Life cycle analysis of a refurbished smartphone in Chile

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Abstract. A complete life cycle analysis (LCA) of a refurbished high-end smartphone in Chile is conducted to find out its environmental impacts and evaluate potential advantages compared to a new one and a modular alternative. The functional unit is defined as the daily use of smartphone for 3 years, including audio, video, and internet. The results show that use and production phase are the most impactful (52,0% and 45,2%, respectively), but phases contribute differently depending on the impact category. It is also found that a refurbished smartphone presents 71% and 60% lower global warming potential than a new version and modular smartphone, respectively. The lower impacts of the refurbished alternative are due to the reutilization of the device avoiding the impacts related to material extraction and device production. However, it is not possible to assess the significance of these differences due to the lack of uncertainty analysis in other studies. In conclusion, refurbishing can avoid extraction and production phases which reduces environmental impacts. Yet, to appropriately compare different circular models, it is imperative to calculate and publish the uncertainty of LCA results.

1 Introduction

Smartphones have a high rate of replacement, whether due to planned obsolescence, user preference, or technological change, among other aspects. This leads to increasing pressure on the environment through the extraction of raw materials and the production of electronic waste. To produce 1.2 billion mobile phones sold worldwide, 84 tonnes of antimony, 7.1 tonnes of beryllium, 12.1 tonnes of palladium and 0.3 tonnes of platinum are required [1]. In addition, a smartphone can emit an average of 40 kg CO_2 eq. over its lifetime [2] and pollute some 60 m^3 of water [3]. Therefore, the life cycle of a smartphone has to account all impact categories because the complexity to produce it can yield different impacts in different life cycle phases. [4]

A study of the environmental impacts of a refurbished iPhone 8 64 MB in Chile (called RePhone) is conducted based on the ISO 14040 and 14044 standards. The main objectives of the study are to compare the environmental impacts between the refurbished smartphone, a new one with the same characteristics and a modular phone, identify the elements with the highest impact in different impact categories in its life cycle, and assess the impact of two types of packaging according to its distribution channel.

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2 Methodology

2.1 Stages

The life cycle is divided into five macro-stages:

(i) Production and import: include all manufacturing processes and transport of spare parts (batteries, glass backcover, and screen) and accessories (USB cable and SIM chip). The manufacturing processes were modelled using secondary data which include raw materials extraction and transport to the manufacturing site. (The cut-off logic is used, so the environmental impacts of the reused inputs production are not considered)

(ii) Refurbishment: processes and material flows required for smartphone refurbishment and packaging. Only the replaced parts' end of life is considered because there were no available data about the equipment or electricity used in the refurbishment process. It is assumed that replaced batteries are taken to a controlled disposal site, while irreparable glass backcovers go to a landfill. Replaced screens are considered to have no environmental impact as they are sold to a secondary market.

(iii) Distribution: there are two sales channels, B2B and B2C. Distances and means of transport vary by each channel. Distribution impacts are the average between the two channels weighted by sales volume.

(iv) Use: phase that considers electricity consumption for 3 years of a full daily recharge (phone recharge plus idle charger connection) and the disposable packaging discarding. 2016 Chilean electricity mix is used.

(v) End of life: 100% of mobile phones are considered to be disposed in landfills. [5]

2.2 Functional unit

The functional unit is the daily use of a RePhone iP8 64GB for 3 years, including audio, video, and internet. The reference flow is one RePhone iP8 64GB device.

2.3 Scope

The scope is *cradle to grave*. Primary data were collected in 2020 for 9 months. The baseline scenario is 3 years of use.

The geographical scope is determined by the location of the company's operations and the origin of imported inputs and equipment and includes Chile, EEUU, China, Japan, and Taiwan. These data influenced the calculation of transport distances and the database selection.

Assumptions are made about the packaging of spare parts, the origin of materials and regional distribution. It is also assumed that during the 3 years of use, there is no change of spare parts.

A closed-loop logic is used, in which the environmental impacts of reused inputs production are not considered (ISO 14044, 2006). However, all processes required for reuse are considered including the transport of input from origin to destination and the material extraction and production to manufacture the replaced parts.

The cellular and internet infrastructure are excluded from the study.

2.4 Data collection

Primary data were provided by the company. For missing data, secondary data sources (ecoinvent and reference articles) were used.

For the modelling the OpenLCA 1.10 software [6] with ecoinvent 2.2 databases [7, 8, 9, 10] and ReCiPe (hierarchical) assessment method at midpoint level [11] were used.

Eighteen impact categories are considered: climate change, water consumption, ecotoxicity, terrestrial acidification, stratospheric ozone depletion, ozone formation, ionising radiation, particulate matter formation, fossil and mineral resource scarcity, carcinogenic and non-carcinogenic human toxicity, water eutrophication and land use.

The following impact categories have been grouped together because their results are very similar:

- Marine and freshwater ecotoxicity,
- Ozone formation damage to human health and to terrestrial ecosystems.

3 Results and comparison

3.1 Life cycle impacts of refurbished smartphone phases

According to the impact assessment, the refurbished smartphone stages with higher impact are the use phase (52.0%) and production and import stage (45.2%). The manufacturer's environmental declaration shows roughly a 20%-80% ratio between use and production phases [12]. The contribution of the production stage in the refurbished smartphone is lower because only a few parts are replaced, saving the environmental burden to extract materials and produce a whole new phone. Nonetheless, each phase contributes differently to each impact category (**Fig. 1**).
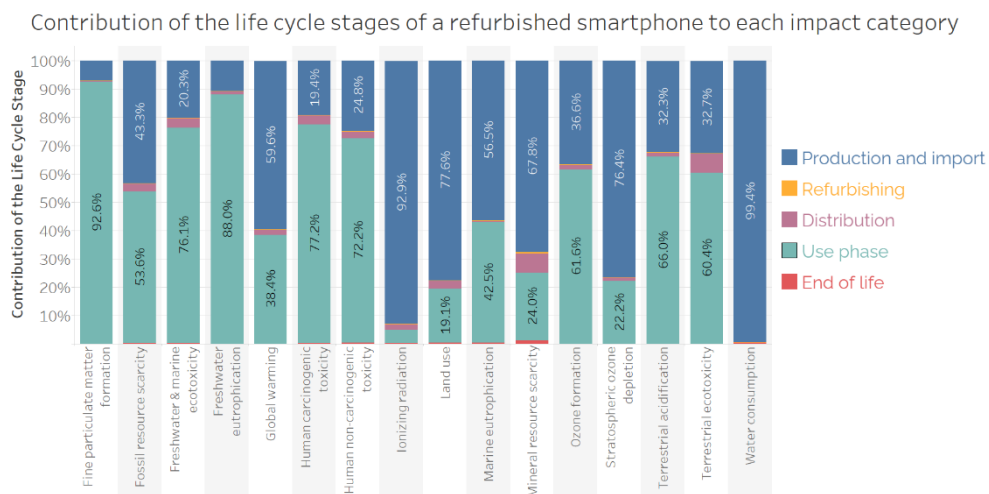

Fig. 1. Contribution of each life cycle stages of a refurbished smartphone for different impact categories. Each impact category was normalized to 100%. Therefore, each column represents a relative percentage of the life cycle stage impact in each impact category. Life cycle stages appear in the same order in each bar. All impacts are potential impacts.

The production and import stage has the highest percentage contribution in water consumption (99.4%), ionizing radiation (92.9%), land use (77.6%) and stratospheric ozone depletion (76.4%). On the other hand, the use phase has the highest contributions to fine

particulate matter formation (92.6%), freshwater eutrophication (88.0%) and human carcinogenic toxicity (77.2%).

A different breakdown is made by manageable elements to direct where the company can put efforts to reduce the environmental impacts of its product (**Fig. 2**). All the manageable elements cover the whole life cycle.

Electricity used for recharges contributes particularly to fine particulate matter formation (92.6%), freshwater eutrophication (88,0%) and human carcinogenic toxicity (77,2%). This is mainly due to the share of coal in the Chilean electricity mix, which presents heavy metals' emissions during coal mining [13]. Chilean electricity mix consists of 55% non-renewable generation sources (34% coal, 18% natural gas and 3% oil) and 45% renewable. Chile's long-term climate strategy aims at 85% share of renewable energy generation by 2040 [14]. Considering that non-renewable sources contribute around 95% of the total impacts in the categories of fine particulate matter formation, freshwater eutrophication, and human toxicity, it is estimated that the impacts on the refurbished smartphone will decrease by 60%, 57% and 50%, respectively.

Battery replacement has more contributions on stratospheric ozone depletion (58.5%), water consumption (36.8%) and ionizing radiation (27.2%). This is mainly due to the high amount of polytetrafluoroethylene (PTFE) used in the manufacture of binders applied between the battery electrodes [15].
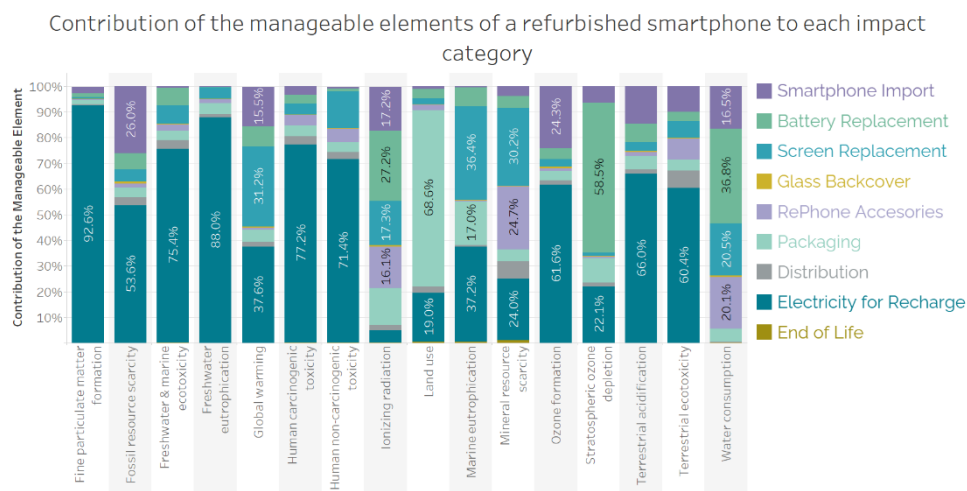

Fig. 2. Impact contribution of the manageable elements of a refurbished smartphone. Each impact category was normalized to 100%. Thus, each column represents a relative percentage of the manageable element in each impact category. All manageable elements cover the whole life cycle of the refurbished phone. Manageable elements appear in the same order in each bar.

Screen replacement shows a predominance in marine eutrophication (36.4%), global warming (31,2%), and mineral resource scarcity (30.2%).

Smartphone imports contribute most to tropospheric fossil resource scarcity (26,0%) and ozone formation (24.3%). This is due to the long distance travelled between the origin (EEUU and Japan) and the destination (Santiago, Chile) involving the combustion of 0.35 kg of oil equivalent for a refurbished unit alone.

Each element contributes differently to each impact category, but to understand the magnitude of each impact, a comparison must be made. Therefore, the impacts of the refurbished smartphone are compared with a new smartphone of the same model, a modular smartphone, and eco-equivalences when data for the other phones are not available.

3.2 Comparisons

The global warming potential is reduced by 41 kg CO_2eq (16.4 vs 57 kg CO_2 eq, 71%) compared to a new smartphone of the same model. This is mainly because the refurbished smartphone requires 87% less virgin materials than a new one (19 g vs 148 g, excluding packaging and accessories) [12]. The reduction implies a dematerialisation of the product, greatly reducing the impacts of material extraction and production.

Due to the lack of other impact categories declared for the original product, eco-equivalences were used to translate the results of environmental impacts into units that consumers can measure [16]. Thus, each impact category was compared to a familiar activity (**Fig 3**)
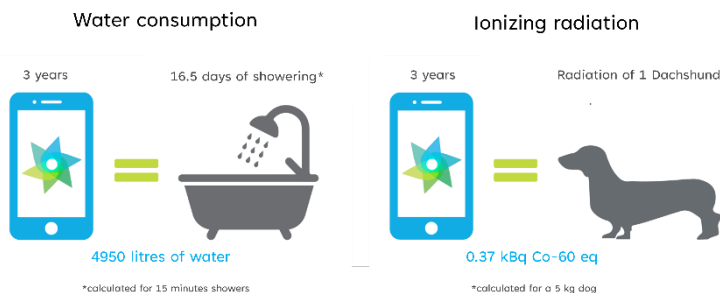

Fig 3. Example of impact comparison with eco-equivalences: water consumption and ionizing radiation.

For example, fine particulate matter formation is equivalent to 13.6 days of car usage, human carcinogenic toxicity is equivalent to eight-day consumption of a 20 cigarettes pack daily, water consumption is equivalent to 16.5 days of 15-minutes shower, and the ionizing radiation to a 5 kg Dachshund dog. These eco-equivalences allowed a better understanding of the magnitude of the refurbished smartphone's life cycle impact and were used in marketing communications.

The modular smartphone FairPhone 3 declares five impact categories based on the CML impact model [17]. Applying the same impact model to the refurbished phone, it is possible to compare both products. As seen in **Fig 4**, some categories have lower impact (global
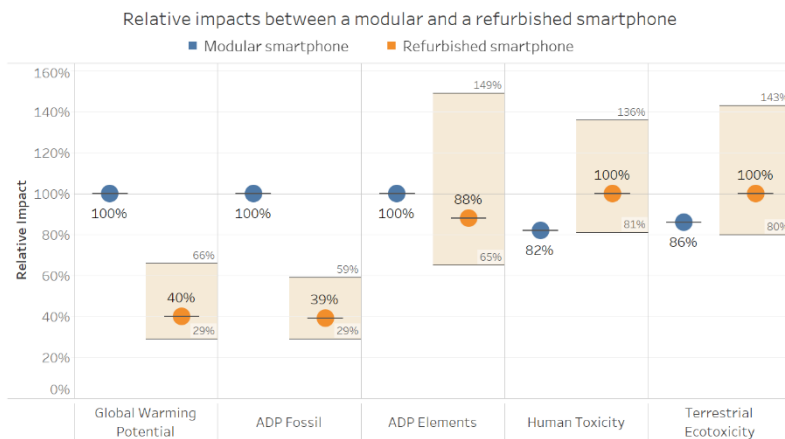

Fig 4. Relative impacts between a modular (blue) and refurbished smartphone (orange). The impact was normalized at 100% for the highest smartphone impact. The circles represent the average declared impact. The shaded bars represent the uncertainty levels. The modular phone does not report its uncertainty levels.

warming and both abiotic resource depletion potentials) whereas others have a higher impact (human and terrestrial ecotoxicity). However, some differences are narrow and might not be significant due to the inherent LCA uncertainty. It is impossible to ascertain the actual environmental benefits because the modular phone does not report uncertainty information. Therefore, it is imperative to publish uncertainty analysis to correctly compare LCA results of different products and make accurate environmental declarations.

4 Conclusion and perspectives

It is concluded that the refurbished mobile phone has environmental advantages when compared to a new smartphone, due to the reuse of most of its components, minimizing material extraction and production. This effect is likely similar for other electronic devices, showing that a design focused on durability and business models based on refurbishment and remanufacturing can significantly reduce the impact on the environment.

However, reductions across impact categories are not straightforward because life cycle stages and phone elements contribute differently to different impact categories. This shows the importance of considering the most elements as possible and declaring all the impact categories for the LCA of mobile phones.

On average, electricity consumption during use phase is what most contributes to the environmental impacts of a refurbished phone (52%). with the highest contributions to fine particulate matter formation (92.6%), freshwater eutrophication (88.0%), and human carcinogenic toxicity (77.2%). Even though, in Chile, around 50% of electrical energy is generated from renewable sources, the non-renewable portion contributes significantly to those impacts. Therefore, it is assumed that a higher contribution from renewables to the electricity matrix can greatly reduce the environmental impacts of a whole range of products.

While the trend indicates that Chilean electricity mix should be decarbonised, battery usage patterns and recharging habits can reduce impacts earlier. For example, the company can educate their customers on the efficient use of mobile phones, lowering energy consumption. Moreover, good usage habits can extend the lifespan of the battery reducing the need to replace the battery in refurbished mobile phones, further lowering its impacts.

Another important element of circular models is the transport. The phones to be refurbished were imported by aircraft, which contributes significantly to the categories of fossil resource scarcity (26.0%) and tropospheric ozone formation (24.3%). Replacing air to sea shipping can decrease the impacts of equipment import by 90% in all impact categories. Therefore, circular business models can pay close attention to the logistics used to further reduce impacts.

This study could improve by adding data on the reconditioning stage processes such as equipment used, energy consumption, and additional inputs. This would allow a better estimation of the stage impacts and open other ways the company could reduce them.

Another improvement is using specific LCA results for the replaced parts such as the battery and screen. Because data for these parts were missing, they were modelled by their components (a glass plus an LCD for the screen) or by a proxy (a scaled laptop battery for the battery). Therefore, to have more accurate results for complex electronic products, it is crucial to have the LCA results for their components. This would likely also help companies to design devices that use parts with lower impacts.

Lastly, calculating and reporting LCA uncertainty is vital to accurately compare products and circular models. Therefore, it is highly recommended that companies and researchers report uncertainty in their studies and when making environmental declarations.

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