Life Cycle Based Greenhouse Gas Footprint Assessment of a Smartphone

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Abstract. A life cycle assessment (LCA) technique has been used to evaluate the greenhouse gas impact of a smartphone. Smartphones are becoming popular due to the advancement in technology, improved connectivity, and cheaper prices. The production of smartphones on a mass scale has an impact on the environment. A Fairphone 1 from Fairphone enterprise has been chosen for this study as the company is trying to promote sustainability and phones with lower environmental impact. Different life cycle stages are chosen for the study, such as production, assembly, transportation, and end-of-life waste treatment. The use phase was excluded from this study for the sake of simplicity. The goal and scope are defined for the study, and the environmental effect is assessed using the ReCiPe\textsuperscript{2016} method. The climate change impact category has been chosen for the study since it is a relatively well-known impact. The impact assessment results show that most of the contribution to the overall impact is due to the production phase (62\%) followed by transportation (27\%). The relative contribution of the production of the components is also represented, and it shows that the most likely impact is from the production of Printed Circuit boards (PCBs).

Keywords. Life cycle assessment (LCA), Life cycle impact assessment, Global warming potential (GWP), Environment, Printed circuit boards (PCBs), Integrated circuits (ICs).

1. Introduction
With the advancements in the modern world's technology, humans have become much dependent on these device's extraordinary capabilities. The planet now faces challenges that are specifically connected with global change and its resulting consequences. Extraordinary climate conditions and the economic, social, and ecological weight added to governments are considered to be related to environmental change. So, there is a huge thrust to develop technologies that will advance greener options. According to the United Nations, the world population was estimated to be 7 billion in October 2011, which is expected to grow by 2 billion in the next 30 years [1]. This population growth places great pressure on Earth's natural capital. Resource scarcity is a vulnerability for governments to deal with these reserves, closely related to the increasing production and consumption rates of the modern world. For the past decades, cell phones have seen some significant changes in the functionalities. The use, therefore, is diverse. Cell phones nowadays are not just being used for communicating but they also possess the capabilities of computations. Even though manufacturers are
adding the newest and technically advanced features in their smartphone models, the lifetime of the product is declining significantly. This technical enhancement in small-sized equipment comes at the expense of the utilisation of some of the rarest and unique elements found on the earth. Figure 1 shows the number of smartphone users worldwide till the year 2020. It is interpreted that this number is expected to reach around 3.8 billion next year [2]. Increasing uses and demand for smartphone production puts a great deal of burden on the environment as it requires more resources. With reduced lifetime, electronic waste generation from obsolete smartphones is also a concern for humans.

A typical smartphone contains a range of rare-earth and precious metals, including gold, silver, platinum, and palladium. These metals require a lot of effort to mine from the Earth's crust and are very expensive to waste. Thus, recycling the e-waste generated is a fair practice to reduce the overall impact on the environment. As per the report of the global E-waste monitor 2020 in 2019, the e-waste amount generated was about 53.6 million metric tonnes with only 17.4% was adequately being collected and sent to recycling [3].

The Central Pollution Control Board (CPCB) conducted a survey in 2005. The e-waste generated in India in the year 2005 was around 135,000 metric tonnes, which was assumed to reach about 800,000 metric tonnes by 2012. With this growth rate, the amount of e-waste is expected to reach nearly 2 million metric tonnes by 2025, as shown in Figure 2 [4].

![Figure 1. Number of global smartphone users](image1.png) ![Figure 2. Growth of e-waste in India](image2.png)

Most of the life cycle assessments studied reported only the Global Warming Potential (GWP) impact [5]. It is estimated that greenhouse gas emission from a Sony Z5 smartphone with accessories is 19 kg of CO₂ equivalent (CO₂-e) per year [6]. Thus, it is necessary to assess the impact caused by the products and processes on the environment. This study focused on the potential environmental impact caused by a smartphone and all of its life stages. The impact assessment tool is utilised to evaluate this potential and recommendations have been made.

2. **Life Cycle Analysis of a Fairphone/Smartphone**

The life cycle assessment (LCA) is an internationally recognized environmental analysis technique with a set of standards to evaluate the possible burdens on the environment and resource consumption in every step of a product or process [7]. This way, the overall impact of a product or service on the environment is assessed.

LCA constitutes of the following stages –

- Goal and scope definition – defining the functional unit and system boundary.
- Inventory analysis – select all life cycle stages, define input and output parameters and the parameter's quantities.
Impact assessment – determine the type and size of pollution.
Interpretation – identifying the large contributor to pollutions and redesigning the stages to reduce
the burdens.

LCA tool requires a lot of detailed input data gathering, time, and monetary resource-intensive
process. Data gathering becomes even more problematic for mobile phones, as there is not much data
available for the components and end-of-life (EoL) stages [8].

Fairphone is a private company that aims to produce smartphones with minimal environmental
impact. Currently, Fairphone smartphones are available in three different versions (Fairphone 1, Fairphone 2, and Fairphone 3). The Fairphone 2 was the first-ever modular smartphone available for
users worldwide [9].

This study uses the LCA method to predict the load on the environment associated with the different
life cycle stages of a Fairphone 1 smartphone. Data obtained for the inventory analysis were modelled
using the dataset from the Ecoinvent database [10]. The data was generated from the product
disassembled for generating Bill of materials (BOM)ables for the Fairphone 1[11].
The product breakdown for Fairphone 1 smartphone is shown in Figure 3[12]. The detailed BOM is
also available for modelling life cycle inventory analysis (LCIA). The analysis shows that the impact
of each life stage chosen for this study's scope. Subsequently, some recommendations can be made for
the reduction of overall environmental impact. The next section will describe the methodology used
for the analysis of this study.

Figure 3. Components of a Fairphone1 smartphone

3. Goal and Scope definition
3.1. Goal
This study aims to recognize the stages in the life cycle of a Fairphone 1 smartphone posing a burden
on the environment and induce specific improvements.
3.2. Scope
For this study, the scope covers the following life cycle stages –
- Manufacturing.
- Assembly of the smartphone.
- Transportation.
• End-of-life.

As mentioned earlier, the inventory data is produced from the BOM, the product breakdown, and the information provided by the suppliers. For this study, the impact category chosen is GWP. It is defined as the heat absorbed by any greenhouse gas than that by the same mass of carbon dioxide. The unit for the respective impact category is kg CO₂-equivalent expressed as CO₂-e unit [13].

The system boundaries depicted in the flow chart are shown in Figure 4. It also shows the relationship between the processes. The use phase of the Fairphone is not considered for this study, and hence it is excluded. This shown system applies to all mobile phones. Component manufacturing and their transport are modelled in the system using datasets from Ecoinvent. The energy required for the assembling process is also modelled in the system. The recycling processes are modelled separately for the Fairphone and the battery. Still, no relevant data is available related to the impact on the environment due to EoL treatment associated with mobile phones.

Figure 4. Life cycle system boundary of the study

4. Life cycle inventory analysis

For inventory analysis, data were obtained from the literature for the available BOM of the Fairphone. In the disassembled product of the Fairphone, additional information such as the weight of the components was obtained. For the system's modelling initially, an open-source software tool OpenLCA by Green Delta was selected. However, due to the lack of database available in OpenLCA, the approach was not adopted. Instead, manual calculations were done later for the impact calculations. Ecoinvent version 3.6 database was used for inventory analysis.

4.1. Extraction of materials

As seen from the system boundary flow chart, it is defined for the component production. Data from the Ecoinvent dataset is used for modelling. Components that are not available in the datasets are modelled using the material composition. These components are listed as follows:

• The camera unit
• The earpiece and the speaker unit.
• The vibrator unit.
4.2. Production of the components

In the data available from the BOM for Fairphone 1, the total components used to manufacture the smartphone were listed. The components were weighed and listed during the product teardown of the Fairphone. After that, each component was matched to the respective data in Ecoinvent for modelling. Table 1 shows the inventory list of components used in producing a Fairphone smartphone and its weight.

Table 1. Inventory list of the components of Fairphone.

| Sr. No. | Component                              | Quantity | The total weight (g) |
|---------|----------------------------------------|----------|----------------------|
| 1       | Mainboard Printed circuit board (PCB)  | 1        | 5.28                 |
| 2       | Daughterboard PCB                      | 1        | 1.15                 |
| 3       | Flexible PCB                           | 2        | 0.89                 |
| 4       | LCD screen                             | 1        | 33.92                |
| 5       | Plastics                               | -        | 2.02                 |
| 6       | Shell                                  | 2        | 29.91                |
| 7       | LEDs                                   | 10       | 0.41                 |
| 8       | ICs                                    | 10       | 1.07                 |
| 9       | Front and back housing                 | 2        | 11.12                |
| 10      | Li-ion battery                         | 1        | 38.6                 |
| 11      | Diodes                                 | 200      | 0.52                 |
| 12      | Transistors                            | 3        | 0.02                 |
| 13      | Capacitor                              | 286      | 0.5                  |
| 14      | Tantalum capacitor                     | 1        | 0.02                 |
| 15      | Camera                                 | 2        | 1.08                 |
| 16      | Vibration motor                        | 1        | 0.72                 |
| 17      | Earpiece                               | 1        | 0.51                 |
| 18      | Speaker                                | 1        | 1.33                 |
| 19      | Battery cap                            | 1        | 24.91                |
| 20      | PCB covers                             | 3        | 3.94                 |
| 21      | Simcard holder                         | 1        | 1.29                 |
| 22      | CTiols                                 | 37       | 0.06                 |
| 23      | Magnetic bead                          | 13       | 0.02                 |
| 24      | Cable                                  | 1        | 0.19                 |
| 25      | Screws                                 | 6        | 0.22                 |
| 26      | Copper coil                            | 1        | 0.03                 |
| 27      | Brass screw                            | 5        | 0.14                 |
| 28      | Connectors                             | -        | 1.91                 |
| 29      | Thin film                              | -        | 0.31                 |
| 30      | Plastic tape                           | -        | 0.24                 |
| 31      | Net                                    | -        | 0.78                 |
| 32      | Unspecified                            | -        | 0.37                 |
| **Total** |                                      |          | **163.48**           |

These next sections explain the assumption for the modelling of a few components.

- Printed circuit boards- PCBs are modelled from Ecoinvent data as 'Printed wiring boards, surface mounted technology.'
- Integrated circuits- Two types of ICs are modelled using 'IC, logic type' and 'IC, memory type' from Ecoinvent.
- Battery- The battery of Fairphone is represented as 'Battery, Li-ion, rechargeable, prismatic' from the database.
• LCD screen- 'LCD glass, at plant' is used to model the Fairphone LCD screen.

• Camera, Earpiece, Speaker, Vibrator, and Unspecified components- Due to the lack of relevant dataset availability, modifications were made. Camera, vibrator, and unspecified components were modelled using 'Electronic component, passive, unspecified, at plant' from the Ecoinvent dataset.

The material composition of the earpiece and speaker is given in table 2, and the weight of the metals was used for the modelling. The weight of each remaining unknown material from the speaker and vibrator was modelled again using 'Electronic component, passive, unspecified, at plant' from the Ecoinvent dataset.

| Materials | Speaker (g) | Earpiece (g) |
|-----------|-------------|--------------|
| Zn        | 0.1729      | 0.074817     |
| Fe        | 0.15295     | 0.2499       |
| Cu        | 0.02793     | 0.047838     |
| Nd        | 0.01197     | 0.0049164    |
| Pr        | 0.0030989   | -            |
| Co        | 0.0026068   | -            |
| Gd        | 0.0017689   | -            |
| Cr        | -           | 0.04947      |
| Ni        | -           | 0.011067     |
| Others    | 0.9443      | 0.078285     |

4.3. Assembly of the smartphone
Dividing the electricity uses by the smartphone produced gave the electricity uses per phone about 0.44 kWh. In the literature [14], it was found out that the total electricity uses for the assembling process was 361Wh. This resembles the data for this study, as well. The electricity mix data of China is used.

4.4. Packaging of the components
Packaging data of the smartphone was provided in the BOM. The weight of the smartphone guide booklet provided is 68 grams. For this, light-weight coated paper data from Ecoinvent is used. Phone packaging uses Kraft paper, and this is represented by 'Kraft paper, unbleached, at plant' in the Ecoinvent dataset.

For the packaging of the components, two packaging factors were calculated based on each component's weight. If the component's weight is more significant than 0.5 gm, the factor was assumed to be 0.1. The packaging is made of plastics and modelled using 'Packaging film, LDPE, at plant.' Whereas if the component's weight is less than 0.5 gm, then the packaging factor was assumed to be 1.94. The packaging material is made of the main polystyrene and modelled using 'polystyrene, high impact, HIPS at plant.'

4.5. Transportation
The information related to the location of the suppliers was available from the BOM. The distance between the assembly plant and supplier was obtained from sourcemap.com. Types of transportation were obtained from the BOM. For transportation from the lorry, 'transport, lorry, 16-32t, EURO5[RE]' was used. For transportation from air flights' transport, aircraft, freight, Intercontinental' and 'transport, aircraft, freight' both were used. For the transportation through canal' transport, barge [RER]' was used, and finally for transportation from rail' operation, coal freight train, diesel [CN]' was used for
modelling. For modelling the components, total weight, including packaging weight obtained from multiplying packaging factor to the component weight, is used.

4.6. Recycling of the smartphone
From the literature [11], it is found that nearly 60% of the Fairphone users are from Germany. For the simplicity of this study, it is assumed that 100% of smartphones collected for recycling are sent to the facilities. The total transportation distance from the user to the recycling facility of the Fairphone is assumed to be about 1500 km. 75% of this transportation is done by lorry and rest 25% by train. The respective Ecoinvent dataset used is 'transport, lorry 20-28t, the fleet average' and 'transport, freight, rail[BE]'. Both mobile phones and batteries are recycled separately after dismantling. Two technologies are generally used to recycle e-waste, the pyro-metallurgical process, and the combined pyro-hydrometallurgical process.

For the recycling of the Fairphone without battery weighing 124.88 gm, the material flow analysis of one ton of waste mobile phone is used [15]. The MFA uses emissions from the pyro-metallurgical process mainly. This way, modelling for recycling of Fairphone without battery is done. For the modelling of recycling the Fairphone battery, process 'disposal, Li-ions batteries, mixed technology/GLO' from the database is taken. The methods used are both hydrometallurgical and pyro-metallurgical recycling.

5. Life cycle Impact Assessment and Interpretation
The method chosen for the calculation of the impact assessment results is ReCiPe 2016. In the current study, midpoint characterization is used. This study's only impact category is climate change or GWP (kg CO₂ equivalent). The results for the impact category are reported below. In Figure 5, the contribution of each life cycle stage is shown for the impact category.

![Figure 5. Climate change impact](image-url)

As seen in the figure, the production and transportation phases have the highest contribution to GWP. This is followed by the assembly, packaging, and recycling processes. From Figure 6, two observations can be made: (1) the production phase contributes to more than 60% of the total GWP impact, (2) the transportation and assembly phase collectively contributes to more than 30% of the total impact.
The impact assessment of the Fairphone 1 smartphone for the climate change category is shown in Table 3.

**Table 3. Climate change impact assessment for each life cycle.**

| ReCipe Midpoint 2016 (H) | Production phase | Transportation phase | Assembly phase | Packaging | Recycling phase | Total | Unit       |
|--------------------------|------------------|----------------------|----------------|----------|----------------|-------|------------|
| Climate change           | 5.0914           | 2.2358               | 0.5365         | 0.181    | 0.1538         | 8.1985| kg CO₂-e   |

The total GWP impact from a Fairphone smartphone, excluding the use phase, is calculated as 8.19 kg CO₂-e or say CO₂ equivalent.

Climate change has the highest contribution from production (62%) and transportation (27%) phases. The contribution of the production of different components can be seen in Figure 7. PCBs have the highest contribution (49%) in the production phase with 2.4884 kg CO₂-equivalent. Improvements can be made by:

- Reducing the PCB surface area during the manufacturing process for future smartphones.
- Focusing on the recycling of the waste PCBs as they contain precious rare earth metals.
A similar interpretation can be made to produce integrated circuits, which have the next highest contribution (20%) in the production phase. The contribution of each process for the overall climate change impact is shown in Figure 8.

Transportation has a significant impact (27%) on global warming, mostly caused by the transportation of smartphones from China to Germany. This impact can be reduced using other modes of transportation, such as rail transport. To reduce the impact from the LCD screen, the size of the display can be minimized adequately. Also, using new technology such as OLED and AMOLED screens will reduce the power consumption by the smartphone.
6. Conclusions
This study found the climate change impact of the Fairphone smartphone with the exclusion of the use phase. The product emits about 8.19 kg CO$_2$ equivalent. More than 50% of this emission comes from the production phase of the 5.09 kg CO$_2$ equivalent. The production phase is followed by the transportation emitting 2.23 kg CO$_2$ equivalent. Potential improvements can be to reduce the overall impact on climate change. These modifications can be applied to future smartphones to reduce the burden on our environment.

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