FRAUNHOFER-INSTITUT FÜR ZUVERLÄSSIGKEIT UND MIKROINTEGRATION IZM

Life Cycle Assessment of the Fairphone 5

Legal notice

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Declaration

This report is a deliverable from a study carried out by Fraunhofer IZM and commissioned by Fairphone B.V. The study was commissioned to reach objective and unbiased conclusions. Fraunhofer IZM declares no conflict of interest.

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Abbreviations

ADP	Abiotic Depletion Potential
AMOLED	Active Matrix Organic Light Emitting Diode
BOM	Bill of Materials
CED	Cumulative Energy Demand
CMOS	Complementary Metal Oxide Semiconductor
CSR	Corporate Social Responsibility
CTUe	Comparative Toxic unit (ecotoxicity)
DIY	Do It Yourself
DRAM	Dynamic Random Access Memory
Ecotox	Ecotoxicity
EoL	End of Life
EP	Eutrophication Potential
FMD	Full Material Declaration
GB	Giga Bite
GEC	Green Energy Certificate
GW	Global Warming
IC	Integrated Circuit
ISO	International Organization for Standardization
IUCN	International Union for Conservation of Nature and Natural Resources
LCA	Life Cycle Assessment
LCD	Liquid Crystal Display
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LUC	Land Use Change
MPU	Main Processing Unit
NAND	Not-AND
OLED	Organic Light Emitting Diodes
PC	Polycarbonate
PCB	Printed Circuit Board
PCBA	Printed Circuit Board Assembly
RAM	Random Access Memory
RoW	Rest of the World
SIM	Single Identity Module
SMT	Surface Mounted Technology
TPU	Thermal Polyurethane
USB	Universal Serial Bus
WU	Water Use

1 Executive Summary

Goals, scope and methodology overview

This report shows the life cycle assessment of the Fairphone 5, a modular smartphone by Fairphone B.V. and its accessories. This life cycle assessment (LCA), is a cradle-to-grave analysis, covering the life cycle stages of the production, transport, use phase as well as end of life of the products and meeting ISO 14040, 14044 and 14067 standards. The specific goals of this study are:

- Assessing the environmental impacts of the Fairphone 5 and its accessories
- Identifying environmental hotspots and main drivers, also in the value chain
- Analyzing the potential benefits and impacts of the use of recycled materials
- Analyzing the effects of employing renewable energy in assembly and battery manufacturing
- Comparing possible product design choices and repair options.

The functional unit for the baseline scenario is *the use of a Fairphone 5 device as sold to consumers for 3 years*. Additionally, assessed accessories are:

- Screen protector: privacy filter and blue light filter
- Soft case
- USB-C to audio jack adapter
- Fairbuds (true wireless earbuds)

The LCA analyses several impact categories to provide a comprehensive picture of environmental effects and possible trade-offs:

- Climate change in conformity with ISO 14067
- Abiotic resource depletion, both elements and fossil, CML methodology
- Ecotoxicity, USETox
- Eutrophication, CML
- Land Use Change, LANCA methodology
- (Blue) Water use (as calculated by the Sphera LCA FE software).

The foreground LCI data for the modelling of the device has been retrieved from various sources, depending on data availability. Whenever possible, primary data from Fairphone B.V. and its suppliers was used and when the data was not available or the activities covered were not in direct control of Fairphone, secondary data was used. Background data was retrieved from the Sphera database (commercial database and Electronics Extension) and the Ecoinvent database.

Key findings

Fairphone 5

The total global warming impact for the life cycle of the Fairphone 5 as in its baseline (3 years of use) is of 42,1 kg CO_2 eq., out of which 32,7 kg CO_2 eq. are related to its production phase. Table 1-1 shows the absolute values for all impact categories.

Table 1-1 - LCA results for the Fairphone 5, baseline scenario (3 years of use), per life cycle phase

	Total	Production	Transport	Use phase	EoL
Abiotic Resource Depletion, elements (kg Sb eq.)	1,25E-03	1,25E-03	5,74E-07	1,48E-06	1,47E-07
Abiotic Resource Depletion, fossil (MJ)	4,99E+02	3,85E+02	4,00E+01	7,39E+01	6,10E-01
Eutrophication (kg Phosphate eq.)	1,64E-02	1,19E-02	2,68E-03	1,81E-03	6,82E-05
Global Warming, 100 years (kg CO2 eq.)	4,21E+01	3,27E+01	2,81E+00	6,59E+00	4,11E-02

Land Use Change (-)	1,57E+02	9,88E+01	5,31E+00	5,25E+01	1,41E-01
Ecotoxicity (CTUe)	1,15E-01	8,96E-02	6,80E-03	1,75E-02	7,45E-04
Blue water consumption (kg)	3,19E+02	2,23E+02	4,62E+00	5,32E+01	3,84E+01
Blue water use (kg)	9,29E+04	4,38E+04	7,60E+02	4,83E+04	9,91E+01

As Figure 1-1 shows, the production phase of the Fairphone 5 drives all impact categories under analysis, spanning between 60% of the total (land use change) to almost 100% (ADP elements). The 3-years use phase is the next smaller contributor, with 10%-20% of the environmental impacts. This is followed by transport of the device with ~10% of the share and finally the end of life shows a minor impact except for water use. This picture is consistent with LCAs of small consumer electronic devices where the production of the semiconductors and boards causes the highest impacts of the entire life cycle, while the contribution of the rest of the life cycle phases is comparatively lower.

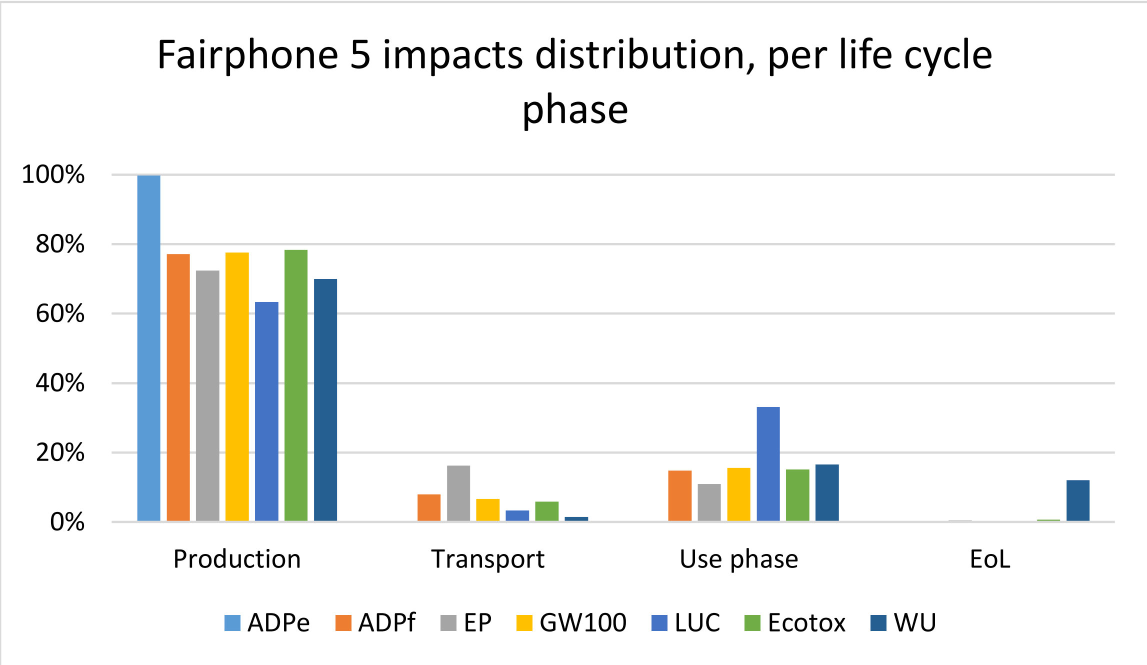

Figure 1-1 - Fairphone 5 environmental impacts distribution per life cycle phase, as % of the total impact

Figure 1-2 shows the impact distribution over the different modules' production. The main contributors are the primary PCBA (20%-70% depending on the impact category) and the display module (up to 50%), followed by the lower but still significant contribution of the cameras (ranging between 5% to 10%). For ecotoxicity, the phone assembly and the battery show a minor contribution and the USB-C connector also shows some impact in the ADPe category. The rest of the modules show comparatively small impacts (below 5% of the total for production).

The primary PCBA's impacts are mostly driven by the manufacturing of the ICs. Their manufacturing is a very energy intensive process, in particular the production of the silicon die, which involves many process steps and, in many cases, additionally intensive use of chemicals. Therefore, for complex chips like memories, the environmental impacts can be high. Similarly, the various camera modules contribute to the environmental impacts mainly due to their image sensors, which are silicon wafers. Finally, the display module shows significant impacts mostly related to the manufacturing of the OLED display. However, the secondary lab-scale data used might not be representative for the actual industrial-level energy use.

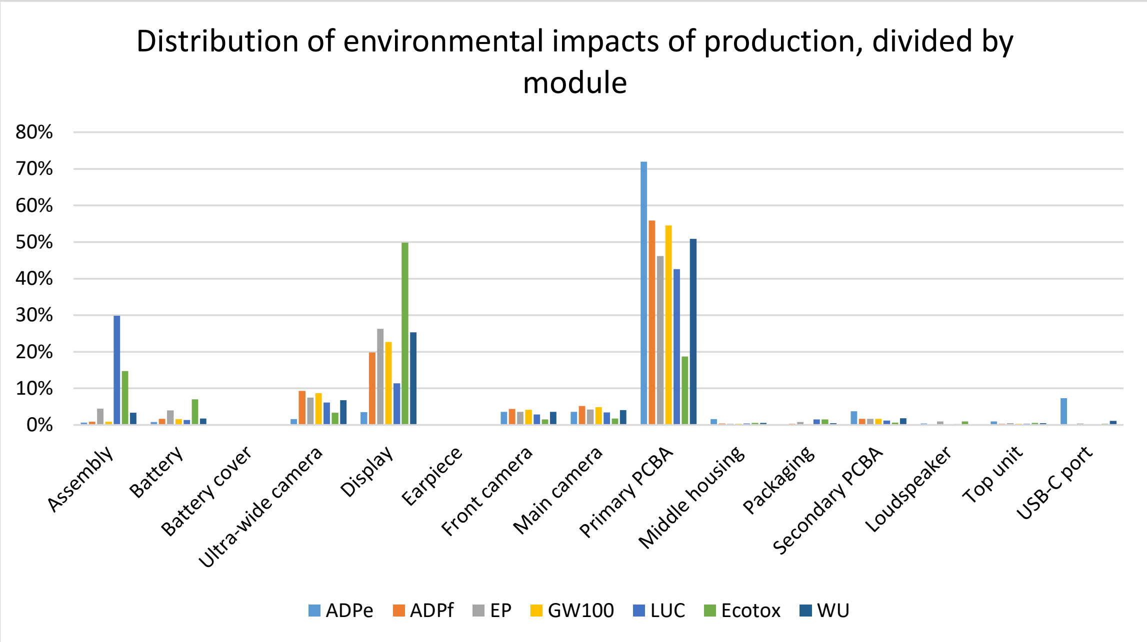

Figure 1-2 - Fairphone 5 production impacts distribution per module, as % of total production impacts

The effects of extending the useful life of the device can be seen when looking at the GW impacts per year of use (see Figure 1-3). With extended lifetime, the absolute use phase related impacts increase, as well as additional impacts for switching the battery. However, as production is the driver of the emissions, there is a net benefit of keeping the device in use that can be of up to 51% for an ideal case of a 10-year lifetime.

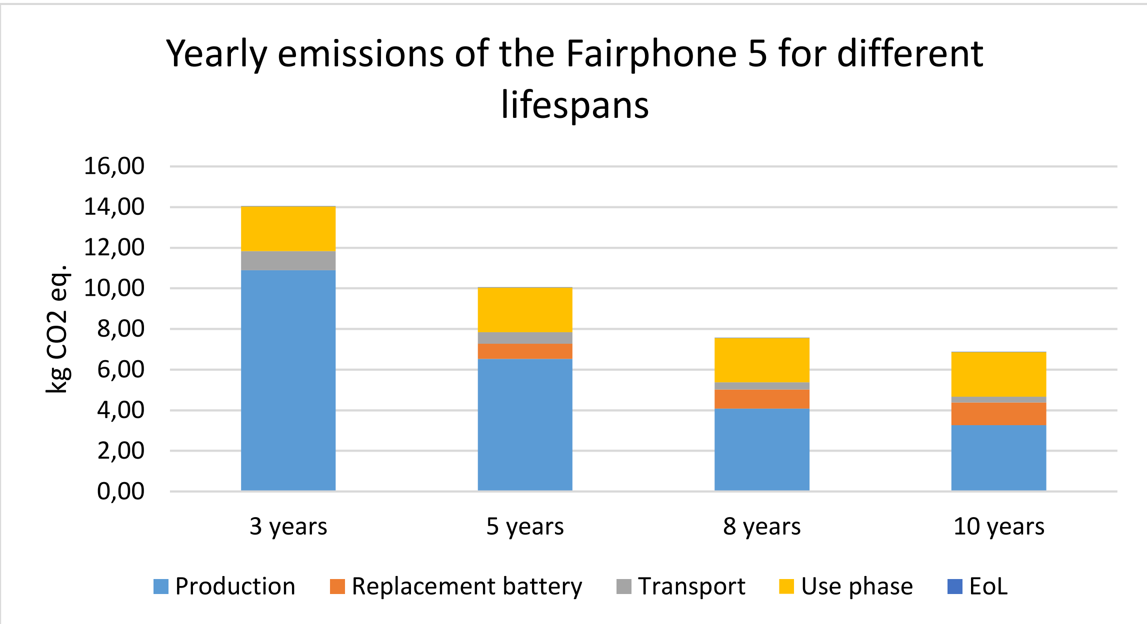

Figure 1-3 - Yearly emissions for different lifetime scenarios, expressed in kg CO2 eq. per year

Fairbuds

The global warming impact of the Fairbuds for a lifetime of 3 years considering all life cycle phases is 3,13 kg CO_2 eq. The table below shows the total values for all impact categories under study, per life cycle phase.

Table 1-2 - Environmental impacts of the Fairbuds per life cycle phase

	Total	Production	Transport	Use phase	EoL
Abiotic Resource Depletion, elements (kg Sb eq.)	2,03E-04	2,03E-04	1,67E-07	7,04E-08	6,32E-08
Abiotic Resource Depletion, fossil (MJ)	3,78E+01	2,82E+01	6,71E+00	2,64E+00	2,45E-01
Eutrophication (kg Phosphate eq.)	2,33E-03	1,76E-03	4,82E-04	6,05E-05	2,78E-05
Global Warming, 100 years (kg CO2 eq.)	3,13E+00	2,40E+00	4,71E-01	2,35E-01	1,66E-02
Land Use Change (-)	9,33E+00	5,84E+00	1,05E+00	2,39E+00	5,73E-02
Ecotoxicity (CTUe)	9,02E-03	6,64E-03	1,31E-03	7,15E-04	3,52E-04
Blue water consumption (kg)	4,84E+01	3,06E+01	8,16E-01	2,11E+00	1,49E+01
Blue water use (kg)	5,10E+03	2,82E+03	1,77E+02	2,06E+03	4,38E+01

Figure 1-4 shows the Fairbuds' impacts per life cycle phase. Most impact categories are driven by the production phase, having a share of 60% or more for all indicators. Transportation follows with 10-20% of the impacts across indicators. The use phase shows some significant contribution for Land Use Change (driven mostly by renewable sources like biogas) and EoL for water use, driven by EoL transportation.

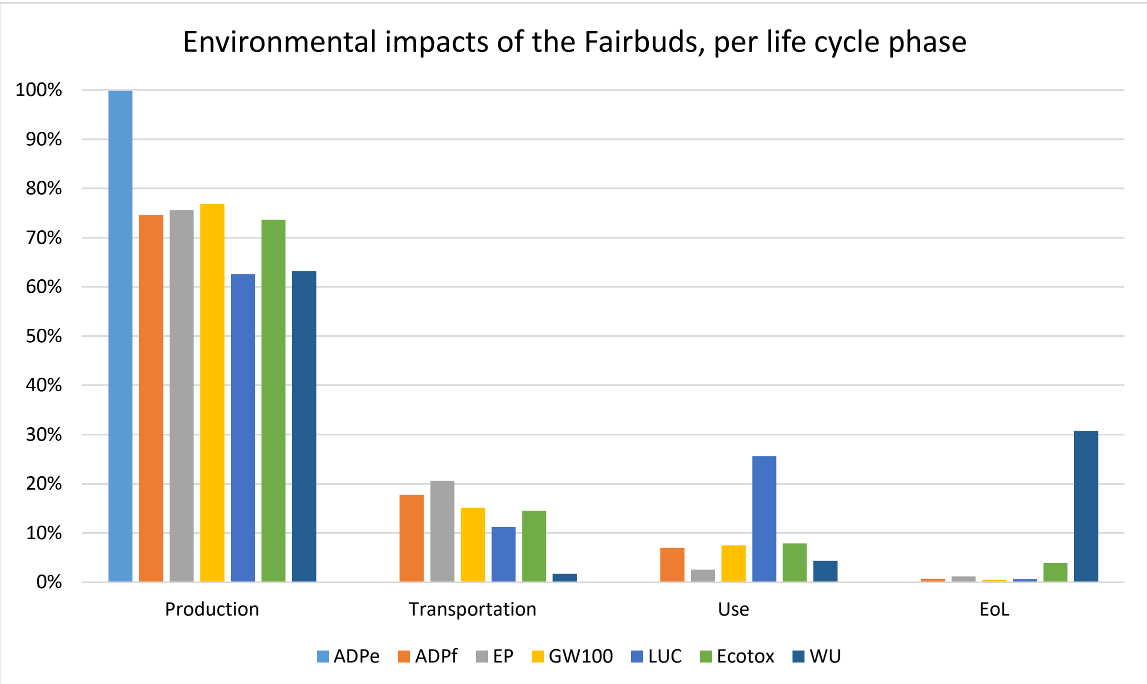

Figure 1-4 - Share of environmental impacts of the Fairbuds per life cycle phase, as % of the total

Figure 1-5 shows that the production related impacts are fairly evenly distributed across modules (i.e. charging case, earphone left and earphone right). Out of the three parts, the charging case shows the highest impacts, mostly because it contains most of the electronics in the device. Both earbuds show similar impact levels of around 20-30% of the total in all categories.

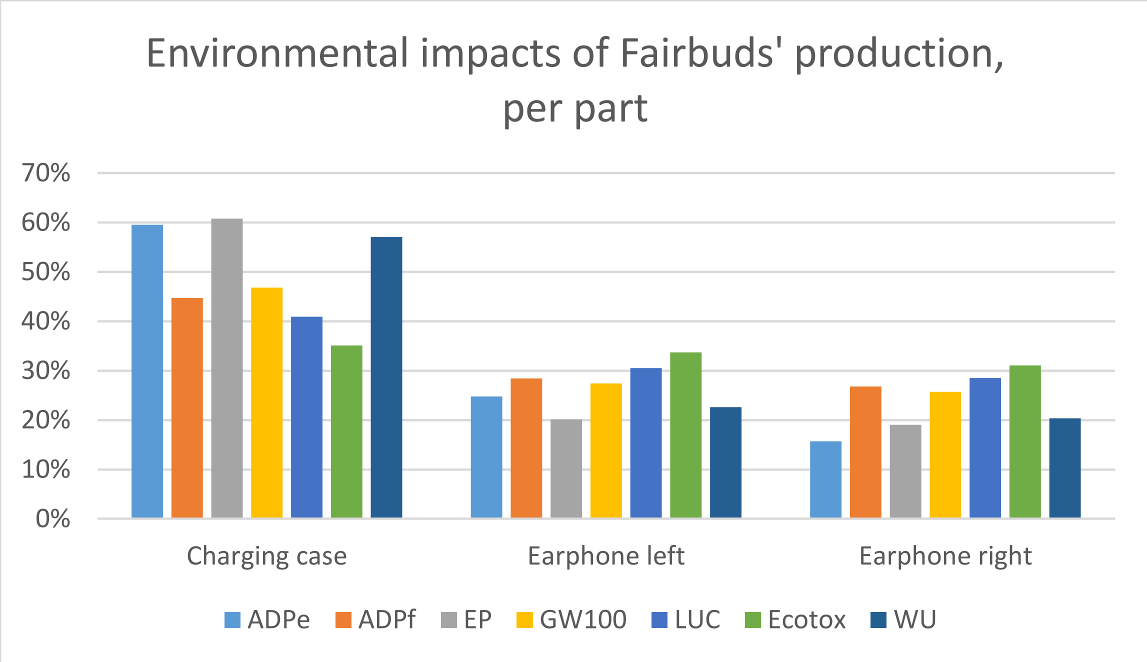

Figure 1-5 - Environmental impacts of the Fairbuds production per module, as % of the total for production

The impacts of the charging case are mainly related to the main battery production, PCBAs and magnets. The battery impacts are mostly related to its gold and lithium content while the magnets' impacts seem to be correlated with the extraction process of the main material praseodymium dioxide. Here, the impact might be overestimated due to the proxy used. Also, the gold content of the pogo pins in the charging case contributes significantly to its impacts. Finally, the environmental impacts of the earbuds are driven by the contained electronics.

Repair

The modular design of all Fairphone devices is intended to make repair easier for the users and thus allow increasing the lifespan of devices and/or parts. Three repair scenarios (repair center module replacement, repair center module-level repair and DIY module replacement) were compared to the usage of two phones without repairs over 6 years (reference scenario).

The analysis shows that all repair strategies represent an improvement compared to the reference scenario (between a 37-40% reductions of emissions). The board-level repair scenario shows a slightly better environmental performance than the replacement scenarios since more parts are kept in use. Since the repaired modules are not very carbon intensive, the difference between replacement and repair is small.

A good way to visualize the required *effort* for the repairs is the environmental payback time i.e. the additional time the device needs to be used for the additional impacts to be worthwhile. Table 6-2 below shows an overview of the estimated values.

Table 1-3 –Payback time module repair for both full module replacement and board level repair. The full repair overhead is considered. For the replacement case, DIY approach is assumed (only module is sent).

	Payback time for DIY module replacement (in days)	Payback time for module repair (in days)
Battery	16	n/a
Battery cover	11	n/a
Display	92	11
Speaker	11	11

Main camera	27	37
Ultra-wide camera	40	40
Front camera	24	24
USB-C port	11	11
Earpiece	11	n/a

Conclusions

In accordance with previous studies, the production phase is still the core of the environmental impacts of the device. Within the production phase, integrated circuits, and semiconductors in general show to have a significant influence (both in the mainboards but also in the scattered electronics across the modules).

Some new modelling approaches when compared to previous LCAs made for Fairphone B.V. have introduced some changes in the results. Firstly, the use of parametric datasets for the ICs that allow for more granular setting of parameters show a decline for all IC related impacts, particularly in ADPe since now chips with no gold content could be modelled accordingly. Furthermore, the change in the display technology from LCD to OLED required changing the LCI data source used in previous studies. The new data shows an increase in the energy-related impacts for display manufacturing that may not reflect the actual differences in the aforementioned technologies. Lastly, the image and CMOS sensors in the cameras were modelled as double-layered to keep up with industry-wide development in camera technology, which also causes an increase in the impact.

Overall, electricity use is consistently found to be the main driving force behind most identified hotspots across modules. However, switching to renewable energies is also shown to come with trade-offs and that while emissions are clearly reduced from increased use of PV or wind energy, other impacts like resource use and land use change increase.

Regarding repair, the LCA shows the benefits of repair and extended use against premature disposal of the device. Following the trend observed from studies of earlier Fairphone models, additional efforts for single-component replacement do not seem to clearly translate into benefits over replacing the full module, except for the display (which comes with great uncertainty due to data quality).

2 Goal of the study

This report presents the life cycle assessment of the Fairphone 5, a modular smartphone by Fairphone B.V. and related accessories.

This document adheres to principles, requirements and guidance from existing international standards on life cycle assessment (LCA), covering the life cycle stages of the production, transport, use phase and end of life of the product.

The project report and life cycle assessment (LCA) were prepared in conformity with the following standards:

- ISO 14040:2006-07 – Life Cycle Assessment principles and framework
- ISO 14044:2021-02 – General principles and requirements for LCA
- ISO 14067:2019-02 – Requirement and guidelines for carbon footprints of products.

This report gives a detailed analysis on the following impact categories (for a more detailed explanation of the categories and the rationale behind their selection, please refer to Section 5.1).

- Climate change in conformity with ISO 14067
- Abiotic resource depletion, both elements and fossil, CML methodology
- Ecotoxicity, USETox
- Eutrophication, CML
- Land Use Change, LANCA methodology
- (Blue) Water use (as calculated by the Sphera LCA FE software).

The study was carried out without a critical review by an independent party.

The specific goals of this study are:

- Assessing the environmental impacts of the Fairphone 5 and its accessories
- Identifying environmental hotspots and main drivers. Additionally, providing further insights as to how these drivers affect the impacts i.e. which supply chain steps or aspects are most relevant and thus are to be prioritized when engaging with suppliers.
- Analyzing the potential benefits and impacts of the use of recycled materials through scenario analysis.
- Analyzing the effects of employing certified renewable energy in certain production steps (assembly, battery manufacturing).
- Comparing possible product design choices in terms of environmental impacts, as well as different use phase assumptions related to repair.

3 Scope of the study

3.1 Functional Unit

The Life Cycle Assessment is a cradle-to-grave analysis that is, covering all relevant processes from raw material acquisition to the product's end of life. The functional unit for the baseline scenario is *the use of a Fairphone 5 device as sold to consumers for 3 years*.

Additionally, other accessories were also assessed within the study:

- Screen protectors (representative for both privacy filter and blue light filter)
- Soft case
- USB-C to audio jack adapter
- Fairbuds

Further scenarios were analysed as described in the following section.

3.2 Reference Service Life (RSL)

The reference service life – the baseline scenario – for this study is the use of one Fairphone 5 over 3 years. The baseline was set to 3 years for two reasons: on the one hand, the study aims to keep continuity with previous LCAs for earlier Fairphone iterations and on the other hand, it reflects the estimated average lifespan of smartphones nowadays[1].The following scenarios were analyzed:

- 3 years (baseline)
- 5 years (due to: EU Ecodesign Directive lifespan, based on software support), assuming one battery replacement for maintenance.
- 8 years (due to: Fairphone 5 target lifespan, based on Fairphone's minimum software support) assuming two battery replacement for maintenance.
- 10 years (due to: Fairphone's vision, aim for software support for Fairphone 5) assuming three battery replacement for maintenance.

3.3 Scenarios analyzed

In order to observe the effects of certain features and approaches in different areas, a set of scenarios were analyzed in this LCA. This sub-section gives an overview of the different scenarios modelled for further analysis.

3.3.1 Recycled content

This set of scenarios studies the effects of including recycled materials in the device. The scenarios here are the following and cover both the current state of the art as well as a hypothetical use of only primary material.

- Baseline. The Fairphone 5 device as sold to the user, with the secondary material content at launch. The specific list of materials and verifiable amounts were provided by Fairphone B.V.
    - Aluminium 94%
    - Copper 46%
    - Indium 77%
    - Magnesium 82%

[1] See https://www.statista.com/statistics/786876/replacement-cycle-length-of-smartphones-worldwide/ and https://www.statista.com/statistics/619788/average-smartphone-life/

- Nickel 28%
- Plastics 69%
- Rare Earth Elements 24%
- Tin 64%
- Zinc 56%

- Recycled w/o – without recycled materials. As a benchmark to allow comparison, a hypothetical scenario of fully primary materials is modelled to identify and quantify the benefits and/or drawbacks of recycled material.

In order to properly account for the recycled content, the recovery routes for the secondary materials in the device were considered. Most of these were modelled based on literature and in some cases, using generic datasets. A more detailed description of the modelling can be found in Section 4.3.1.

3.3.2 Renewable energy use

Fairphone B.V.'s supplier already uses renewable energy for the device assembly and it is planned that the same will happen for the battery manufacturing. In this scenario, therefore, the potential effect of this change is analysed. A further description of the renewable electricity mix used can be found further down when discussing the final assembly (Section 4.4.1.1.15).

3.3.3 Repair

The modular design of all Fairphone devices is conceived to make repair easier for the users and thus allows increasing the lifespan of devices and/or parts. In order to analyze the potential benefits of the repairs that the design of the Fairphone 5 allows for, the following scenarios were considered.

- Reference scenario – In order to serve as the benchmark, the reference scenario depicts a situation where, during an extended lifetime of 6 years two entire devices are purchased, used and discarded. No repair takes place.
- Scenario 1 – Repair center module replacement scenario. Broken parts of the phone are assumed to be replaced by new ones at Fairphone's repair center in France. Then the phone is sent back to the user.
- Scenario 2 – Module level repair scenario. In this scenario it is assumed that only the broken component is replaced keeping the rest of the module in use. Only transport of the faulty module is considered.
- Scenario 3 – DIY module replacement scenario. Broken parts are assumed to be replaced by new ones by the user who receives the spare part by post.

The modules assumed to fail for the repair scenarios are based on actual module sales data for the Fairphone 4 via the official website and matched with the modules of this device. For scenario 2, the repaired components for each module were assumed by selecting the most representative component of the module. In all cases the transport overhead for the broken modules and the device is based on the same geographical distribution than the main device transport.

The life span for the repair scenarios was calculated based on user surveys performed by Fairphone B.V. reflecting expected lifetime extension by the users.

3.3.4 PCBA update

PCBA update scenarios. The goal of these scenarios is to analyse the potential impacts and benefits of PCBA reusing and refurbishing approaches. Two cases are under study:

- Reference scenario. For the reference scenario it is assumed that over a period of 9 years, three entire devices are purchased.
- PCBA update. In this scenario, over the same 9 years period, three PCBA modules (primary PCBA) are used while keeping the rest of the initial phone in use.

- PCBA refurbishment. In this case, during the 9 years period three phones are purchased but in all three the PCBA is refurbished i.e. it has been recovered and repaired from a previous device.

The 9-year period is a proxy for a long use time, not based on any particular evidence or user case (and accommodates three devices as referenced in the baseline scenario).

For the PCBA update scenario the same environmental impacts for each new PCBA were assumed, since no solid correlation could be found between environmental impacts and increased functionalities.

For the PCBA refurbishment scenario, three main processes were identified as required for refurbishment: testing[2], cleaning and flashing[3]. No inventory data specific to PCBA refurbishment could be found and was therefore extracted from the board assembly data provided by Fairphone's supplier, covering testing (two steps–automated optical inspection and an additional undefined testing-) and cleaning (solvent based).

3.4 Product description

The Fairphone 5 is a modular smartphone with an OLED display, exchangeable battery and dual SIM (one physical and one eSIM). The size of the phone is 6.46'' and it has a weight of 212 g. It contains 8 GB RAM and 256 GB internal storage. The smartphone storage can be extended by a microSD card, which is not part of the covered system boundaries. The Fairphone 5 consists of the following modules:

- Battery
- Display
- Top unit
- Main camera
- Ultra-wide camera
- Front camera
- Back cover
- USB-C port
- Loudspeaker
- Earpiece
- Screws kit
- Primary PCBA
- Secondary PCBA
- Middle Frame

Plus, the packaging.

3.5 System boundaries

This LCA covers a cradle-to-grave study. The modelling thus covers the following phases:

- Production phase, including:
    - Raw material acquisition
    - Production transport
    - Intermediate product manufacturing
    - Device assembly

[2] https://www.wevolver.com/article/test-pcb-everything-you-need-to-know

[3] https://www.techwalla.com/articles/what-happens-to-phones-when-they-are-flashed

- Transport
- Use phase
- End of Life

A more detailed description of the modelling for each life cycle phase can be found in Section 4.

3.6 Geographical coverage

Fairphone B.V. provided a list of suppliers, thus whenever possible, modelling has been adapted to the actual location of the production activities (more information in Section 4.4). For generic datasets it was sometimes possible to pick a geographically representative dataset while in other cases (mainly electronics) the geographical coverage was more general (representing average energy mixes from global manufacturers). A more detailed overview for the background data is provided in Annex.

For the final assembly, photovoltaic energy in China has been used, as the respective supplier works under the Green Energy Certificate (GEC) programme (RE100 Climate Group, 2020).

For the use phase, the energy mix selected has been based on the sales split as provided by Fairphone B.V.

3.7 Reference Year

The foreground system was modelled based on data for the reference year 2023 in which the Fairphone 5 was introduced to the market. The temporal coverage of the background data varies. More insight on that will be given in Section 4.4.

3.8 Criteria for the exclusion of inputs and outputs

In principle the only exclusion criteria considered was the lack of available data: either because no suitable dataset was found in the LCA software or because no external data could be found in order to build one. Otherwise, no quantitative or qualitative criteria has been used to pre-emptively exclude processes.

4 Life cycle inventory

4.1 Data collection and calculation procedures

The data for this LCA has been retrieved from various sources, ranging from primary data provided by Fairphone B.V. (e.g. Bill of Materials, Full Material Declaration) to secondary data from literature (e.g. display manufacturing inventory data, inventory data for secondary material production). Furthermore, ready-made datasets from Sphera and Ecoinvent databases were used. A more detailed description of the data sources on a case-to-case basis can be found in Section 4.4.

4.2 Background data and data quality

For the LCA modeling the software Sphera LCA for Experts was used in combination with the Sphera LCA Database and Ecoinvent 3.9 database.

Whenever possible, background datasets were further adjusted to specific components and processes from the foreground system. All unit processes are documented in the annex table in Section 0.

In the annex table an overview of the data quality can also be found. The table below presents the criteria and grading system used to assess and communicate the data quality.

Table 4-1 – Data Quality Requirements (DQR) criteria followed for the data quality assessment, with explanation of the different quality levels (as recommended by the Environmental Footprint (EF) framework)

Table 5.5.2. How to assess the value of the DQR criteria when secondary datasets are used.

	TiR	*TeR*	*G_R*
1	*The EF report publication date happens within the time validity of the dataset*	*The technology used in the EF study is exactly the same as the one in scope of the dataset*	*The process modelled in the EF study takes place in the country the dataset is valid for*
2	*The EF report publication date happens not later than 2 years beyond the time validity of the dataset*	*The technologies used in the EF study is included in the mix of technologies in scope of the dataset*	*The process modelled in the EF study takes place in the geographical region (e.g. Europe) the dataset is valid for*
3	*The EF report publication date happens not later than 4 years beyond the time validity of the dataset*	*The technologies used in the EF study are only partly included in the scope of the dataset*	*The process modelled in the EF study takes place in one of the geographical regions the dataset is valid for*
4	*The EF report publication date happens not later than 6 years beyond the time validity of the dataset*	*The technologies used in the EF study are similar to those included in the scope of the dataset*	*The process modelled in the EF study takes place in a country that is not included in the geographical region(s) the dataset is valid for, but sufficient similarities are estimated based on expert judgement.*
5	*The EF report publication date happens later than 6 after the time validity of the dataset*	*The technologies used in the EF study are different from those included in the scope of the dataset*	*The process modelled in the EF study takes place in a different country than the one the dataset is valid for*

4.3 Allocations

This product needed no co-product allocations since no co-products are produced. However, allocation for recycling was indeed needed and is presented in the following sub-sections.

4.3.1 Use of secondary materials

In the manufacturing of the Fairphone 5 and the accessories several secondary materials are used. In the baseline scenario, the amount of secondary material was reflected as included in the Fairphone 5 at market introduction.

Aluminum (94% secondary in Fairphone 5 at launch)

Secondary aluminum production was modelled using a generic dataset for remelting of aluminium ingots from scrap. The dataset includes data by European Aluminium from 2015, covering the EU-28 region. Dataset owned by Sphera.

Copper (46% secondary in Fairphone 5 at launch)

Secondary copper production was modelled using Ecoinvent datasets for copper smelting and electrolytic refining from electronics scrap. The geographical coverage of the dataset is RoW (Rest of the World), meaning that the data has been adapted from the original, which covered a different region.

Indium (77% recycled in Fairphone 5 at launch)

Secondary indium production was modelled using inventory data from (Amato, Rocchetti, Fonti, Ruello, & Beolchini, 2015), which describes a process of indium recovery from end-of-life LCDs. The process involves three main steps: washing, leaching and cementation. The inventory data used includes both energy and material inputs. Sorting and transport of the waste LCDs prior to the indium recovery is not included in the scope.

Magnesium (82% recycled in Fairphone 5 at launch)

Magnesium recovery inventory data was extracted from (Ehrenberger, 2013) in which magnesium recovery from vehicle waste is described. The process includes pre-treatment, preparation and secondary magnesium production. The data used in the reference study is based on a real company in Germany.

Nickel (28% recycled in Fairphone 5 at launch)

Due to the lack of better data, nickel was modelled using Ecoinvent datasets for copper smelting and electrolytic refining, following the approach of the extended EoL modelling for the Fairphone 5 itself (see Section 4.4.1.3).

Rare Earths (24% recycled in Fairphone 5 at launch)

Rare Earths include Neodymium, praseodymium and dysprosium. However, due to lack of data available, only neodymium has been considered. Secondary neodymium production is modelled using inventory data extracted from (Wang, Sun, Gao, Chen, & Nie, 2022), in which an LCA was performed for NdFeB magnetic material recovery on a representative recycling company in China. The modelling includes the pre-treatment of the waste magnets, milling and sintering. It includes both energy and material inputs to the process.

Zinc (56% recycled in Fairphone 5 at launch)

The inventory data for secondary zinc production was extracted from (Genderen, Wildnauer, Santero, & Sidi, 2016) in which data for primary zinc production is provided. The paper divides the main processes into two big steps: mining/beneficiation and smelting. It is assumed that the smelting is needed for producing zinc from waste, while mining is left out of scope. Data used in the paper is from 2012 and based on primary data from 18 smelters operating in Africa, Australia, Europe and North America. In our modelling energy input and direct emissions were considered.

Polycarbonate (PC) (69% recycled in Fairphone 5 at launch)

Secondary PC production was modelled using generic datasets, in particular:

- A generic dataset for plastic injection molding as the main processing step, owned by Sphera.
- A dataset for secondary plastic granulate with low metal contamination, owned by Sphera.

Thermal Polyurethane (TPU) – (90% recycled in soft case)

The secondary TPU was modelled using the same approach as for the secondary PC.

Tin (64% recycled in Fairphone 5 at launch)

Although the Fairphone 5 also includes recycled tin no data could be found on secondary tin production and thus it has been excluded from the modelling.

4.3.2 Allocation for reuse, recycling and recovery

In this LCA a 100/0 approach has been used for the allocation of recycling. All activities related to the recovery of the recycled content of the Fairphone 5 from their previous useful life is allocated to this device (further description of the modelling of these processes can be seen in Section 4.3.1 above). In order to avoid double counting, the efforts related to the recovery of materials at the end of life of the Fairphone 5 are thus allocated to its next use. This means that all recycling activities after the pre-treatment of the electronics scrap are out of scope for the baseline scenario. Thus, the baseline EoL scenario includes only transport to recovery site, depollution and shredding.

However, to fully capture these activities and possible results variations due to the choice of allocation procedure, the opposite approach is also analysed as part of the sensitivity analysis (see Section 6).

4.4 Life Cycle Inventory (LCI) analysis

4.4.1 Fairphone 5

4.4.1.1 Production

The manufacturing and raw material acquisition phase was modelled based on the bill-of-materials (BOM) accompanied with material data by the suppliers and a tear-down of the device carried out by Fraunhofer IZM. This is described on module level in section 4.4.1.1.1.

4.4.1.1.1 Intermediary products and components

Extraction of all raw materials is included in the generic datasets used for the modelling, retrieved from the databases of Sphera and Ecoinvent. For most intermediary products (e.g. components and parts), generic datasets have been used as well.

For some intermediary products, where suitable datasets were not found, the modelling has been done using primary data for their material composition and for their manufacturing either primary data or secondary data from literature, depending on availability. The specific approach per component is detailed in the following sub-sections.

4.4.1.1.2 Cross module approaches

Several component types are found in several modules and modelled similar is the LCA.

Printed circuit boards

Printed circuit boards were modelled according to the number of layers and the area. For the main and the secondary PCB, production layouts were available to account for the cut-offs (see Figure 4-1). For the other PCB (display), the smallest rectangular was used to model the production size.

- Main board: 12 layers, 37.3 cm^2
- Secondary PCB: 4 layers, 11.4 cm^2
- Display board: 1 layer, 23 cm^2

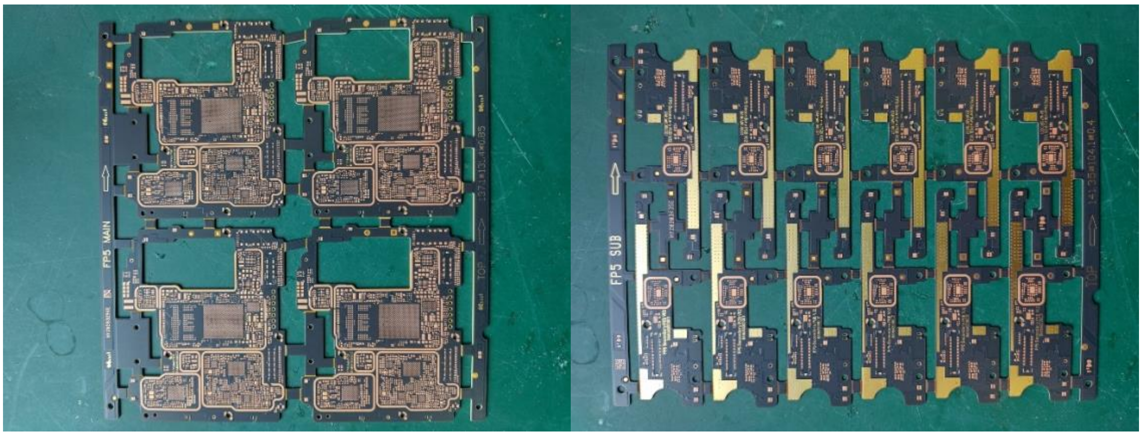

Figure 4-1: Production layouts for main (left) and secondary (right) PCB

Furthermore, flexboards are modelled on the basis of the smallest rectangular area and using a 1-layer flexible board generic dataset by Sphera.

Electronic components

Electronic components like capacitors, resistors, etc. were modelled based on generic data sets scaled by weight, as provided by Fairphone B.V. within the Full Material Declaration.

The environmental impact of integrated circuits was determined by the processed die area within the package. The die size of the majority of ICs was identified by a third party and provided by Fairphone B.V. For the modelling of ICs in the baseline scenario, a parametric dataset by Sphera has been used where several key parameters can be adjusted individually, including (but not limited to):

- Type of die (e.g. DRAM, CMOS, MPU…).
- Technology node.
- Packaging mass.
- Gold mass (in contacts).
- Substrate area.

For each IC the relevant data was extracted from both the BoM and the FMD. All non-memory and non-processor chips were assumed as CMOS.

For the small ICs, the die size was not determined and, in many cases further data was not available (e.g. material composition). For these, the modelling was done using generic datasets chosen based on IC type and packaging format. The die size is therefore assumed within the dataset itself.

Connectors

Connectors were modelled based on their material composition adding electricity and water use extracted from the inventory of Ecoinvent datasets[4] and rescaled by mass. Energy mix is selected based on the production location in China.

4.4.1.1.3 Battery

The Fairphone 5 contains a removable and rechargeable lithium-ion battery with the following specifications:

- Weight: 68.3 g
- Capacity: 4200 mAh

The modelling has been done using material data provided by Fairphone B.V. within the FMD and primary data from the supplier for the energy required for manufacturing. Energy mix has been chosen considering the manufacturing location in China.

4.4.1.1.4 Display

The Fairphone 5 has a 6.4-inch OLED display.

The OLED display was modelled according to the material composition as described in the FMD provided by Fairphone B.V. Furthermore, the energy consumption for manufacturing of an OLED display was based on (Amasawa, Ihara, Ohta, & Hanaki, 2016) on the production of a 5 inch OLED smartphone display. The energy consumption was scaled by display size and, since manufacturing takes place in China, electricity use is modelled based on the Chinese grid mix.

The display PCBA is modelled according to the BOM.

4.4.1.1.5 Top unit

The top unit includes mainly housing elements and a flex cable with the SIM connector. The main modelling approaches and assumptions used were:

- Housing elements have been modelled based on material composition, including a generic dataset for plastic injection molding to account for the manufacturing on the part.
- The flex cable has been modelled as a one-layer flexible PCB, scaled based on area.
- The connectors have been modelled on a material basis, following the FMD provided by Fairphone B.V.

4.4.1.1.6 Cameras

The Fairphone 5 contains three cameras as individual modules:

- Main camera
- Ultra-wide camera
- Front camera

The cameras were modelled similarly:

- Injection-molded polyethylene housing, using generic datasets for both the material and the manufacturing process.
- Flex boards plus electronic components according to the BOM, using generic datasets.

[4] https://ecoquery.ecoinvent.org/3.10/cutoff/dataset/8825/documentation

- In order to represent state of the art[5] double layered image sensing dies, which combine CMOS and logic (YOLE Intelligence, 2023), the sensor and logic die are both modelled assuming their size equal to the area of the sensor i.e. two times the area measured on the component. Modelled using a parametric dataset, housing removed.
- Additional parts are modelled according to their material composition as detailed in the FMD.

4.4.1.1.7 Back cover

The back cover weighs 13 g and is modelled as injection-molded polycarbonate plus conductive film (based on material composition).

4.4.1.1.8 USB-C port

The USB-C connector weighs 0.7 g and is modelled according to the material composition plus a one-layer flexible PCB.

4.4.1.1.9 Loudspeaker

The loudspeaker consists of the bottom speaker box (3.8 g) and the vibration motor (1.1 g) and is modelled according to the material composition plus a one layered flexible printed circuit board.

4.4.1.1.10 Earpiece

The earpiece weighs 0.9 g and is modelled according to the material composition.

4.4.1.1.11 Primary PCBA

The primary PCBA is comprised by the main Printed Circuit Board and most of the device’s electronics including mainly ICs, other semiconductors, passives and shielding. The approach followed for the PCB, the semiconductors and passive components can be found summarized in Section 4.4.1.1.2. As for the shielding, the modelling was performed following the material composition as detailed by the FMD provided by Fairphone B.V.

4.4.1.1.12 Secondary PCBA

The secondary PCBA has been modelled following the same approach as with the primary PCBA.

4.4.1.1.13 Middle Frame

The middle frame weighs 45 g and is modelled according to the material composition. This includes the mid frame as such as well as several mechanical elements like nuts, button seals etc.

4.4.1.1.14 Packaging

Packaging has been modelled following primary data provided by Fairphone B.V. The packaging modelling includes:

- Phone box.
- Carton (for 20 pcs).
- Pallet (for 1200 pcs).
- Boxes modules.

All items were scaled by weight and the respective share allocated to a single piece.

[5] https://www.makeuseof.com/what-is-stacked-camera-sensor-how-does-it-work/

4.4.1.1.15 Final assembly

Final assembly was modelled based on primary data from Fairphone B.V. and includes electricity use of 2.46 kWh for the SMT process, display module glue dispensing, final assembly and testing, packing and nano coating. Additionally, the use of nitrogen gas (0.7 kg) and cleaning agents (0.6 g) and cloth (0.3 g) was also considered.

4.4.1.2 Transport and use phase

Two tiers of transport are considered. Tier 1 refers to transport from the final assembly to Europe whereas transport during the manufacturing phase, meaning transport from suppliers to final assembly, is referred to as tier 2 transport. Distances are calculated based on supplier lists. Transported weights are based on component weight plus a packaging overhead of 10% of components above 1 g and 90% below 1 g.

These transports result in the following (all per Fairphone 5 unit):

- 1388,54 kgkm per air freight, representing 30% of the tier 1 transport
- 299,65 kgkm per road transport, representing 100% of the tier 2 transport
- 3255,81 kgkm per sea transport, representing 70% of the tier 1 transport

The baseline scenario for the Fairphone 5's use phase was based on the following pattern:

- 3 years of use
- One full charging cycle every 1.5 days has been set as the usage intensity, following Fairphone B.V. internal sources.
- One charging cycle consumes 27 Wh on average, resulting in 6.57 kWh/a.

The energy per charging cycle was based on measurements provided by Fairphone B.V. The energy mix assumed as a mix of different country mixes and was based on the sales forecast for the Fairphone 5.

Additionally, three further scenarios were modelled:

- 5 years of use, 1 replacement battery
- 8 years of use, 2 replacement batteries
- 10 years of use, 3 replacement batteries

For the number of replacement batteries information from ageing tests performed in a previous Fairphone LCA study was used. Here, two out of three batteries used in the Fairphone 3 survived 1000 charging cycles with a remaining capacity at 80% of the original capacity. All three out of three managed at least 850 cycles at 80% or above (Proske, Sánchez, Clemm & Baur, 2020). It was therefore assumed that the average user would exchange the battery every three years.

For the replacement batteries transport and packaging were also modelled. No additional inputs were needed in the use phase.

4.4.1.3 End of Life

The End of Life modelling follows mostly the modelling performed for previous iterations of the Fairphone LCAs (Proske, Sanchez, Clemm, & Baur, 2020). Although figures for collection rates are uncertain and vary depending on the source, ranging from rather low (~33%)[6] to higher values up to ~54%[7]. Recycling rates for the collected fraction are nonetheless reportedly high[8]. However, more specifically for mobile phones and smartphones, it seems that, according to (Buchert, Manhart, Bleher, & Pingel, 2012), *mobile phones are normally fed into pyro-metallurgical plants such as e.g. a Umicore facility in Belgium*. Furthermore, the same report states that it can be assumed that most of the non-collected mobile phones are likely stored by the users and thus a late end-of-life treatment can be expected.

The same assumptions for End of Life transport were applied as they were in previous Fairphone model LCAs. Likewise, the plastic fraction of the device is assumed to be small enough to burn in the smelting process alongside the rest of the device.

The following steps were considered for the EoL:

- EoL transport: mix of train and truck transport, assumed distance of 1,500 km.
- Depollution: the removal of the battery is assumed to be manual and thus has no additional impacts associated with it.
- Battery recycling: Battery recycling has two steps i.e. battery sorting and treatment. Battery sorting is automatized and uses diesel, water and electricity. Battery treatment represents a mix of pyrometallurgical and hydrometallurgical processes.
- Shredding: considered as a pre-treatment for the depollutsed smartphone.
- Metal recovery: consisting of three main steps i.e. copper smelting, electrolytic refining and precious metals recovery.

All process steps have been modelled using generic Ecoinvent datasets. As outlined earlier (see Section 4.3.2), the baseline scenario covers only process up to (and including) shredding in order to avoid double counting with the recycled content in the device. However, as part of the sensitivity analysis, an alternative allocation approach is analyzed where the EoL phase covers all of the aforementioned steps.

4.4.2 Accessories

For all accessories the entire life cycle was considered. For the screen protector, soft case and cable adapter no use phase is included since no direct impacts have been identified during this phase. The following sub-sections give further detail on the main modelling assumptions.

4.4.2.1 Fairphone 5 screen protector

Although Fairphone B.V. offers two different screen protectors (privacy filter and blue light filter), these two are practically identical in terms of material composition and were thus modelled as a single, generic screen protector.

The product consists of:

- Packaging (cardboard, paper)
- Wet wipe

[6] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_statistics_-_electrical_and_electronic_equipment&oldid=556612#Electrical_and_electronic_equipment_.28EEE.29_put_on_the_market_and_WEEE_processed_in_the_EU (Figure 1)

[7] https://www.scycle.info/new-study-update-of-weee-collection-rates-targets-flows-and-hoarding/

[8] https://www.interregeurope.eu/find-policy-solutions/webinar/collection-and-recycling-of-weee-key-learnings

- Cloth to dedust
- Transparent plastics
- Screen protector.

All parts have been modelled using generic datasets by Sphera. The transparent plastics have been modelled as Low-Density PE and the protector as such as flat glass. The weight per part is based on primary data provided by Fairphone B.V.

The manufacturer is located in China from where the transport happens in two stages: Direct transport from manufacturer to stock and from stock to users. The main transport assumptions were thus kept from the Fairphone 5 model (see Section 4.4.1.2 for more details).

The EoL is modelled considering the same EoL assumptions for the transport to disposal site as for the Fairphone 5 (see Section 4.4.1.3). Beyond transport, plastic incineration is considered as the main process, assuming the protector ends up in the household waste. A generic dataset by Sphera has been used.

4.4.2.2 Fairphone 5 soft case

The soft case is a protective case for the Fairphone 5 composed by two main parts: the soft shell and the hard buttons. Both are made of TPU, 100% recycled in the case of the soft shell and 90% recycled in the case of the buttons. For more details on the modelling approach for secondary TPU, please refer to Section 4.3.1.

For the transport and EoL, the same assumptions as in the screen protector were applied.

4.4.2.3 USB-C to audio jack adapter

The data of the USB-C to audio jack cable adapter stems from several sources. The cable part of the adapter has been modelled based on data provided by Fairphone B.V. for the assessment of the charger cable analysed as part of the Fairphone 4 LCA (Sánchez, Proske, & Baur, 2022) and its manufacturing has been modelled using a generic Sphera dataset. The audio jack connector modelling is based on primary material data provided by Fairphone for the Fairphone 3 LCA (Proske, Sanchez, Clemm, & Baur, 2020). Finally, the USB-C connector is modelled based on the material data of the Fairphone 5 USB-C port.

Transport was modelled using the same assumptions as used in the soft case and screen protector (see sub-sections above).

Since the cable is electronics waste, the EoL was modelled like for the Fairphone 5. Same transport assumptions apply and, as EoL process, shredding is considered.

4.4.2.4 Fairbuds

The Fairbuds are true wireless stereo earbuds and have been modelled based on primary data provided by Fairphone B.V. The full Bill of Materials and the Full Material Declaration was made available and has been the main source for the modelling of the production phase. All the cross-module approaches presented in Section 4.4.1.1.2 above applied in this model as well, with the following exceptions:

- Integrated Circuits were modelled using generic, non-parametric datasets owned by Sphera, since the die size information was not known. The modelling was then made based on the IC type and the package type and size, using the package size as a proxy scaling parameter.
- The batteries were modelled based on the material composition provided by Fairphone B.V. The manufacturing energy was taken from the Fairphone 5 battery model and re-scaled based on the weight of the Fairbuds' batteries. The electronics within the battery enclosure have been modelled based on the information contained in the FMD, rescaled by mass and using generic datasets from the Sphera Electronics Extension.

The Fairbuds also contain recycled content. More specifically 30% of its magnets' weight and 97% of its plastics weight, mainly used in the charging case (entirety of its housing, battery frame and some other mechanical elements) and the R and L earbuds (full housing and some mechanical elements). Recycled content has been modelled following the same principles outlined in Section 4.3.1. The recycled magnets production has been modelled using the same source as for the secondary neodymium, as it feeds from EoL magnets.

Transport has been modelled based on primary data on suppliers and logistics provided by Fairphone B.V.

The main assumptions for the use phase have been taken from the Fairphone 4 LCA (Sánchez, Proske, & Baur, 2022), where the previous true wireless earbuds iteration was modelled. Considering the identical capacity of the Fairbuds' main battery and the lack of usage data, the assumptions were still deemed reasonable. They can be summarized as follows:

- Since the charging case is used for charging the earbuds, only the case was taken into account for the energy use estimation.
- The new battery, like the previous one, has a 500 mAh capacity (for 3,7V), meaning 1,85 Wh of energy per full charge.
- Considering a typical playtime of 20h per full charge of the charging case's battery, one charging cycle every 3 days was assumed. Thus, the yearly charging cycles amount to 122 and the total energy expenditure to 265 Wh per year.
- A lifespan of 3 years has been assumed, in line with Fairbuds' extended manufacturer warranty and the baseline scenario of the Fairphone 5.

The EoL was modelled following the Fairphone 5 approach thus including: EoL transport, depollution and shredding. Please refer to Section 4.4.1.3 for a more detailed description of the Fairphone 5 EoL main modelling assumptions). Furthermore, the plastic in the device is assumed to go to the smelter mixed with the metal fraction due to its small size and being likely shredded as a whole (after depollution).

Finally, the Fairbuds analysis also includes repair scenarios. In this case, no general repair scenarios have been added and instead the focus is on the module to module basis. Furthermore, when compared with the modelling of the repair for the Fairphone 5, only the module-level repair and DIY replacement scenarios have been considered, under the assumption that due to the simplicity of the product, module replacement in the repair center shall not be necessary. In this regard, the modules and spare parts considered are the following:

- Charging case battery
- Charging case core
- Charging case outer shell
- Earbuds battery kit
- Eartips replacement
- Right and left earbdus
- Silicon rings

5 Life Cycle Impact Assessment (LCIA)

In this section the results of the Life Cycle Impact Assessment will be presented in a tabular form for all impact categories under analysis. The hot spot analysis and interpretation of the results is outlined and explained in the next chapter, Section 6.

5.1 Definition of impact categories

This LCA calculates environmental impacts in the following impact categories, for which then the results are given and interpreted in the following sections.

- Global Warming (GW): “Global warming is considered as a global effect. Global warming - or the “greenhouse effect” - is the effect of increasing temperature in the lower atmosphere. The lower atmosphere is normally heated by incoming radiation from the outer atmosphere (from the sun). A part of the radiation is normally reflected from the surface of the earth (land or oceans). The content of carbon dioxide (CO2) and other “greenhouse” gasses (e.g. methane (CH4), nitrogen dioxide (NO2), chlorofluorocarbons etc.) in the atmosphere reflect the infrared (IR)-radiation, resulting in the greenhouse effect i.e. an increase of temperature in the lower atmosphere to a level above normal. […] The GWP for greenhouse gases is expressed as CO2-equivalents, i.e. the effects are expressed relatively to the effect of CO2.” (Stranddorf, Hoffman, & Schmidt, 2005).
- Resource depletion: “The model of abiotic resource depletion […] is a function of the annual extraction rate and geological reserve of a resource. In the model as presently defined, the ultimate reserve is considered the best estimate of the ultimately extractable reserve and also the most stable parameter for the reserve parameter. However, data for this parameter will by definition never be available. As a proxy, we suggest the ultimate reserve (crustal content).” (van Oers & Guinée, The Abiotic Depletion Potential: Background, Updates and Future, 2016)
    - Abiotic resource depletion (ADP) elements: “The impact category for elements is a heterogeneous group, consisting of elements and compounds with a variety of functions (all functions being considered of equal importance).” Although ADPe measures generally mineral and metal depletion, it does so by weighting the different minerals on the basis of their relative scarcity (i.e. both considering the extraction rate and the known reserves). According to the latest update of the ADPe model (van Oers, Guinée, & Heijungs, 2020), currently the main contributors to the indicator are gold, copper and silver. Therefore, ADPe tends to be heavily influenced by these, particularly gold. The indicator is expressed in kg Sb equivalents, since antimony was selected as the reference material.
    - ADP fossil: “The resources in the impact category of fossil fuels are fuels like oil, natural gas, and coal, which are all energy carriers and assumed to be mutually substitutable. As a consequence, the stock of the fossil fuels is formed by the total amount of fossil fuels, expressed in Megajoules (MJ).” Although originally part of the generic ADP impact, in 2009 it was created as a separate indicator and uncoupled from antimony as reference. Instead, the indicator is now expressed as MJ which refers to the energy capacity of all fossil resources used, regardless of the origin. Please not that, in its current state, the indicator does not consider uranium as a fossil energy carrier, even though that is its current main use.
- Ecotoxicity: “The impact category ecotoxicity covers the possible effects of toxic substances released during the life cycle of a product to the environment.” (Stranddorf, Hoffman, & Schmidt, 2005). Impact potentials are expressed in comparative toxic units (CTUe), which provides an estimate of the potentially affected fraction of species (PAF) integrated over time and volume per

unit mass of a chemical emitted.[9] In its current version of the methodology, USETox has only yet implemented freshwater ecotoxicity (Bijster, et al., 2018).

- Eutrophication: Eutrophication covers all impacts of excessively high environmental levels of macronutrients in water bodies or soil, where the most relevant are nitrogen (N) and phosphorus (P). This high presence of nutrients has several effects e.g. increased growth of algae (Payen & Ledgard, 2017). As such, the methodology chosen (Heijungs, et al., 1992) uses kg phosphate equivalents to express the impact. The indicator used in this study combines both aquatic and terrestrial eutrophication.
- Land Use Change: This impact as modelled via the LANCA methodology (Bos, Horn, Beck, Lindner, & Fischer, 2016) is defined by the effects on land quality of the occupation and/or transformation of land. The land quality is estimated through several sub-impact categories i.e. erosion, infiltration reduction, physicochemical filtration reduction, groundwater regeneration reduction and biotic (biomass) production loss. Various factors influence these impacts mainly: site specific conditions (geography), time of land use, used land area and land use types e.g. industrial real estate, permanent crops, road network etc. For this LCA however, in order to simplify its readability, we present an aggregated indicator for the LANCA impact categories developed by JRC (Castellani, et al., 2018), which is expressed as a dimensionless soil quality index, the higher the value the higher the impact.
- Water use: Water use is calculated directly by Sphera LCA FE. Both water use and water consumption[10] are calculated in this LCA. Water use represents the *total amount of water withdrawn from its source*. Water consumption, in contrast, accounts only for the fraction of said water that *is not returned to the original water source*. Both water use and water consumption are presented in terms of volume, m^3.

These indicators have been chosen in order to be translatable to the Science Based Target Network methodology [11] for company environmental footprint calculations. Moreover, and in contrast with the previous LCAs of Fairphone products, biodiversity was also being targeted in the analysis. Although no unified indicator currently exists, following (Winter, Lehmann, Finogenova, & Finkbeiner, 2017), it is understood that several of the chosen categories (eutrophication, land use change, water use, ecotoxicity) partially reflect impacts on species and ecosystems.

5.2 Life Cycle Impact Assessment results for Fairphone 5 and accessories

In this section the numerical values for the LCIA results of the baseline scenario are presented for production, transport, use and EoL. Furthermore, more detailed results for the main contributing modules are also presented. The full tables with all scenarios and modules can be found in the annex in Section 0.

Table 5-1 - LCIA results for the entire life cycle of the Fairphone 5 (baseline scenario, 3 years of use)

	Total	Production	Transport	Use phase	EoL

9 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9889776/#:~:text=For%20ecotoxicity%2C%20impact%20potentials%20are,mass%20of%20a%20chemical%20emitted.

10 https://www.wri.org/insights/whats-difference-between-water-use-and-water-consumption

11 https://sciencebasedtargetsnetwork.org/how-it-works/the-first-science-based-targets-for-nature/

Abiotic Resource Depletion, elements (kg Sb eq.)	1,25E-03	1,25E-03	5,74E-07	1,48E-06	1,47E-07
Abiotic Resource Depletion, fossil (MJ)	4,99E+02	3,85E+02	4,00E+01	7,39E+01	6,10E-01
Eutrophication (kg Phosphate eq.)	1,64E-02	1,19E-02	2,68E-03	1,81E-03	6,82E-05
Global Warming, 100 years (kg CO2 eq.)	4,21E+01	3,27E+01	2,81E+00	6,59E+00	4,11E-02
Air craft emissions (kg CO2 eq.)	2,10E-01	2,10E-01	0,00E+00	8,74E-06	1,04E-09
Biogenic GHG emissions (kg CO2 eq.)	4,23E+00	2,14E+00	3,40E-03	2,09E+00	5,71E-04
Biogenic GHG removal (kg CO2 eq.)	-4,13E+00	-2,10E+00	-2,84E-03	-2,02E+00	-5,77E-04
Emissions from land use change (dLUC) (kg CO2 eq.)	1,49E-02	1,39E-02	2,09E-04	7,88E-04	1,54E-05
Fossil GHG emissions (kg CO2 eq.)	4,18E+01	3,24E+01	2,81E+00	6,52E+00	4,11E-02
Land Use Change (-)	1,57E+02	9,88E+01	5,31E+00	5,25E+01	1,41E-01
Ecotoxicity (CTUe)	1,15E-01	8,96E-02	6,80E-03	1,75E-02	7,45E-04
Blue water consumption (kg)	3,19E+02	2,23E+02	4,62E+00	5,32E+01	3,84E+01
Blue water use (kg)	9,29E+04	4,38E+04	7,60E+02	4,83E+04	9,91E+01

Table 5-2 - LCIA results for the Fairphone 5 production, split per module, final assembly and packaging

	Total	Assembly	Battery	Back cover	Ultra wide camera
Abiotic Resource Depletion, elements (kg Sb eq.)	1,25E-03	8,30E-06	1,01E-05	3,07E-08	2,04E-05
Abiotic Resource Depletion, fossil (MJ)	3,85E+02	3,49E+00	6,44E+00	4,30E-01	3,59E+01
Eutrophication (kg Phosphate eq.)	1,19E-02	5,25E-04	4,73E-04	8,81E-06	8,84E-04
Global Warming, 100 years (kg CO2 eq.)	3,27E+01	2,82E-01	5,25E-01	2,92E-02	2,84E+00
Air craft emissions (kg CO2 eq.)	2,10E-01	2,34E-08	2,31E-04	1,38E-08	3,49E-03
Biogenic GHG emissions (kg CO2 eq.)	2,14E+00	1,10E-02	2,55E-02	2,78E-03	2,08E-01
Biogenic GHG removal (kg CO2 eq.)	-2,10E+00	-1,12E-02	-2,51E-02	-2,65E-03	-2,07E-01

Emissions from land use change (dLUC) (kg CO2 eq.)	1,39E-02	5,90E-04	3,97E-04	9,89E-06	4,80E-04
Fossil GHG emissions (kg CO2 eq.)	3,24E+01	2,82E-01	5,24E-01	2,91E-02	2,84E+00
Land Use Change (-)	9,88E+01	2,95E+01	1,31E+00	7,86E-02	6,07E+00
Ecotoxicity (CTUe)	8,96E-02	1,32E-02	6,29E-03	7,28E-05	2,96E-03
Blue water consumption (kg)	2,23E+02	7,49E+00	3,87E+00	1,93E-01	1,52E+01
Blue water use (kg)	4,38E+04	3,22E+03	9,37E+02	3,71E+01	3,55E+03
	Display	Earpiece	Front camera	Main camera	Primary PCBA
Abiotic Resource Depletion, elements (kg Sb eq.)	4,40E-05	1,71E-06	4,49E-05	4,46E-05	9,01E-04
Abiotic Resource Depletion, fossil (MJ)	7,62E+01	5,22E-02	1,69E+01	1,99E+01	2,15E+02
Eutrophication (kg Phosphate eq.)	3,12E-03	3,52E-06	4,23E-04	4,96E-04	5,48E-03
Global Warming, 100 years (kg CO2 eq.)	7,41E+00	3,99E-03	1,34E+00	1,57E+00	1,78E+01
Air craft emissions (kg CO2 eq.)	1,93E-06	3,37E-10	3,42E-03	3,45E-03	1,92E-01
Biogenic GHG emissions (kg CO2 eq.)	2,75E-01	1,76E-04	9,95E-02	1,17E-01	1,34E+00
Biogenic GHG removal (kg CO2 eq.)	-2,69E-01	-1,77E-04	-9,86E-02	-1,15E-01	-1,32E+00
Emissions from land use change (dLUC) (kg CO2 eq.)	5,27E-03	6,70E-06	2,40E-04	2,83E-04	6,06E-03
Fossil GHG emissions (kg CO2 eq.)	7,40E+00	3,99E-03	1,33E+00	1,57E+00	1,76E+01
Land Use Change (-)	1,12E+01	2,06E-02	2,87E+00	3,37E+00	4,21E+01
Ecotoxicity (CTUe)	4,47E-02	9,62E-05	1,32E-03	1,60E-03	1,67E-02
Blue water consumption (kg)	5,65E+01	6,72E-02	7,91E+00	9,11E+00	1,14E+02
Blue water use (kg)	8,72E+03	5,38E+01	1,61E+03	1,92E+03	2,16E+04
	Middle frame	Secondary PCBA	Loudspeaker	Top unit	USB-C port
Abiotic Resource Depletion, elements (kg Sb eq.)	2,04E-05	4,72E-05	4,92E-06	1,21E-05	9,19E-05
Abiotic Resource Depletion, fossil (MJ)	1,42E+00	6,50E+00	3,61E-01	1,29E+00	6,67E-01

Eutrophication (kg Phosphate eq.)	3,90E-05	1,97E-04	1,14E-04	5,46E-05	4,34E-05
Global Warming, 100 years (kg CO2 eq.)	1,05E-01	5,37E-01	2,89E-02	1,14E-01	5,56E-02
Air craft emissions (kg CO2 eq.)	5,40E-08	7,18E-03	3,75E-09	3,57E-08	1,34E-08
Biogenic GHG emissions (kg CO2 eq.)	6,29E-03	3,87E-02	1,18E-03	7,30E-03	6,55E-03
Biogenic GHG removal (kg CO2 eq.)	-6,05E-03	-3,75E-02	-1,14E-03	-6,46E-03	-6,24E-03
Emissions from land use change (dLUC) (kg CO2 eq.)	6,50E-05	3,08E-04	6,40E-05	8,89E-05	6,33E-05
Fossil GHG emissions (kg CO2 eq.)	1,04E-01	5,28E-01	2,88E-02	1,13E-01	5,52E-02
Land Use Change (-)	3,54E-01	1,20E+00	2,27E-01	2,79E-01	1,70E-01
Ecotoxicity (CTUe)	4,78E-04	5,60E-04	8,28E-04	5,15E-04	2,64E-04
Blue water consumption (kg)	1,22E+00	4,03E+00	3,90E-01	1,02E+00	2,50E+00
Blue water use (kg)	6,71E+02	6,37E+02	3,90E+02	3,38E+02	1,24E+02
	Packaging				
Abiotic Resource Depletion, elements (kg Sb eq.)	4,95E-08				
Abiotic Resource Depletion, fossil (MJ)	1,26E+00				
Eutrophication (kg Phosphate eq.)	9,56E-05				
Global Warming, 100 years (kg CO2 eq.)	7,42E-02				
Air craft emissions (kg CO2 eq.)	1,94E-08				
Biogenic GHG emissions (kg CO2 eq.)	9,02E-03				
Biogenic GHG removal (kg CO2 eq.)	-2,24E-02				
Emissions from land use change (dLUC) (kg CO2 eq.)	7,15E-04				
Fossil GHG emissions (kg CO2 eq.)	8,69E-02				
Land Use Change (-)	1,49E+00				

Ecotoxicity (CTUe)	1,38E-03
Blue water consumption (kg)	1,00E+00
Blue water use (kg)	8,78E+01

Table 5-3 - LCIA results for the primary PCBA of the Fairphone 5, per component group

	Total	Connectors	Integrated Circuits	Other semiconductors	Passive components
Abiotic Resource Depletion, elements (kg Sb eq.)	9,01E-04	5,35E-05	7,26E-04	6,33E-06	4,78E-06
Abiotic Resource Depletion, fossil (MJ)	2,15E+02	3,69E-01	1,97E+02	3,23E-01	8,68E-01
Eutrophication (kg Phosphate eq.)	5,48E-03	2,25E-05	4,83E-03	1,00E-05	3,45E-05
Global Warming, 100 years (kg CO2 eq.)	1,78E+01	3,13E-02	1,62E+01	2,85E-02	6,93E-02
Air craft emissions (kg CO2 eq.)	1,92E-01	7,40E-09	1,92E-01	5,95E-09	1,02E-08
Biogenic GHG emissions (kg CO2 eq.)	1,34E+00	3,65E-03	1,23E+00	1,67E-03	1,78E-03
Biogenic GHG removal (kg CO2 eq.)	-1,32E+00	-3,53E-03	-1,22E+00	-1,65E-03	-1,68E-03
Emissions from land use change (dLUC) (kg CO2 eq.)	6,06E-03	3,91E-05	3,73E-03	1,22E-05	1,25E-05
Fossil GHG emissions (kg CO2 eq.)	1,76E+01	3,11E-02	1,60E+01	2,85E-02	6,92E-02
Land Use Change (-)	4,21E+01	1,09E-01	3,77E+01	4,68E-02	6,43E-02
Ecotoxicity (CTUe)	1,67E-02	7,52E-05	1,51E-02	1,69E-05	3,16E-05
Blue water consumption (kg)	1,14E+02	1,42E+00	1,00E+02	3,02E-01	4,04E-01
Blue water use (kg)	2,16E+04	2,59E+01	2,00E+04	2,98E+01	1,23E+02
	Printed Circuit Board	Rest			
Abiotic Resource Depletion, elements (kg Sb eq.)	1,01E-04	1,02E-05			
Abiotic Resource Depletion, fossil (MJ)	1,61E+01	4,71E-01			

Eutrophication (kg Phosphate eq.)	5,60E-04	2,87E-05
Global Warming, 100 years (kg CO2 eq.)	1,47E+00	4,39E-02
Air craft emissions (kg CO2 eq.)	5,16E-07	6,71E-09
Biogenic GHG emissions (kg CO2 eq.)	9,76E-02	2,44E-03
Biogenic GHG removal (kg CO2 eq.)	-8,97E-02	-2,42E-03
Emissions from land use change (dLUC) (kg CO2 eq.)	2,21E-03	5,47E-05
Fossil GHG emissions (kg CO2 eq.)	1,46E+00	4,38E-02
Land Use Change (-)	3,96E+00	2,14E-01
Ecotoxicity (CTUe)	1,29E-03	2,72E-04
Blue water consumption (kg)	1,08E+01	5,83E-01
Blue water use (kg)	1,31E+03	7,87E+01

Table 5-4 - LCIA results for the secondary PCBA of the Fairphone 5, per component group

	Total	Connectors	Integrated Circuits	Other semiconductors	Passive components
Abiotic Resource Depletion, elements (kg Sb eq.)	4,72E-05	3,29E-05	9,67E-07	0,00E+00	2,02E-06
Abiotic Resource Depletion, fossil (MJ)	6,50E+00	2,18E-01	3,92E+00	0,00E+00	4,65E-01
Eutrophication (kg Phosphate eq.)	1,97E-04	1,42E-05	9,73E-05	0,00E+00	2,20E-05
Global Warming, 100 years (kg CO2 eq.)	5,37E-01	1,82E-02	3,09E-01	0,00E+00	3,78E-02
Air craft emissions (kg CO2 eq.)	7,18E-03	4,22E-09	7,18E-03	0,00E+00	2,88E-09
Biogenic GHG emissions (kg CO2 eq.)	3,87E-02	2,21E-03	2,52E-02	0,00E+00	3,25E-04
Biogenic GHG removal (kg CO2 eq.)	-3,75E-02	-2,13E-03	-2,49E-02	0,00E+00	-2,99E-04

Emissions from land use change (dLUC) (kg CO2 eq.)	3,08E-04	2,24E-05	5,28E-05	0,00E+00	3,98E-06
Fossil GHG emissions (kg CO2 eq.)	5,28E-01	1,81E-02	3,01E-01	0,00E+00	3,78E-02
Land Use Change (-)	1,20E+00	6,08E-02	7,03E-01	0,00E+00	1,20E-02
Ecotoxicity (CTUe)	5,60E-04	7,08E-05	3,46E-04	0,00E+00	6,10E-06
Blue water consumption (kg)	4,03E+00	8,76E-01	1,51E+00	0,00E+00	2,45E-01
Blue water use (kg)	6,37E+02	2,98E+01	3,72E+02	0,00E+00	7,74E+01
	Printed Circuit Board	Rest			
Abiotic Resource Depletion, elements (kg Sb eq.)	1,08E-05	4,21E-07			
Abiotic Resource Depletion, fossil (MJ)	1,81E+00	8,67E-02			
Eutrophication (kg Phosphate eq.)	6,11E-05	2,31E-06			
Global Warming, 100 years (kg CO2 eq.)	1,64E-01	7,36E-03			
Air craft emissions (kg CO2 eq.)	5,46E-08	3,12E-09			
Biogenic GHG emissions (kg CO2 eq.)	1,00E-02	8,69E-04			
Biogenic GHG removal (kg CO2 eq.)	-9,31E-03	-8,44E-04			
Emissions from land use change (dLUC) (kg CO2 eq.)	2,24E-04	4,04E-06			
Fossil GHG emissions (kg CO2 eq.)	1,63E-01	7,33E-03			
Land Use Change (LUC)	3,89E-01	3,38E-02			
Ecotoxicity (CTUe)	1,28E-04	8,61E-06			
Blue water consumption (kg)	1,32E+00	6,78E-02			
Blue water use (kg)	1,40E+02	1,70E+01			

Table 5-5 - LCIA results for the ultra-wide camera module of the Fairphone 5, per part

	Total	Ultra-wide camera component	Housing	Flex cable
Abiotic Resource Depletion, elements (kg Sb eq.)	2,04E-05	1,93E-05	1,18E-15	1,04E-06
Abiotic Resource Depletion, fossil (MJ)	3,59E+01	3,59E+01	8,64E-07	8,72E-02
Eutrophication (kg Phosphate eq.)	8,84E-04	8,80E-04	3,21E-11	3,51E-06
Global Warming, 100 years (kg CO2 eq.)	2,84E+00	2,83E+00	2,93E-08	8,16E-03
Air craft emissions (kg CO2 eq.)	3,49E-03	3,49E-03	2,79E-15	2,70E-09
Biogenic GHG emissions (kg CO2 eq.)	2,08E-01	2,08E-01	1,36E-09	5,41E-04
Biogenic GHG removal (kg CO2 eq.)	-2,07E-01	-2,06E-01	-1,37E-09	-4,72E-04
Emissions from land use change (dLUC) (kg CO2 eq.)	4,80E-04	4,74E-04	6,31E-12	6,29E-06
Fossil GHG emissions (kg CO2 eq.)	2,84E+00	2,83E+00	2,93E-08	8,09E-03
Land Use Change (-)	6,07E+00	6,05E+00	2,22E-08	2,00E-02
Ecotoxicity (CTUe)	2,96E-03	2,95E-03	1,60E-09	6,43E-06
Blue water consumption (kg)	1,52E+01	1,51E+01	6,44E-07	7,79E-02
Blue water use (kg)	3,55E+03	3,54E+03	8,20E-06	7,13E+00

Table 5-6 - LCIA results for the main camera module of the Fairphone 5, per part

	Total	Main camera component	Housing	Flexcable
Abiotic Resource Depletion, elements (kg Sb eq.)	4,46E-05	4,38E-05	4,72E-15	8,34E-07
Abiotic Resource Depletion, fossil (MJ)	1,99E+01	1,98E+01	3,46E-06	6,98E-02
Eutrophication (kg Phosphate eq.)	4,96E-04	4,93E-04	1,29E-10	2,80E-06
Global Warming, 100 years (kg CO2 eq.)	1,57E+00	1,57E+00	1,17E-07	6,53E-03
Air craft emissions (kg CO2 eq.)	3,45E-03	3,45E-03	1,12E-14	2,16E-09
Biogenic GHG emissions (kg CO2 eq.)	1,17E-01	1,16E-01	5,44E-09	4,33E-04
Biogenic GHG removal (kg CO2 eq.)	-1,15E-01	-1,15E-01	-5,46E-09	-3,78E-04
Emissions from land use change (dLUC) (kg CO2 eq.)	2,83E-04	2,78E-04	2,52E-11	5,03E-06

Fossil GHG emissions (kg CO2 eq.)	1,57E+00	1,56E+00	1,17E-07	6,47E-03
Land Use Change (-)	3,37E+00	3,35E+00	8,87E-08	1,60E-02
Ecotoxicity (CTUe)	1,60E-03	1,59E-03	6,39E-09	5,14E-06
Blue water consumption (kg)	9,11E+00	9,05E+00	2,58E-06	6,23E-02
Blue water use (kg)	1,92E+03	1,91E+03	3,28E-05	5,71E+00

Table 5-7 - LCIA results for the front camera module of the Fairphone 5, per part

	Total	Front camera component	Housing	Flexcable
Abiotic Resource Depletion, elements (kg Sb eq.)	4,49E-05	4,45E-05	1,36E-14	4,17E-07
Abiotic Resource Depletion, fossil (MJ)	1,69E+01	1,69E+01	3,53E-06	3,49E-02
Eutrophication (kg Phosphate eq.)	4,23E-04	4,21E-04	1,45E-10	1,40E-06
Global Warming, 100 years (kg CO2 eq.)	1,34E+00	1,34E+00	1,24E-07	3,27E-03
Air craft emissions (kg CO2 eq.)	3,42E-03	3,42E-03	1,12E-14	1,08E-09
Biogenic GHG emissions (kg CO2 eq.)	9,95E-02	9,93E-02	5,46E-09	2,16E-04
Biogenic GHG removal (kg CO2 eq.)	-9,86E-02	-9,84E-02	-5,51E-09	-1,89E-04
Emissions from land use change (dLUC) (kg CO2 eq.)	2,40E-04	2,38E-04	2,70E-11	2,52E-06
Fossil GHG emissions (kg CO2 eq.)	1,33E+00	1,33E+00	1,24E-07	3,23E-03
Land Use Change (-)	2,87E+00	2,86E+00	1,05E-07	8,01E-03
Ecotoxicity (CTUe)	1,32E-03	1,32E-03	6,52E-09	2,57E-06
Blue water consumption (kg)	7,91E+00	7,88E+00	2,60E-06	3,12E-02
Blue water use (kg)	1,61E+03	1,60E+03	4,62E-05	2,85E+00

Table 5-8 - LCIA results for the display module of the Fairphone 5, per part

	Total	Display frame	Display PCBA	AMOLED display
Abiotic Resource Depletion, elements (kg Sb eq.)	4,40E-05	8,38E-08	1,51E-05	2,88E-05
Abiotic Resource Depletion, fossil (MJ)	7,62E+01	1,64E-01	2,43E+00	7,36E+01
Eutrophication (kg Phosphate eq.)	3,12E-03	4,33E-06	9,20E-05	3,02E-03
Global Warming, 100 years (kg CO2 eq.)	7,41E+00	1,78E-02	2,26E-01	7,16E+00
Air craft emissions (kg CO2 eq.)	1,93E-06	2,14E-09	7,82E-08	1,85E-06
Biogenic GHG emissions (kg CO2 eq.)	2,75E-01	3,17E-04	1,59E-02	2,59E-01
Biogenic GHG removal (kg CO2 eq.)	-2,69E-01	-3,11E-04	-1,44E-02	-2,55E-01
Emissions from land use change (dLUC) (kg CO2 eq.)	5,27E-03	5,97E-06	1,59E-04	5,11E-03
Fossil GHG emissions (kg CO2 eq.)	7,40E+00	1,78E-02	2,24E-01	7,16E+00
Land Use Change (-)	1,12E+01	1,43E-02	6,02E-01	1,06E+01
Ecotoxicity (CTUe)	4,47E-02	1,40E-05	1,73E-04	4,45E-02
Blue water consumption (kg)	5,65E+01	1,07E-01	1,89E+00	5,45E+01
Blue water use (kg)	8,72E+03	4,66E+01	2,19E+02	8,46E+03

Table 5-9 - LCIA results for the loudspeaker module of the Fairphone 5, per part

	Total	Bottom speaker box	Linear vibrator
Abiotic Resource Depletion, elements (kg Sb eq.)	4,92E-06	1,64E-06	3,29E-06
Abiotic Resource Depletion, fossil (MJ)	3,61E-01	1,53E-01	2,08E-01
Eutrophication (kg Phosphate eq.)	1,14E-04	7,86E-06	1,06E-04
Global Warming, 100 years (kg CO2 eq.)	2,89E-02	1,20E-02	1,69E-02
Air craft emissions (kg CO2 eq.)	3,75E-09	1,96E-09	1,79E-09
Biogenic GHG emissions (kg CO2 eq.)	1,18E-03	4,86E-04	6,91E-04
Biogenic GHG removal (kg CO2 eq.)	-1,14E-03	-4,78E-04	-6,67E-04
Emissions from land use change (dLUC) (kg CO2 eq.)	6,40E-05	1,28E-05	5,11E-05
Fossil GHG emissions (kg CO2 eq.)	2,88E-02	1,20E-02	1,68E-02
Land Use Change (-)	2,27E-01	4,81E-02	1,79E-01
Ecotoxicity (CTUe)	8,28E-04	2,16E-04	6,11E-04
Blue water consumption (kg)	3,90E-01	1,35E-01	2,55E-01
Blue water use (kg)	3,90E+02	1,24E+02	2,66E+02

Table 5-10 - LCIA results for transport Fairphone 5, per transport section

	Total	To assembly	To stock (NL)	To customer
Abiotic Resource Depletion, elements (kg Sb eq.)	5,74E-07	1,59E-07	3,07E-07	1,08E-07
Abiotic Resource Depletion, fossil (MJ)	4,00E+01	6,80E-01	3,38E+01	5,50E+00
Eutrophication (kg Phosphate eq.)	2,68E-03	3,72E-05	2,29E-03	3,60E-04
Global Warming, 100 years (kg CO2 eq.)	2,81E+00	4,86E-02	2,38E+00	3,86E-01
Air craft emissions (kg CO2 eq.)	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Biogenic GHG emissions (kg CO2 eq.)	3,40E-03	3,53E-04	2,54E-03	5,01E-04
Biogenic GHG removal (kg CO2 eq.)	-2,84E-03	-3,09E-04	-2,11E-03	-4,21E-04
Emissions from land use change (dLUC) (kg CO2 eq.)	2,09E-04	2,36E-05	1,55E-04	3,03E-05
Fossil GHG emissions (kg CO2 eq.)	2,81E+00	4,86E-02	2,37E+00	3,86E-01
Land Use Change (-)	5,31E+00	4,09E-01	4,11E+00	7,90E-01
Ecotoxicity (CTUe)	6,80E-03	5,41E-04	5,24E-03	1,02E-03
Blue water consumption (kg)	4,62E+00	9,82E-02	3,89E+00	6,32E-01
Blue water use (kg)	7,60E+02	4,24E+01	6,15E+02	1,03E+02

Table 5-11 - LCIA results for EoL of the Fairpone 5, per treatment step (baseline modelling, material recovery not included)

	Total	EoL transport	Depollution	Shredding
Abiotic Resource Depletion, elements (kg Sb eq.)	1,47E-07	7,93E-08	0,00E+00	6,77E-08
Abiotic Resource Depletion, fossil (MJ)	6,10E-01	5,12E-01	0,00E+00	9,84E-02
Eutrophication (kg Phosphate eq.)	6,82E-05	5,32E-05	0,00E+00	1,49E-05

Global Warming, 100 years (kg CO2 eq.)	4,11E-02	3,37E-02	0,00E+00	7,33E-03
Air craft emissions (kg CO2 eq.)	1,04E-09	1,04E-09	0,00E+00	0,00E+00
Biogenic GHG emissions (kg CO2 eq.)	5,71E-04	3,41E-04	0,00E+00	2,30E-04
Biogenic GHG removal (kg CO2 eq.)	-5,77E-04	-3,45E-04	0,00E+00	-2,32E-04
Emissions from land use change (dLUC) (kg CO2 eq.)	1,54E-05	4,34E-07	0,00E+00	1,49E-05
Fossil GHG emissions (kg CO2 eq.)	4,11E-02	3,38E-02	0,00E+00	7,31E-03
Land Use Change (-)	1,41E-01	1,11E-01	0,00E+00	2,98E-02
Ecotoxicity (CTUe)	7,45E-04	6,86E-05	0,00E+00	6,77E-04
Blue water consumption (kg)	3,84E+01	3,84E+01	0,00E+00	5,15E-02
Blue water use (kg)	9,91E+01	4,30E+01	0,00E+00	5,61E+01

6 Life cycle interpretation and sensitivity analysis

The initial focus of this interpretation of the LCA findings for the Fairphone 5 will be centered on identifying the primary factors driving the phone's environmental impact. Afterwards, the main alternative scenarios regarding reparability and upgradeability are presented and interpreted i.e. the repair scenarios and the PCBA reuse/refurbishment scenarios. Finally, the sensitivity analysis is presented, analysing the effects on the results of the main uncertainty points.

6.1 General Fairphone 5 baseline results

An overview of the impact distribution over the life cycle phases can be seen in Figure 6-1. The most significant contributor to all impact categories under analysis is the production phase (incl. raw material extraction, intermediate goods production, and the manufacturing of the device), ranging between 60% (Land Use Change) and almost 100% (metal resource use, ADPe). The use phase of the device for the assumed three years of lifespan is the next smaller contributor, with 10%-20% of the environmental impacts. This is followed by transport of the device with ~10% of the share and finally the end of life shows a minor impact except for water use. This picture is consistent with LCAs of small consumer electronic devices where the production of the semiconductors and boards causes the highest impacts of the entire life cycle, while the contribution of the rest of the life cycle phases is comparatively lower. Furthermore, the baseline modelling only considers EoL up to and including the shredding of the device, which in part explains the very minor contribution to the overall impacts (see the sensitivity analysis on the allocation approach in Section 6.1.5.5 for an extended modelling of the recycling of the device).

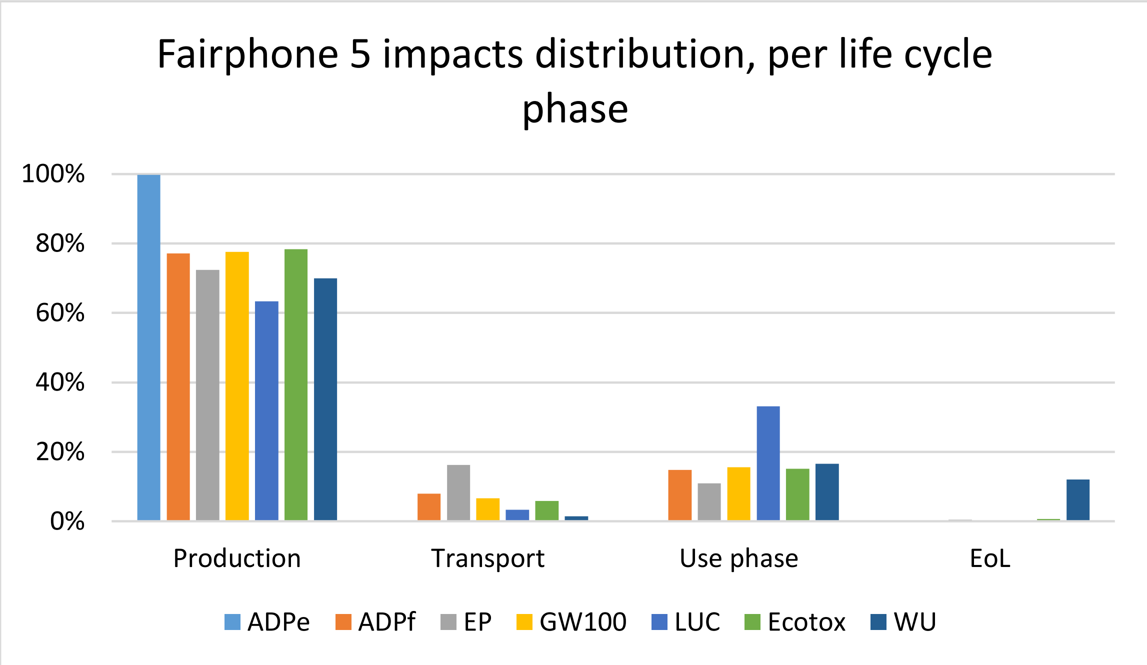

Figure 6-1 - Fairphone 5 environmental impacts distribution per life cycle phase, as % of the total impact

In order to visualize the effects of extending the useful life of the device the estimated *yearly emissions* are calculated i.e. the overall impacts of a year's worth of use for the device. Table 6-1 and Figure 6-2 showcase the benefits of extended lifetime. With extended lifetime the absolute use phase related impacts increase, as well as additional impacts for switching the battery. However, as can be seen, production is ultimately the driver of the emissions and there is a net benefit of keeping the device in use that can be of up to 51% for an ideal case of a 10-year lifetime.

Table 6-1 - Yearly emissions reduction through extension of the lifespan in comparison to the baseline scenario

Lifespan	Yearly emission reduction against baseline (3 years)
5 years	-28%
8 years	-46%
10 years	-51%

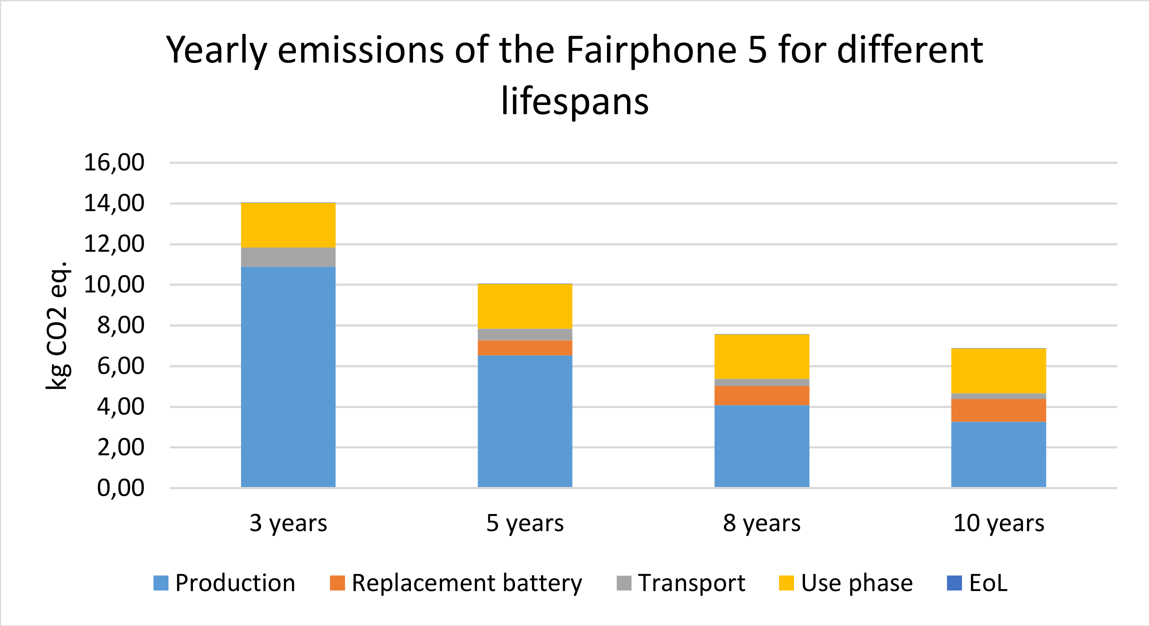

Figure 6-2 - Yearly emissions for different lifetime scenarios, expressed in kg CO2 eq. per year

6.1.1 Production phase

From Figure 6-1 above it is clear that the environmental impacts of the device are mostly linked to the production phase. In this section the main contributors for the production impacts will be analyzed. Figure 6-3 shows the impact distribution over the different modules' production. The main contributors are the primary PCBA (20%-70% depending on the impact category) and the display module (up to 50%), followed by a lower but still significant contribution of the cameras (ranging between 5% to 10%). For ecotoxicity the phone assembly and the battery show a minor contribution and the USB-C connector also shows some impact in the ADPe category. The rest of the modules show comparatively small impacts (below 5% of the total for production).

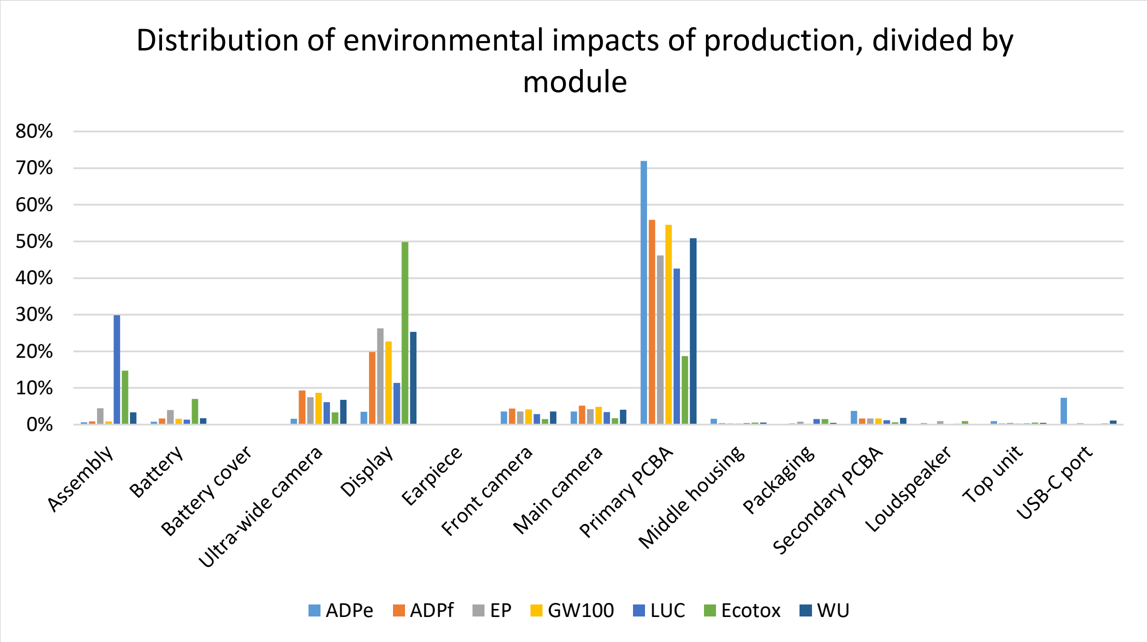

Figure 6-3 - Fairphone 5 production impacts distribution per module, as % of total production impacts

The following sub-sections takes a closer look at the main three contributors: primary PCBA, display module and big angle camera.

6.1.1.1 Primary PCBA

The primary PCBA is the biggest contributor to the environmental impact of the production of the Fairphone 5. Figure 6-4 shows with further detail the impacts distribution for the primary PCBA. Around 90% of the impacts are related to the ICs while most of the remaining impacts are attributed to the PCB itself. The rest of the components (other semiconductors, passive components, connectors, and others) do not show a significant contribution to any impact category under analysis, except for connectors that show some contribution to metal resource use (around 5% of the PCBA totals).

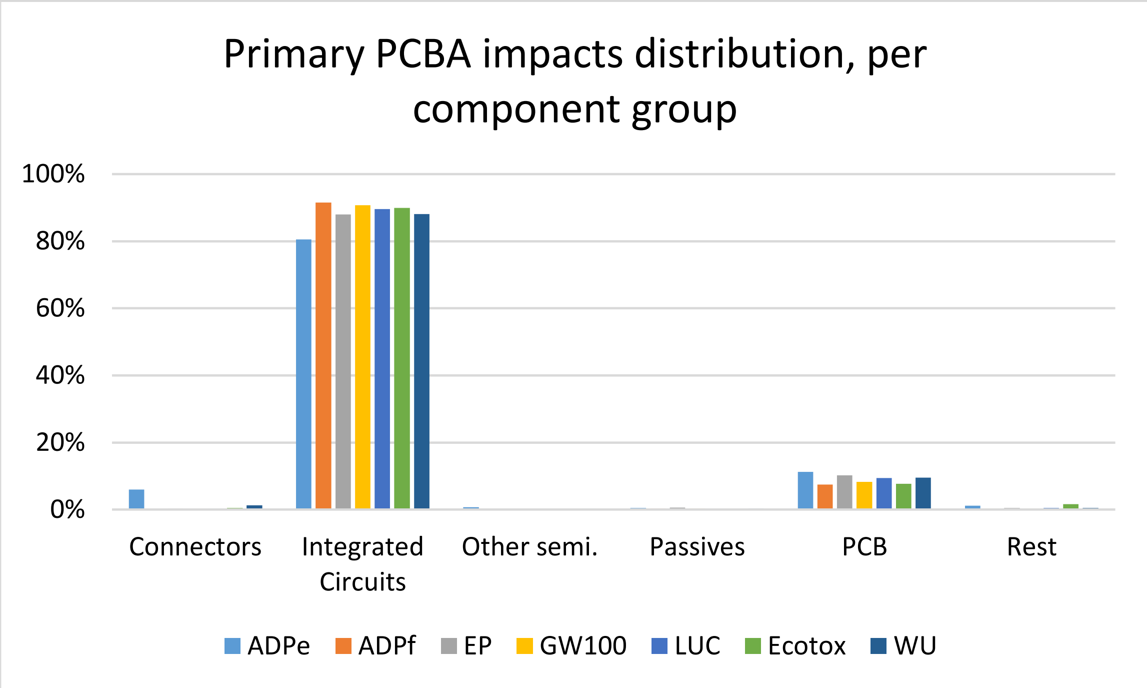

Figure 6-4 - Primary PCBA impacts distribution per component group, as % of the total primary PCBA impacts

Figure 6-5 shows an overview of the environmental impacts of the chips, grouped per functionality. The memory is a single chip and stands out as the main contributor spanning from ~37% to over 45% of the IC impacts depending on the indicator. Furthermore, the processor chip shows a contribution of roughly 8% for most impact categories. Others show significant aggregated impacts e.g. all chips devoted to connectivity add up to around 10% of the impact.

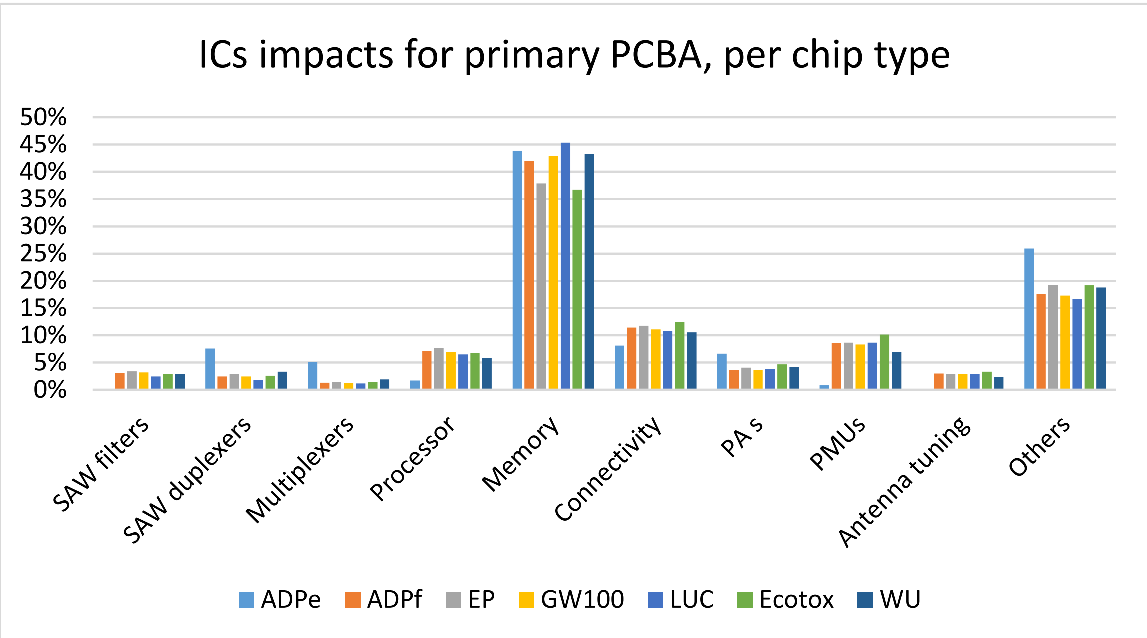

Figure 6-5 - IC-related impact distribution per functionality, as % of the total IC impacts in the primary PCBA

For the modelling of the ICs, a parametric dataset by Sphera has been used, which allows for further granularity when compared with generic datasets. Manufacturing of Integrated Circuits is usually divided into two phases: front-end and back-end. Front-end commonly refers to the first part of IC manufacturing in which the desired circuits are drawn onto the silicon wafer (usually through substractive method) and back-end is the last part where the connections are done, the chip is packaged and it is finally tested. Front-end is also commonly understood to include the manufacturing of the bare silicon wafer itself. Figure 6-6 shows the breakdown of the impacts within chip manufacturing for the memory chip. It shows that most of the impacts are related to the wafer manufacturing and processing, i.e. the front-end processing of the chip. The memory alone has 13 dies within a single package, which adding up to 5 cm^2 of die (more than half of the total die area of all chips in the device combined) which in turn correlates to high front-end impacts.

For ADP elements however, it's the gold in the inner wiring of the chip and in the packaging that has the biggest contribution. This is because, although ADPe measures generally mineral and metal depletion, it does so by weighting the different minerals on the basis of their relative scarcity (i.e. both considering the extraction rate and the known reserves). According to the latest update of the ADPe model (van Oers, Guinée, & Heijungs, 2020), currently the main contributors to the indicator are gold, copper and silver. Therefore, ADPe tends to be heavily influenced by these, particularly gold.

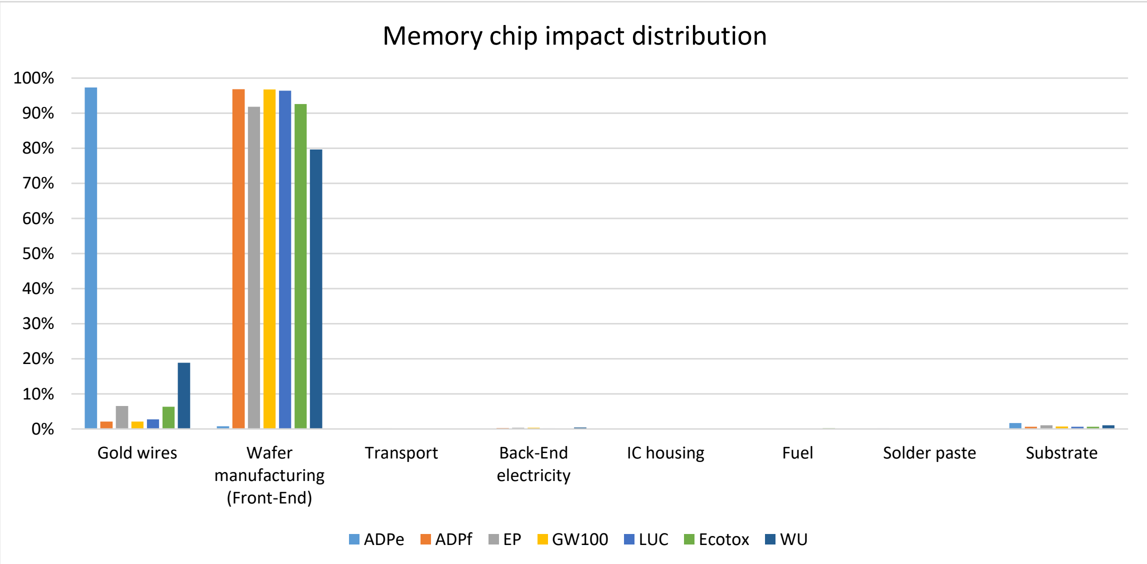

Figure 6-6 - Memory chip impact distribution per front-end/back-end process, in %

Although literature on LCA for chips is scarce, there are some studies that investigate the environmental impacts of chip manufacturing. (Kuo, Kuo, & Chen, 2022) show that the manufacturing of chips is responsible for around 90% of their global warming impact while the materials' related emissions are just 10%. Furthermore, (Nagapurkar & Das, 2022) provides a more detailed view on the Cumulative Energy Demand (CED) for different production factors in chip manufacturing, specifically NAND, DRAM and logic. The study shows that front-end processes are the most energy intensive of the whole production chain (ranging from ~23 to almost 35 MJ/cm^2, as opposed to the maximum of 5 MJ/cm^2 for the back-end processes). These observations are in line with what has been presented in our analysis above.

Another recent study by (Jones, 2023) takes a closer look at front-end processes, by analysing logic, NAND and DRAM chips manufacturing and considering direct electricity use by equipment, natural gas burning for heat, air circulation in clean rooms and process chemicals used and emitted. According to this study, in all cases direct electricity use accounts for around 50% to 90% of the emissions per cm^2 (NAND in the first case and logic and DRAM for the latter). As ICs gain complexity and the circuitry drawn onto the silicon wafer becomes denser, more process steps are required which correlates directly with equipment electricity use. This paper also shows that when die layers are stacked, direct process gas emissions become increasingly relevant due to the additional etching steps[12] required (as is the case for complex NANDs, where increased functionality in small packages is achieved by stacking dies on top of each other). However, potential counter-tendencies to this trend could be identified by looking at (Boakes, et al., 2023). In this study, the manufacturing of a logic chip is modelled for different technology nodes (i.e. chip generations). In this analysis, direct emissions are found to be a not so significant fraction of the final emissions (6-8%) and their relative contribution seems to decrease with further generations, as direct electricity use becomes more relevant and abatement becomes more used in the manufacturing.

6.1.1.2 OLED display

When further looking at the details of the display module results as shown in Figure 6-7, it becomes apparent that the biggest contributor is the display assembly, while the display PCBA and the display frame contribute to a minor extent. Figure 6-8 shows the proportion in which the material content and the manufacturing energy contribute to the display assembly impacts, clearly showing the electricity in production as a hot spot (87% of the total display-related emissions). Since no generic dataset representing this technology could be found and previously consulted sources only applied for LCD, the inventory data was retrieved from both the supplier's material declaration and (Amasawa, Ihara, Ohta, & Hanaki, 2016). The consulted paper employs primary data from lab-scale production to processes used at industry scale and then applies estimations and simulations to project the industry scale energy consumption, which is the data point used in the current modelling. Therefore, the current value might be over-dimensioned. The energy mix for the modelling was assumed to be the national grid mix for the production site (China).

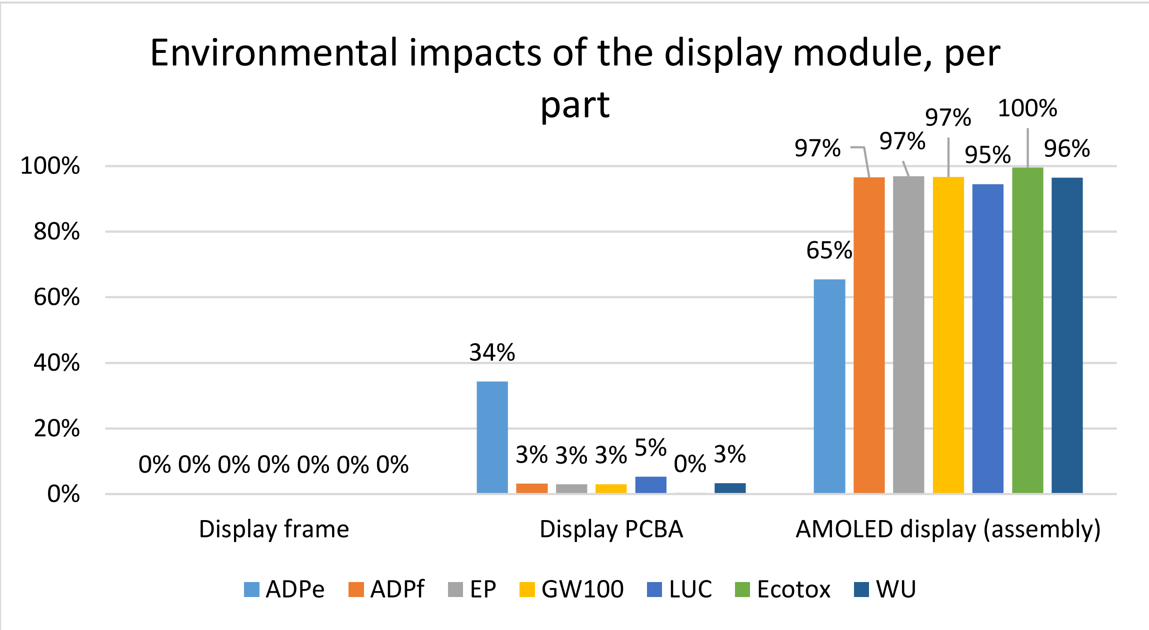

Figure 6-7 - Display module impact distribution

[12] Etching refers to a step in IC manufacturing where, after drawing the circuit on the wafer, excess material is removed by a chemical bath. This process is chemical intensive and results in some direct emissions with significant global warming potential.

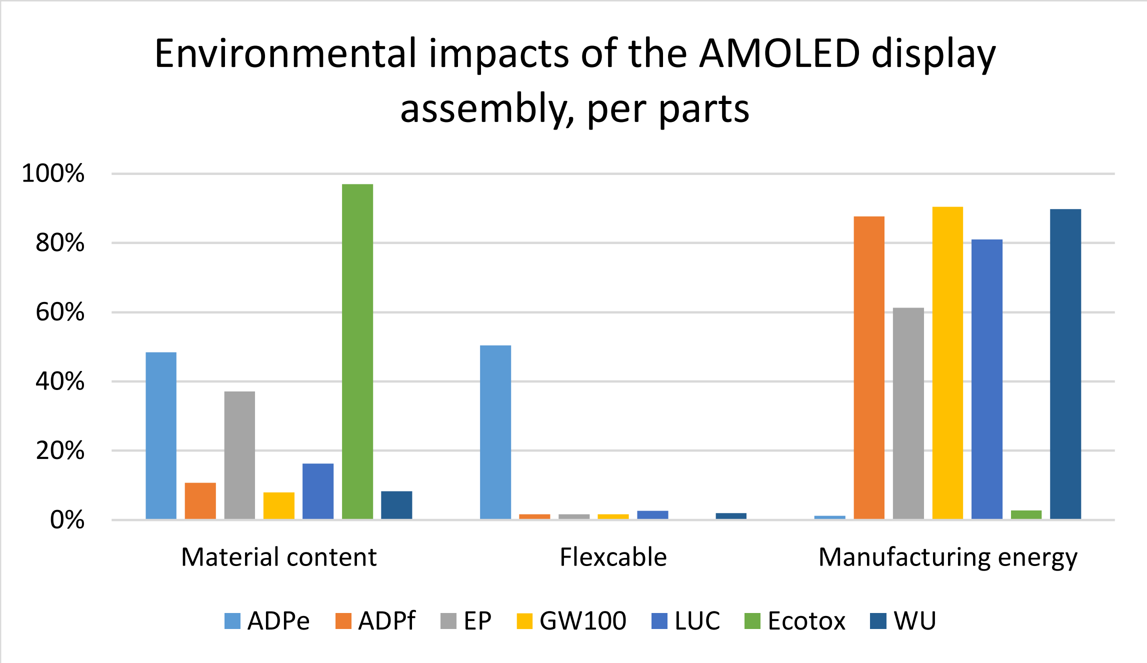

Figure 6-8 - Display assembly impacts, divided into material content, flex cable and electricity use in manufacturing. Mix of primary and secondary data.

To further improve the accuracy of the modelling in the future, it is important to gather primary data on this aspect of the display production. In Section 6.1.5.1 a sensitivity analysis has been performed in order to assess how this modelling differs from other options, used for LCD modelling.

Regarding other impacts, ADPe concentrates mostly in the display assembly, PCBA and the flex cable since gold can be found in all of them. Lastly, the polarizing film used as one of the materials of the display assembly, modelled as polarizer, shows to be the main contributor for ecotoxicity. A further inquiry into the dataset[13] shows that ecotoxicity is also driven by the electricity consumption during polarizer production, modelled by Ecoinvent as a global average mix of electricity production[14]. The energy mix assumed for China within the Ecoinvent datasets is heavy on coal burning. In the Ecoinvent background modelling, hard coal burning seems to be relevant for the ecotoxicity indicator due to the assumed treatment of coal ash residues via landfilling, which incur in direct emissions to water. The dataset is reported to have been compiled in 2015, so it is unclear how representative these assumptions are currently.

The modeling of the OLED display reveals significantly higher GW results compared to the previous LCD display used in the Fairphone 4. However, this disparity does not necessarily mean that manufacturing the OLED display is inherently more harmful than its predecessor. Instead, this is rather a consequence of using different data sources and modeling techniques. Unlike in the case of the Fairphone 4 where the display was an LCD, this time it is an AMOLED. The lack of sufficient and coherent inventory data for both technologies prevents a clear conclusion on their environmental differences.

[13] https://ecoquery.ecoinvent.org/3.10/cutoff/dataset/5846/documentation

[14] https://ecoquery.ecoinvent.org/3.10/cutoff/dataset/13269/documentation

6.1.1.3 Cameras

The camera modules have a comparably large impact on the environmental impact on the production of the Fairphone 5. In Figure 6-9 the main camera's impact distribution is shown, as an example for all three cameras in the device. As it can be seen, except from ADPe which dominates the impacts of the flex-board on which the camera is mounted, all other impacts are mainly caused by the camera component itself. The housing of the camera component shows a very low contribution in relation to the other parts, below 1% for all impact categories under analysis.

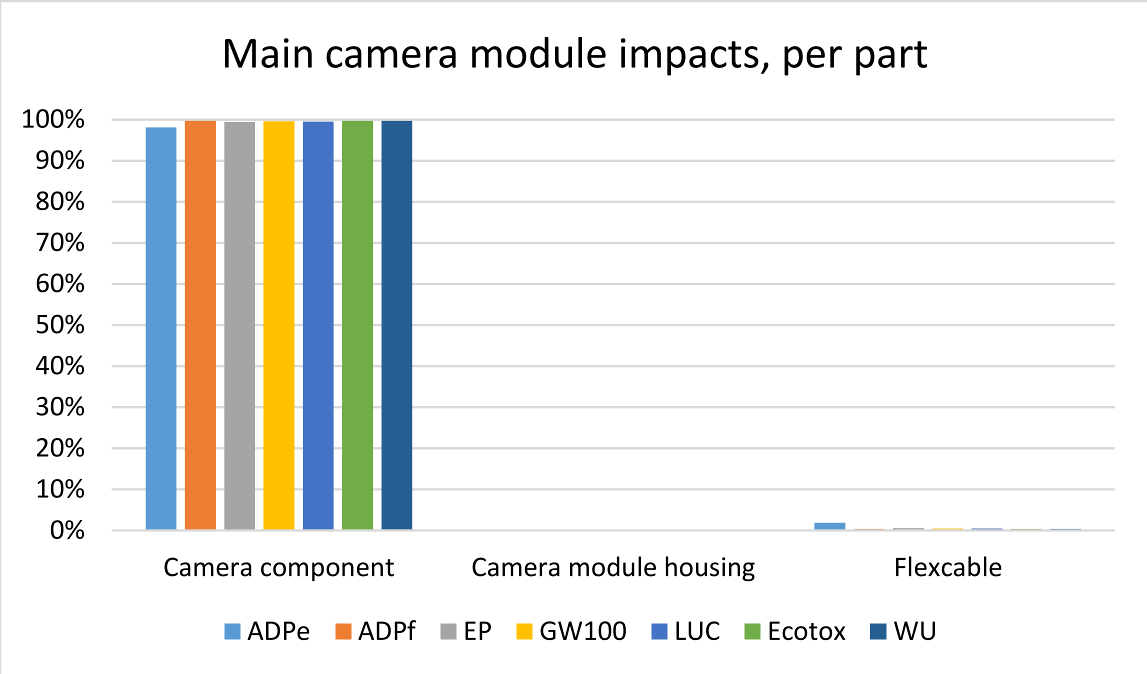

Figure 6-9 - Main camera module impacts distribution, expressed in %.

Within it, the stacked layered sensor (see Section 4.4.1.1.6 above for more details on the sensor modelling and why it is currently modelled as a multi-layered sensor) makes up between 92% and 100% of the impacts for all categories, except ADPe in which it is much less relevant (6% of the total camera component impact). Similarly to the memory chip, most impacts related to the sensor are connected to the manufacturing of the two dies used: the sensor layer and the CMOS layer. This is the case for most impacts under analysis except ADPe where the substrate also plays a role, as displayed in the figure below. This chip was modelled without a package since the sensor lays bare on the board, protected by the camera housing, so back-end processing has no contribution. An overview of the contributions can be seen in Figure 6-10.

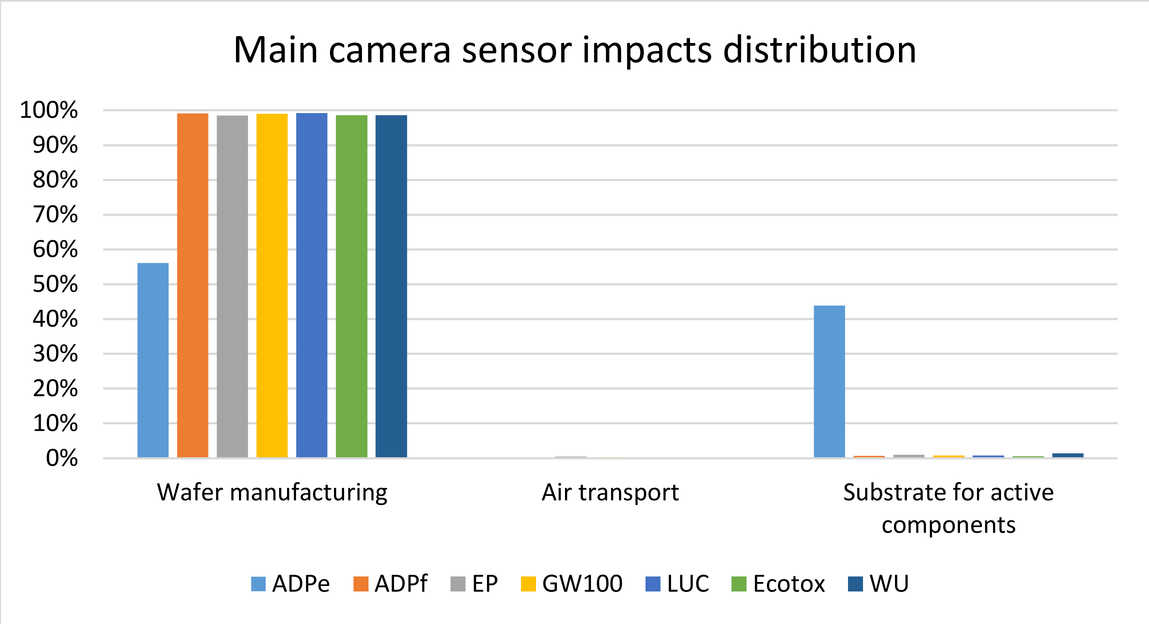

Figure 6-10 - Main camera sensor impact distribution, expressed as % of the total sensor chip impacts

6.1.2 Downstream processes

Figure 6-11 shows the impact distribution of the transport related impacts. Since transport from assembly site to Europe involves a small fraction of air transport, this causes most of the impacts, except ADPe and Land Use Change which are more tied to land transport and are therefore more evenly distributed across the logistics chain.

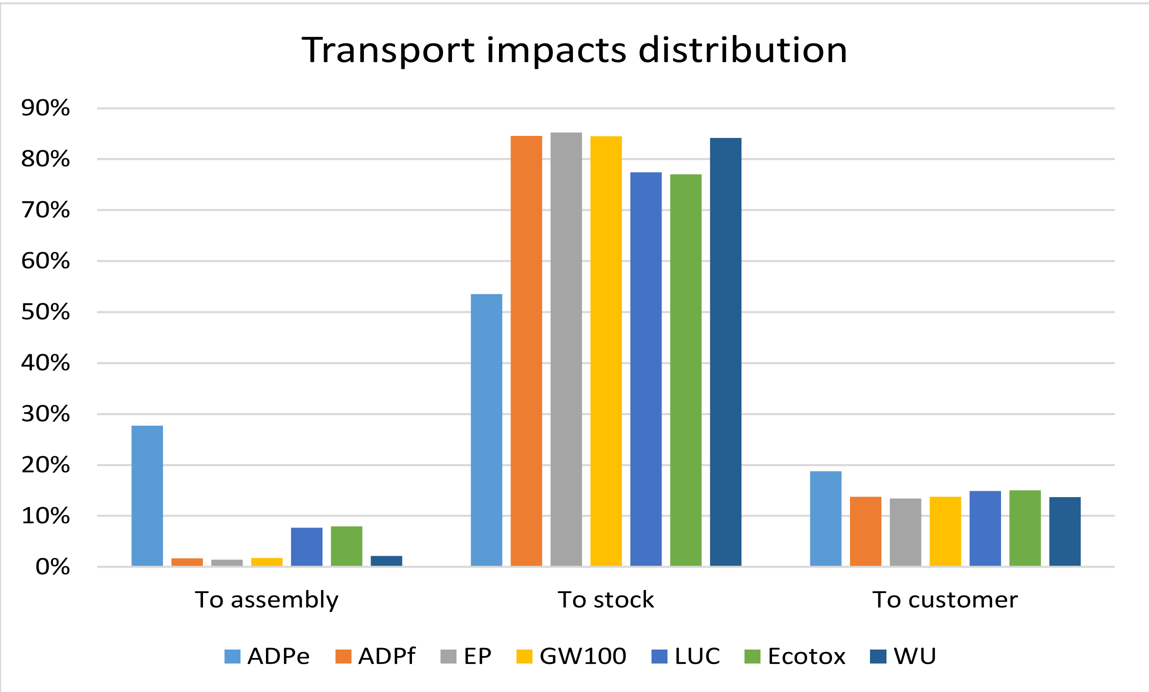

Figure 6-11 - Transport related impacts distribution, per logistics step, expressed in % of the total transport impacts

Regarding the EoL (in its cut-off version for the baseline modelling, see sensitivity analysis for the extended results), transportation to the disposal site shows the highest impacts, as observable in Figure 6-12. The exception is ecotoxicity in which shredding is the hotspot. The Ecoinvent documentation for the used dataset[15] shows that the ecotoxicity impact comes from various sources: around 58% of it is related to the electricity supply (global, medium voltage), 41% is traceable to direct emissions of metals during the materials production for infrastructure building (factory and machinery). Similar to what has already been noted in Section 6.1.1.2 when discussing the ecotoxicity of the polarizer film in the display, this dataset for electronics scrap shredding was compiled in 2005 and it is unclear whether the background assumptions still hold. The remaining 1% is a cumulated effect of direct emissions of metal ions.

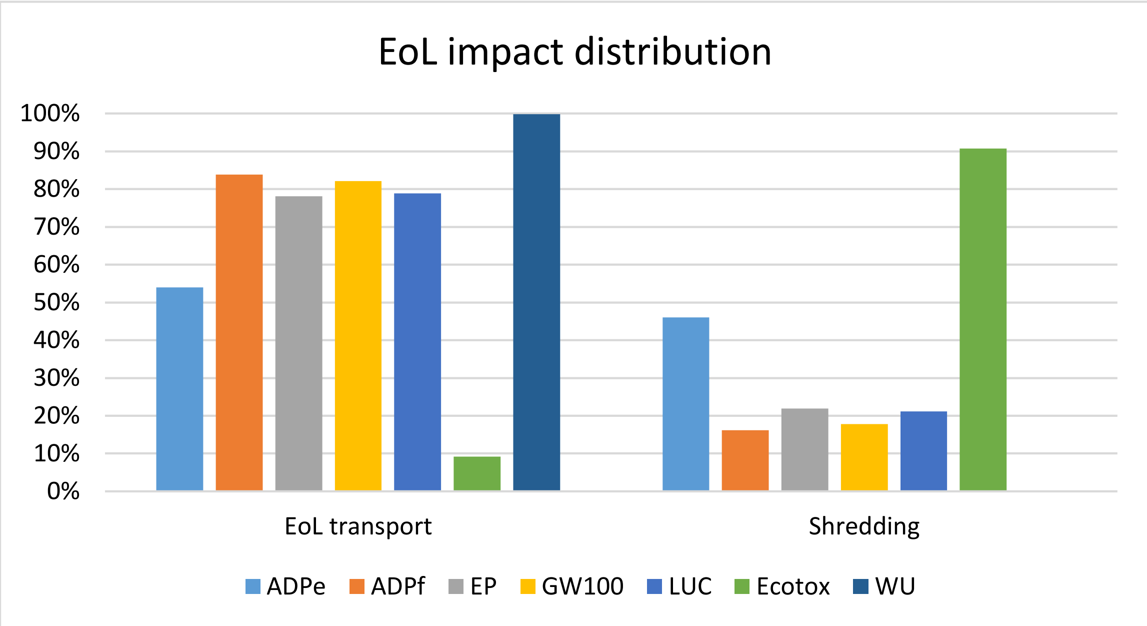

Figure 6-12 - EoL impacts distribution, expressed as % of the total EoL impacts

6.1.3 Repair scenarios

In order to further analyze the potential benefits and tradeoffs of repair, a set of scenarios has been modelled, including a reference scenario to serve as a benchmark:

- **Reference scenario.** No repair is undertaken and within a span of 6 years, 2 full phones are purchased (Fairphone 5). No battery replacement is assumed.
- **Scenario 1: Repair center module replacement scenario.** Faulty modules are replaced by Fairphone B.V. In this case the user sends the full phone and gets it back with the new module.
- **Scenario 2: Module level repair scenario.** Faulty modules are repaired, meaning that only the faulty component is replaced by a new one, keeping the rest of the module in use. The full phone is thus not transported in this scenario. The repair is performed by Fairphone B.V.
- **Scenario 3: DIY module replacement scenario.** Like in scenario 1, faulty modules are replaced for new ones. In this case however, the user performs the replacement and only the modules are sent to the user.

[15] https://ecoquery.ecoinvent.org/3.10/cutoff/dataset/480/documentation

Across the scenarios, there is some key data points and assumptions made that are important for result interpretation:

- Lifetime extension resulting from repair is estimated based on survey data provided by Fairphone B.V. In this survey, 3045 Fairphone 3 users were asked how much longer they expected to keep their devices in use. The average lifetime of the surveyed devices at the time of the questionnaire was 2,48 years. The average expected additional life expectancy for the devices was set between 3,3 and 3,6 years. Please note that this expected additional lifetime does not refer exclusively to repaired devices, but also to not repaired ones (at the time of the survey). Due to the lack of more specific data, this has been deemed as a good approximation as to how much longer Fairphone users keep their devices (assuming that many will indeed make use of its modularity). Therefore, the total assumed use time is then 6 years (baseline of 3 years + extra 3 years).
- The list of faulty modules is based on spare parts sales data for the Fairphone 4 provided by Fairphone B.V. For the repair scenarios, the repair overhead is estimated as a weighted average of the environmental impacts of repairing/replacing all these modules, in order to account for a wider range of use cases. These modules are:
    - Battery
    - Battery cover
    - Display module
    - Loudspeaker module
    - Main camera
    - Ultra-wide camera
    - Front camera.
    - USB-C port module
- For scenario 2, a repaired component (or several) per module was assumed for its replacement. The full list:
    - Battery and battery cover: fully replaced.
    - Display module: frame and glass.
    - Speaker module: speaker box.
    - USB-C connector module: Connector (i.e. flex-board is kept)

An overview of the scenarios can be seen in Figure 6-13. It seems that all repair strategies represent an improvement compared to the reference scenario (between a 37-40% reductions of emissions). When it comes to comparing the different approaches, they are very similar, with the board-level repair showing a slightly better environmental performance since it keeps more of the modules in use. For the general repair scenarios the primary PCBA has not been considered as a spare part since it is not sold as such. In order to still assess the benefits of board level repair for this module, it is nonetheless included in the module level analysis, see Section 6.1.3.1. Therefore, the modules that are repaired are overall not as carbon intensive and thus the difference between replacement and repair is small.

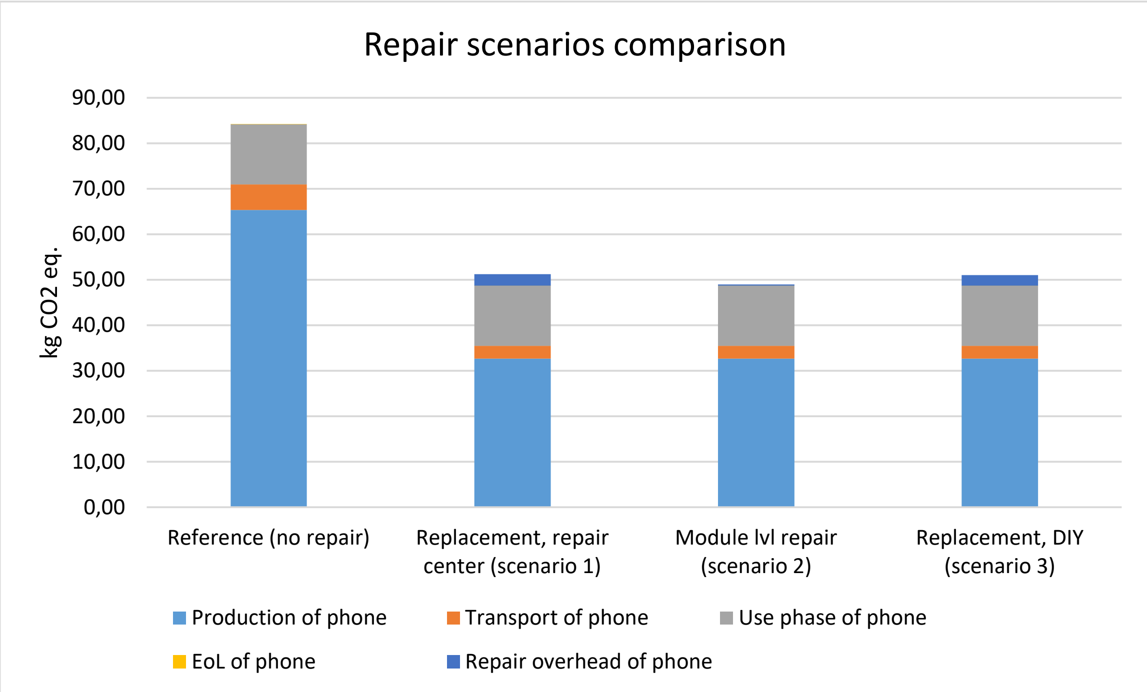

Figure 6-13 - Repair scenario comparison for global warming, expressed in kg CO2 eq. and subdivided in life cycle phases of the phone and repair overhead (repair overhead includes: new modules or part, additional transport and additional EoL activities)

A good way to visualize the required *effort* for the repairs is the environmental payback time i.e. an estimated payback time for repair activities based on the yearly allocated emissions, which considers the repair overhead (please refer to (Sánchez, Proske, & Baur, 2022) for a more detailed explanation of the indicator). The payback time refers to the additional time the device needs to be used for the additional impacts to be worthwhile. Table 6-2 below shows an overview of the estimated values. The payback times of both DIY repair (entire module replacement) and module level repair (replacement of the broken component/s) is in the same range.

Table 6-2 –Payback time for the list of repaired modules (unweighted), for both full module replacement and board level repair. The full repair overhead is considered. For the replacement case, DIY approach is assumed (only module is sent).

	Payback time for DIY module replacement (in days)	Payback time for module repair (in days)
Battery	16	n/a
Battery cover	11	n/a
Display	92	11
Speaker	11	11

Main camera	27	37
Ultra-wide camera	40	40
Front camera	24	24
USB-C port	11	11
Earpiece	11	n/a

In general, the payback times are rather short since the repaired modules do not have a very high impact and thus the penalty for refurbishment or repair is not high. The replacement of the entire display module stands out due to its comparatively large impacts. For the same reason, it is the module for which module level repair shows the biggest potential. For the rest of modules, the difference between the strategies is not significant.

6.1.3.1 Module level analysis

In order to better understand the benefits or drawbacks of each repair scheme, it is useful to take a closer look at the repair overhead per module. The repair overhead includes the production of the new module or part, additional transport, additional EoL activities and, in the case of module level repair, the required electricity for the component change. Table 6-3 shows an overview of the results.

Table 6-3 - Repair overhead per module for the different repair scenarios. The table shows the values for Global Warming, expressed in kg CO_2 equivalents

GW100 (kg CO_2 eq.)	Scenario 1 (Repair center, full replacement)	Scenario 2 (Repair center, part replacement)	Scenario 3 (DIY full replacement)
Battery	0,617	N/A	0,568
Battery cover	0,110	N/A	0,038
Ultra-wide camera	2,921	2,845	2,844
Display	7,493	0,044	7,431
Earpiece	0,082	N/A	0,005
Front camera	1,417	1,349	1,340
Main camera	1,652	1,583	1,575
Loudspeaker	0,108	0,026	0,032
USB-C port	0,133	0,056	0,056
Primary PCBA	17,909	6,959	17,840

In all cases, the less environmentally efficient alternative is the first scenario i.e. sending the full device to have the broken module replaced in the repair center. In this case, the full effort of transporting the entire device in many cases is comparatively too taxing. This is particularly obvious for smaller modules, for example, the USB-C connector module. Figure 6-14 shows how much the additional transport effort adds up in comparison to the other scenarios.

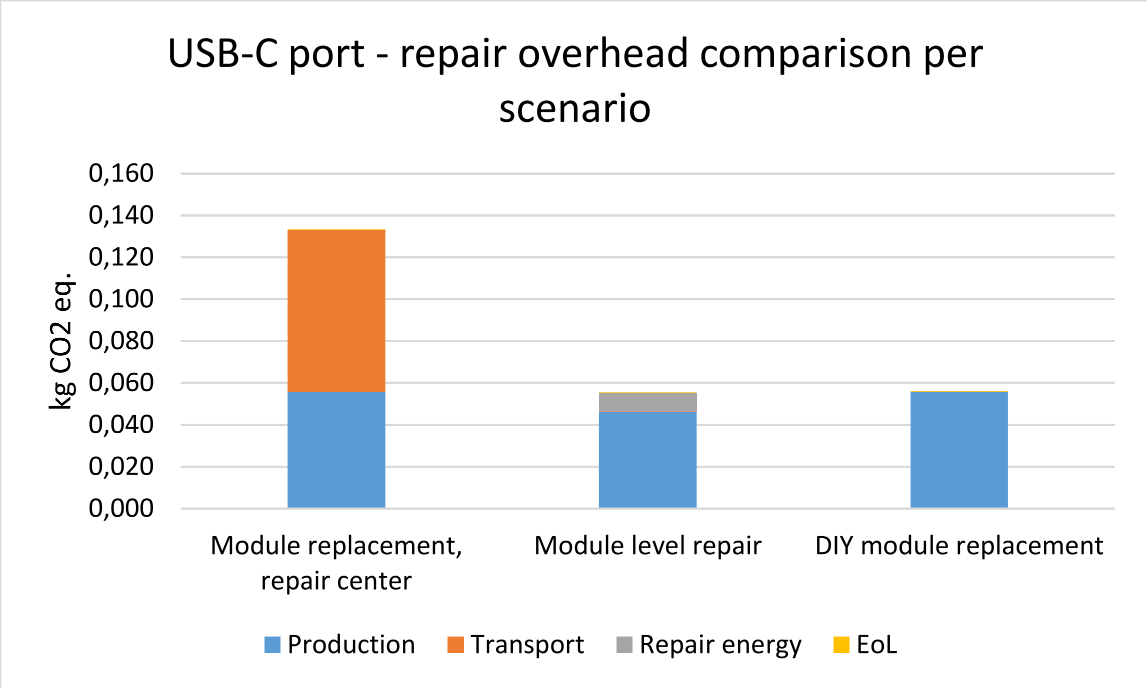

Figure 6-14 - Comparison of the repair overhead of each scenario for the USB-C connector module

Between the other two scenarios (DIY module replacement and part replacement) the results are mixed. The deciding factor is the relationship between the total module impact and the impacts associated with the replaced part. An example of this are the camera modules. Figure 6-15 below shows this comparison for the main camera, where more than 90% of the impacts of the module are tied to the camera component. Thus, the additional effort used for keeping the rest of the module in use does not pay off.

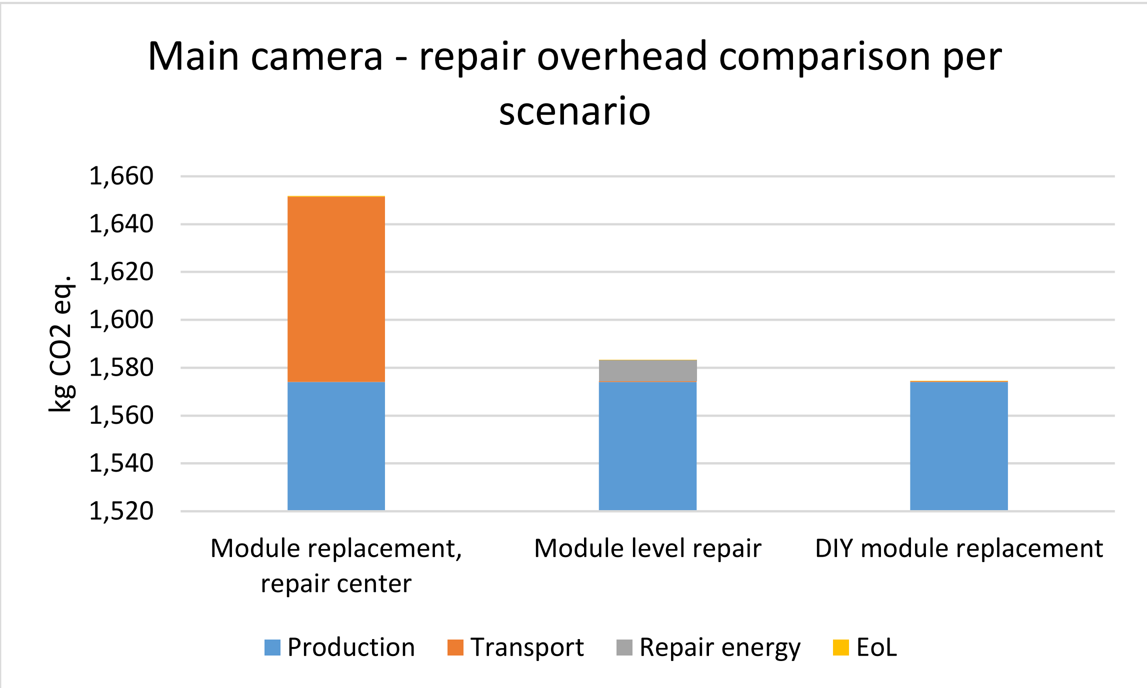

Figure 6-15 - Comparison of the repair overhead of each scenario for the main camera module

On the other side we can find the primary PCBA, see Figure 6-16. In this case it was assumed that the memory chip is replaced. Even then, due to the elevated impact of the whole assembly in comparison with the single part, keeping the rest in use incurs in significantly lower impacts than replacing it fully. In contrast, the transport overhead for scenarios 1 and 3 here plays a smaller role.

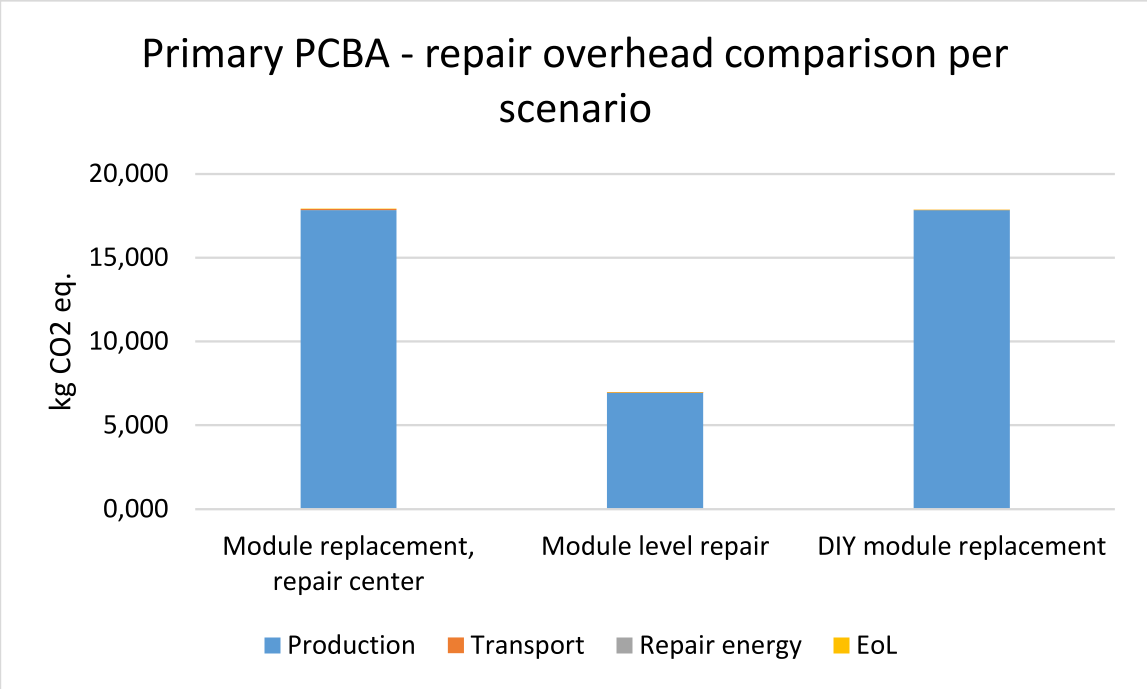

Figure 6-16 - Comparison of the repair overhead of each scenario for the primary PCBA module

6.1.4 PCB reuse

In the previous LCA for the Fairphone 4 (Sánchez, Proske, & Baur, 2022), the core module was identified as a key component for repair. In order to gain further insight into the improvement potential in this area, two PCBA reuse scenarios are analyzed: PCBA update and PCBA refurbishment. The details for each are the following:

- **Reference scenario.** For the reference scenario it is assumed that in a period of 9 years, three entire devices are purchased.
- **PCBA update.** In this scenario, over the same 9 years period, three PCBA modules (primary PCBA) are used while keeping the rest of the initial phone in use. The following elements are included in the scope of this scenario, besides the manufacturing of the first full device:
    - Full manufacturing of the additional PCBs.
    - Transport of the additional PCBs to the user.
    - Additional EoL activities related to the extra PCBs.
- **PCBA refurbishment.** In this case, during the 9 years period three phones are purchased but in all three the PCBA is refurbished i.e. it has been recovered and repaired from a previous device. The following processes are included in the scope of this scenario:
    - Manufacturing of the three smartphones, except the primary PCBA.
    - Refurbishment of the PCBAs i.e. electricity use for repair and testing, additional transport.

Some relevant assumptions to be considered are:

- In the PCBA update scenario, the same manufacturing impacts are assumed for all three boards, effectively assuming them to be identical. While in reality that may not be the case (especially in an update context). No sound evidence was found correlating increased functionality and a specific increase/decrease on impacts since this is influenced by many factors.
- In the PCBA refurbishment scenario, the manufacturing efforts for the boards are allocated to their original products. Therefore, the only impacts considered for these boards are the refurbishing efforts, modelled as a board level repair (more on the assumptions and sources in Section 3.3.4), additional components and transport.

Figure 6-17 shows the comparison for GW. The refurbished PCBAs scenario shows the lowest impacts when compared to the PCBA update scenario, while both show to an improvement compared to the reference. The primary PCBA is the most carbon intensive module in the device and therefore the most beneficial strategy is taking advantage of already used mainboards and extending their lifetime. The PCBA update scenario, in turn, shows that there is still benefit on just renewing the mainboard while keeping the rest of the phone in use. It is relevant to note however that these results are very sensitive to the modelling assumptions, for example:

- that the purchased PCBAs in the PCBA update scenario are indeed new and not refurbished themselves or
- that the manufacturing impacts of the refurbished PCBA scenario can be allocated fully to its *first life.*

What these scenarios point towards however, is that there is a net benefit in keeping either the mainboards or the rest of the device in use.

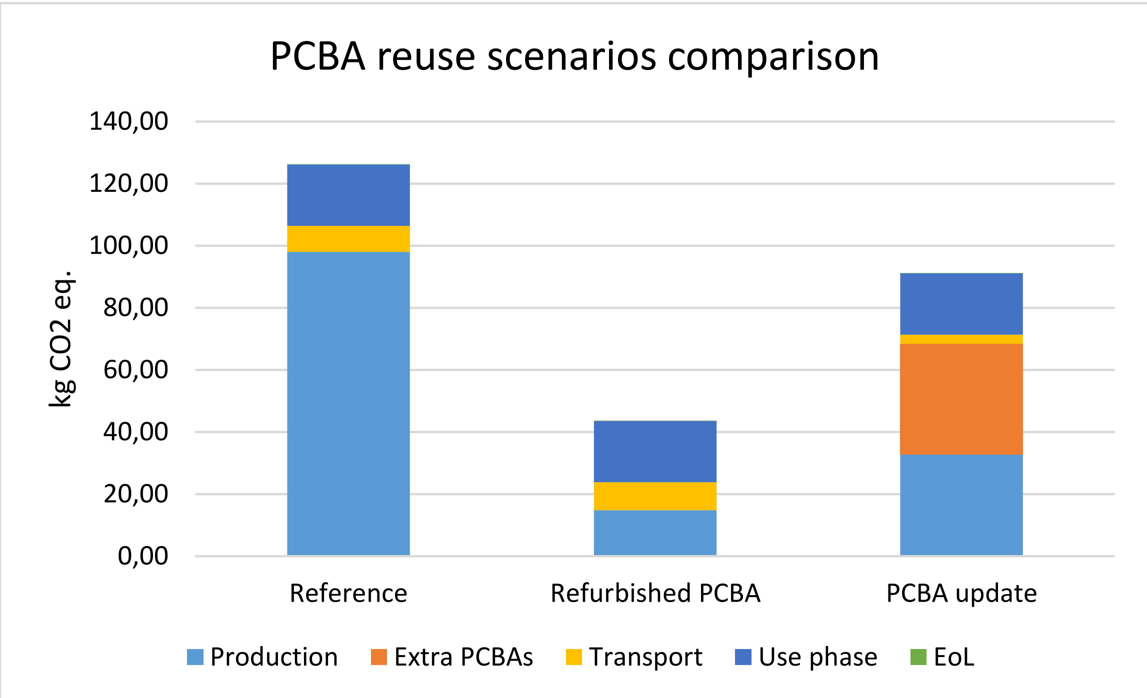

Figure 6-17 - PCBA reuse scenarios comparison for global warming, expressed in kg CO2 eq. and sub-divided in life cycle phases incl. additional PCBAs

6.1.5 Sensitivity analysis

In the previous section an overview of the main LCA results has been provided and some uncertainty points and/or modelling dependencies have been signaled. In this section, a further assessment of these is explored. Moreover, some alternative scenarios are also presented in order to weigh in the effects of some design choices.

6.1.5.1 Display modeling

Since the Fairphone 5 changed the display technology from LCD to OLED, the display assembly is modeled from the ground up, relying on material composition data provided by the manufacturer and energy consumption figures from a study by Amasawa et al. (2016). This study estimated energy consumption from small-scale to large-scale manufacturing, potentially overestimating the impact, especially given possible industry advancements since the data's collection in 2016 (with underlying data from 2014). On the other hand, for the Fairphone 4, a different approach was taken due to a lack of comprehensive data on display manufacturing. CSR data from an LCD display manufacturer was used, scaled down based on production volume.

Considering that the inventory data is retrieved from different sources and the modelling methodologies (bottom up vs top down) are also different, a direct comparison between both displays technologies is deemed not feasible.

For the sensitivity analysis and to show the range of variability, however, the Fairphone 5 display was modelled using four different approaches, also utilizing the approach taken for the Fairphone 4:

- The baseline scenario as described above, using manufacturer material data and literature data for manufacturing energy consumption.
- A mixed-LCD modelling approach using materials from the manufacturer's material declaration, but manufacturing energy usage data pulled from a CSR report of an LCD manufacturer (AUO, 2022).
    - This is comparable to the approach used for the Fairphone 4 but scaled to fit the data for the Fairphone 5.
- Using a generic dataset on LCD display from Sphera LCA FE scaled to the Fairphone 5 display specifications.
    - subtracting the backlight and electronics, as these do not exist in OLED displays/are placed in a different part of the phone.
- Using a generic dataset on LCD display from Ecoinvent[16] scaled to the Fairphone 5 display specifications.

Comparing these four modelling approaches yields results shown in Figure 6-18:

[16] https://ecoquery.ecoinvent.org/3.10/cutoff/dataset/24581/documentation

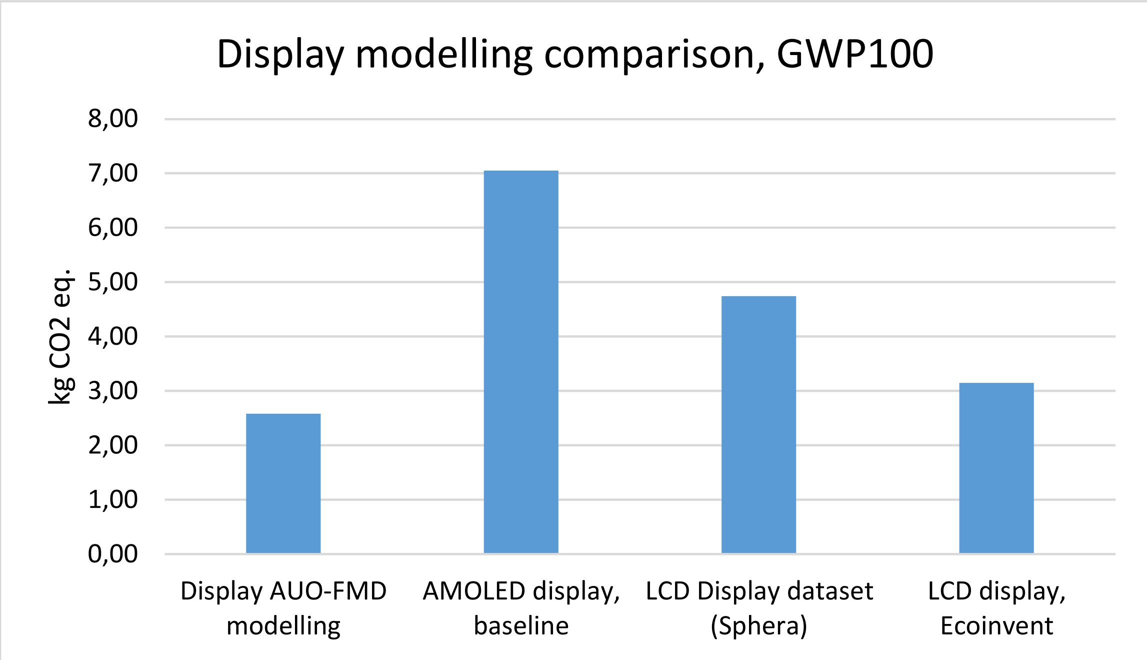

Figure 6-18: Sensitivity analysis of the display modelling for the Fairphone 5, comparing global warming potential (in kg CO2) for four scenarios (from left to right): hybrid LCD modelling combining primary material data and secondary energy data; baseline modelling of AMOLED display with primary material data and secondary energy data, generic parametric Sphera dataset and generic aggregated Ecoinvent dataset.

As can be seen from the graph, the results vary significantly between 2.5 kg CO2e and 7 kg CO2e, with the AMOLED modelling approach having by far the highest impact. Except for the Sphera parametric dataset, which is built differently, the rest of the analyzed options can be broken down into material content and manufacturing energy. Table 6-4 shows an overview of the contributions. Overall, it can be seen that the specific build for the material content i.e. parts and components of the assembly differs (in the first two cases primary data on material composition is used while the last case uses generic Ecoinvent datasets for parts and components). For all cases however, the manufacturing energy is the dominant aspect and thus the main reason for the observed differences amongst alternatives.

Table 6-4 - Display modeling breakdown, comparing material- and energy-related contributions for three of the four modelling options under analysis

	Material content	**Manufacturing (energy)**
Baseline (AMOLED)	0,57 kg CO_2 e	6,48 kg CO_2 e
	8 %	92 %
AUO data + FMD data (LCD)	0,57 kg CO_2 e	2,01 kg CO_2 e
	22 %	78 %
	1,24 kg CO_2 e	1,87 kg CO_2 e

Ecoinvent (LCD)[17]	40 %	60 %

This shows that acquiring primary data and further insight on display assembly manufacturing is relevant for a more accurate modelling and a better insight into the technology change.

6.1.5.2 IC modeling

Another relevant change in the modelling approach for this device has been the use of parametrised IC models (Sphera) as opposed to regular datasets (Sphera) and self-built datasets (Fraunhofer IZM, Boyd). The main reason for this change has been to allow a more accurate modelling in terms of material content and die-to-package ratio, since the FMD provided by Fairphone's suppliers revealed that different chips on the device had significantly different material bills. In order to better understand how this change has impacted the result, the previously followed approach (generic black-box datasets) and the new one have been compared.

While the previously used datasets would re-scale all inventory data on the basis of the input die size, the new datasets allow for a more granular input of the data, which for example makes it possible to model a chip with a big die size and no gold wires, or a chip with a small die area and a bigger package. The effects of this modelling change can be seen in Table 6-5.

The new parametric modelling shows, in general, lower values than the generic one. While for most impact categories the change remains significant but limited (ranging from a variation of 7% to 23%), ADP elements shows the biggest variation with the generic modelling resulting in twice as much impact as the current modelling. This is a result of the fact that the actual amount of gold (which sometimes is not used, according to the FMD provided by the suppliers) can be inputted in the dataset and thus get a more accurate depiction of the resource use.

Table 6-5 - Variations in LCA results (total baseline results) of the old modelling approach (i.e. using generic IC datasets) in reference to the new on. A + sign means that the previous modelling approach is higher.

Environmental impact	Difference (as % of baseline modelling, ICs only)
ADP elements (kg Sb eq.)	+295%
ADP fossil (MJ)	+7%
Eutrophication potential (kg Phosphate eq.)	+21%
Global Warming Potential (kg CO_2 eq.)	+7%
Land Use Change (-)	+8%
Ecotoxicity (CTUe)	+5%

[17] From the documentation it is unclear which parts and components are included in the assembly. The 0,5kg CO2e correspondent to the PCBA are already subtracted.

Water use (m3 world eq.)	+27%

6.1.5.3 Use of renewable energy

Some suppliers of Fairphone B.V. have recently started using renewable energy in their processes, under the aforementioned Chinese GEC system. Currently, this is applied only in the final assembly process (modelled accordingly in the baseline) but will soon include, among other parts, battery manufacturing. In order to track the effects of this change in the LCA results, different scenarios have been compared.

Figure 6-19 displays the change in energy source for battery manufacturing to use fully solar energy. The impact category showing the biggest reduction is global warming (23%) followed by water use and fossil depletion. Conversely, impact categories like ADPe and land use change increase (2% and 9% respectively). This confirms that the use of renewable energies, while net beneficial, does have its trade-offs. Their severity and specific impacts, thou, vary depending on the reference energy mix and the selected renewable energy source.

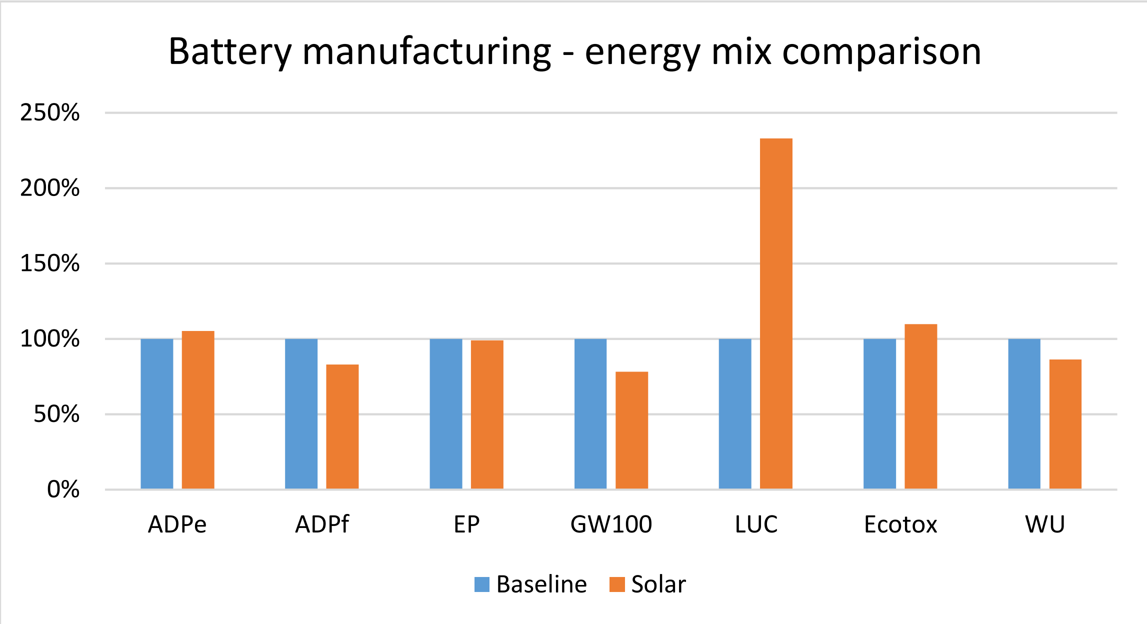

Figure 6-19 - Battery impacts comparing both energy mix scenarios: baseline (CN mix) and RE (photovoltaic). Impact values only for the battery, not the total.

From a cradle-to-grave LCA on PV plants (Piasecka, Baldowska-Witos, Piotrowska, & Tomporowski, 2020) the main contributors for ADPe are mostly the copper and tin used for the building of the PV panels themselves. Regarding ecotoxicity, extraction of copper and nickel is identified in the same paper as the main source during production, while copper disposal at the panels' EoL also contributes significantly. Additional infrastructure including the inverter unit for the plant seem to contribute less to the overall impacts of PV energy generation. Regarding land use Land Use Change, a report published on biodiversity impacts and mitigation of PV and wind parks (International Union for Conservation of Nature and Natural Resources (IUCN), 2021) identifies several routes through which biodiversity is affected by PV energy generation: the space occupied by the parks is a direct source of some impacts (e.g. loss of habitat, bird collision or electrocution) while other impact sources are indirect (e.g. displacement due to attraction to reflective surfaces, habitat degradation, pollution etc.). This of course will highly depend on the specific characteristics of the PV parks used in each country to produce electricity.

6.1.5.4 Recycled content

Fairphone B.V. puts effort in using recycled material in several parts of their device. In order to analyse the effects of this use of secondary material, an alternative scenario containing only primary materials has been modelled. In Table 6-6, the comparison of the relevant modules is shown for global warming, ADP elements and ecotoxicity. It is important to remember that for the baseline scenario, the efforts related to the recovery of the secondary materials is also considered i.e. they do not enter the system burden-free. Therefore, it can be seen that overall, the impact of using secondary materials in the device is rather limited, of around 1% for emissions and ADPe and even lower for ecotoxicity.

Table 6-6 - Overview of the mass % of recycled content in FP5 modules, their relative importance for selected impact categories and the observed effect of replacing them with primary materials

		GW100		ADPe		Ecotox	
Module	Recycled content %	Impact weight (in relation to total production impacts)	Change %	Impact weight (in relation to total production impacts)	Change %	Impact weight (in relation to total production impacts)	Change %
Battery	0,15%	1,61%	0,01%	0,81%	0,00%	7,41%	0,00%
Display	11,56%	22,66%	1,44%	3,53%	0,01%	52,67%	0,05%
Middle frame	69,12%	0,32%	269,57%	1,63%	0,44%	0,57%	61,73%
Speaker	3,57%	0,10%	8,69%	0,40%	0,24%	0,99%	1,64%
Primary PCBA	36,34%	54,59%	0,04%	72,29%	0,02%	19,76%	0,02%
Secondary PCBA	43,61%	1,64%	0,02%	3,78%	0,24%	0,66%	0,01%
Earpiece	1,12%	0,01%	-0,98%	0,14%	0,00%	0,11%	-0,01%
TOTAL	22,00%		1,26%		1,75%		0,40%

It is also important to consider how much recycled material is used and where it is used. As it can be seen, the ultimate effect of recycling is not very visible because in some cases it is used in modules that don't have an overall high contribution to the total (e.g. middle frame) or in modules where the material-related impacts are superseded by the manufacturing-energy related impacts (e.g. PCBAs, where most of the impact is related to the manufacturing process of the chips on the board). As seen in previous sections, this last point is true for most modules in the phone.

6.1.5.5 Allocation approach

As mentioned in the beginning, the baseline scenario's scope includes the effort needed to extract the secondary materials to be used in the device and thus, in order to avoid double counting, excludes the efforts needed to recover materials at its end of life, covering only EoL pre-treatment. In order to still get some insights on the processes left out of scope, the opposite scenario has been modelled, that is: recycled material enters the system burden free while the recycling of the device at its end of life is included in the system boundaries. Figure 6-20 shows the comparison for global warming. As it can be seen, while production emissions are slightly lower in this alternate scenario, the EoL emissions are in turn higher, actually minimally increasing the overall emissions (~1%).

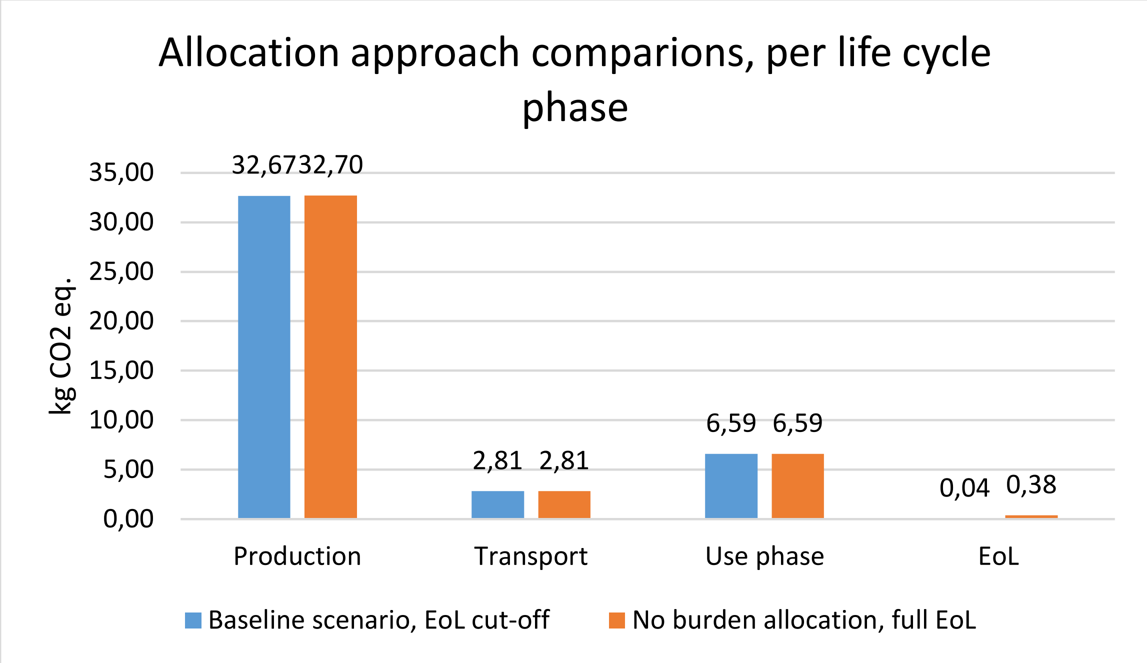

Figure 6-20 - Comparison of emissions per life cycle phase for both allocation approaches, expressed in kg CO2 eq. and divided into life cycle phasesYES

Figure 6-21 depicts the impacts distribution for the extended End of Life modelling (including material recovery), divided per treatment step across the different impact categories under analysis. From the material recovery activities, battery recycling and copper smelting stand out as main contributors.

Battery recycling is composed by a mix of pyrometallurgical and hydrometallurgical treatments, both modelled via Ecoinvent[18]. According to the documentation, their contribution to eutrophication is connected mainly by additional associated waste treatment activities mainly connected to waste plastic and graphic paper streams, as well as electricity consumed during both the hydro- and pyrometallurgical treatment of metal fractions. Regarding ecotoxicity, the main contributor is the production of chemicals used in the process (sodium hydroxide and sulphuric acid mostly) and the electricity used in the metal fraction processing. Similar hotspots are documented for ADP elements.

For global warming, the copper smelting process is the main contributor. This has also been modelled using an Ecoinvent dataset[19] and following its documentation, most emissions (89%) are attributed to direct emissions occurring during production of quicklime, which is used in different steps in metallurgical processes like smelting, mostly to purify metals[20].

[18] https://ecoquery.ecoinvent.org/3.10/cutoff/dataset/2239/documentation and https://ecoquery.ecoinvent.org/3.10/cutoff/dataset/5110/documentation

[19] https://ecoquery.ecoinvent.org/3.10/cutoff/dataset/598/exchanges

[20] https://www.calcinor.com/en/news/product-reviews/lime-an-essential-component-in-the-steel-industry

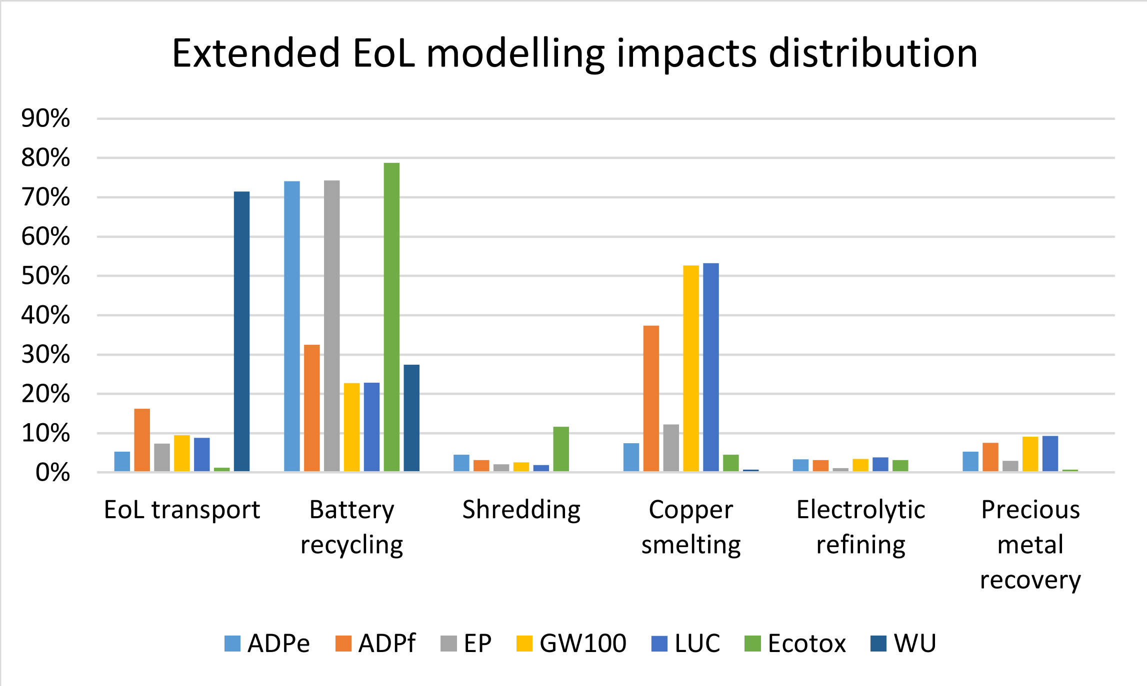

Figure 6-21 - EoL impact distribution for extended modelling (i.e. including material recovery) expressed in % of the total EoL impacts, divided by treatment step

6.2 Accessories

In this section the environmental impacts of the accessories to the Fairphone 5 are presented separately. In the following sub-sections, a closer look to the environmental hot spots for each accessory is presented.

6.2.1 Screen protector

Table 6-7 below shows the absolute values for the entire life cycle of the screen protector.

Table 6-7 - Environmental impacts of the screen protector, divided by life cycle phase

	Total	Production	Transport	EoL
Abiotic Resource Depletion, elements (kg Sb eq.)	3,21E-07	4,03E-08	2,60E-07	2,01E-08
Abiotic Resource Depletion, fossil (MJ)	3,56E+00	1,18E+00	2,24E+00	1,41E-01
Eutrophication (kg Phosphate eq.)	1,89E-04	3,66E-05	1,36E-04	1,64E-05
Global Warming, 100 years (kg CO2 eq.)	2,54E-01	2,72E-02	1,59E-01	6,82E-02
Air craft emissions (kg CO2 eq.)	9,55E-09	8,60E-09	0,00E+00	9,49E-10
Biogenic GHG emissions (kg CO2 eq.)	9,98E-03	9,09E-03	6,36E-04	2,60E-04
Biogenic GHG removal (kg CO2 eq.)	-4,01E-02	-3,93E-02	-5,53E-04	-2,57E-04
Emissions from land use change (dLUC) (kg CO2 eq.)	1,41E-04	9,75E-05	4,17E-05	1,35E-06

Fossil GHG emissions (kg CO2 eq.)	2,84E-01	5,73E-02	1,59E-01	6,82E-02
Land Use Change (-)	2,10E+00	1,29E+00	7,84E-01	3,29E-02
Ecotoxicity (CTUe)	1,58E-03	5,26E-04	1,03E-03	1,93E-05
Blue water consumption (kg)	9,52E+00	3,97E-01	2,88E-01	8,84E+00
Blue water use (kg)	1,29E+02	3,07E+01	8,55E+01	1,23E+01

Figure 6-22 below shows graphically the impact distribution across its life cycle. Most impact categories show to be driven by the transport phase with the exception of land use change and water use. Water use is driven by the EoL transport to the disposal site. LUC, on the other side, is driven by the cardboard production used in the packaging of the screen protector. Furthermore, emissions are mostly driven by the transport phase although a significant fraction is related to the EoL, in particular the municipal waste incineration.

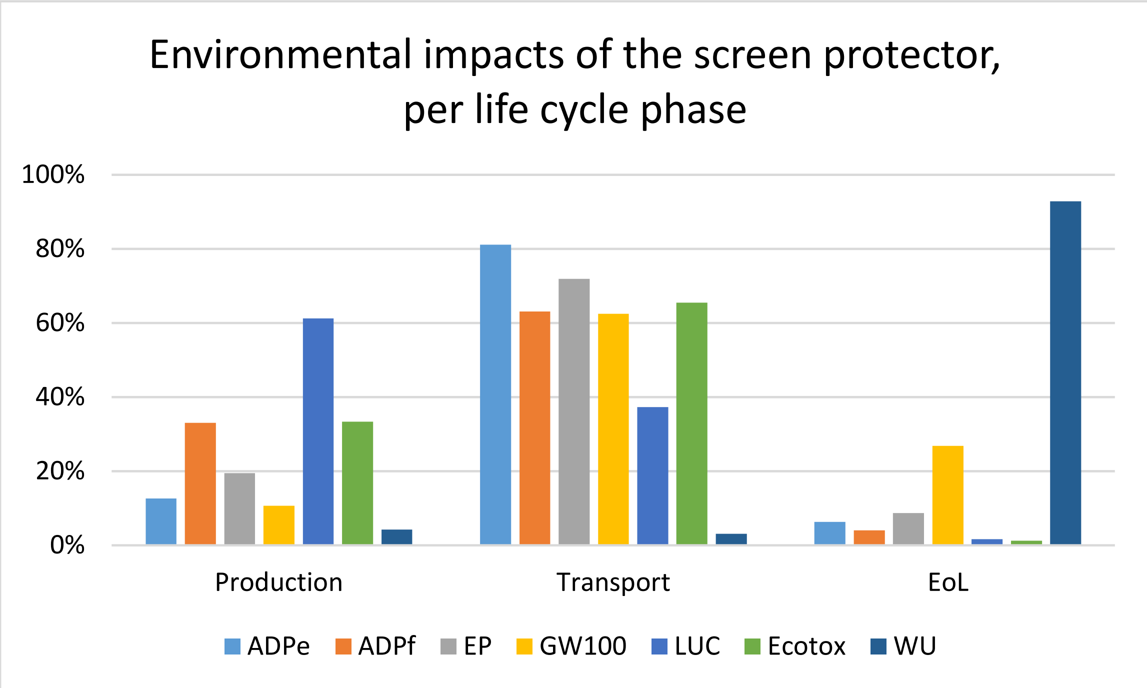

Figure 6-22 - Environmental impacts of screen protector, per life cycle phase. Presented as % of the total life impacts.

6.2.2 Soft case

The environmental impacts of the different life cycle phases of the soft case are presented in Table 6-8 below.

Table 6-8 - Environmental impacts of the soft case, divided by life cycle phase

	Total	Production	Transport	EoL
Abiotic Resource Depletion, elements (kg Sb eq.)	1,88E-07	3,79E-09	1,72E-07	1,23E-08
Abiotic Resource Depletion, fossil (MJ)	1,99E+00	4,13E-01	1,49E+00	9,28E-02
Eutrophication (kg Phosphate eq.)	1,17E-04	1,17E-05	8,97E-05	1,51E-05

Global Warming, 100 years (kg CO2 eq.)	2,23E-01	4,28E-02	1,05E-01	7,51E-02
Air craft emissions (kg CO2 eq.)	1,78E-08	1,72E-08	0,00E+00	5,28E-10
Biogenic GHG emissions (kg CO2 eq.)	3,65E-03	3,09E-03	4,21E-04	1,40E-04
Biogenic GHG removal (kg CO2 eq.)	-3,54E-03	-3,04E-03	-3,66E-04	-1,36E-04
Emissions from land use change (dLUC) (kg CO2 eq.)	4,87E-05	2,09E-05	2,76E-05	1,77E-07
Fossil GHG emissions (kg CO2 eq.)	2,23E-01	4,28E-02	1,05E-01	7,51E-02
Land Use Change (-)	6,37E-01	9,75E-02	5,19E-01	2,06E-02
Ecotoxicity (CTUe)	7,18E-04	2,19E-05	6,84E-04	1,26E-05
Blue water consumption (kg)	6,40E+00	3,15E-01	1,90E-01	5,89E+00
Blue water use (kg)	1,26E+02	6,12E+01	5,66E+01	7,96E+00

Figure 6-23 below shows the impact share across life cycle phases. As it can be seen, the production impacts are comparably low in relation to the impacts associated with the product's distribution. EoL impacts also show to be relatively low except from water use, which is driven by the truck transport fraction to the disposal site. The PU fraction incineration at the EoL also shows a significant contribution on Global Warming (above 30% of the total). Finally, although comparatively small, the production phase also shows some contribution for both ADP fossil and GW, in both cases mostly driven by the electricity needed for the final manufacturing of the case.

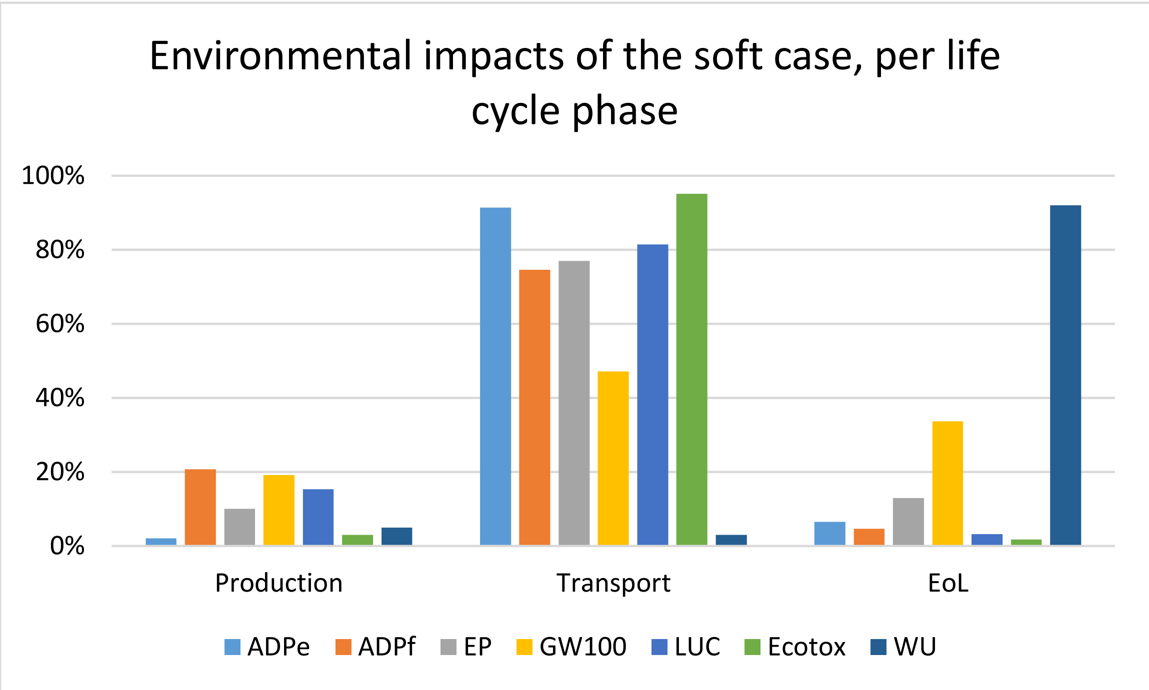

Figure 6-23 -Environmental impacts of soft case, per life cycle phase. Presented as % of the total life impacts.

6.2.3 USB-C to audio jack adapter

Table 6-9 below shows the environmental impacts of the entire life cycle of the adapter.

Table 6-9 - Environmental impacts of the USB-C to audio jack adapter, divided by life cycle phase

	Total	Production	Transport	EoL
Abiotic Resource Depletion, elements (kg Sb eq.)	1,22E-04	1,22E-04	7,05E-09	1,09E-09
Abiotic Resource Depletion, fossil (MJ)	8,56E-01	7,91E-01	6,08E-02	4,00E-03
Eutrophication (kg Phosphate eq.)	6,32E-05	5,90E-05	3,67E-06	4,59E-07
Global Warming, 100 years (kg CO2 eq.)	6,83E-02	6,37E-02	4,31E-03	2,71E-04
Air craft emissions (kg CO2 eq.)	1,40E-08	1,40E-08	0,00E+00	6,34E-12
Biogenic GHG emissions (kg CO2 eq.)	7,81E-03	7,79E-03	1,72E-05	4,14E-06
Biogenic GHG removal (kg CO2 eq.)	-7,51E-03	-7,49E-03	-1,50E-05	-4,18E-06
Emissions from land use change (dLUC) (kg CO2 eq.)	7,76E-05	7,64E-05	1,13E-06	1,36E-07
Fossil GHG emissions (kg CO2 eq.)	6,79E-02	6,34E-02	4,30E-03	2,71E-04
Land Use Change (-)	2,33E-01	2,11E-01	2,12E-02	9,44E-04
Ecotoxicity (CTUe)	8,98E-04	8,63E-04	2,80E-05	6,45E-06
Blue water consumption (kg)	3,37E+00	3,12E+00	7,79E-03	2,35E-01
Blue water use (kg)	1,33E+02	1,30E+02	2,32E+00	7,63E-01

A graphic representation of the values above can be seen in Figure 6-24. Unlike the previous accessories, the environmental impacts of the adapter cable are heavily driven by the production phase, while the contribution of the transport and EoL remain comparatively low.

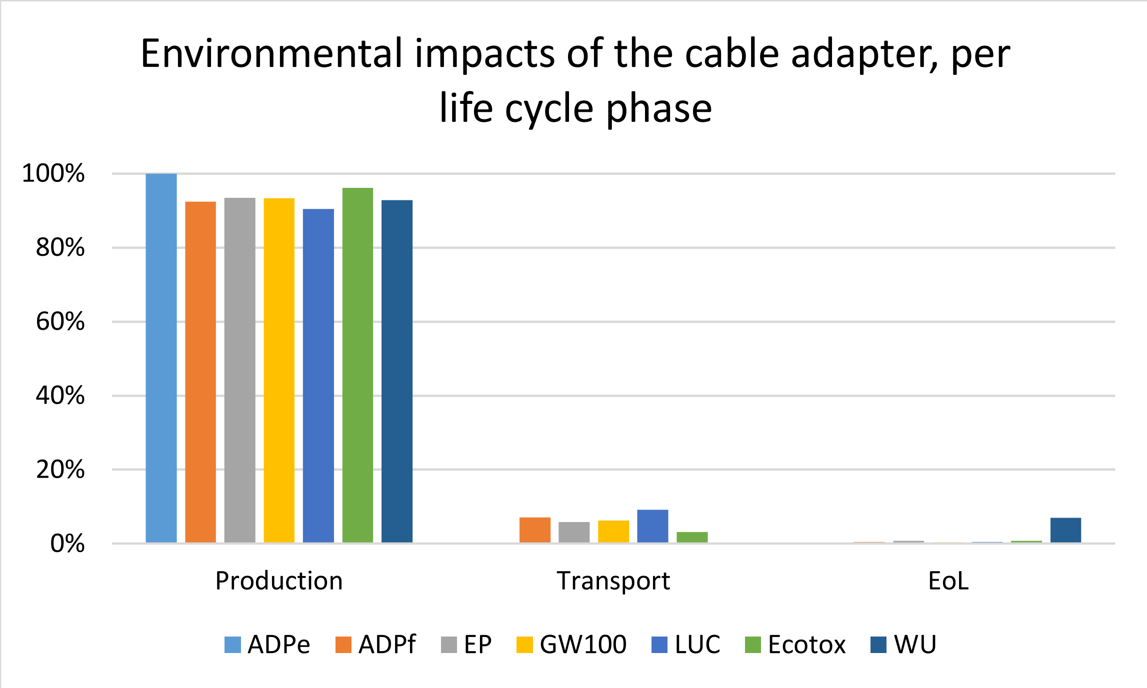

Figure 6-24 - Impact share of the USB-C to audio jack adapter, per life cycle phase

Figure 6-25 shows a closer look into the environmental impact distribution for the adapter cable production, divided into its parts. Both connectors show significantly higher impacts than the cable, the USB-C connector being the main driver in general. The impacts for the USB-C connector are in turn mostly dominated by its gold and chromium content.

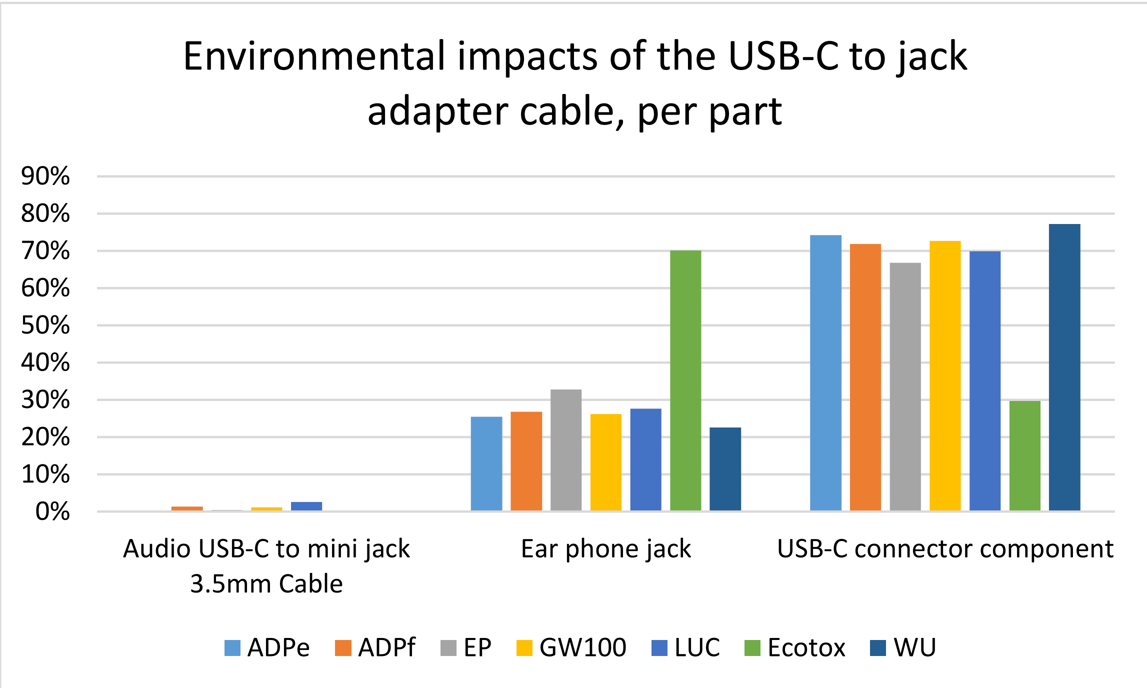

Figure 6-25 - Environmental impacts of the adapter, divided into its parts: audio jack, USB-C connector and cable

For ecotoxicity however, the earphone jack shows a higher impact. This is related to the triphenyl phosphate used in the manufacturing process of the audio jack (according to the Fairphone 3 material data). This has been modelled using an Ecoinvent dataset[21]. According to its documentation the ecotoxicity can be traced back to solid emissions via air and ground that take place higher up in the supply chain during the production of various chemicals e.g. benzene. It is to be noted however that the dataset is old and, as commented in other points earlier, Ecoinvent datasets sometimes overestimate the ecotoxicity values.

6.2.4 Fairbuds

In this section the results for the Fairbuds LCA will be presented. First the baseline results will be analysed, followed by a discussion on the secondary and primary material use scenarios and finally, an overview of the repair overheads.

6.2.4.1 Baseline results

Table 6-10 below shows the absolute values for the selected impact categories for the Fairbuds, throughout their entire life cycle.

Table 6-10 - Environmental impacts of the Fairbuds per life cycle phase

	Total	Production	Transport	Use phase	EoL
Abiotic Resource Depletion, elements (kg Sb eq.)	2,03E-04	2,03E-04	1,67E-07	7,04E-08	6,32E-08
Abiotic Resource Depletion, fossil (MJ)	3,78E+01	2,82E+01	6,71E+00	2,64E+00	2,45E-01
Eutrophication (kg Phosphate eq.)	2,33E-03	1,76E-03	4,82E-04	6,05E-05	2,78E-05
Global Warming, 100 years (kg CO2 eq.)	3,13E+00	2,40E+00	4,71E-01	2,35E-01	1,66E-02
Air craft emissions (kg CO2 eq.)	1,73E-03	1,73E-03	0,00E+00	4,38E-07	4,51E-10
Biogenic GHG emissions (kg CO2 eq.)	2,92E-01	1,93E-01	8,16E-04	9,74E-02	2,47E-04
Biogenic GHG removal (kg CO2 eq.)	-3,28E-01	-2,32E-01	-6,90E-04	-9,47E-02	-2,49E-04
Emissions from land use change (dLUC) (kg CO2 eq.)	1,83E-03	1,72E-03	5,53E-05	4,34E-05	7,36E-06
Fossil GHG emissions (kg CO2 eq.)	3,18E+00	2,46E+00	4,71E-01	2,32E-01	1,66E-02
Land Use Change (-)	9,33E+00	5,84E+00	1,05E+00	2,39E+00	5,73E-02
Ecotoxicity (CTUe)	9,02E-03	6,64E-03	1,31E-03	7,15E-04	3,52E-04
Blue water consumption (kg)	4,84E+01	3,06E+01	8,16E-01	2,11E+00	1,49E+01
Blue water use (kg)	5,10E+03	2,82E+03	1,77E+02	2,06E+03	4,38E+01

[21] https://ecoquery.ecoinvent.org/3.10/cutoff/dataset/16636/documentation

A graphic representation of the environmental impacts of the Fairbuds per life cycle phase is shown in Figure 6-26 below. Most impact categories are driven by the production phase, having a share of 60% or more for all indicators. Transportation follows with 10-20% of the impacts across indicators. The use phase shows some significant contribution for Land Use Change (driven mostly by renewable sources in the electricity mix, like wind or PV due to their direct use of land or biofuel and its indirect use of land) and EoL for water use, driven by the EoL transportation effort.

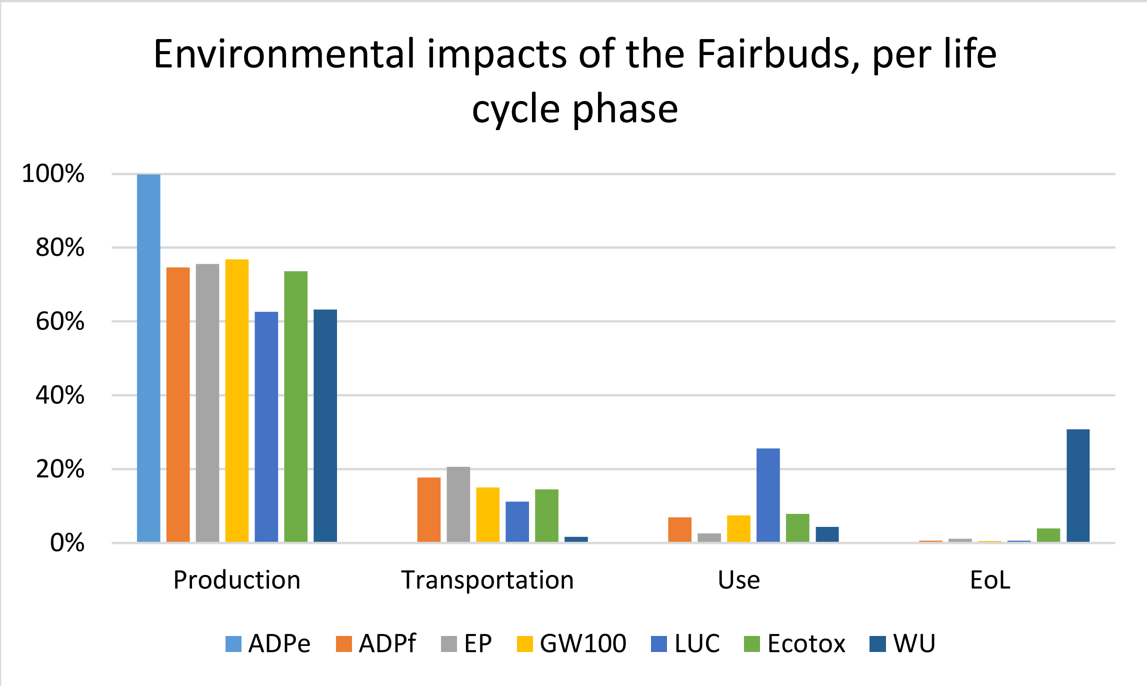

Figure 6-26 - Share of environmental impacts of the Fairbuds per life cycle phase, as % of the total

When taking a closer look at the production phase, the situation depicted in Figure 6-27 can be seen. The graph shows the environmental impacts of production divided by module (following the spare parts list), including package. Both earbuds show similar impact levels, around 20-30% of the total across the board and are the main drivers, followed by the charging case core which contributes around 20% of the production totals for most impact categories. The charging case shell follows with a slightly lower contribution, while the rest of the modules show a comparatively low impact. The absolute values can be seen in Table 6-11.

Table 6-11 - Environmental impacts of Fairbuds production, by module

	Total	Charging case battery	Charging case core	Charging case outer shell	Earbuds battery kit
Abiotic Resource Depletion, elements (kg Sb eq.)	2,03E-04	1,57E-05	1,04E-04	4,71E-07	1,11E-06
Abiotic Resource Depletion, fossil (MJ)	2,82E+01	2,01E+00	5,60E+00	3,90E+00	7,78E-01
Eutrophication (kg Phosphate eq.)	1,76E-03	1,59E-04	2,07E-04	5,68E-04	6,09E-05
Global Warming, 100 years (kg CO2 eq.)	2,40E+00	1,94E-01	4,92E-01	3,72E-01	7,51E-02

Air craft emissions (kg CO2 eq.)	1,73E-03	4,42E-06	2,39E-04	1,48E-07	6,48E-09
Biogenic GHG emissions (kg CO2 eq.)	1,93E-01	3,51E-03	3,53E-02	1,47E-02	1,07E-03
Biogenic GHG removal (kg CO2 eq.)	-2,32E-01	-3,87E-03	-3,38E-02	-1,43E-02	-1,09E-03
Emissions from land use change (dLUC) (kg CO2 eq.)	1,72E-03	6,27E-05	4,82E-04	2,83E-04	3,56E-05
Fossil GHG emissions (kg CO2 eq.)	2,46E+00	1,94E-01	4,90E-01	3,72E-01	7,51E-02
Land Use Change (-)	5,84E+00	2,05E-01	1,17E+00	6,16E-01	5,20E-02
Ecotoxicity (CTUe)	6,64E-03	4,53E-04	1,36E-03	2,96E-04	3,13E-04
Blue water consumption (kg)	3,06E+01	9,53E-01	5,30E+00	8,35E+00	2,63E-01
Blue water use (kg)	2,82E+03	7,09E+01	6,80E+02	2,33E+02	7,17E+01

	Earphone left (bare)	Earphone right (bare)	Eartips kit	Silicone rings	Packaging
Abiotic Resource Depletion, elements (kg Sb eq.)	4,96E-05	3,13E-05	3,20E-07	4,83E-08	9,55E-09
Abiotic Resource Depletion, fossil (MJ)	7,75E+00	7,27E+00	2,38E-01	3,59E-02	5,92E-01
Eutrophication (kg Phosphate eq.)	3,53E-04	3,32E-04	4,68E-06	7,06E-07	7,90E-05
Global Warming, 100 years (kg CO2 eq.)	6,43E-01	6,00E-01	1,87E-02	2,83E-03	4,85E-03
Air craft emissions (kg CO2 eq.)	7,44E-04	7,44E-04	9,95E-09	1,50E-09	2,97E-09
Biogenic GHG emissions (kg CO2 eq.)	4,21E-02	3,88E-02	8,13E-03	1,23E-03	4,84E-02
Biogenic GHG removal (kg CO2 eq.)	-4,06E-02	-3,75E-02	-7,87E-03	-1,19E-03	-9,20E-02
Emissions from land use change (dLUC) (kg CO2 eq.)	3,29E-04	2,94E-04	1,51E-05	2,28E-06	2,21E-04
Fossil GHG emissions (kg CO2 eq.)	6,50E-01	6,07E-01	1,85E-02	2,78E-03	4,82E-02
Land Use Change (-)	1,59E+00	1,48E+00	5,14E-01	7,76E-02	1,30E-01
Ecotoxicity (CTUe)	1,97E-03	1,81E-03	2,47E-05	3,72E-06	4,14E-04
Blue water consumption (kg)	6,81E+00	6,10E+00	1,57E-01	2,37E-02	2,64E+00
Blue water use (kg)	8,77E+02	8,39E+02	2,81E+01	4,24E+00	1,58E+01

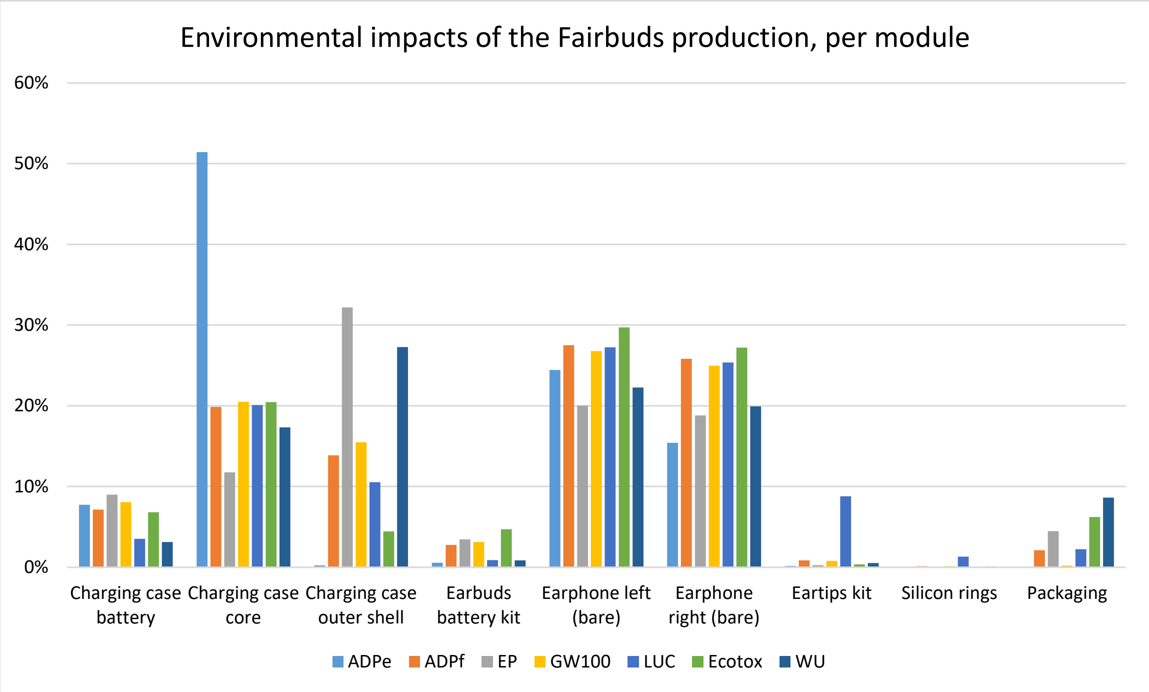

Figure 6-27 - Environmental impacts of the Fairbuds production per module, as % of the total for production

Figure 6-28 shows the impacts related to the earbuds, adding both the right and left earbuds. The electronics on the small PCBAs within the earbuds drive from 60% to almost 95% of the earbuds' production impacts, while the casing, the micro speakers and the various smaller mechanical elements a less significant role.

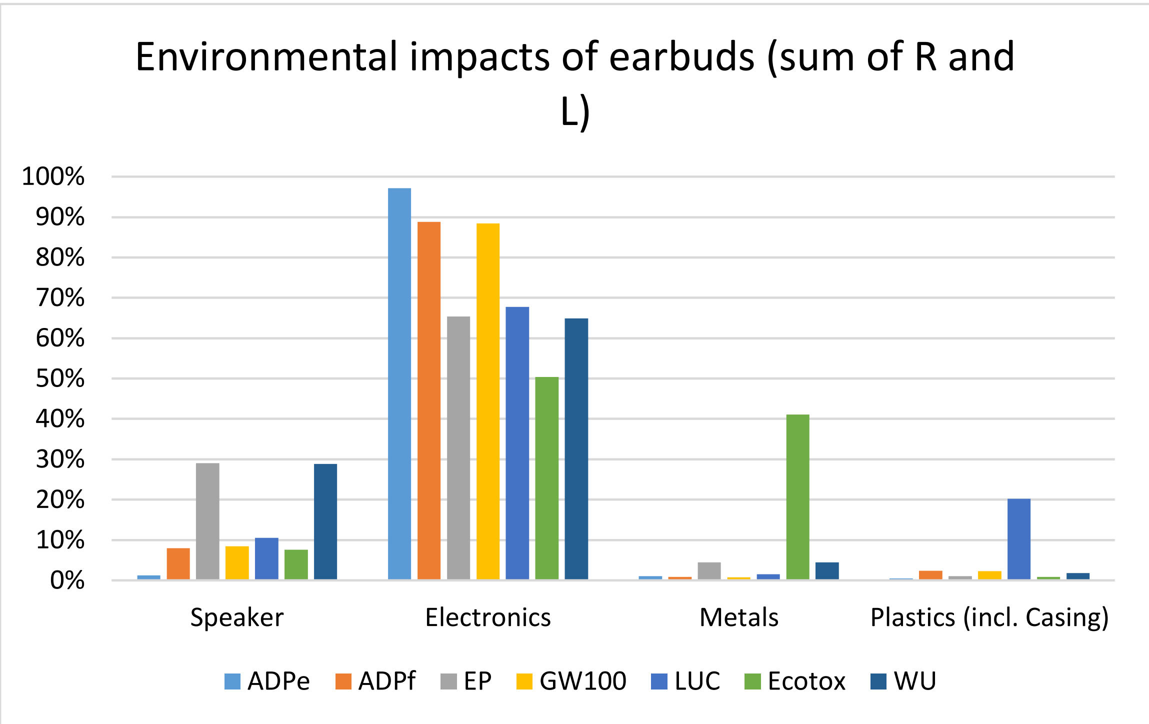

Figure 6-28 - Environmental impacts of the production of the headphones. This graph includes the impacts of both right and left earbuds, divided per component type.

Figure 6-29 below shows a breakdown of the charging case production impacts, divided by its parts. The figure includes both, charging core (mostly the electronics and part of the housing) and the shell (external housing and magnets). The main drivers of the charging case production impacts are the magnets and the main PCBA. The pogo-pin boards show significant contributions for some impact categories. The rest of the parts such as the charge board (i.e. the USB-C PCBA) and the housing show a comparatively negligible impact. Smaller mechanical elements grouped under category 'others' all show contributions lower than 1% across all impact categories and are therefore removed from the graph.

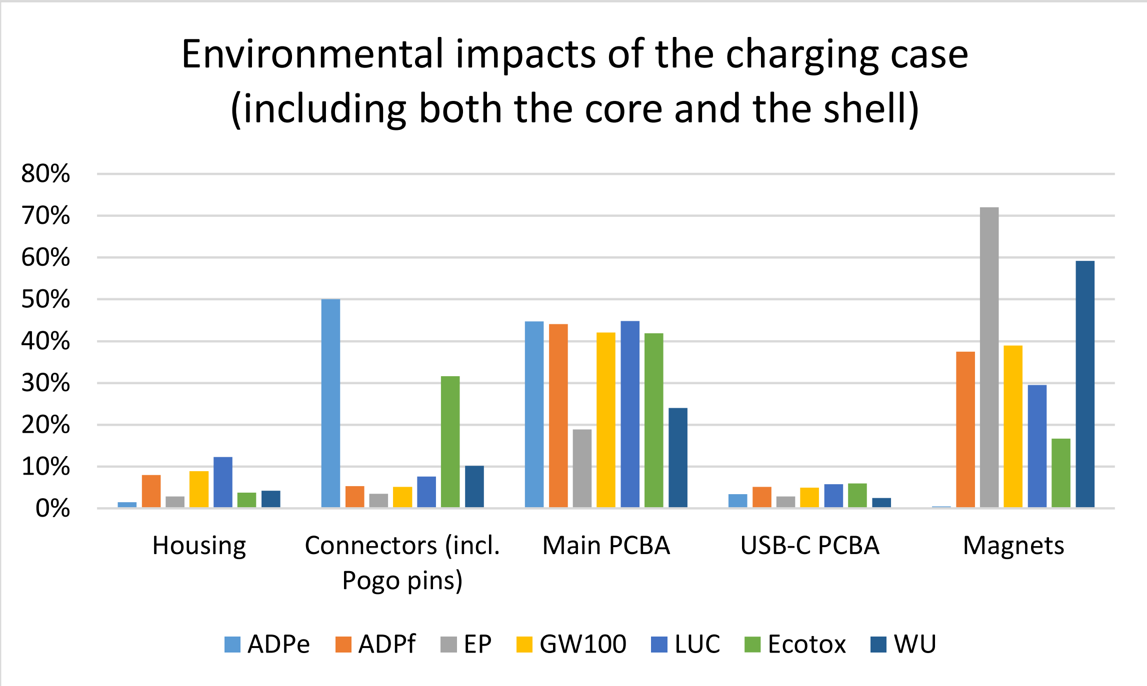

Figure 6-29 - Environmental impacts of charging case production per part

The impacts of the magnets are related mostly to the manufacturing of the praseodymium dioxide, modelled due to the lack of a better fit as praseodymium oxide. The current Sphera database offers two datasets for Praseodymium oxide production: the Bayan Obo route and the Sichuan route. The former was chosen on the basis of the proximity of the actual supplier to the main mining site. While literature on this particular material is scarce, a study from 2018 performing an LCA on magnet production from different routes (Marx, Schreiber, Zapp, & Walachowicz, 2018) does identify the Bayan Obo route as performing worse environmentally than the other two routes under study: Mount Weld (Malaysia) and Mountain Pass (US). There are several reasons for this but can be linked mostly to the heavy use of chemicals, a comparatively unfavorable energy mix and poor recovery rates within the process that require an increased amount of raw material input. Furthermore, the paper also points to an outdated and not-renovated tailing treatment system, which likely affects indicators like ecotoxicity. It is noteworthy however that the paper also points out their Bayan Obo modelling was the one with lowest data quality of the three and it is therefore unclear to what extent the dataset used in this LCA properly reflects the actual production route and its impacts.

The impacts related to the pogo pin boards are mostly due to the gold production for the contacts. Gold shows to be of relevance also for the battery related impacts where ADPe, Ecotox and WU are mainly caused by its production. The rest of battery associated impacts are mostly driven by the lithium cobalt oxide production. In this case the manufacturing energy for the battery does not play a significant role in its impacts.

As for the main PCBA, Figure 6-30 below shows a breakdown of its impacts. Since this is a not very densely populated board (as compared to the Fairphone 5 primary board), the PCB itself shows to be driving all impacts, while the ICs are the secondary drivers. After that passive components and other semiconductors show a lower but still significant contribution while the connectors show a comparatively low effect.

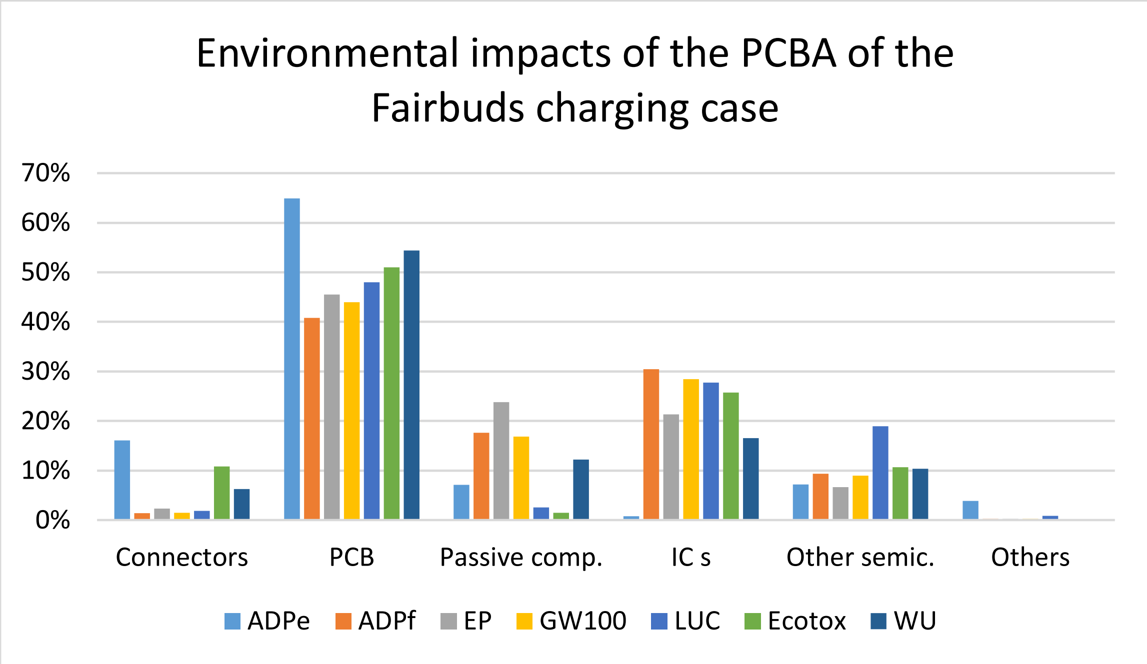

Figure 6-30 - Environmental impacts of the main PCBA if the Fairbuds in the charging case, per component type

6.2.4.2 Recycled content vs primary materials

The Fairbuds use above 90% of recycled plastic for most of the housing and around 30% in weight of recycled magnets. In order to estimate the benefits of that design choice, an alternative scenario has been built using exclusively primary materials. Figure 6-31 below shows the comparison between both for climate change. The graphic shows how the recycled magnets show the biggest improvement of around 30% for the outer shell module (in combination with the plastic housing). For the other modules i.e. charging case core and both earbuds, the effects of using secondary plastic are more limited, mostly because the main impact driver in these modules is the electronics.

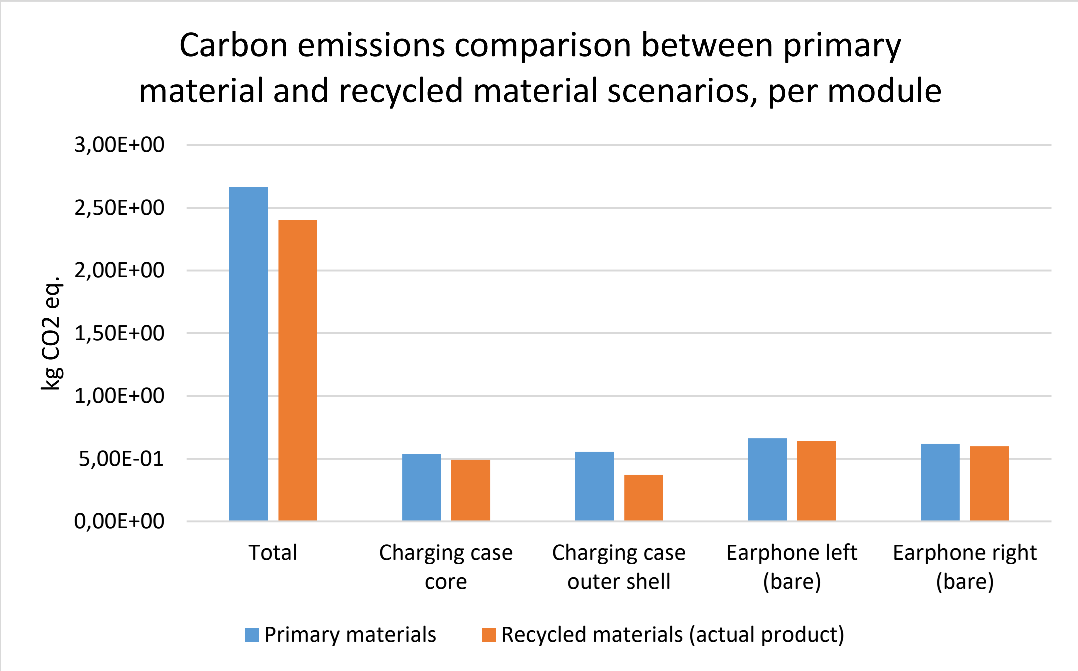

Figure 6-31 - Comparison between baseline scenario (actual product with secondary materials) and primary material scenarios, carbon emissions. The figure includes only the modules in which recycled content is used.

Table 6-12 below shows the reduction in environmental impacts related to the use of recycled materials. For most cases the reduction is of between 10% and 16% with exception of ADPe and LUC, in which the reduction is much more limited, particularly for ADPe since none of the materials critical to this indicator are targeted in the design.

Table 6-12 - Reduction on environmental impacts due to the use of recycled materials (primary materials scenario as reference)

Impact categories	Change of total impact for Fairbuds' production
Abiotic Resource Depletion, elements (kg Sb eq.)	0%
Abiotic Resource Depletion, fossil (MJ)	-16%
Eutrophication (kg Phosphate eq.)	-13%
Global Warming, 100 years (kg CO2 eq.)	-10%
Land Use Change (-)	-4%
Ecotoxicity (CTUe)	-10%
Blue water consumption (kg)	-13%

6.2.4.3 Repair scenarios

In order to estimate the environmental impacts of repair activities, two main repair scenarios have been analysed: replacement and repair. In this instance no general repair scenario has been built, focusing instead on the module-per-module analysis. For the module level repair scenarios, the following components were assumed to be replaced:

- Charging case core: USB-C board (full PCBA).
- Charging case outer shell: both magnets.
- Earbuds (R and L): Microphone component.

Figure 6-32 shows a comparison of both the replacement and repair scenarios for all modules, broken down per repair overhead element: production of spare parts, electricity use during repair (only for module level repair), transport of spare part and additional EoL. Full values can be found in Table 6-13 below.

Table 6-13 - Global Warming emissions for the replacement and repair of the Fairbuds' modules, absolute values (in kg CO2 eq.)

Module / Part repair	Spare part	Repair effort	Transport	EoL
Charging case battery	1,94E-01		1,42E-03	1,95E-03
Charging case core	4,92E-01		3,30E-03	5,96E-03
Charging case outer shell	3,72E-01		3,35E-03	4,12E-02
Earbuds battery kit	7,51E-02		6,00E-04	8,23E-04
Eartips replacement	1,87E-02		3,35E-04	4,13E-03
R earbud	6,00E-01		6,55E-04	1,18E-03
L earbud	6,43E-01		6,55E-04	1,18E-03
Silicon rings	2,83E-03		5,05E-05	6,22E-04
Charging case core	4,26E-02	8,36E-04	5,71E-03	1,45E-04
Charging case outer shell	3,36E-01	8,36E-04	5,80E-03	2,77E-03
R earbud	5,26E-02	8,36E-04	1,13E-03	2,24E-04
L earbud	5,26E-02	8,36E-04	1,13E-03	2,24E-04

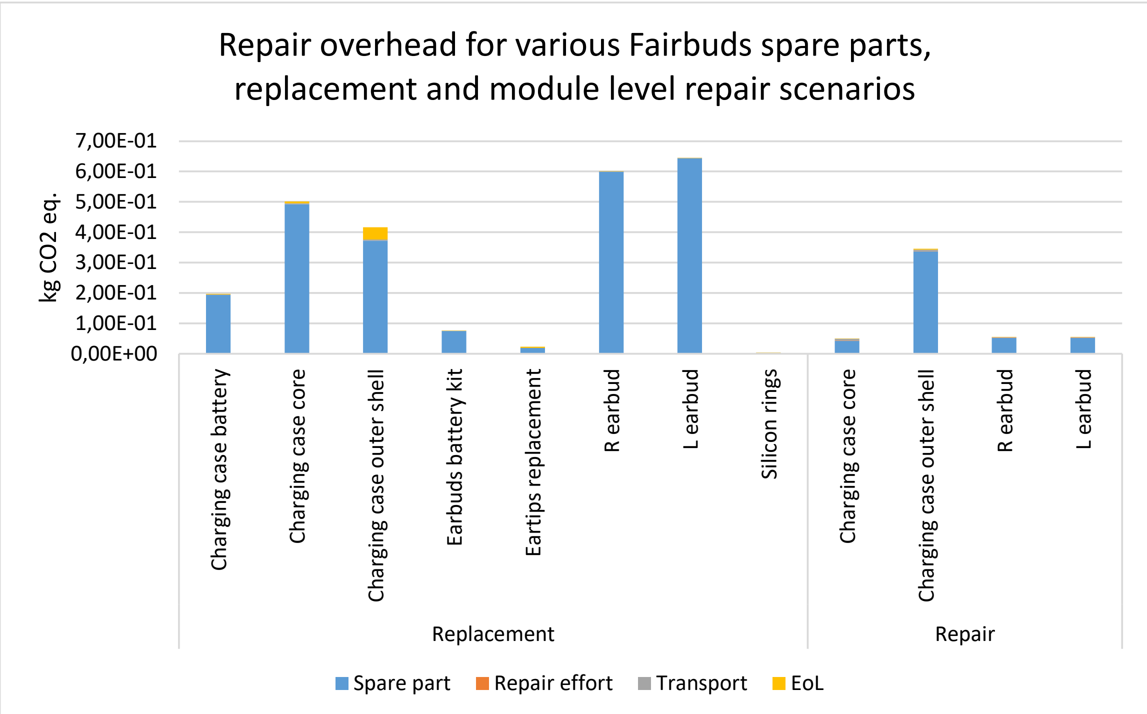

Figure 6-32 - Repair overhead for the Fairbuds’ modules, carbon emissions

The part showing the highest repair overhead are the earbuds, since they are the modules with the highest impacts and therefore the production of the spare part has significant associated effects. For the same reason, these also show a very significant benefit potential with regards to module level repair, since part of the module then can be kept in use. Similarly, the charging case core also shows significant benefits when module level repair is performed. In general, for all options the production of the spare part dominates the repair overhead beyond all other aspects.

As a more direct way of visualizing the repair impacts and following what was shown for the Fairphone 5 in Section 6.1.3, the environmental payback time has been estimated, please find the values in the Table 6-14 below.

Table 6-14 - Estimated environmental payoff time for replacement or repair of the Fairbuds modules

Module / Part repair	Replacement payoff	Repair payoff
Charging case battery	43 days	
Charging case core	4 months	5 days
Charging case outer shell	3 months	2,5 months
Earbuds battery kit	12 days	
Eartips replacement	< 1 day	
R earbud	5 months	7 days
L earbud	5 months	7 days
Silicon rings	< 1 day	

7 Conclusions and recommendations

7.1 Fairphone 5

In accordance with previous studies, the production phase is still the core of the environmental impacts of the device. Within the production phase, integrated circuits, and semiconductors in general show to have a significant influence (both in the mainboards but also in the scattered electronics across the modules).

In this LCA a new modelling approach has been applied to the ICs, which allows more flexibility and accuracy in terms of the die-to-package ratio but also in terms of the critical metals contained. This change has resulted in a drop of the environmental impacts associated with chips on the mainboard, as the previously used generic datasets tended to overestimate slightly most of the analyzed impacts. However, from literature we know that the ongoing trends in semiconductor industry (miniaturization but also 3D architecture and higher transistor density, see comments made in Section 6.1.1.1) involve more energy intensive processes and may be driving impacts up.

The display module modelling has also been changed with respect to previous iterations in order to reflect the new technology utilized. The results show a significant impact of the display manufacturing energy use, which in this LCA has been modelled using secondary data. Therefore, acquiring real data from the specific suppliers may help ameliorate the current level of uncertainty.

Other important differences in modelling have to do with the camera modules, in particular with the image sensors within. It has been discovered that it is common practice to have stacked layered sensors with at least one imaging silicon die and one CMOS silicon die beneath. The industry trend with increasingly high resolution and versatile cameras seems to be of further 3D integration, which is also expected to rise the related impacts.

Overall, another insight from the results is that electricity use is consistently found to be the main driving force behind most identified hotspots across modules. Fairphone B.V. is currently engaging with suppliers in order to bring more renewable energiy into the supply chain, which shows clear potential for improving the overall impacts and counterbalance other industry trends. However, it has also been seen that this energy transition does not come without trade-offs and that while emissions are clearly reduced from increased use of PV or wind energy, other impact categories like resource use and land use change may be negatively impacted.

Regarding repair, the results show once again the clear benefits of repair and extended use against premature disposal of the device. The environmental payback time also shows that in general a repair pays off relatively quickly. Following a trend observed from previous iterations of the device, there seems to be no significant difference between the full module replacement and board level repair approaches, except in the case of the display module (although, as already clarified above, this comes with great uncertainty). Given the comparatively low impacts of the single modules, the additional efforts for single-component replacement do not seem to clearly translate into benefits. Regarding the PCBA reuse scenarios, the benefits against short lifespan renewals shows to be clear. However, as it also happens with the use of secondary materials and extended lifetime in general, the allocation of impacts across multiple *lives* shows significant effect in the results. Furthermore, a more detailed definition of the use case may shed more light into trade-offs and the extent of the benefits since this is also directly affected by non-technical aspects (e.g. social obsolescence).

This LCA also takes a look at the effect of using secondary material. The LCA results however do not show a clear benefit. This has various causes: to begin with, as discussed earlier, energy (and in particular electricity) has been identified as a very relevant factor across the supply chain. While using secondary material avoids the extraction of yet more primary material, secondary materials also need to be extracted from the technosphere. While usually less energy intensive than primary production, secondary production also entails efforts and energy use. Secondly, many environmental hot spots of the device are related to energy use in manufacturing of intermediate products, where the impacts related to the material content are usually less environmentally relevant comparatively. Lastly, circularity is an aspect that is not yet fully integrated in LCA and that poses a challenge since it usually involves activities and benefits that span across different products. It is therefore also the case that no single impact category used in this study single-handedly captures the effects of circularity. The one coming closest is likely ADPe, which is however very focused in only certain metals. The use of credits to avoided production may help, but it poses questions and challenges of its own and the risk of double counting.

Finally, when looking at how this device's LCA results compare to the previous model's (Sánchez, Proske, & Baur, 2022), some challenges arise. There have been significant modelling changes and data source changes that make it difficult to directly compare many of the modules' impacts (ICs, Display, Cameras). For the modules where no significant changes have occurred, continuity can be observed. It is therefore more likely than not, that this device's impacts are very much in line with the previous one. Some aspects have been clearly improved e.g. renewable energy is used in some processes already, the device uses less total PCB area than the previous one which reduces the PCB related impacts. Other aspects are likely to have increased as, for example, the semiconductor industry shows increasing efficiency but also increasingly energy intensive production lines.

7.2 Accessories

In general, the accessories analyzed in this LCA show very low environmental impacts when compared with the main product since they are less complex devices.

Regarding the screen protector and the soft case, due to their significantly low production impact, transport becomes the environmental hot-spot which suggests that a logistics strategy that considers environmental aspects when deciding how to ship these products (i.e. which means of transport, alongside the main product or separate, etc.) may be the most efficient way of impact reduction. Furthermore, the soft case shows that in such products the use of secondary material does support the reduction of production-based impacts.

The accessories including electronics however, do show a more central role of the production phase when it comes to their environmental performance. In the case of the adapter cable the focus should lay clearly in the connectors (most relevantly in the USB-C side) and their material composition. Strategies like the use of secondary materials (e.g. gold) or decarbonized supply chains may be of interest, although it is also important to keep in mind that in absolute terms their impact is low.

Finally, when looking at the Fairbuds, the first noteworthy point is that in absence of complex ICs the production impact remains low (around 3 kg CO_2eq.) despite it being an electronic product. Within its production however several hot spots can be identified. On the one hand, some key elements regarding material use are highlighted such as the pogo pins for the earphone-case connection and the magnets for fixing them. When looking at the analysis of the use of secondary material, it can be seen that the use of secondary material shows more clear benefits than in the case of the smartphone, mostly because this is a much smaller product with a lower contribution of the electronics to the general impacts. Moreover, the use of recycled magnets is the main contributing factor in this regard, although as mentioned in the results discussion above, the modelling of both the primary and secondary magnets is subjected to significant uncertainty due to the lack of sufficient quality data and thus it should be treated with caution.

Here once again, efforts like secondary material use and pushing for increased use of renewable energy in supply chains seem like clear pathways for improvement. On the other hand, when looking at the electronics, the PCBs show to be the impact drivers and thus potential further reduction could be achieved through a reduction of the number/size of the used PCBs insofar technically feasible. Lastly, analysis of repair scenarios shows an overall low repair overhead with clear benefits of board level repair in some cases. However, since the production impacts of the Fairbuds are generally low, the absolute savings via repair and extended lifetime are also limited, especially when compared with the main product.

8 Annex

The full results' tables as well as the quality assessment matrix are presented in separate documents for easier reading and for confidentiality issues.

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