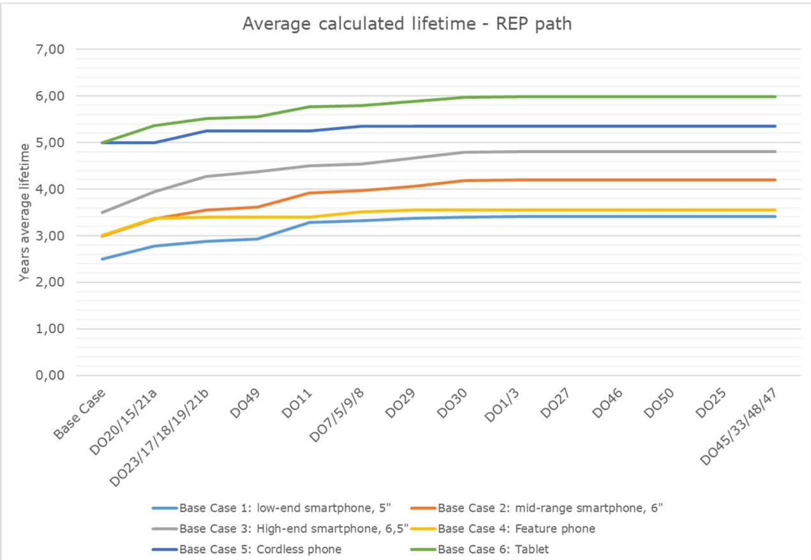


Figure 22 : All Base Cases – Calculated average product lifetime with implementing design options on the REP path

The increase in lifetime is achieved through extended first use and additional second (or even third) use. The analysis does not distinguish which effect is dominating – except for the design options on data erasure and data transfer (DO29, DO30), which explicitly target at reuse -, but it can be assumed, that an extended first life is the more relevant case. From the lifetime extension forecast the conclusion can be drawn that approximately 30% of all devices in use at the point of LLCC are either devices with an extended first use or reused devices beyond the current market share of reused devices. This leads to an estimate of a 5-15% market share of reused devices beyond the current status. It is likely, that the reuse market is able to absorb this amount of devices – although limitations in some market segments might apply – and thus capacity of the reuse market is not likely to limit the calculated lifetime extension.

The analysis per Base Case above indicates that almost all options are expected to be at least cost-neutral from the user perspective. Environmental impacts decrease consecutively through implementing options, with only few exceptions.

The point of societal Least Life Cycle Costs (calculated with updated societal costs, see Task 5) is reached together with the Best-Available-Technology point once all relevant options are implemented in almost all cases.

The REP path provides a higher savings potential in terms of LCC and environmental impacts than the DUR path, although the latter also yields significant changes.

For the smartphone Base Cases 1-3, the LCC potential savings are in the range of 20%, for tablets (Base Case 6) roughly 15%, and significantly less for feature phones (Base Case 4) and cordless phones (Base Case 5). The savings potential is higher when societal damages are accounted for.

Design options with particularly high savings potential through consecutive implementation are

- Moderate reparability option (D20/15/20a)
- Broad reparability option (D20/23/1715/18/19/21a)
- Increased battery endurance per full charge (DO49)
- Improved battery management and information provision (DO7/5/9/8)
- Extended OS support (DO11)
- Improved data erasure and confidence in processes (DO29)
- Unbundling of device and accessories (DO27)

An implementation of changes in the upstream lifecycle (manufacturing, distribution) results in significant environmental savings at almost no change in LCC for the consumer (DO46, DO45/33/48/47).

It should be noted that these findings are largely based on the failure mode evidence and consumer behaviour presented in earlier tasks, particularly Task 3. Furthermore, this analysis is, inter alia, based

- on the assumption that there is still significant potential for a growing reuse market (relevant for e.g. the data deletion and transfer options, effect of improved take back / collection);
- on the assumption that consumers are willing to go for more repairs if the process is significantly simplified and less costly, as more repairs can be done by the individual (whereas repair costs by professionals is factored in, repair time by the consumer is considered at no cost);
- on costs that in general are assumed averages, while from an individual perspective life cycle costs might look very different and depend whether or not a certain defect actually arises in an individual case;
- simplified repair requires significant product design changes and are partly in conflict with high durability; therefore the analysis provides also a more conservative path (DUR path) and implementing better reparability should not reduce overall durability of the device.

To reduce the complexity of the LLCC and BAT analysis, several design options have not been taken into account for the calculations. However, it should be noted that these additional options are frequently a useful complement to other options, or might provide alternative pathways to reach overall low LCC at low environmental impacts.

6 SUBTASK 6.4 – LONG TERM POTENTIAL (BNAT) & SYSTEMS ANALYSIS

BNAT indicates long-term possibilities and helps to define the exact scope and definition of possible measures (Kemna et al. 2005). The technical potential of BNAT is discussed in the following based on research results described in the Task 4 report chapter 2.5.

6.1 Product system level

If self-healing display glasses, ceramics housing and advanced batteries reach a sufficient level of maturity, broad implementation in ICT devices may notably increase the reliability of products in scope of this study, thereby effectively increasing technical product lifetime. Solid state batteries are expected to enter the mass market in the automotive sector before the year 2030. A similar timeline may be expected for ICT devices. Self-healing display glass technology has been patented for foldable smartphones, but it is unclear if and when it may reach the mass market. Ceramics housing has already been implemented in several smartphones, such as the Samsung Galaxy S10 Plus or the Essential Phone, but also by Xiaomi and Oppo and some others. Implications on reliability are not immediately clear when compared to glass, metal or plastics housing materials.

Fully modular products do currently not appear to be the primary focus of the smartphone and tablet industry. However, technological advancements may increase the future feasibility, leading to devices that can easily be repaired in case of defects, but also upgraded to increase their technical lifetime. Environmental impacts of modular devices are not entirely understood: On the one hand, reparability is increased, but effects on reliability may be detrimental to some degree (ingress protection). The opportunity to tailor components to user-needs may reduce environmental impacts of manufacturing by avoiding over-dimensioning of components, on the other hand, frequent release of new modules may actually lead to increased material consumption. These innovations appear less relevant for feature phones and DECT phone which to a lesser degree rely on computational performance to fulfil their functionality.

Releasable and removable adhesives present a major opportunity to resolve the conflict between protection of devices against water and dust ingress and ease of reparability. Depending on the implementation, devices may therefore benefit from the increased reliability of being sealed with adhesives while also being easily reparable when a defect occurs.

6.2 System change

Smartphones may one day become redundant and superseded by a novel product group. In the past, a range of wearables has been thought to have the potential to substitute smartphones by offering similar functions while removing the need to carry a heavy object (dematerialization). Examples may be smartwatches that allow for phone calls and the installation of apps just like smartphones, and smart glasses that project information onto the glass or directly into its users' eyes. However, smartwatches to date appear to complement smartphones rather than replace them, and smart glasses have so far not reached a notable popularity with consumers.

Several companies have made attempts to enhance the functionality of smartphones by utilizing the ever-increasing computational performance to substitute other product groups, such as personal and notebook computers. In such concepts, smartphones are connected to accessories, such as external displays and mice, to effectively replace the core computational components of PCs or notebooks. So far, these concepts have not made an impact on the mainstream market.

Another relevant system change is correlated with improving recycling technologies. Whereas Design for Recycling seems to be of limited additional value currently, a broader adoption of sophisticated dismantling, separation, and recycling technology would make a significant change. Adapting product design to such technologies can help to keep many more resources in the loop, but not to harvest much more value out of these products (Nissen et al. 2021).

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8 ANNEX

8.1 Exemplary Additional Environmental Indicator results

8.1.1 Base Case 1 – LLCC and BAT analysis, additional environmental indicators

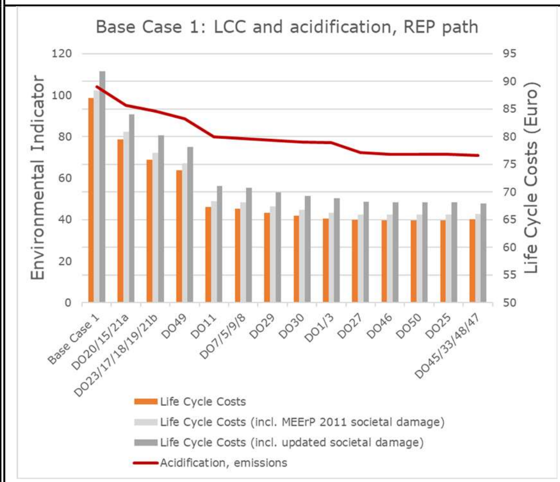
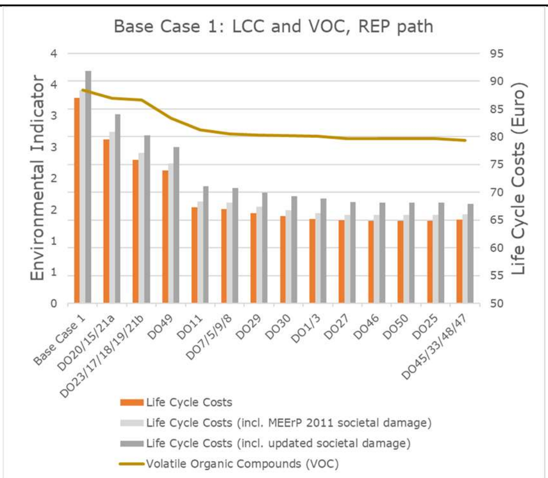
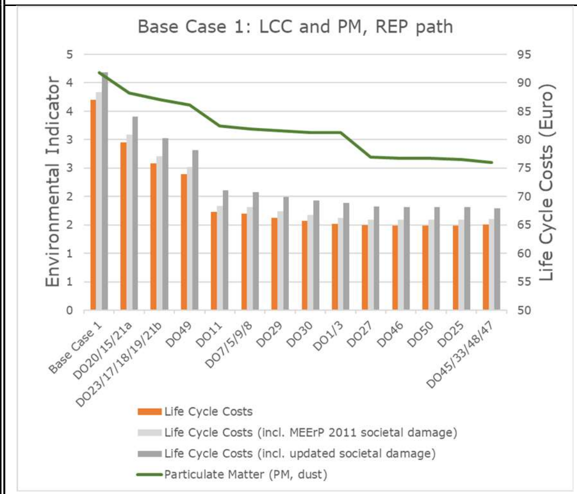
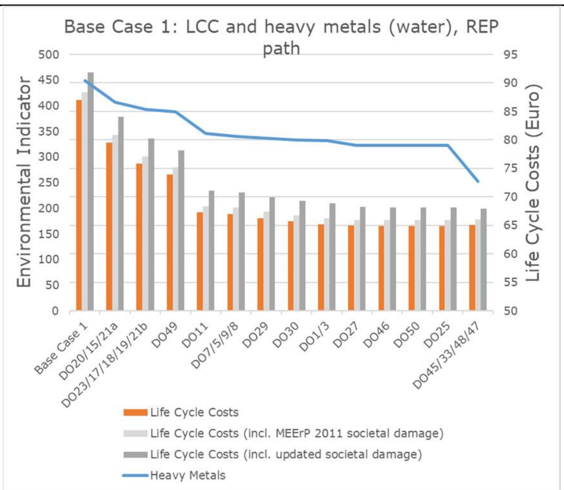
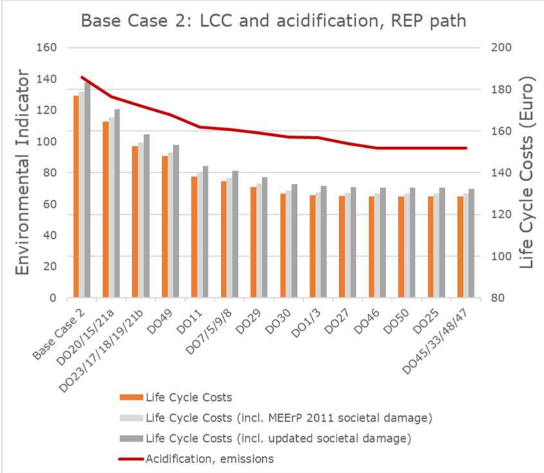
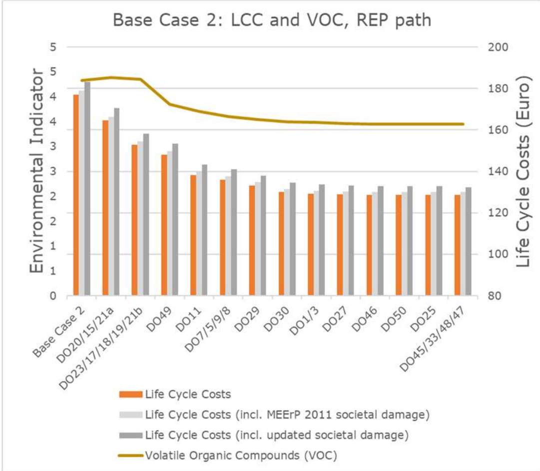
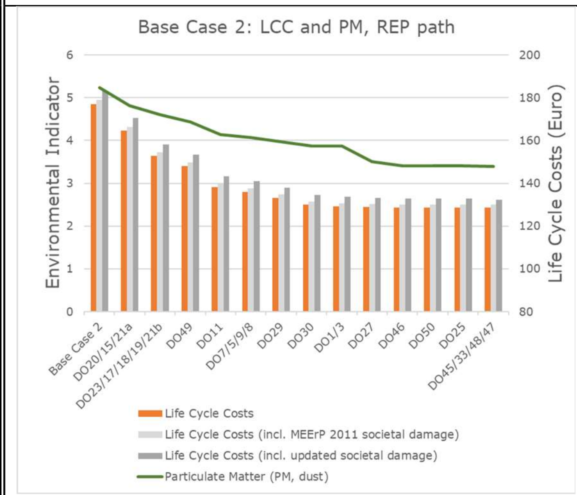
BASE CASE 1 – REP PATH	
Acidification (in g SO2 eq.)	**Volatile Organic Compounds (in g)**
	
Particulate Matter (in g)	**Heavy metals (to water, in mg Ni-eq.)**
	

Figure 23 : Base Case 1 – LLCC, BAT Analysis, additional environmental indicators, all values per year of use

8.1.2 Base Case 2 – LLCC and BAT analysis, additional environmental indicators

<table>
<tr><td colspan="2">BASE CASE 2 – REP PATH</td></tr>
<tr><td>Acidification (in g SO2 eq.)</td><td>Volatile Organic Compounds (in g)</td></tr>
<tr><td>


</td><td>


</td></tr>
<tr><td>Particulate Matter (in g)</td><td>Heavy metals (to water, in mg Ni-eq.)</td></tr>
<tr><td>


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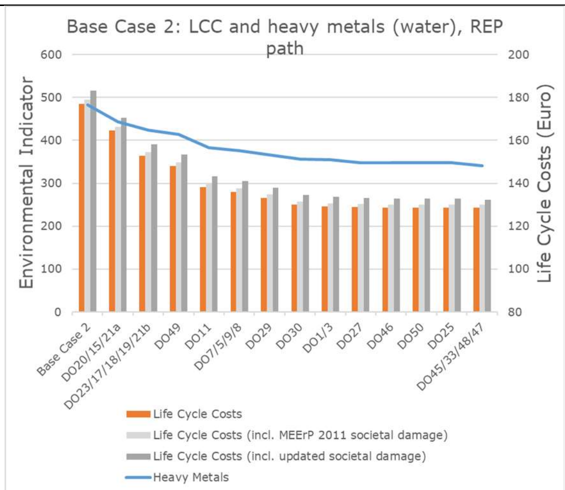


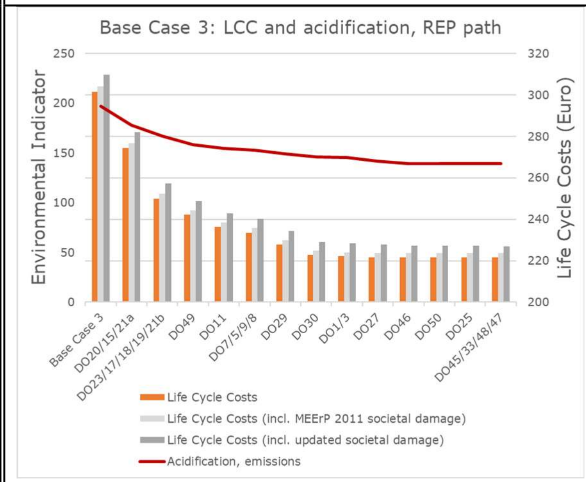
</td></tr>
</table>

Figure 24 : Base Case 2 – LLCC, BAT Analysis, additional environmental indicators, all values per year of use

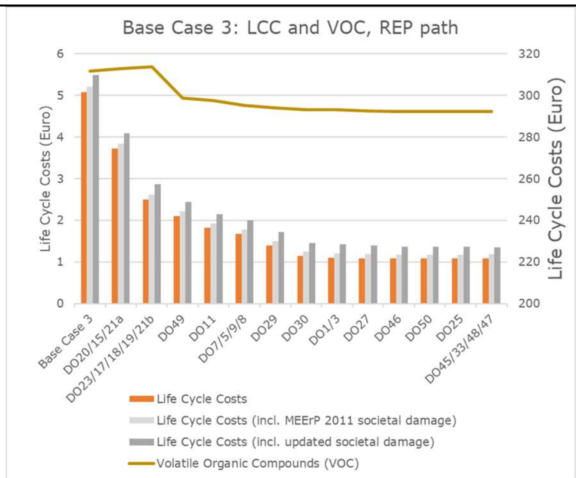
8.1.3 *Base Case 3 – LLCC and BAT analysis, additional environmental indicators*

BASE CASE 3 – REP PATH

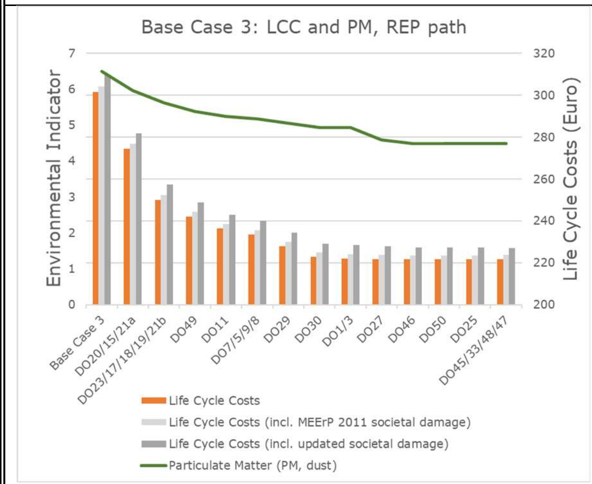
Acidification (in g SO2 eq.)



Volatile Organic Compounds (in g)



Particulate Matter (in g)



Heavy metals (to water, in mg Ni-eq.)

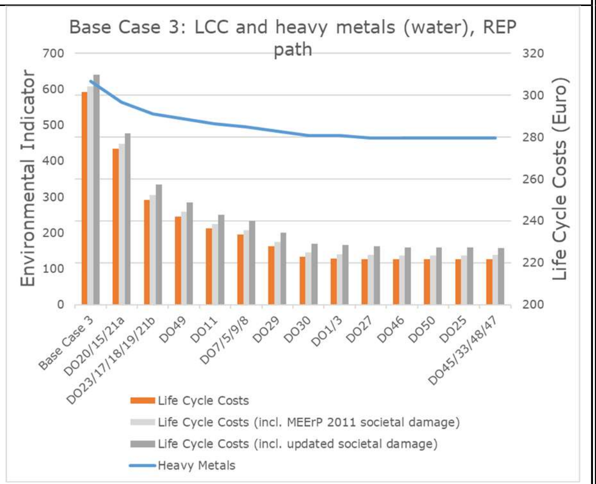
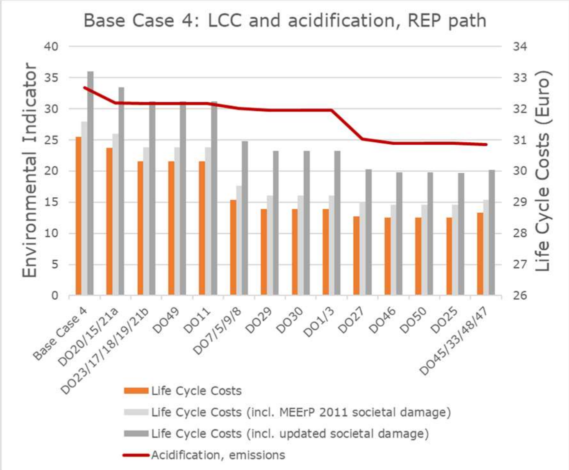


Figure 25 : Base Case 3 – LLCC, BAT Analysis, additional environmental indicators, all values per year of use

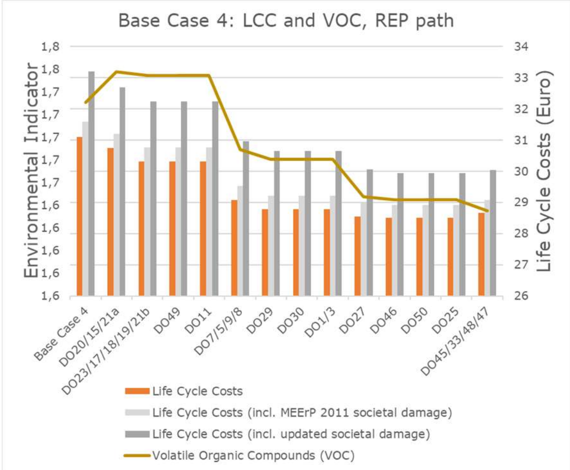
8.1.4 Base Case 4 – LLCC and BAT analysis, additional environmental indicators

BASE CASE 4 – REP PATH

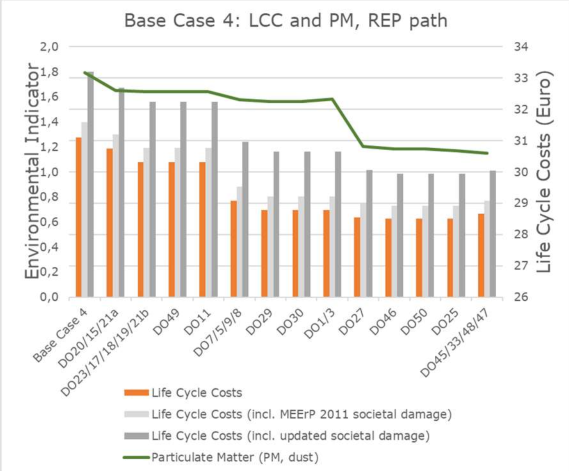
Acidification (in g SO2 eq.)



Volatile Organic Compounds (in g)



Particulate Matter (in g)



Heavy metals (to water, in mg Ni-eq.)

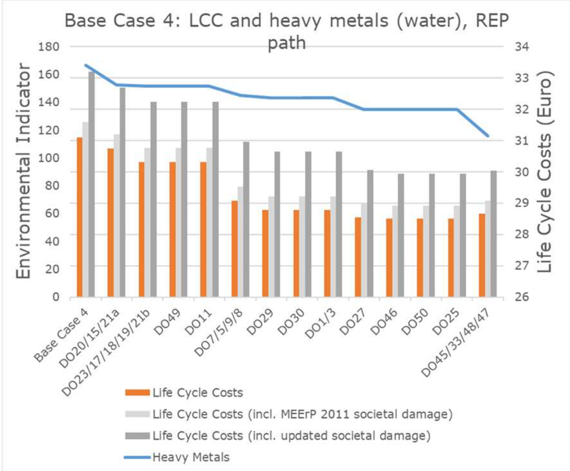
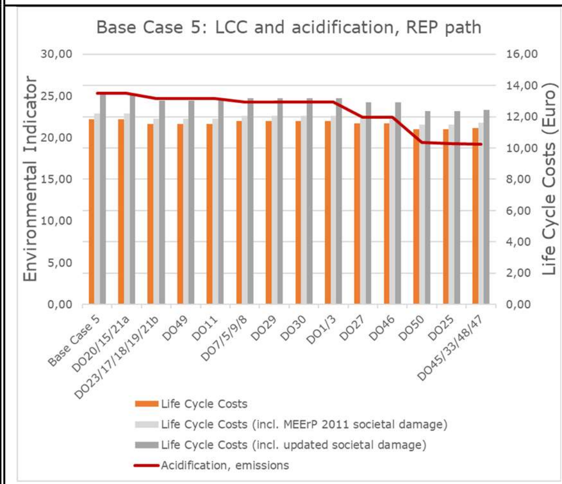
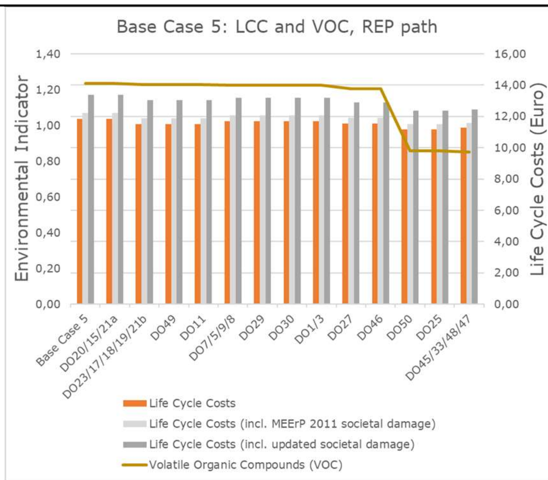
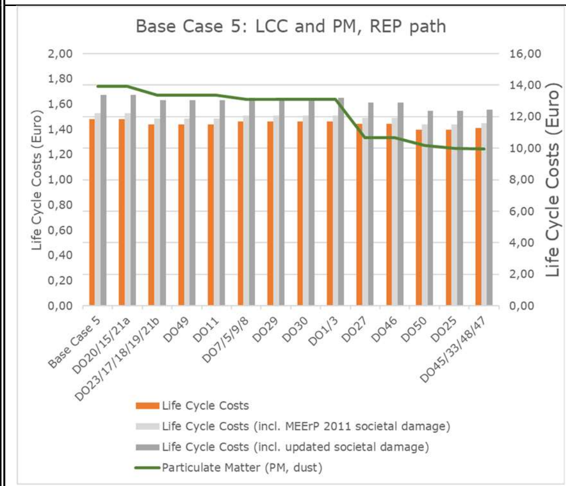


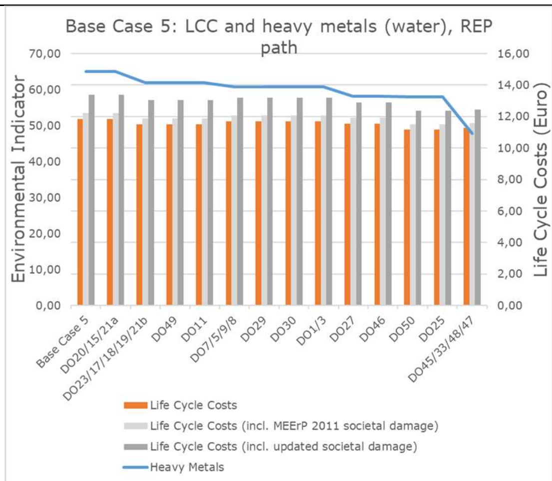
Figure 26 : Base Case 4 – LLCC, BAT Analysis, additional environmental indicators, all values per year of use

8.1.5 Base Case 5 – LLCC and BAT analysis, additional environmental indicators

<table>
<tr><th colspan="2">BASE CASE 5 – REP PATH</th></tr>
<tr><td>Acidification (in g SO2 eq.)</td><td>Volatile Organic Compounds (in g)</td></tr>
<tr><td>


</td><td>


</td></tr>
<tr><td>Particulate Matter (in g)</td><td>Heavy metals (to water, in mg Ni-eq.)</td></tr>
<tr><td>


</td><td>


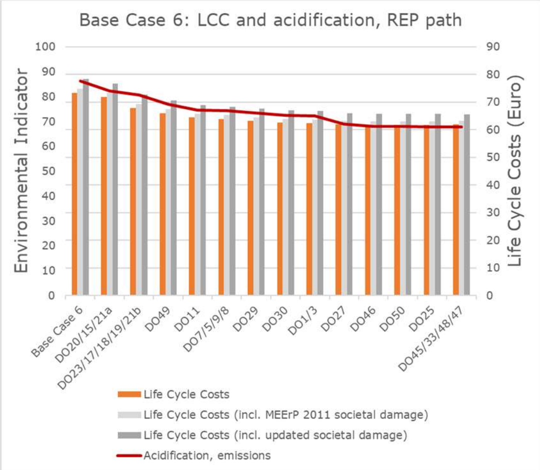
</td></tr>
</table>

Figure 27 : Base Case 5 – LLCC, BAT Analysis, additional environmental indicators, all values per year of use

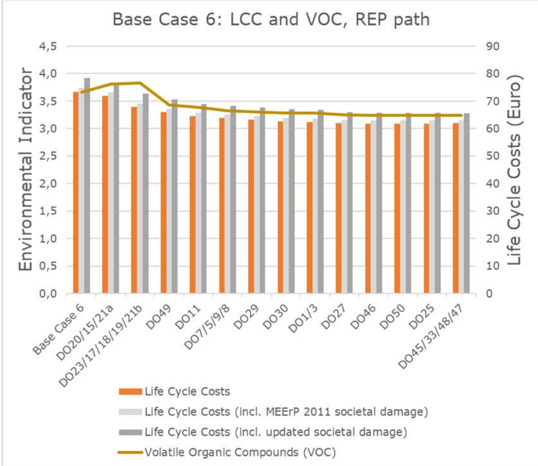
8.1.6 Base Case 6 – LLCC and BAT analysis, additional environmental indicators

BASE CASE 6 – REP PATH

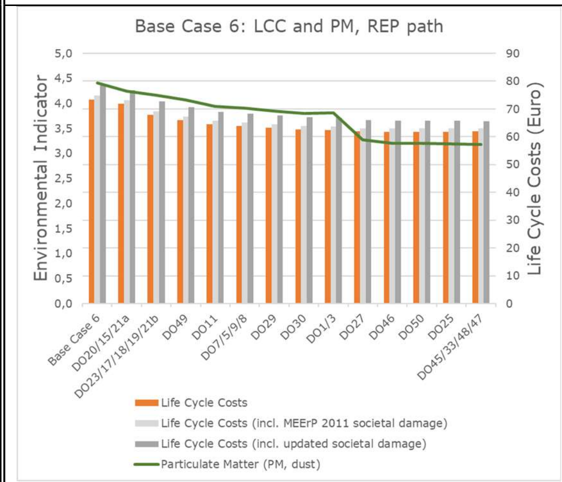
Acidification (in g SO2 eq.)



Volatile Organic Compounds (in g)



Particulate Matter (in g)



Heavy metals (to water, in mg Ni-eq.)

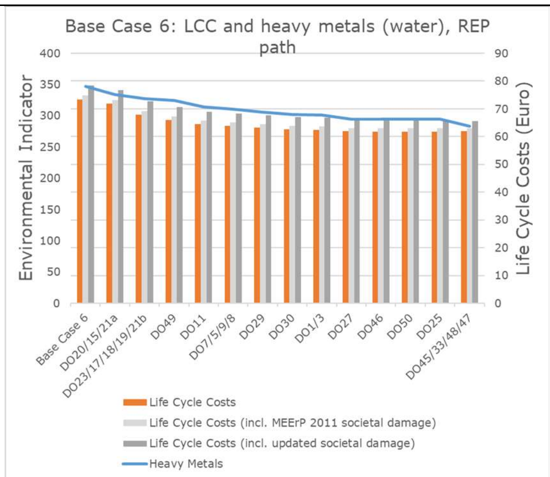


Figure 28 : Base Case 6 – LLCC, BAT Analysis, additional environmental indicators, all values per year of use

8.2 Life Cycle Costs and Environmental Indicator tables

All values in the tables below refer to 1 year of use of a given device, i.e., impacts from the manufacturing phase and purchase prices are allocated proportionally to each year of use, over an extended lifetime, where this matters.

Options are consecutively implemented from left to right.

For consistency reasons, data is also provided for those options, which do not apply for a given Base Case. Data then logically remains unchanged compared to the implemented option before.

8.2.1 Base Case 1 – LLCC and BAT analysis, results of consecutive implementation of all calculated options

Table 35 : Base Case 1 – LLCC and BAT analysis, REP path

	Base Case 1		Base Case 1	DO20/15/21a	DO23/17/18/19/21b	DO49	DO11	DO7/5/9/8	DO29	DO30	DO1/3	DO27	DO46	DO50	DO25	DO45/33/48/47
	Other Resources & Waste															
11	Total Energy (GER)	MJ	197,13	184,73	180,77	165,42	153,13	151,73	150,50	149,50	149,31	129,04	126,10	126,10	125,78	121,79
12	of which, electricity (in primary MJ)	MJ	118,72	113,89	112,28	97,76	92,85	92,38	91,89	91,49	91,34	90,58	90,58	90,58	90,50	87,61
13	Water (process)	ltr	98,91	89,31	86,23	84,90	75,58	74,65	73,72	72,97	72,70	70,97	70,97	70,97	70,94	57,71
14	Water (cooling)	ltr	41,72	37,81	36,57	35,45	31,80	31,46	31,10	30,80	31,10	30,01	30,01	30,01	29,77	29,77
15	Waste, non-haz./ landfill	g	809,80	732,35	707,89	691,11	617,97	610,76	603,47	597,54	597,38	576,17	573,36	573,36	572,68	570,56
16	Waste, hazardous/ incinerated	g	55,24	49,90	48,19	47,27	42,16	41,69	41,18	40,76	40,61	40,18	40,12	40,12	40,10	40,10
	Emissions (Air)															
17	Greenhouse Gases in GWP100	kg CO2 eq.	12,33	11,43	11,14	10,44	9,55	9,44	9,36	9,28	9,26	7,80	7,57	7,57	7,55	6,29
18	Acidification, emissions	g SO2 eq.	104,05	95,08	92,25	88,54	79,92	79,00	78,14	77,44	77,23	72,28	71,61	71,61	71,54	71,04
19	Volatile Organic Compounds (VOC)	g	3,42	3,29	3,26	2,96	2,78	2,72	2,70	2,68	2,67	2,64	2,64	2,64	2,64	2,60
20	Persistent Organic Pollutants (POP)	ng i-Teq	0,67	0,62	0,60	0,56	0,52	0,51	0,51	0,50	0,50	0,36	0,35	0,35	0,35	0,35
21	Heavy Metals	mg Ni eq.	116,11	104,89	101,35	99,88	89,00	87,79	86,70	85,81	85,50	84,31	84,17	84,17	84,17	83,61
22	PAHs	mg Ni eq.	2,08	1,88	1,82	1,76	1,58	1,57	1,55	1,53	1,53	0,75	0,68	0,68	0,68	0,68
23	Particulate Matter (PM, dust)	g	4,18	3,82	3,70	3,61	3,24	3,19	3,15	3,12	3,13	2,69	2,67	2,67	2,65	2,60
	Emissions (Water)															
24	Heavy Metals	mg Hg/20	449,19	406,51	393,36	388,52	346,32	340,56	336,30	332,83	331,67	322,36	322,36	322,36	322,36	252,60
25	Eutrophication	g PO4	5,05	4,59	4,45	4,39	3,92	3,85	3,81	3,77	3,75	3,71	3,71	3,71	3,71	3,37
	LCC (in Euros/year)															
	Life Cycle Costs		86,95	79,55	75,82	73,94	67,26	67,02	66,27	65,66	65,16	64,92	64,87	64,87	64,87	65,06
	incl. MEErP 2011 societal damage		88,38	80,85	77,09	75,16	68,36	68,10	67,34	66,72	66,22	65,96	65,91	65,91	65,91	66,07
	incl. updated societal damage		91,85	84,05	80,20	78,12	71,05	70,76	69,97	69,33	68,82	68,20	68,09	68,09	68,09	67,94

Table 36 : Base Case 1 – LLCC and BAT analysis, DUR path

	Base Case 1		Base Case 1	DO20/15/21a	DO49	DO11	DO7/5/9/8	DO29	DO30	DO4	DO1/3	DO27	DO46	DO50	DO25	DO45/33/48/47
	Other Resources & Waste															
11	Total Energy (GER)	MJ	197,13	184,73	168,61	156,17	154,09	152,78	151,70	150,86	150,47	129,97	127,00	127,00	126,66	122,63
12	of which, electricity (in primary MJ)	MJ	118,72	113,89	98,99	94,02	93,28	92,76	92,33	91,99	91,75	90,99	90,99	90,99	90,91	87,98
13	Water (process)	ltr	98,91	89,31	87,31	77,88	76,43	75,44	74,63	73,97	73,55	71,79	71,79	71,79	71,77	58,38
14	Water (cooling)	ltr	41,72	37,81	36,41	32,71	32,17	31,78	31,46	31,30	31,54	30,44	30,44	30,44	30,19	30,19
15	Waste, non-haz./ landfill	g	809,80	732,35	710,22	636,21	624,95	617,17	610,79	606,01	604,64	583,18	580,33	580,33	579,64	577,50
16	Waste, hazardous/ incinerated	g	55,24	49,90	48,59	43,41	42,66	42,12	41,67	41,31	41,07	40,63	40,57	40,57	40,55	40,55
	Emissions (Air)															
17	Greenhouse Gases in GWP100	kg CO2 eq.	12,33	11,43	10,67	9,77	9,62	9,52	9,44	9,38	9,35	7,86	7,63	7,63	7,62	6,34
18	Acidification, emissions	g SO2 eq.	104,05	95,08	90,79	82,07	80,67	79,75	79,00	78,39	78,03	73,02	72,35	72,35	72,28	71,78
19	Volatile Organic Compounds (VOC)	g	3,42	3,29	3,01	2,83	2,76	2,74	2,72	2,71	2,70	2,66	2,66	2,66	2,66	2,63
20	Persistent Organic Pollutants (POP)	ng i-Teq	0,67	0,62	0,58	0,53	0,52	0,51	0,51	0,51	0,50	0,36	0,35	0,35	0,35	0,35
21	Heavy Metals	mg Ni eq.	116,11	104,89	102,72	91,72	89,90	88,74	87,78	87,01	86,52	85,31	85,17	85,17	85,17	84,60
22	PAHs	mg Ni eq.	2,08	1,88	1,81	1,63	1,60	1,58	1,57	1,55	1,55	0,76	0,69	0,69	0,69	0,69
23	Particulate Matter (PM, dust)	g	4,18	3,82	3,70	3,33	3,26	3,22	3,19	3,17	3,17	2,73	2,70	2,70	2,69	2,63
	Emissions (Water)															
24	Heavy Metals	mg Hg/20	449,19	406,51	399,77	357,09	348,97	344,41	340,67	337,66	335,79	326,37	326,37	326,37	326,37	255,77
25	Eutrophication	g PO4	5,05	4,59	4,52	4,04	3,95	3,89	3,85	3,82	3,80	3,76	3,76	3,76	3,76	3,42
	LCC (in Euros/year)															
	Life Cycle Costs		86,95	79,55	76,96	70,26	69,49	68,69	68,02	68,02	68,12	67,89	67,83	67,83	67,83	68,02
	incl. MEErP 2011 societal damage		88,38	80,85	78,21	71,39	70,60	69,78	69,11	69,10	69,20	68,94	68,88	68,88	68,88	69,04
	incl. updated societal damage		91,85	84,05	81,24	74,14	73,31	72,46	71,76	71,73	71,82	71,20	71,09	71,09	71,08	70,94

8.2.2 Base Case 2 – LLCC and BAT analysis, results of consecutive implementation of all calculated options

Table 37 : Base Case 2 – LLCC and BAT analysis, REP path

	Base Case 2		Base Case 2	DO20/15/21a	DO23/17/18/ 19/21b	DO49	DO11	DO7/5/9/8	DO29	DO30	DO1/3	DO27	DO46	DO50	DO25	DO45/33/48/ 47
	Other Resources & Waste															
11	Total Energy (GER)	MJ	**233,83**	**220,25**	**213,76**	**191,57**	**182,17**	**180,45**	**177,67**	**174,56**	**174,28**	**157,70**	**145,73**	**145,73**	**145,60**	**145,16**
12	of which, electricity (in primary MJ)	MJ	**153,19**	**146,56**	**143,46**	**122,72**	**118,40**	**117,82**	**116,58**	**115,16**	**114,96**	**114,34**	**114,34**	**114,34**	**114,30**	**113,95**
13	Water (process)	ltr	**106,86**	**96,09**	**91,15**	**89,32**	**82,47**	**81,47**	**79,49**	**77,23**	**76,94**	**75,53**	**75,53**	**75,53**	**75,52**	**74,94**
14	Water (cooling)	ltr	**57,50**	**51,76**	**49,20**	**47,49**	**44,03**	**43,58**	**42,58**	**41,45**	**41,64**	**40,69**	**40,69**	**40,69**	**40,59**	**40,59**
15	Waste, non-haz./ landfill	g	**1.117,80**	**1.006,05**	**955,82**	**928,50**	**859,58**	**849,69**	**829,72**	**807,05**	**805,75**	**788,07**	**776,63**	**776,63**	**776,35**	**776,13**
16	Waste, hazardous/ incinerated	g	**80,95**	**72,60**	**68,84**	**67,28**	**62,15**	**61,48**	**60,01**	**58,33**	**58,11**	**57,75**	**57,52**	**57,52**	**57,52**	**57,52**
	Emissions (Air)															
17	Greenhouse Gases in GWP100	kg CO2 eq.	**14,51**	**13,51**	**13,04**	**12,01**	**11,32**	**11,19**	**10,99**	**10,76**	**10,74**	**9,54**	**8,61**	**8,61**	**8,61**	**7,13**
18	Acidification, emissions	g SO2 eq.	**140,98**	**128,51**	**122,80**	**117,04**	**109,06**	**107,79**	**105,46**	**102,83**	**102,52**	**98,54**	**95,84**	**95,84**	**95,81**	**95,76**
19	Volatile Organic Compounds (VOC)	g	**4,33**	**4,38**	**4,35**	**3,84**	**3,71**	**3,60**	**3,54**	**3,50**	**3,49**	**3,46**	**3,45**	**3,45**	**3,45**	**3,45**
20	Persistent Organic Pollutants (POP)	ng i-Teq	**1,03**	**0,94**	**0,90**	**0,84**	**0,79**	**0,78**	**0,77**	**0,75**	**0,75**	**0,64**	**0,58**	**0,58**	**0,58**	**0,58**
21	Heavy Metals	mg Ni eq.	**168,09**	**151,70**	**144,13**	**141,15**	**130,48**	**128,69**	**125,55**	**122,03**	**121,58**	**120,64**	**120,06**	**120,06**	**120,06**	**120,03**
22	PAHs	mg Ni eq.	**4,24**	**3,80**	**3,61**	**3,50**	**3,24**	**3,21**	**3,13**	**3,05**	**3,04**	**2,41**	**2,12**	**2,12**	**2,12**	**2,12**
23	Particulate Matter (PM, dust)	g	**5,23**	**4,81**	**4,61**	**4,44**	**4,13**	**4,06**	**3,97**	**3,87**	**3,87**	**3,51**	**3,41**	**3,41**	**3,40**	**3,40**
	Emissions (Water)															
24	Heavy Metals	mg Hg/20	**483,04**	**442,82**	**423,01**	**413,57**	**383,39**	**375,95**	**366,72**	**356,62**	**355,38**	**347,82**	**347,81**	**347,81**	**347,81**	**340,47**
25	Eutrophication	g PO4	**6,18**	**5,69**	**5,44**	**5,32**	**4,93**	**4,84**	**4,72**	**4,59**	**4,57**	**4,54**	**4,54**	**4,54**	**4,54**	**4,53**
	LCC (in Euros/year)															
	Life Cycle Costs		**176,94**	**164,62**	**152,68**	**148,02**	**138,26**	**136,03**	**133,24**	**129,98**	**129,17**	**128,81**	**128,60**	**128,60**	**128,60**	**128,59**
	incl. MEErP 2011 societal damage		**178,89**	**166,40**	**154,38**	**149,65**	**139,78**	**137,53**	**134,70**	**131,41**	**130,59**	**130,22**	**130,00**	**130,00**	**130,00**	**129,97**
	incl. updated societal damage		**183,27**	**170,44**	**158,27**	**153,30**	**143,20**	**140,91**	**138,01**	**134,64**	**133,81**	**133,14**	**132,71**	**132,71**	**132,71**	**132,32**

Table 38 : Base Case 2 – LLCC and BAT analysis, DUR path

	Base Case 2		Base Case 2	DO20/15/21a	DO49	DO11	DO7/5/9/8	DO29	DO30	DO4	DO1/3	DO27	DO46	DO50	DO25	DO45/33/48/47
	Other Resources & Waste															
11	Total Energy (GER)	MJ	234	220	197	188	184	181	178	177	176	160	147	147	147	147
12	of which, electricity (in primary MJ)	MJ	153	147	125	121	120	118	117	116	116	115	115	115	115	115
13	Water (process)	ltr	107	96	93	86	84	82	80	79	79	77	77	77	77	77
14	Water (cooling)	ltr	58	52	49	46	45	44	43	43	43	42	42	42	42	42
15	Waste, non-haz./ landfill	g	1.118	1.006	968	898	880	859	835	826	824	806	794	794	794	793
16	Waste, hazardous/ incinerated	g	81	73	70	65	64	62	60	60	59	59	59	59	59	59
	Emissions (Air)															
17	Greenhouse Gases in GWP100	kg CO2 eq.	15	14	12	12	11	11	11	11	11	10	9	9	9	7
18	Acidification, emissions	g SO2 eq.	141	129	122	114	111	109	106	105	104	100	98	98	98	98
19	Volatile Organic Compounds (VOC)	g	4	4	4	4	4	4	4	4	3	3	3	3	3	3
20	Persistent Organic Pollutants (POP)	ng i-Teq	1	1	1	1	1	1	1	1	1	1	1	1	1	1
21	Heavy Metals	mg Ni eq.	168	152	147	137	133	130	126	125	124	123	123	123	123	123
22	PAHs	mg Ni eq.	4	4	4	3	3	3	3	3	3	2	2	2	2	2
23	Particulate Matter (PM, dust)	g	5	5	5	4	4	4	4	4	4	4	3	3	3	3
	Emissions (Water)															
24	Heavy Metals	mg Hg/20	483	443	434	403	388	379	368	364	362	354	354	354	354	347
25	Eutrophication	g PO4	6	6	6	5	5	5	5	5	5	5	5	5	5	5
	LCC (in Euros/year)															
	Life Cycle Costs		177	165	157	147	144	141	137	136	135	135	135	135	135	135
	incl. MEErP 2011 societal damage		179	166	159	149	145	142	139	138	137	136	136	136	136	136
	incl. updated societal damage		183	170	163	153	149	145	142	141	140	139	139	139	139	139

8.2.3 Base Case 3 – LLCC and BAT analysis, results of consecutive implementation of all calculated options

Table 39 : Base Case 3 – LLCC and BAT analysis, REP path

	Base Case 3		Base Case 3	DO20/15/21a	DO23/17/18/19/21b	DO49	DO11	DO7/5/9/8	DO29	DO30	DO1/3	DO27	DO46	DO50	DO25	DO45/33/48/47
	Other Resources & Waste															
11	Total Energy (GER)	MJ	287,27	270,00	259,41	228,87	224,84	223,14	219,45	216,08	215,95	200,81	190,35	190,35	190,34	190,34
12	of which, electricity (in primary MJ)	MJ	202,70	192,69	186,50	157,97	155,85	155,21	153,27	151,44	151,31	150,61	150,61	150,61	150,61	150,61
13	Water (process)	ltr	124,77	110,94	102,54	100,57	97,71	96,80	94,19	91,75	91,57	90,28	90,28	90,28	90,28	90,28
14	Water (cooling)	ltr	83,38	74,47	69,15	66,50	64,70	64,17	62,52	60,97	61,21	59,92	59,92	59,92	59,91	59,91
15	Waste, non-haz./ landfill	g	1.485,08	1.327,27	1.232,94	1.191,66	1.158,96	1.148,38	1.118,48	1.090,53	1.090,01	1.073,25	1.063,26	1.063,26	1.063,25	1.063,25
16	Waste, hazardous/ incinerated	g	120,43	107,14	99,13	96,49	93,77	92,97	90,48	88,14	87,96	87,61	87,41	87,41	87,41	87,41
	Emissions (Air)															
17	Greenhouse Gases in GWP100	kg CO2 eq.	17,85	16,55	15,77	14,34	14,04	13,92	13,64	13,39	13,38	12,30	11,49	11,49	11,49	9,56
18	Acidification, emissions	g SO2 eq.	197,16	178,26	166,96	158,39	154,35	152,93	149,24	145,82	145,58	141,96	139,60	139,60	139,60	139,60
19	Volatile Organic Compounds (VOC)	g	5,59	5,64	5,69	4,94	4,87	4,76	4,69	4,66	4,65	4,63	4,61	4,61	4,61	4,61
20	Persistent Organic Pollutants (POP)	ng i-Teq	0,97	0,89	0,84	0,77	0,75	0,75	0,73	0,72	0,72	0,62	0,57	0,57	0,57	0,57
21	Heavy Metals	mg Ni eq.	247,78	221,68	206,10	200,86	195,23	193,15	188,00	183,23	182,87	182,04	181,53	181,53	181,53	181,53
22	PAHs	mg Ni eq.	4,12	3,73	3,47	3,33	3,24	3,22	3,14	3,06	3,05	2,50	2,25	2,25	2,25	2,25
23	Particulate Matter (PM, dust)	g	6,50	5,96	5,63	5,38	5,24	5,17	5,05	4,93	4,94	4,58	4,49	4,49	4,49	4,49
	Emissions (Water)															
24	Heavy Metals	mg Hg/20	621,54	564,15	530,49	517,28	503,26	495,66	482,79	471,40	470,50	463,90	463,89	463,89	463,89	463,89
25	Eutrophication	g PO4	7,90	7,21	6,79	6,61	6,43	6,33	6,17	6,03	6,02	5,98	5,98	5,98	5,98	5,98
	LCC (in Euros/year)															
	Life Cycle Costs		301,47	274,29	250,03	242,13	236,27	233,54	227,93	222,81	222,08	221,77	221,59	221,59	221,59	221,74
	incl. MEErP 2011 societal damage		304,17	276,73	252,32	244,31	238,39	235,64	229,98	224,81	224,08	223,75	223,56	223,56	223,56	223,68
	incl. updated societal damage		309,83	281,92	257,23	248,88	242,85	240,06	234,30	229,04	228,31	227,71	227,33	227,33	227,33	227,00

Table 40 : Base Case 3 – LLCC and BAT analysis, DUR path

	Base Case 3		Base Case 3	DO20/15/21a	DO49	DO11	DO7/5/9/8	DO29	DO30	DO4	DO1/3	DO27	DO46	DO50	DO25	DO45/33/48/47
	Other Resources & Waste															
11	Total Energy (GER)	MJ	**287,27**	**270,00**	**237,48**	**233,26**	**229,81**	**225,94**	**222,38**	**222,41**	**222,11**	**206,14**	**195,09**	**195,09**	**195,09**	**195,09**
12	of which, electricity (in primary MJ)	MJ	**202,70**	**192,69**	**162,51**	**160,28**	**159,06**	**157,03**	**155,13**	**155,14**	**154,92**	**154,18**	**154,18**	**154,18**	**154,18**	**154,18**
13	Water (process)	ltr	**124,77**	**110,94**	**106,46**	**103,47**	**101,82**	**99,09**	**96,53**	**96,54**	**96,24**	**94,88**	**94,88**	**94,88**	**94,87**	**94,87**
14	Water (cooling)	ltr	**83,38**	**74,47**	**70,46**	**68,58**	**67,55**	**65,83**	**64,22**	**64,29**	**64,47**	**63,10**	**63,10**	**63,10**	**63,10**	**63,10**
15	Waste, non-haz./ landfill	g	**1.485,08**	**1.327,27**	**1.263,53**	**1.229,33**	**1.208,38**	**1.177,13**	**1.147,98**	**1.148,30**	**1.146,43**	**1.128,74**	**1.118,19**	**1.118,19**	**1.118,18**	**1.118,18**
16	Waste, hazardous/ incinerated	g	**120,43**	**107,14**	**102,46**	**99,61**	**98,04**	**95,44**	**93,01**	**93,01**	**92,71**	**92,35**	**92,14**	**92,14**	**92,14**	**92,14**
	Emissions (Air)															
17	Greenhouse Gases in GWP100	kg CO2 eq.	**17,85**	**16,55**	**14,99**	**14,68**	**14,41**	**14,13**	**13,86**	**13,86**	**13,84**	**12,70**	**11,85**	**11,85**	**11,85**	**9,81**
18	Acidification, emissions	g SO2 eq.	**197,16**	**178,26**	**167,21**	**162,99**	**160,12**	**156,27**	**152,69**	**152,69**	**152,27**	**148,46**	**145,96**	**145,96**	**145,96**	**145,96**
19	Volatile Organic Compounds (VOC)	g	**5,59**	**5,64**	**5,07**	**5,00**	**4,73**	**4,67**	**4,62**	**4,62**	**4,61**	**4,58**	**4,57**	**4,57**	**4,57**	**4,57**
20	Persistent Organic Pollutants (POP)	ng i-Teq	**0,97**	**0,89**	**0,80**	**0,79**	**0,78**	**0,76**	**0,75**	**0,75**	**0,74**	**0,65**	**0,59**	**0,59**	**0,59**	**0,59**
21	Heavy Metals	mg Ni eq.	**247,78**	**221,68**	**213,16**	**207,27**	**203,08**	**197,69**	**192,69**	**192,69**	**192,07**	**191,21**	**190,67**	**190,67**	**190,67**	**190,67**
22	PAHs	mg Ni eq.	**4,12**	**3,73**	**3,53**	**3,44**	**3,39**	**3,30**	**3,22**	**3,22**	**3,21**	**2,63**	**2,36**	**2,36**	**2,36**	**2,36**
23	Particulate Matter (PM, dust)	g	**6,50**	**5,96**	**5,67**	**5,53**	**5,38**	**5,25**	**5,13**	**5,13**	**5,14**	**4,76**	**4,66**	**4,66**	**4,66**	**4,66**
	Emissions (Water)															
24	Heavy Metals	mg Hg/20	**621,54**	**564,15**	**546,35**	**531,68**	**516,24**	**502,75**	**490,45**	**490,45**	**488,92**	**481,95**	**481,93**	**481,93**	**481,93**	**481,93**
25	Eutrophication	g PO4	**7,90**	**7,21**	**6,98**	**6,79**	**6,60**	**6,42**	**6,27**	**6,27**	**6,25**	**6,22**	**6,22**	**6,22**	**6,22**	**6,22**
	LCC (in Euros/year)															
	Life Cycle Costs		**301,47**	**274,29**	**260,34**	**254,28**	**249,25**	**243,45**	**238,24**	**238,24**	**237,26**	**236,93**	**236,73**	**236,73**	**236,73**	**236,89**
	incl. MEErP 2011 societal damage		**304,17**	**276,73**	**262,64**	**256,52**	**251,45**	**245,59**	**240,34**	**240,34**	**239,35**	**239,00**	**238,80**	**238,80**	**238,80**	**238,92**
	incl. updated societal damage		**309,83**	**281,92**	**267,44**	**261,21**	**256,05**	**250,09**	**244,74**	**244,74**	**243,74**	**243,11**	**242,71**	**242,71**	**242,71**	**242,36**

8.2.4 Base Case 4 – LLCC and BAT analysis, results of consecutive implementation of all calculated options

Table 41 : Base Case 4 – LLCC and BAT analysis, REP path

	Base Case 4		Base Case 4	DO20/15/21a	DO23/17/18/19/21b	DO49	DO11	DO7/5/9/8	DO29	DO30	DO1/3	DO27	DO46	DO50	DO25	DO45/33/48/47
	Other Resources & Waste															
11	Total Energy (GER)	MJ	111,97	105,39	104,96	104,96	104,96	102,88	102,25	102,25	102,44	83,23	80,40	80,40	80,15	79,05
12	of which, electricity (in primary MJ)	MJ	58,40	57,18	57,11	57,11	57,11	56,76	56,65	56,65	56,68	56,01	56,01	56,01	55,95	55,24
13	Water (process)	ltr	46,91	42,00	41,68	41,68	41,68	40,27	39,82	39,82	39,84	38,31	38,31	38,31	38,29	33,24
14	Water (cooling)	ltr	11,74	10,67	10,61	10,61	10,61	10,34	10,25	10,25	10,60	9,60	9,60	9,60	9,39	9,39
15	Waste, non-haz./ landfill	g	390,35	350,99	348,53	348,53	348,53	337,85	334,38	334,38	336,09	315,83	313,13	313,13	312,60	311,96
16	Waste, hazardous/ incinerated	g	8,83	7,95	7,90	7,90	7,90	7,67	7,60	7,60	7,60	7,19	7,13	7,13	7,12	7,12
	Emissions (Air)															
17	Greenhouse Gases in GWP100	kg CO2 eq.	6,51	6,06	6,03	6,03	6,03	5,88	5,84	5,84	5,85	4,45	4,24	4,24	4,22	3,99
18	Acidification, emissions	g SO2 eq.	33,43	30,97	30,81	30,81	30,81	30,01	29,78	29,78	29,80	25,12	24,48	24,48	24,43	24,29
19	Volatile Organic Compounds (VOC)	g	1,73	1,76	1,75	1,75	1,75	1,69	1,68	1,68	1,68	1,65	1,64	1,64	1,64	1,64
20	Persistent Organic Pollutants (POP)	ng i-Teq	0,44	0,41	0,40	0,40	0,40	0,40	0,39	0,39	0,39	0,26	0,25	0,25	0,25	0,25
21	Heavy Metals	mg Ni eq.	20,80	19,01	18,88	18,88	18,88	18,12	17,91	17,91	17,92	16,80	16,66	16,66	16,66	16,45
22	PAHs	mg Ni eq.	1,60	1,44	1,43	1,43	1,43	1,39	1,37	1,37	1,37	0,66	0,59	0,59	0,59	0,59
23	Particulate Matter (PM, dust)	g	1,79	1,65	1,64	1,64	1,64	1,58	1,56	1,56	1,58	1,20	1,18	1,18	1,17	1,15
	Emissions (Water)															
24	Heavy Metals	mg Hg/20	166,53	152,46	151,40	151,40	151,40	144,82	143,16	143,16	143,16	134,98	134,98	134,98	134,97	115,77
25	Eutrophication	g PO4	2,11	1,94	1,92	1,92	1,92	1,84	1,82	1,82	1,82	1,78	1,78	1,78	1,78	1,62
	LCC (in Euros/year)															
	Life Cycle Costs		31,09	30,74	30,31	30,31	30,31	29,07	28,77	28,77	28,77	28,55	28,50	28,50	28,50	28,66
	incl. MEErP 2011 societal damage		31,59	31,20	30,77	30,77	30,77	29,52	29,22	29,22	29,22	28,97	28,92	28,92	28,92	29,07
	incl. updated societal damage		33,19	32,68	32,24	32,24	32,24	30,96	30,64	30,64	30,64	30,05	29,95	29,95	29,94	30,03

Table 42 : Base Case 4 – LLCC and BAT analysis, DUR path

	Base Case 4		Base Case 4	DO20/15/21a	DO49	DO11	DO7/5/9/8	DO29	DO30	DO4	DO1/3	DO27	DO46	DO50	DO25	DO45/33/48/47
	Other Resources & Waste															
11	Total Energy (GER	MJ	**111,97**	**105,39**	**105,39**	**105,39**	**103,31**	**102,67**	**102,67**	**102,18**	**102,36**	**83,19**	**80,37**	**80,37**	**80,12**	**79,02**
12	of which, electrici	MJ	**58,40**	**57,18**	**57,18**	**57,18**	**56,84**	**56,72**	**56,72**	**56,63**	**56,66**	**55,99**	**55,99**	**55,99**	**55,93**	**55,22**
13	Water (process)	ltr	**46,91**	**42,00**	**42,00**	**42,00**	**40,58**	**40,12**	**40,12**	**39,74**	**39,76**	**38,24**	**38,24**	**38,24**	**38,22**	**33,18**
14	Water (cooling)	ltr	**11,74**	**10,67**	**10,67**	**10,67**	**10,40**	**10,31**	**10,31**	**10,31**	**10,66**	**9,66**	**9,66**	**9,66**	**9,46**	**9,46**
15	Waste, non-haz./	g	**390,35**	**350,99**	**350,99**	**350,99**	**340,34**	**336,79**	**336,79**	**334,18**	**335,88**	**315,66**	**312,97**	**312,97**	**312,44**	**311,80**
16	Waste, hazardous	g	**8,83**	**7,95**	**7,95**	**7,95**	**7,73**	**7,65**	**7,65**	**7,58**	**7,58**	**7,17**	**7,12**	**7,12**	**7,10**	**7,10**
	Emissions (Air)															
17	Greenhouse Gase	kg CO2 eq.	**6,51**	**6,06**	**6,06**	**6,06**	**5,91**	**5,87**	**5,87**	**5,83**	**5,84**	**4,45**	**4,23**	**4,23**	**4,22**	**3,99**
18	Acidification, emi	g SO2 eq.	**33,43**	**30,97**	**30,97**	**30,97**	**30,18**	**29,93**	**29,93**	**29,74**	**29,76**	**25,09**	**24,46**	**24,46**	**24,40**	**24,26**
19	Volatile Organic C	g	**1,73**	**1,76**	**1,76**	**1,76**	**1,69**	**1,68**	**1,68**	**1,68**	**1,68**	**1,65**	**1,64**	**1,64**	**1,64**	**1,63**
20	Persistent Organi	ng i-Teq	**0,44**	**0,41**	**0,41**	**0,41**	**0,40**	**0,39**	**0,39**	**0,39**	**0,39**	**0,26**	**0,25**	**0,25**	**0,25**	**0,25**
21	Heavy Metals	mg Ni eq.	**20,80**	**19,01**	**19,01**	**19,01**	**18,25**	**18,04**	**18,04**	**17,88**	**17,88**	**16,76**	**16,63**	**16,63**	**16,63**	**16,42**
22	PAHs	mg Ni eq.	**1,60**	**1,44**	**1,44**	**1,44**	**1,40**	**1,38**	**1,38**	**1,37**	**1,37**	**0,66**	**0,59**	**0,59**	**0,59**	**0,59**
23	Particulate Matter	g	**1,79**	**1,65**	**1,65**	**1,65**	**1,59**	**1,57**	**1,57**	**1,56**	**1,58**	**1,20**	**1,18**	**1,18**	**1,17**	**1,15**
	Emissions (Water)															
24	Heavy Metals	mg Hg/20	**166,53**	**152,46**	**152,46**	**152,46**	**145,90**	**144,21**	**144,21**	**142,90**	**142,90**	**134,73**	**134,73**	**134,73**	**134,73**	**115,57**
25	Eutrophication	g PO4	**2,11**	**1,94**	**1,94**	**1,94**	**1,85**	**1,83**	**1,83**	**1,82**	**1,82**	**1,78**	**1,78**	**1,78**	**1,78**	**1,62**
	LCC (in Euros/year)															
	Life Cycle Costs		**31,09**	**30,74**	**30,74**	**30,74**	**30,67**	**29,16**	**29,16**	**29,49**	**29,49**	**29,27**	**29,22**	**29,22**	**29,22**	**29,22**
	incl. MEErP 2011 societal damage		**31,59**	**31,20**	**31,20**	**31,20**	**31,12**	**29,61**	**29,61**	**29,94**	**29,94**	**29,69**	**29,64**	**29,64**	**29,64**	**29,63**
	incl. updated societal damage		**33,19**	**32,68**	**32,68**	**32,68**	**32,57**	**31,04**	**31,04**	**31,36**	**31,36**	**30,77**	**30,67**	**30,67**	**30,66**	**30,59**

8.2.5 Base Case 5 – LLCC and BAT analysis, results of consecutive implementation of all calculated options

Table 43 : Base Case 5 – LLCC and BAT analysis, REP path

	Base Case 5		Base Case 5	DO20/15/21a	DO23/17/18/19/21b	DO49	DO11	DO7/5/9/8	DO29	DO30	DO1/3	DO27	DO46	DO50	DO25	DO45/33/48/47
	Other Resources & Waste															
11	Total Energy (GER)	MJ	**88,10**	**88,10**	**86,22**	**86,22**	**86,22**	**85,49**	**85,49**	**85,49**	**85,49**	**79,01**	**79,01**	**63,40**	**62,69**	**62,17**
12	of which, electricity (in primary MJ)	MJ	**54,03**	**54,03**	**53,74**	**53,74**	**53,74**	**53,63**	**53,63**	**53,63**	**53,63**	**53,30**	**53,30**	**37,68**	**37,50**	**37,22**
13	Water (process)	ltr	**23,92**	**23,92**	**22,79**	**22,79**	**22,79**	**22,37**	**22,37**	**22,37**	**22,37**	**21,73**	**21,73**	**21,73**	**21,69**	**17,68**
14	Water (cooling)	ltr	**11,71**	**11,71**	**11,27**	**11,27**	**11,27**	**11,09**	**11,09**	**11,09**	**11,09**	**10,45**	**10,45**	**9,76**	**8,92**	**8,92**
15	Waste, non-haz./ landfill	g	**114,88**	**114,88**	**110,68**	**110,68**	**110,68**	**109,02**	**109,02**	**109,02**	**109,02**	**102,15**	**102,15**	**94,10**	**92,83**	**92,52**
16	Waste, hazardous/ incinerated	g	**4,99**	**4,99**	**4,79**	**4,79**	**4,79**	**4,71**	**4,71**	**4,71**	**4,71**	**4,56**	**4,56**	**4,32**	**4,27**	**4,27**
	Emissions (Air)															
17	Greenhouse Gases in GWP100	kg CO2 eq.	**4,81**	**4,81**	**4,68**	**4,68**	**4,68**	**4,63**	**4,63**	**4,63**	**4,63**	**4,18**	**4,18**	**3,51**	**3,48**	**3,39**
18	Acidification, emissions	g SO2 eq.	**25,32**	**25,32**	**24,68**	**24,68**	**24,68**	**24,29**	**24,29**	**24,29**	**24,29**	**22,40**	**22,40**	**19,45**	**19,31**	**19,22**
19	Volatile Organic Compounds (VOC)	g	**1,24**	**1,24**	**1,23**	**1,23**	**1,23**	**1,22**	**1,22**	**1,22**	**1,22**	**1,21**	**1,21**	**0,86**	**0,86**	**0,85**
20	Persistent Organic Pollutants (POP)	ng i-Teq	**0,33**	**0,33**	**0,32**	**0,32**	**0,32**	**0,32**	**0,32**	**0,32**	**0,32**	**0,27**	**0,27**	**0,24**	**0,24**	**0,24**
21	Heavy Metals	mg Ni eq.	**9,77**	**9,77**	**9,33**	**9,33**	**9,33**	**9,17**	**9,17**	**9,17**	**9,17**	**8,74**	**8,74**	**8,58**	**8,58**	**8,42**
22	PAHs	mg Ni eq.	**1,60**	**1,60**	**1,57**	**1,57**	**1,57**	**1,51**	**1,51**	**1,51**	**1,51**	**1,19**	**1,19**	**1,15**	**1,15**	**1,15**
23	Particulate Matter (PM, dust)	g	**1,74**	**1,74**	**1,67**	**1,67**	**1,67**	**1,64**	**1,64**	**1,64**	**1,64**	**1,33**	**1,33**	**1,27**	**1,25**	**1,25**
	Emissions (Water)															
24	Heavy Metals	mg Hg/20	**65,02**	**65,02**	**61,93**	**61,93**	**61,93**	**60,79**	**60,79**	**60,79**	**60,79**	**58,04**	**58,04**	**57,97**	**57,97**	**47,87**
25	Eutrophication	g PO4	**0,99**	**0,99**	**0,95**	**0,95**	**0,95**	**0,93**	**0,93**	**0,93**	**0,93**	**0,91**	**0,91**	**0,91**	**0,91**	**0,78**
	LCC (in Euros/year)															
	Life Cycle Costs		**11,83**	**11,83**	**11,52**	**11,52**	**11,52**	**11,70**	**11,70**	**11,70**	**11,70**	**11,55**	**11,55**	**11,18**	**11,18**	**11,29**
	incl. MEErP 2011 societal damage		**12,21**	**12,21**	**11,89**	**11,89**	**11,89**	**12,07**	**12,07**	**12,07**	**12,07**	**11,90**	**11,90**	**11,50**	**11,49**	**11,59**
	incl. updated societal damage		**13,39**	**13,39**	**13,03**	**13,03**	**13,03**	**13,19**	**13,19**	**13,19**	**13,19**	**12,90**	**12,90**	**12,36**	**12,35**	**12,42**

Table 44 : Base Case 5 – LLCC and BAT analysis, DUR path

	Base Case 5		Base Case 5	DO20/15/21a	DO49	DO11	DO7/5/9/8	DO29	DO30	DO4	DO1/3	DO27	DO46	DO50	DO25	DO45/33/48/47
	Other Resources & Waste															
11	Total Energy (GER)	MJ	**88,10**	**88,10**	**88,10**	**88,10**	**87,36**	**87,36**	**87,36**	**87,36**	**87,36**	**80,19**	**80,19**	**64,58**	**63,83**	**63,29**
12	of which, electricity (in primary MJ)	MJ	**54,03**	**54,03**	**54,03**	**54,03**	**53,92**	**53,92**	**53,92**	**53,92**	**53,92**	**53,57**	**53,57**	**37,95**	**37,77**	**37,47**
13	Water (process)	ltr	**23,92**	**23,92**	**23,92**	**23,92**	**23,48**	**23,48**	**23,48**	**23,48**	**23,48**	**22,82**	**22,82**	**22,82**	**22,77**	**18,56**
14	Water (cooling)	ltr	**11,71**	**11,71**	**11,71**	**11,71**	**11,54**	**11,54**	**11,54**	**11,54**	**11,54**	**10,87**	**10,87**	**10,17**	**9,30**	**9,30**
15	Waste, non-haz./ landfill	g	**114,88**	**114,88**	**114,88**	**114,88**	**113,23**	**113,23**	**113,23**	**113,23**	**113,23**	**105,84**	**105,84**	**97,79**	**96,45**	**96,13**
16	Waste, hazardous/ incinerated	g	**4,99**	**4,99**	**4,99**	**4,99**	**4,91**	**4,91**	**4,91**	**4,91**	**4,91**	**4,75**	**4,75**	**4,50**	**4,45**	**4,45**
	Emissions (Air)															
17	Greenhouse Gases in GWP100	kg CO2 eq.	**4,81**	**4,81**	**4,81**	**4,81**	**4,76**	**4,76**	**4,76**	**4,76**	**4,76**	**4,26**	**4,26**	**3,59**	**3,56**	**3,54**
18	Acidification, emissions	g SO2 eq.	**25,32**	**25,32**	**25,32**	**25,32**	**25,05**	**25,05**	**25,05**	**25,05**	**25,05**	**22,97**	**22,97**	**20,02**	**19,87**	**19,78**
19	Volatile Organic Compounds (VOC)	g	**1,24**	**1,24**	**1,24**	**1,24**	**1,23**	**1,23**	**1,23**	**1,23**	**1,23**	**1,21**	**1,21**	**0,86**	**0,86**	**0,85**
20	Persistent Organic Pollutants (POP)	ng i-Teq	**0,33**	**0,33**	**0,33**	**0,33**	**0,33**	**0,33**	**0,33**	**0,33**	**0,33**	**0,28**	**0,28**	**0,24**	**0,24**	**0,24**
21	Heavy Metals	mg Ni eq.	**9,77**	**9,77**	**9,77**	**9,77**	**9,60**	**9,60**	**9,60**	**9,60**	**9,60**	**9,15**	**9,15**	**8,99**	**8,99**	**8,81**
22	PAHs	mg Ni eq.	**1,60**	**1,60**	**1,60**	**1,60**	**1,58**	**1,58**	**1,58**	**1,58**	**1,58**	**1,24**	**1,24**	**1,20**	**1,19**	**1,19**
23	Particulate Matter (PM, dust)	g	**1,74**	**1,74**	**1,74**	**1,74**	**1,71**	**1,71**	**1,71**	**1,71**	**1,71**	**1,27**	**1,27**	**1,21**	**1,18**	**1,18**
	Emissions (Water)															
24	Heavy Metals	mg Hg/20	**65,02**	**65,02**	**65,02**	**65,02**	**63,82**	**63,82**	**63,82**	**63,82**	**63,82**	**60,93**	**60,93**	**60,86**	**60,85**	**50,25**
25	Eutrophication	g PO4	**0,99**	**0,99**	**0,99**	**0,99**	**0,97**	**0,97**	**0,97**	**0,97**	**0,97**	**0,96**	**0,96**	**0,96**	**0,95**	**0,82**
	LCC (in Euros/year)															
	Life Cycle Costs		**11,83**	**11,83**	**11,83**	**11,83**	**12,03**	**12,03**	**12,03**	**12,03**	**12,03**	**11,87**	**11,87**	**11,50**	**11,50**	**11,50**
	incl. MEErP 2011 societal damage		**12,21**	**12,21**	**12,21**	**12,21**	**12,40**	**12,40**	**12,40**	**12,40**	**12,40**	**12,22**	**12,22**	**11,82**	**11,81**	**11,81**
	incl. updated societal damage		**13,39**	**13,39**	**13,39**	**13,39**	**13,56**	**13,56**	**13,56**	**13,56**	**13,56**	**13,25**	**13,25**	**12,70**	**12,69**	**12,68**

8.2.6 Base Case 6 – LLCC and BAT analysis, results of consecutive implementation of all calculated options

Table 45 : Base Case 6 – LLCC and BAT analysis, REP path

	Base Case 6		Base Case 6	DO20/15/21a	DO23/17/18/19/21b	DO49	DO11	DO7/5/9/8	DO29	DO30	DO1/3	DO27	DO46	DO50	DO25	DO45/33/48/47
	Other Resources & Waste															
11	Total Energy (GER)	MJ	185,18	180,36	178,18	159,94	156,62	155,92	154,51	153,11	153,07	139,57	134,80	134,80	134,51	133,78
12	of which, electricity (in primary MJ)	MJ	124,62	122,33	121,32	103,48	102,02	101,84	101,22	100,60	100,51	99,83	99,83	99,83	99,76	99,21
13	Water (process)	ltr	82,06	77,10	75,16	74,48	71,88	71,52	70,42	69,31	69,20	67,94	67,94	67,94	67,92	66,96
14	Water (cooling)	ltr	34,00	31,92	31,16	30,16	29,19	29,08	28,67	28,25	28,47	27,20	27,20	27,20	26,92	26,92
15	Waste, non-haz./ landfill	g	734,65	690,99	674,34	660,41	638,40	635,23	625,92	616,52	617,01	601,31	596,81	596,81	596,21	595,82
16	Waste, hazardous/ incinerated	g	44,52	41,84	40,80	40,21	38,83	38,67	38,09	37,49	37,43	37,12	37,03	37,03	37,01	37,01
	Emissions (Air)															
17	Greenhouse Gases in GWP100	kg CO2 eq.	10,73	10,41	10,26	9,46	9,23	9,18	9,08	8,99	8,98	8,03	7,66	7,66	7,65	6,44
18	Acidification, emissions	g SO2 eq.	86,26	82,29	80,68	76,88	74,64	74,24	73,28	72,33	72,26	68,98	67,90	67,90	67,84	67,77
19	Volatile Organic Compounds (VOC)	g	3,66	3,81	3,83	3,43	3,39	3,32	3,30	3,29	3,28	3,25	3,24	3,24	3,24	3,24
20	Persistent Organic Pollutants (POP)	ng i-Teq	0,90	0,86	0,84	0,79	0,77	0,77	0,76	0,75	0,75	0,66	0,64	0,64	0,64	0,64
21	Heavy Metals	mg Ni eq.	94,26	89,41	87,38	86,57	83,64	83,06	81,81	80,58	80,45	79,73	79,50	79,50	79,50	79,45
22	PAHs	mg Ni eq.	3,50	3,29	3,21	3,15	3,04	3,03	2,98	2,94	2,93	2,33	2,21	2,21	2,21	2,21
23	Particulate Matter (PM, dust)	g	4,41	4,24	4,16	4,07	3,94	3,91	3,85	3,80	3,81	3,28	3,21	3,21	3,19	3,18
	Emissions (Water)															
24	Heavy Metals	mg Hg/20	347,46	333,69	327,20	324,54	313,94	310,67	306,09	301,74	301,36	294,97	294,97	294,97	294,96	283,49
25	Eutrophication	g PO4	5,42	5,25	5,16	5,12	4,95	4,91	4,83	4,77	4,76	4,72	4,72	4,72	4,72	4,71
	LCC (in Euros/year)															
	Life Cycle Costs		73,28	71,79	67,82	65,96	64,45	63,90	63,28	62,66	62,46	61,87	61,77	61,77	61,77	61,90
	incl. MEErP 2011 societal damage		74,77	73,21	69,21	67,31	65,75	65,20	64,56	63,92	63,72	63,10	63,00	63,00	63,00	63,10
	incl. updated societal damage		78,37	76,69	72,62	70,55	68,91	68,33	67,65	66,97	66,77	65,90	65,71	65,71	65,71	65,45

Table 46 : Base Case 6 – LLCC and BAT analysis, DUR path

	Base Case 6		Base Case 6	DO20/15/21a	DO49	DO11	DO7/5/9/8	DO29	DO30	DO4	DO1/3	DO27	DO46	DO50	DO25	DO45/33/48/47
	Other Resources & Waste															
11	Total Energy (GER)	MJ	185,18	180,36	162,09	158,81	157,37	155,88	154,43	153,69	153,68	140,05	135,24	135,24	134,94	134,21
12	of which, electricity (in primary MJ)	MJ	124,62	122,33	104,24	102,80	102,48	101,83	101,19	100,86	100,77	100,08	100,08	100,08	100,01	99,45
13	Water (process)	ltr	82,06	77,10	76,05	73,48	72,82	71,66	70,52	69,92	69,79	68,51	68,51	68,51	68,49	67,52
14	Water (cooling)	ltr	34,00	31,92	30,76	29,79	29,59	29,16	28,73	28,60	28,96	27,67	27,67	27,67	27,40	27,40
15	Waste, non-haz./ landfill	g	734,65	690,99	674,29	652,56	646,48	636,71	627,02	622,41	623,34	607,49	602,94	602,94	602,34	601,94
16	Waste, hazardous/ incinerated	g	44,52	41,84	41,01	39,64	39,36	38,75	38,14	37,82	37,73	37,42	37,33	37,33	37,31	37,31
	Emissions (Air)															
17	Greenhouse Gases in GWP100	kg CO2 eq.	10,73	10,41	9,61	9,38	9,28	9,18	9,08	9,02	9,02	8,06	7,69	7,69	7,68	6,45
18	Acidification, emissions	g SO2 eq.	86,26	82,29	78,34	76,12	75,32	74,32	73,33	72,81	72,72	69,41	68,32	68,32	68,26	68,18
19	Volatile Organic Compounds (VOC)	g	3,66	3,81	3,51	3,47	3,32	3,29	3,27	3,26	3,26	3,22	3,22	3,22	3,22	3,21
20	Persistent Organic Pollutants (POP)	ng i-Teq	0,90	0,86	0,81	0,78	0,78	0,77	0,76	0,75	0,75	0,67	0,64	0,64	0,64	0,64
21	Heavy Metals	mg Ni eq.	94,26	89,41	88,51	85,62	84,42	83,11	81,83	81,15	80,98	80,25	80,02	80,02	80,02	79,98
22	PAHs	mg Ni eq.	3,50	3,29	3,21	3,10	3,08	3,04	2,99	2,96	2,96	2,34	2,23	2,23	2,23	2,23
23	Particulate Matter (PM, dust)	g	4,41	4,24	4,15	4,03	3,96	3,90	3,85	3,82	3,83	3,30	3,23	3,23	3,21	3,20
	Emissions (Water)															
24	Heavy Metals	mg Hg/20	347,46	333,69	332,80	322,37	315,19	310,37	305,82	303,30	302,75	296,31	296,30	296,30	296,30	284,72
25	Eutrophication	g PO4	5,42	5,25	5,24	5,08	4,97	4,89	4,82	4,78	4,77	4,74	4,74	4,74	4,74	4,72
	LCC (in Euros/year)															
	Life Cycle Costs		73,28	71,79	69,04	67,62	66,59	66,00	65,43	65,14	65,10	64,76	64,66	64,66	64,66	64,79
	incl. MEErP 2011 societal damage		74,77	73,21	70,41	68,95	67,91	67,29	66,71	66,40	66,36	66,00	65,90	65,90	65,90	66,00
	incl. updated societal damage		78,37	76,69	73,71	72,16	71,08	70,42	69,80	69,47	69,43	68,81	68,62	68,62	68,62	68,35

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