The economic and ecological impact of shifting to a modular smartphone design

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Abstract

The number of smartphones sold increases with the effect of growth in E-waste. A solution to prevent the growth in E-waste might be modular smartphones. This kind of smartphone design allows consumers to increase the lifecycle of their smartphone due to the opportunity of replacing parts relatively easily single-handed. However, the economic and ecologic effect of shifting to modular smartphone design is not apparent.

In this paper, four non-modular smartphones will be designed as modular smartphones based on the design of Fairphones. These designs will be compared against each other economically and ecologically. A simulation will run over five years for both effects wherein the replacement of parts and the smartphone itself will be simulated. The repair costs can be determined for the economic effect with the amount of replaced parts. The ecological effect will be determined by applying the kg CO2e parts produced. With this information, advice will be given on which design will be better for the economy of consumers and which design will be less harmful to the planet by producing less kg CO2e.

Keywords

Modular smartphone, modular design, economic, ecologic, Global Warming Potential (GWP), Life Cycle Assessment (LCA).

1. Introduction

Electrical and Electronic Equipment (EEE) is a standard in everyone's life and helps improve the quality of life of many. However, these products will one day break down or be replaced by a better version that makes them obsolete. When the user decides to dump the EEE, it becomes a WEE, Waste Electrical and Electronic Equipment.

WEE, also known as e-waste, is becoming more significant due to increasing electronic waste generation per capita. In 2019, 53.6 million metric tons[8] of e-waste were generated worldwide; this is 7.3 kilograms per capita. These millions of tons consist of six groups according to The Global E-waste Monitor[8]: temperature exchange equipment (10.8 Mt), screens and monitors (6.7 Mt), lamps (0.9 Mt), large equipment (13.1 Mt), small equipment (17,4 Mt), and Small IT and Telecommunication equipment (4.7 Mt). Each of these groups grew in waste production by at least two per cent per year compared to 2014, except for screens and monitors, which shrank by 1%. For 2030, The Global E-waste Monitor expects 74.7 million metric tons to be the total volume. Countries need to recycle these products to prevent this e-waste from filling up landfills. According to E-waste Monitor, 17.4%, 9.3 Mt, of this e-waste was formally documented to be collected and recycled. For the other 44.3 Mt of e-waste, it is not clear what happened with it; options are dumped, traded or recycled in a non-environmentally way.

Looking more closely at Small IT and Telecommunication equipment, a device herein is the smartphone. Smartphones include many kinds of materials that create kg CO_2 equivalent (CO_2e) during production. This specific value is used to calculate the Global Warming Potential (GWP) and indicates how much kg CO2 would be produced equal to the gases created by processing materials[19]. Ercan et al.[5] and Joshi et al.[12] describe how much kg CO_2e smartphone components produce mainly during the production phase. Next to that, the research of Makov et al.[14] found the interest of consumers repairing their smartphone declines after two years, and Daniel Research Group collected data[3] in the United States showing a consumer replaces a smartphone after 2.75 years in 2021. This replacement cycle is declining in the upcoming years resulting in consumers replacing their smartphones earlier.

On the website of iFixit, tutorials can be found on how to fix devices[10]. These tutorials contain a grade from 1 to 10 on how well a device can be repaired, named the repairability score. Of the thirteen smartphones used in the paper of Makov et al., four have a rate under six, three have a six, and the rest have a grade higher than a six. When more attention is given to the iFixit's repairability score[11], even more, newer smartphones do not have a grade higher than a six. However, smartphones with a particular design result in a repairability score of 10, mainly modular smartphones.

Modular smartphones, such as Fairphone 4 and Shift 6m, are designed to replace components for repair or upgrading. These designs should help lower repair costs, reducing E-waste and increase user experience. For Fairphone, this concept is successful as their annual review of 2020[7] describes an amount of 94,985 smartphones sold. This number is 0.007% of the total 1,378.72 million[10] smartphones sold in 2020. Most other smartphone brands do not try to develop a modular smartphone. A few exceptions

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include Google Ara[18], which failed, and recently Xiaomi patented a modular design[13].

Why not more brands produce modular smartphones is unclear, and research on modular smartphones is mainly about the potential. Proske[16] performed research to understand the benefits and the risks of modular smartphones. Herein came forward that the success of modular smartphones mainly depends on the user's desires. Another research of Chen[2] concluded that the market growth of modular smartphones would be challenging due to, for example, missing market standards for module connectors and the culture of the consumers.

What is lacking is the economic and ecologic effect of designing ordinary smartphones in a modular design. This economic effect would give insight into which design will be better for the consumer's pouch. A modular design will describe the ecologic effect with the produced kg CO2e. To create insight in these effects, this paper uses the following research question:
What is the economic and ecological impact of shifting to a modular smartphone design?
To achieve finding an answer to this question, the following sub-questions will be researched:

1) *What components do smartphones contain?*
2) *What is the lifecycle of a smartphone, and which components break down?*
3) *How would the modular design of an existing ordinary smartphone look?*
4) *How does a modular and ordinary smartphone simulation look?*
5) *What is the economic effect of a modular smartphone?*
6) *What is the ecological effect of a modular smartphone?*

2. Methodology

At the moment, there is a wide variety of smartphones available, which makes research difficult. To make this research more viable, the focus will lay on three brands: Fairphone, Apple and Samsung. Fairphone is the biggest brand for modular smartphones, and Apple and Samsung are the biggest overall[4]. Fairphone will contribute as a benchmark for the other brands. From every brand, their best smartphone has been used from the year 2015, Fairphone 2, iPhone 6S, Galaxy S6, and for newer models, the Fairphone 4 (2021), iPhone 11 (2019) and Galaxy S10 (2019) will be used. The Apple and Samsung smartphone models from 2019 are chosen since this will contribute to finding components and their prices. The decision of two different periods allows researching how smartphones' lifespan is and the effect on modularity by newer specifications. Together, these smartphones will help support the research question with the following steps. Most of the steps will also include financial values since this will help divide parts better when information is lacking.

2.1 What components do smartphones contain?

Before other sub-questions can be elaborated, information is required about smartphones. Gathering the smartphone components will detail how expensive parts are and how they are placed. The corresponding components of the other smartphones and their price will be gathered via webshops. Also, the release price of the smartphones will be collected.

2.2 What is the lifecycle of a smartphone, and which components break down?

To determine whether replacing a part or the complete smartphone in later sub-questions is required, this question will reveal how long the lifecycle is of an ordinary smartphone and which components break down the most.

2.3 How would the modular design of an existing ordinary smartphone look?

From the six smartphones that will be investigated, only the Fairphones are modular. To give the other four smartphones a proper modular design, these two Fairphones will be used as a guideline for the four non-modular smartphones. The Fairphone 2 will guide the iPhone 6S and Galaxy S10, and the Fairphone 2 will guide the other two smartphones.
First, it will be checked whether components are at the exact location in the Fairphone. When this is not the case, a decision has to be made whether a component will be replaced for the modular design or not. The design of the Fairphone will be leading when the decision becomes unclear.
Since a modular smartphone brings extra opportunities to replace components, it will also be investigated whether the replacement cycle of a modular smartphone is different from an ordinary one. With this, the ordinary replacement cycles found for question 2.2. will be used.

2.4 How does a modular and ordinary smartphone simulation look?

A simulation has to be designed to determine the economic and ecologic effect wherein the amount of replaced parts and smartphones will be counted. To achieve this, InsightMaker[20] will create the simulation and the information gained by answering 2.1. till 2.3. will be used. The same model will replace the smartphone when replacement is required by the found replacement cycles.

2.5 What is the economic effect of a modular smartphone?

The concept of a modular smartphone is that components or groups of components can be changed the moment they break down. However, is replacing only a component economical justifiable when other parts will also break down within a slight time difference. Combining the previous information on the component's cost and the simulation will give insight into which design has lower repair costs over five years. In this analysis, the ordinary smartphones will be repaired by a repair shop, and the consumer will repair the modular smartphones. Next to this, when a smartphone needs to be replaced, the same smartphone will be cheaper due to depreciation. Thus the financial depreciation of smartphones will also be taken into account.

2.6 What is the ecological effect of a modular smartphone?

The ecological effect of every smartphone differs and depends mainly on the production, as Malmodin described. Fairphone and Apple release a paper wherein the environmental effect of their products is discussed. These papers will come into use to determine how much ordinary smartphones affect the environment. For Samsung, more research is required since they do not give this information. With this information, the kg CO2e produced by parts will be applied to the simulation outcomes of sub-question 2.3.

3. Results

3.1 What components do smartphones contain?

Since the Fairphone 2 and 4 will be the benchmarks, their components will be necessary for the modular design in sub-question 3. Thus, these components will determine which components need to be found for the iPhones and Galaxys. The Fairphone web shop[21] contains all the information for these Fairphone components, mainly modules. In Appendix A.1., an overview is given of Fairphone 1's modules, including their price and which components are included, and Appendix A.2. gives the same overview for Fairphone 4. These two tables give a clear overview of which components need to be found for the iPhones and Galaxys, resulting in Appendix A.3. till A.6. The iPhone components have been found at the webshop FixjeiPhone[22], and for more detail of more complicated components, such as the Lightning connectors, iFixit was used. The Galaxy S6 components are also found on FixjeiPhone, including more information from iFixit. However, the Galaxy S10 was more complicated since no website contained all components. Most of the parts were found in the PhoneGigant webshop[23]. The headphone jack information came from the gsmschermkapot webshop[19] and the rear cameras mmobiel[24].
The release prices are collected via Tweakers[25] and can be found in Appendix A.7.

3.2 What is the lifecycle of a smartphone, and which components break down?

3.2.1. Consumers' replacement cycle depreciation

The consumer determines when their smartphone will be replaced. As mentioned in the introduction, the Daniel Research group has researched when consumers replace their smartphones[3]. This moment of replacement is essential for ordinary smartphones since these have another replacement period than modular smartphones. The smartphones used in this research were released in 2015, 2019 and 2021, resulting in the corresponding replacement cycles: 2.53, 2.96 and 2.75 years.

3.2.2. Break down of components

Smartphone components do not have the same lifecycles; for example, a display can break more quickly than a motherboard. How long the lifecycle exactly is, is hard to predict. However, a German smartphone repair shop, ClickReperatur, performed a repair study together with its parent company, WERTGARANTIE, and Statista in 2019[28]. In figure 1, the most common breakdowns from this research can be found.

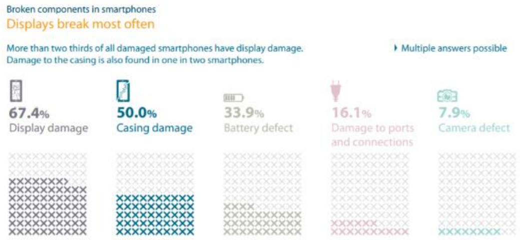

Figure 1. Broken components in smartphones, a snapshot from the ClickRepair study.

These breakdowns give a clear overview of which components need to be replaced often in five years. However, the group "Damage to ports and connections" is unclear. This issue also comes forward in the lifecycle assessment of the Fairphone 3[17]. Fairphone decided to divide the 16.1% into the charging port, 7%, and the earphone jack connector, 9%. This division will also be applied in this research. Combining these two papers result in the replacement percentage of components over five years, as shown in Table 1.

Table 1. Replacement percentage of individual smartphone components over five years.

Component	Replacement percentage in five years.
Display	67.4%
Back cover	50.0%
Battery	33.9%
Charging port	7%
Earphone jack connector	9%
Camera	7.9%

3.3 How would the modular design of an ordinary smartphone look?

In part 3.1, information is gathered on what components are included in the Fairphones' modules and how expensive these components are for iPhones and Galaxys. What is missing is the costs of the modules' sub-housing and extra connectors. This missing information can be found in the lifecycle assessment, LCA, of the Fairphone 2[22].

3.3.1. Sub housing of modules

In the LCA of the Fairphone 2, an overview is given of which materials are used for the sub-housing of modules. By looking for these materials on the internet, an estimation of the sub-housing costs can be made. The price of the raw materials and the raw material costs for the sub housings can be found in Appendix B.1. and Appendix B.2.

Next to these raw material costs, production and other costs are required to complete these sub housings. Following the cost breakdown of the Fairphone 2[6], a small calculation can be made. 230.30 euro is invested in materials for a 525 euro costing Fairphone 2, which means that for every euro invested in materials, revenue is created of 2.28 euros. Applying this to the sub housings costs from Appendix B.2., a selling price is determined as shown in table 2.

Table 2. Selling price per sub housings

Sub housing	Selling price
Top module	€ 0.02
Camera module	€ 0.01
Bottom module	€ 0.02

3.3.2. Extra connectors of modules

Modularity requires sturdy connectors such that consumers can disconnect them themselves. Making this possible requires extra printed circuit boards (PCBs) for bigger connectors. In the LCA of the Fairphone 2, the amount of extra PCB per module is described in cm^2. The costs for these PCBs and the total motherboard surface are, on the other hand, not described.

3.3.2.1. Motherboard surface

To estimate the costs of the motherboard, the first step was measuring it. This surface could be measured by using SketchAndCalc[29]. This tool can upload a picture, and a surface can be drawn to create a benchmark. In this case, the surface of the bottom module connector was used. After the benchmark is created, other surfaces can be drawn, and the corresponding surface will be given, 18.78 cm^2, for the Fairphone 2 motherboard. The pictures with the surfaces can be found in Appendix B.3.

3.3.2.2. PCB costs

Knowing the total surface of the motherboard makes it possible to estimate how expensive the extra PCBs will be. Only the motherboard price is unknown; thus, the motherboard needed to be stripped to calculate the price of only the circuit board. The Fairphone 2 has a price of 525 euros, removing all the prices of the modules results in an outstanding amount of 325 euros. This price is assumed to be the motherboard's total price, including all the components on the board. Using the Fairphone 2 breakdown of iFixIt[9], an overview of all components on the motherboard is found. Looking up these parts on the internet and removing their price, a price of 72.28 euros is created for a plane motherboard. This breakdown can be found in Appendix B.4. With knowing these costs and the surface of a plain motherboard, the costs of the module PCBs can be calculated. Every cm^2 of PCB costs 3.85 euros, and applying this to every module PCB creates table 3.

Table 3. PCB costs of every module.

PCB part	Surface (cm2)	Price
Total motherboard	**18.78**	**€ 72.28**
Extra PCB Mainboard	9.86	€ 37.95
Display board	2.7	€ 10.39
Top module board	2.88	€ 11.08
Bottom module board	0.72	€ 2.77
Camera module board	1.47	€ 5.66

3.3.3. Design of modular iPhones and Galaxys

With the knowledge of the sub-housing, PCB costs and the component costs of the iPhones and Galaxys, modular designs can be made based on the Fairphone module designs. In Appendix B.5. all the modular designs can be found. Table 4 gives an example by showing the modular design of the iPhone 6S. Every bold part stands for a modular part, and the non-bold parts are an element of the above bold written module. Some modular parts or smartphones require extra information; the following subparts will explain.

Table 4. Modular design of iPhone 6S.

Parts	Price
Battery	**€ 12.50**
Display	**€ 46.29**
Display	€ 27.95
Home button	€ 7.95
PCB Display	€ 10.39
Top module (earphone jack in bottom module)	**€ 28.95**
Front camera and sensor cable	€ 7.95
Wi-Fi antenna	€ 4.95
Earpiece speaker	€ 4.95
Sub housing	€ 0.02
PCB Top Module	€ 11.08
Bottom module	**€ 25.64**
Lightning connector and earphone jack	€ 8.95
Loudspeaker	€ 6.95
Vibrator	€ 6.95
Sub housing	€ 0.02
PCB Bottom module	€ 2.77
Camera module (flashlight in top module)	**€ 21.62**
Rear camera 12 MP	€ 15.95
Sub housing	€ 0.01
PCB Camera Module	€ 5.66
Back Cover	**€ 45.67**
Back Cover	€ 29.95
Size increase	€ 15.72
Motherboard	**€ 52.90**
Motherboard	€ 14.95
PCB mainboard	€ 37.95

3.3.3.1. Back cover

The back cover for every smartphone required a size increase due to the PCB increase. As mentioned in table 3 the extra PCB mainboard has a surface of 9.86 cm2 which is 53% of the total surface of the motherboard. This increase in size affects the smartphone's size; thus, the back cover will also grow by 53%. The price for this is 53% of the original back cover prize.

3.3.3.2. PCB of modules

The Fairphone 4 has a different component build than the Fairphone 2, the top and bottom modules are missing, and a loudspeaker and the loudspeaker, earpiece speaker, and selfie camera are modules. This results in not having the correct extra PCB and sub-housing calculation. Instead of removing these PCB and sub-housing costs, the costs for the bottom module are used to give these modules a correct price.

3.3.3.3. Changes to particular smartphone models

The original earphone jack of the iPhone 6S is in the same part as the lightning connector. This design resulted in the modular design switching the earphone jack from top to bottom.
The Galaxy S10 has an earphone jack, while the Fairphone 4 does not have this part. The earphone jack is added to the Port Module to keep this function.

3.3.3.4. The release price of the modular designs

Making the smartphones modular affects the release price. Every smartphone has increased in size due to the extra PCB. These extra PCBs bring extra costs, and the sub-housing also have value. This change results in table 5, wherein the new release prices of the smartphones can be found. The Fairphones will also be added to the table as a benchmark.

Table 5. The release price of the ordinary and modular design.

Smartphone	Release price ordinary design	Release price modular design
Fairphone 2	€ 525.00	€ 525.00
Fairphone 4	€ 579.00	€ 579.00
iPhone 6S	€ 749.00	€ 806.86
iPhone 11	€ 809.00	€ 876.86
Galaxy S6	€ 699.00	€ 766.86
Galaxy S10	€ 899.00	€ 966.86

3.3.4. The replacement cycle of a modular smartphone

Replacing smartphones within three years is based on the consumers' decision. Their main reasons, according to Watson[30], are as follows: 13% "want latest software", 47% "Want latest phone model", and 40% "Existing phone not functioning". When modular smartphones respond to these reasons, the replacement cycle can be increased.

3.3.4.1. Want latest software

Looking at software support [30], Android smartphones are significantly shorter supported than iOs. Apple has the policy of supporting their smartphones for at least five years, while the average Android support is three years. The software support of Fairphone is different.
At the moment, Fairphone is testing to update the operating system of the Fairphone 2 to Android 10[31]. The release is planned for early 2022 and is achieved with the help of an open-source community. For their Fairphone 3[32], the aim is to update the system to android 11, the latest version. This shows that Fairphone is applying its commitment to supporting a smartphone for at least five years and indirectly in five newer versions of the operating system. When every Android has this support, an increase of 66% would be made.
In comparison to iOs, Fairphone is supporting their smartphones worse. Apple is applying their iOs updates directly on the release date to all supported iPhones. For iOs 15 is the oldest iPhone, the 6s[33], which comes down to support of six years. Since Apple is updating the software directly, and Fairphone takes at least two years to update a newer version, the supports are different. This makes comparison hard, and a comparison is required in operating systems. The Fairphone 2 has six different operating systems, and the iPhone 6s has seven. This means that there is a decrease of 14%.
Adding these comparisons together of 66% and minus 14% results in an average software increase of 26%.

3.3.4.2. Want latest phone model

47% of the customers buy a new smartphone due to wanting the latest model. Modular smartphones can respond to this due to their modularity. When a customer, for example, wants a better camera, a better camera module can be installed. However, these modular upgrades are not possible for every part at the moment. When looking at Fairphone, the only upgrade allowed is for the front and back camera. The Fairphones used in this research have seven or nine parts, including the core module, making eight parts on average.
The first three Fairphones got a possibility of a camera upgrade; thus is assumed that the Fairphone 4 also gets this. This results in the opportunity to upgrade two parts for both smartphones, the front and back camera. In other words, 25% of the parts can be upgraded to a better version.

3.3.4.3. Existing phone not functioning

According to Cordella, there are five parts whereby the main failures come forward, table 6.
In this table, almost all main failures can be fixed by applying modular parts. All display and back cover failures can be repaired by placing a new display module or back cover.
The battery issues can be fixed by placing a new battery for the loss of performance, and the charging issue can be fixed by placing a new port/bottom module or a new battery.
When this issue comes to the motherboard connectors, no repair is possible. Overheating can happen with the slightest break in a cable, which is hard to detect, assuming this cannot be fixed. The operating system software issues are already solved by 3.5.1.1. and will not be considered.

Table 6. Main failures of smartphones, affected parts and failure and degradation mechanisms.

Part	Main Failures	Failure and degradation mechanisms
Display	Display glass cracked, scratched, splintered	Accidental drops or other mechanical stresses (shocks, vibrations)
	LCD failure: black screen, broken/dead pixels, no background light	
	The touchscreen does not respond as expected	
Back Cover	Breakage (e.g. cracks, scratches)	Accidental drops or other mechanical stresses (shocks, vibrations)
Battery	Loss of performance	Ageing Battery
	Battery not charging	External power supply/charging port/battery connection failure
	Overheating	Increased internal resistance
Operating System	Malfunctioning/loss of security and performance	Software, OS and/or security updates not available
		Lack of sufficient capacity (memory) or performance (low RAM, outdated SoC)
Electronics	Short circuits, disconnection of parts	Stress conditions (e.g. water and dust exposure, shocks, vibration)

The issues with insufficient capacity or performance are hard to repair since there are only modular parts to improve the camera. Thus this problem cannot be solved.
As of last, the electronics problem can be solved partly. When a part is disconnected, it can be connected again or replaced so that the connections will work again.
From these nine failures, eight are considered. A modular smartphone can fix 6.5 failures, resulting in 81% being fixable.

3.3.4.4. Adjusting lifecycle

Assuming that a replacement cycle of an ordinary smartphone can be divided in the percentages of Watson, a smartphone released in 2015 has the corresponding replacement cycles, 2.53 years: 0.33(13%), 1.19(47%), and 1.01 (40%) years.
Applying the just found opportunities for modular smartphones will increase 26% in the replacement cycle. As the 13% desire is good for 0.33 years of the replacement cycle, this extended software support would increase the cycle to 0.42 years.
The desire for the latest phone model is 47%, and 25% of the parts in a modular smartphone can be upgraded. This means that the 1.19 years can be increased to 1.49 years by just the opportunity of upgrading a camera.
As of last, 81% of the main failures of the smartphone can be tackled by using a modular smartphone. This results in that cycle increasing from 1.01 to 1.83 years.
Shifting an ordinary smartphone released in 2015 to modular results in a lifecycle change from 2.53 to 3.74 years.
Applying this to the other lifecycles used in this research, a modular smartphone from 2019 gets the lifecycle of 4.37 years, and from 2021 a cycle of 4.06 years.

3.4 How does a modular and ordinary smartphone simulation look?

Whether the modular design has a positive or negative economic and ecologic effect can be determined by simulation. The simulation, figure 2, counts the number of times parts are replaced. This counting can in the later sub-questions be used to calculate the repair cost and kg CO2e emission.
The following sub-sections will describe a few key components that let the code work. At the end of this section, the simulated counts will be given.

3.4.1. Setting up the simulation

This simulation requires all of the founded chances of table 1 and must be filled into the corresponding "Chance new…". A chance must be filled in with this variable as follows: 19% is entered as 19. Some modular smartphones will have their port and headphone jack in the same part; thus, a particular variable is created wherein the chances are added together.

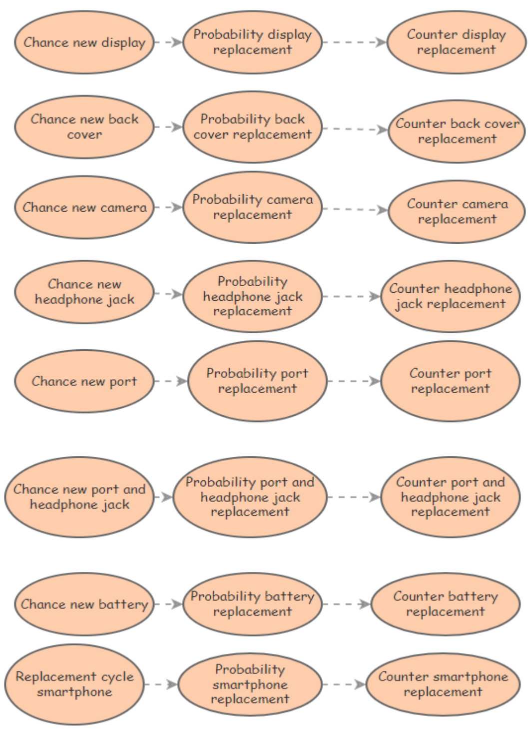

Figure 2. Replacement counter

Also, the replacement cycle needs to be added to "Replacement cycle smartphone" since this will create the time stamp when a smartphone needs to be replaced. It is required that this is in months.

3.4.1.1. "Probability…" variables

A more complex calculation determines when a part needs to be replaced. Table 1 contains the chance of replacing a part within five years, and these chances will all be used when a smartphone has this part. These chances are for a total period of five years and not per month. This requires rewriting the chances since replacing a part should increase due to usage every month. Using an exponential formula whereby the exponent stands for a month, and the base for the chance of replacing a part is the solution. To achieve this, every "Probability …" does the "Chance new…" to the power of 1/60 to create an exponential base.
This variable will also create a probability by giving a 1 or 0 by a normal distribution. As a result, it is a challenge to create an increased chance of responding with a 1 when a part is not replaced in a while. A macro is used since no variable has a memory and cannot be created by bi-directional arrows. The macro looks as follows:

```
LastCamera <- 0
LastTop <- 0
LastBottom <- 0
LastHousing <- 0
LastBattery <- 0
Vector <- {LastDisplay, LastCamera, LastTop, LastBottom,
LastHousing, LastBattery}
Function ProbabilityCalc(Memory,Base)
   if Randboolean(Base^(Months()-Vector{Memory}))
     then
        Vector{Memory} <- Months()
        return 1
     else
        return 0
   end if
End Function
```

In this code, every part that may break down has its variable. This "memory" is recognisable by beginning with *Last*. These "memories" are added to V*ector*, giving them a callable number in a vector. Then the function *ProbabilityCalc* starts to determine whether a part will be replaced. Every "Probability replacing…" will call this function and first gives the vector number of its corresponding "Memory" variable. The other value they will give the function is their base for the replacement probability "Base".
In the function, a Randboolean is used to create a binary distribution. This distribution is based on the probability of replacing a part by multiplying "Base" to the power of the current month. When this Randboolean becomes true, it should be remembered that a part is replaced. This True state is when *Vector* is used with all the "memories". Every time the Randboolean becomes True, *Vector* is called, and the current month is saved to the corresponding "memory". This "memory" is not 0 anymore and will influence the distribution. Every time the distribution is now used, the exponent will be decreased by the "memory" to take the chance of replacing a part again smaller. In the fifth year, this "memory" prevents parts from being replaced every month. In the end, this function will give its distribution of 1 or 0 back to the "Probability…" variable.

3.4.1.2. Simulation run

In every simulation, the "Counter…" variables will at the end of a simulation count the number of times a "Probability…" variable has given a 1. When running this 2000 times for every ordinary and modular smartphone with its corresponding lifecycle, table 7 and 8 rollouts.

Table 7. Amount of parts replaced for ordinary smartphones

Part	Fairphone 2	iPhone 6s	Galaxy S6	Fairphone 4	iPhone 11	Galaxy S10
Display	2	2	2	2	2	2
Back cover	2	2	2	2	2	2
Earphone jack	1	1	1	x	x	1
Port	1	1	1	1	1	1
Battery	1	1	1	1	1	1
Camera	1	1	1	1	1	1
Smartphone	2	2	2	2	2	2

Table 8. Amount of parts replaced for modular smartphones

Part	Fairphone 2	iPhone 6s	Galaxy S6	Fairphone 4	iPhone 11	Galaxy S10
Display	2	2	2	2	2	2
Back cover	2	2	2	2	2	2
top module	1	x	1	x	x	x
bottom module without earphone jack	1	x	1	1	1	x
bottom module with earphone jack	x	1		x	x	1
Battery	1	1	1	1	1	1
Camera	1	1	1	1	1	1
Smartphone	2	2	2	2	2	2

3.5 What is the economic effect of a modular smartphone?

By knowing how often parts are replaced, table 7 and 8 requires getting the last information on repair costs. The costs are given in Appendix B for the modular designs, but the information is yet lacking for the ordinary designs. Appendix D.1. is created by looking on the internet wherein all costs can be found. Next to that, the financial depreciation of smartphones is required. To determine this, the first sub-section will describe this depreciation.

3.5.1. Financial depreciation

According to BankMyCell[26], a company specialising in giving the best trade-in price for gadgets, smartphones can be divided into three groups with a corresponding deprecation: iOs, Flagship Android and budget Android. The exact depreciation percentages can be found in figure 3.

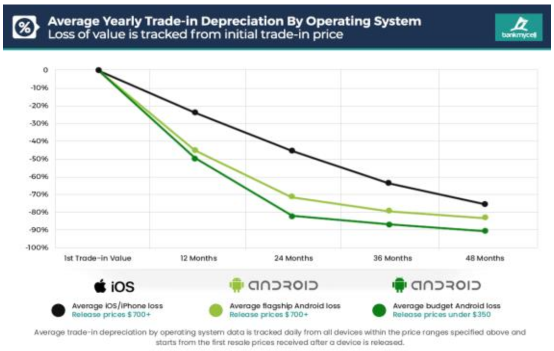

Figure 3. Average Yearly Trade-in Depreciation By Operating System from BankMyCell

Following figure 1 gives a problem for the Fairphones since the price is in-between the 700 dollars of the flagship Androids and 350 dollars of the budget Android (613 and 306 euro following a course of 1 dollar = 0.876191 euro). The price of the Fairphones is closer to the flagship Android; thus, the depreciation of flagship Android used.
Figure 1 is usable in a simulation when it is a formula. This transition can be achieved by uploading the numbers to WolframAlpha[27]. WolframAlpha gave two formulas, one for iOs and one for flagship Android. These formulas can be found in Table 9.

Table 9. Depreciation formula of a smartphone, based on Operating system.

Operating system	Formula (X = months in use)
iOs	(X-48)*(((2.30999*(10^-6)-1.00469*(10^-8)*(X-12))*(X-24)+0.00013316)*X-0.0157458)-0.7558
Flagship Android	(X-48)*(((-2.64837*10^-7*(X-12)-3.91107*10^-6)*(X-24)+0.000517187)*X-0.0173417)-0.8324

These formulas will be used to determine the price of smartphones when they are replaced in the financial simulation.

3.5.2. Simulation outcomes

Table 10 can be created to give an overview over five years of repair cost with this extra founded information. This table also gives a percentage of the modular designs. This percentage stands for the price compared to the ordinary design. A percentage above 100% means the modular design is more expensive than the ordinary. An overview including all costs can be found in Appendix D.

Table 10. Overview of repair cost over five years

Smartphone	Repair cost over five years	Price compared to ordinary design
Fairphone 2	€ 1,330.73	
iPhone 6s ordinary	€ 1,995.83	
iPhone 6s modular	€ 1,851.51	93%
Galaxy S6 ordinary	€ 2,089.59	
Galaxy S6 modular	€ 2,015.62	96%
Fairphone 4	€ 1,507.78	
iPhone 11 ordinary	€ 2,367.91	
iPhone 11 modular	€ 2,232.92	94%
Galaxy S10 ordinary	€ 2,883.87	
Galaxy S10 modular	€ 2,584.64	90%

3.6 What is the ecological effect of a modular smartphone?

Understanding the ecological effect of the modular design requires a similar approach as the economic effect, using tables 7 and 8. However, for the ecological effect, every replaced part will be measured in kg CO_2e. With this value, a five-year evaluation can determine how much kg CO_2e Ordinary and modular designed smartphones produce. Before this can be applied in the simulation, it is required to know the CO_2e emission of every smartphone and its components.

3.6.1. CO_2e emission per smartphone and component

3.6.1.1. Fairphone

Fairphone is open about their CO_2e emission per smartphone and its components in their lifecycle assessment. For the Fairphone 2[15], this overview is straightforward and found in Appendix E.1. However, the Fairphone 4 does not have an LCA yet, since this will be released a short year after release. To assume the CO_2e emission of the Fairphone 4, a calculation will be made with the change in Co_2e between the Fairphone 2 and 3. The LCA of the Fairphone 3[17] suggests that 71.6% of the total production of Co_2e comes from the core module. Next to that, the core module of the Fairphone 3 produced over four years 3% more Co2e. A difference in build is that the Fariphone 4 does not have a top and bottom module but a selfie camera, USB-C port and earpiece module. The loudspeaker module also became bigger.

To solve this, the top and bottom modules will be divided to let their parts fit as good as possible to other modules:

- Loudspeaker module (.2%)→ Loudspeaker module (.2%)
- Top module (4%) → Earpiece module (.2%), selfie camera module (2.75%), and Loudspeaker module (1.05%)
- Bottom module (2%) → USB-C port module (1%), and Loudspeaker module (1%)

Combining this information and applying it to Fairphone 3 module creates the following numbers for the Fairphone 4 in table 11.

Table 11. Kg Co2e produced by Fairphone 4.

Fairphone 4	Emission (kg CO_2e)
Production	32.70
Assembly	1.80
Back cover	0.03
Battery	1.57
Camera module	1.80
Core module	23.41
Display module	1.96
Packaging	0.03
Speaker module	0.74
Selfie camera module	0.90
USB-C port module	0.33
Earpiece module	0.07
Accessories	0.07

3.6.1.2. PCB emission

The modular designs will produce extra emissions due to extra PCBs. The extra emission can be calculated by looking into the Co2e emission of the Fairphone 2 PCBs. According to the LCA of the Fairphone 2, modularity creates 1.62 extra kg of Co_2e. Using the surface of the extra PCB mentioned in the LCA again, just as in table 4, a calculation can be made how much kg CO_2e is produced extra per PCB. This is applied in table 12.

Table 12. Kg CO2e produced per extra cm2 PCB.

PCB	cm^2	kg Co_2e
Total PCB	17.63	1.96
Mainboard	9.86	1.10
Display board	2.7	0.30
Top module board	2.88	0.32
Bottom module board	0.72	0.08
Camera module board	1.47	0.16

3.6.1.3. iPhone

With the iPhones, another problem has to be solved. Apple releases for every smartphone directly environment report. However, this only contains the total Co_2e of the product and can be divided between production, consumer use, transport and recycling. Using this report for the iPhone 6S[1] gives a Co_2e emission of 54 kg and for the iPhone 11[54] an emission of 72 kg. To understand how much emission every part produces, the kg CO_2e emission of the Fairphone 2 and 4 will be applied to the smartphones. For the ordinary design of the iPhone 6S, applying the top and bottom module contribution is not applicable. However, a lightning connector and headphone jack exist. Thus, both ports will be assumed to create the same amount of emission as the USB-C port module of the Fairphone 4. The missing amount of emission will be placed under "Rest". Next to that, the earphone jack will be placed again in the bottom module since it follows the ordinary design better. The iPhone 11 will not have this problem since the top and bottom modules do not exist for the Fairphone 4.
The extra emission due to the extra PCBs and the 53% increase in back cover size will also be applied to modular designs. These emission contributions of the smartphones can be found in Appendix E.2. till E.5. The emission contribution of the iPhone 6S will be given as an example in table 13.

Table 13. Kg Co2e produced by modular iPhone 6S.

Part	Emission (kg CO_2e)
Production total modular	**45.2**
Assembly	5.78
Battery module	2.35
Display module	3.52
Packaging	0.24
Camera module	2.48
Top module	1.44
Back cover	0.16
Bottom module	1.15
Core module	28.09

3.6.1.4. Galaxy

A more difficult problem than the emissions from Apple is those from Samsung. Samsung does not give their produced Co_2e emission per product. Only percentages per product can be found in how much of the total GWP goes to, for example, manufacturing.
However, TechInsights released a teardown of the Galaxy S6 [techInsight s6 teardown] whereby the integrated circuits' surface, ICs, is described.

The LCA of the Fairphone 2 calculated the CO_2e for ICs, which is 5.4 kg of Co_2e per cm^2. This paper also describes how much IC emission is part of the motherboard. Then, the motherboard is described as a part of the total production going a step further.

Applying this to the information of TechInsights creates table 14, wherein the emission of the Galaxy S6 motherboard can be found.

Table 14. Kg CO_2e produced by Galaxy S6 motherboard.

Smartphone	Fairphone 2	Galaxy S6
Motherboard	22.26	19.05
Total IC	17.83	15.26
Percentage of motherboard	80.1%	80.1%

Applying the kg CO_2e of the motherboard into the total emission during production results in the tables found in Appendix E.6. and E.7. for the Galaxy S6 modular and ordinary design.
The Galaxy S10 also has a teardown from TechInsights. However, this teardown is less detailed in the field of the semiconductor surface. This lack of information makes it not possible to apply this method.

3.6.2. Emission per smartphone

Knowing the emission of smartphones and their parts allows applying the values to tables 7 and 8. Table 15 will overview all emissions over five years, whereby a percentage will be given to the modular designs. This percentage stands for the price compared to the ordinary design. A percentage above 100% means the modular design produces more kg CO_2e.
A complete overview of the emissions created can be found in Appendix E.8.

Table 15. Kg CO_2e produced per smartphone design.

Smartphone	Kg CO_2e over five years	Emission compared to ordinary design
Fairphone 2	83.21	
iPhone 6s ordinary	98.59	
iPhone 6s modular	99.75	101%
Galaxy S6 ordinary	69.59	
Galaxy S6 modular	77.47	111%
Fairphone 4	73.07	
iPhone 11 ordinary	127.13	
iPhone 11 modular	131.85	104%

4. Discussion

4.1 General

Smartphones contain many parts whereby the parts exist of many materials. Due to this complexity, not everything is considered when making modular designs, for example, screws. Next to that, not all information could be found about parts which may result in missing parts in a module. In the simulation, it is assumed that a replacement will happen with exact the same smartphone model. When looking at the support of some smartphones, this would not be logical.

4.2 Smartphone components

The smartphones released in 2015 are already multiple years on the market, resulting in a price decrease of parts, and this is not considered. Besides, not every part may be the original part.
Determining the parts on the motherboard of the Fairphone 2 have the same issue. Next to that, some parts were unable to find; thus, similar parts were used to determine the price.

4.3 Replacement cycles

The replacement cycle for ordinary smartphones may depend on the smartphone, user, and producer. Apple, for example, still supports the newest operating system for the iPhone 6S, while that stopped for the Galaxy S6 in 2018. Next to that, the information for the modular replacement cycle is based on rather abstract replacement reasons. It is also not confident whether the reasons given have a specific effect on the replacement cycle.

4.4 Economic effect

The economic simulation shows that modular smartphones are cheaper over five years, table 8. It has to be taken into account that ordinary smartphones can potentially be repaired cheaper, and some consumers have the skill to replace a part themselves.

4.5 Ecologic effect

The ecologic effect is different since modular smartphones produce more kg CO_2e per five years. Looking at the designs, this is logical due to the extra parts for modularity. The ordinary and modular smartphones both need a complete replacement due to the replacement.
For this research, no information, including the desired knowledge, could be found about every smartphone except the Fairphone 2. This lack of information resulted in assuming every emission of smartphone designs based on the Fairphone 2.
Ercan et al.[5] include averages GWP on parts in the production process. These averages are close to the values of the Galaxy S6 when in proportion. This coincidence could mean that the assumed production GWP of the Galaxy S6 is close to the real numbers. The other designs are not in line with Ercan. Comparing the designs to Joshi does neither find a match. These papers conclude that the IC and PCB produce the most GWP, and this research confirms this. However, again this research is mainly based on the values of the Fairphone 2.

5. Conclusion

This paper researched the economic and ecologic effects of making a modular design of ordinary smartphones. As a result, this modular design has a positive effect on the economy of consumers since the consumer has less cost over five years.
For the ecologic effect, the outcome is negative. The results show that modular smartphones produce more kg CO_2e over five years.
This research is based on many assumptions since it lacks information about smartphone emissions.

In future research, more research can be done on those uncertain topics. More insight can be created in the replacement cycle of modular smartphones since replacing parts can have an influence. Next, more emission information can be gathered about the iPhones and Galaxys to perform better research.

6. Acknowledgement

This research's papers and statistics were found using ScienceDirect, Google Scholar and Statista. Within these databases, at least the following search terms were used: "smartphone", "lifecycle", "modular", "components", "GWP". Next to these sources, papers recommended by the supervisor are used.

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Appendix

A. Component overview including cost and release price

A.2. Components overview and their costs of Fairphone 2

Module	Price	Contains
Battery	€ 15.00	
Display Module	€ 65.00	
Top Module (2MP)	€ 15.00	2MP front camera, call receiver
Top module (5MP)	€ 30.00	5 MP front camera, call receiver, headset connector, noise-cancelling microphone, led light, proximity sensor
Bottom Module	€ 25.00	Speaker, vibration motor, USB connector, primary microphone
Camera Module 8MP	€ 20.00	8MP back camera, flash
Camera Module 12 MP	€ 45.00	12MP back camera, flash
Slim Case	€ 20.00	

A.3. Components overview and their costs of Fairphone 4

Module	Price	Contains
Rear Cameras	€ 79.95	48MP main camera, 48 MP ultrawide, 5G network, flash
Selfie Camera	€ 29.95	
Earpiece	€ 14.95	
Loudspeaker	€ 19.95	Loudspeaker, part of 5G antenna, vibration motor
Display	€ 79.95	
Battery	€ 29.95	
USB-C Port	€ 14.95	
Back Cover	€ 19.95	

A.4. Components overview and their costs of iPhone 6S

Part	Price
Battery	€ 12.50
Display	€ 27.95
Home Button	€ 7.95
Front camera and sensor cable	€ 7.95
Earpiece speaker	€ 4.95
Dock Connector (lightning connector, headphone jack, cellular antenna and microphone)	€ 8.95
Loudspeaker	€ 6.95
Vibrator	€ 6.95
Rear camera 12 MP	€ 15.95
Back cover	€ 29.95
Wi-Fi antenna	€ 4.95

A.5. Components overview and their costs of iPhone 11

Part	Price
Battery	€ 29.95
Display	€ 89.95
Loudspeaker	€ 14.95
Vibrator	€ 13.95
Rear camera	€ 65.95
Wi-Fi antenna	€ 19.95
Right-side antenna	€ 14.95
Sensor cable	€ 19.95
Earpiece	€ 13.95
Selfie camera	€ 34.95
Lightning connector (including cellular antenna and microphone)	€ 29.95
Back cover	€ 39.95

A.6. Components overview and their costs of Galaxy S6

Part	Price
Battery	€ 24.95
Display	€ 29.95
Home Button	€ 7.95
Front camera	€ 7.95
Earpiece speaker	€ 6.95
Charging board (USB port, headphone jack, menu touch sensors, primary microphone	€ 9.95
Loudspeaker	€ 8.95
Vibrator	€ 6.95
Rear camera	€ 14.95
Back Cover	€ 29.95

A.7. Components overview and their costs of Galaxy S10

Part	Price
Battery	€ 22.95
Display	€ 229.95
Loudspeaker	€ 14.95
Vibrator	€ 12.95
Rear cameras	€ 26.99

Wi-Fi antenna	€ 5.95
Cellular antenna	€ 11.95
Earpiece speaker	€ 9.95
Selfie camera	€ 10.95
Port	€ 12.95
Headphone jack	€ 12.95
Back cover	€ 24.95
Microphone	€ 9.95

A.8. Components overview and their costs of Galaxy S10

Smartphone	Release Price
Fairphone 2	€ 525.00
Fairphone 4	€ 579.00
iPhone 6S	€ 749.00
iPhone 11	€ 809.00
Galaxy S6	€ 699.00
Galaxy S10	€ 899.00

B. Modular design

B.2. Raw material costs

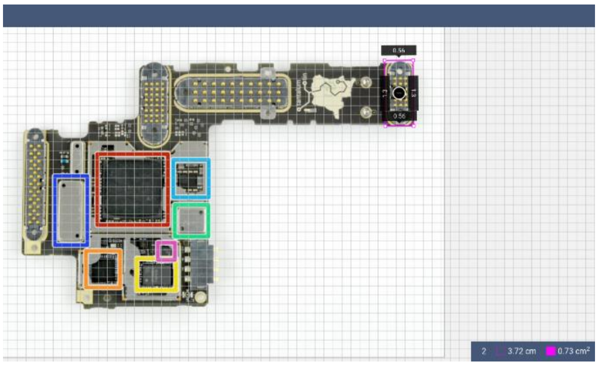
Material	Price per kg	Source
Polycarboante granulate (pc)	€ 1.05	[34]
Glass fibers	€ 0.70	[35]
Stainless steel cold rolled coil (304)	€ 3.74	[36]
Polyamide 6.6 granulate (PA 6.6) Mix	€ 1.26	[34]
Brass (CuZn20)	€ 8.01	[37]

B.3. Raw material costs for every sub-housing

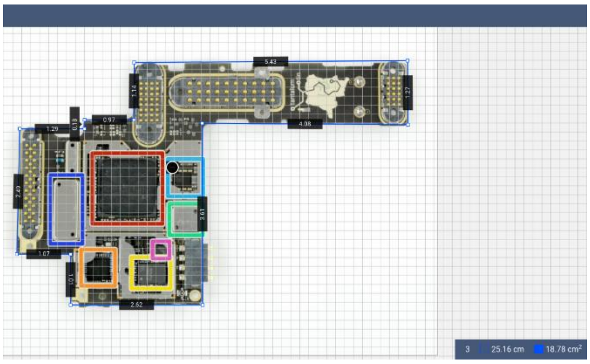
Part	Raw material	weight (mg	Price of raw material
Top module	Polycarbonate granulate (pc)	1602.3	€ 0.0017
	Glass fibres	686.7	0.0005
	Stainless steel cold rolled coil (304)	1100	€ 0.0041
	Polyamide 6.6 granulate (PA 6.6) Mix	773	€ 0.0010
	Glass fibres	773	€ 0.0005
Total price			€ 0.0078
Camera module	Stainless steel cold rolled coil (304)	688	€ 0.0026
	Polyamide 6.6 granulate (PA 6.6) Mix	506.5	€ 0.0006
	Glass fibres	506.5	€ 0.0004
Total price			€ 0.0036
Bottom module	Polyamide 6.6 granulate (PA 6.6) Mix	1355.5	€ 0.0017
	Glass fibres	1355.5	€ 0.0010
	Brass (CuZn20)	84	€ 0.0007
	Polycarbonate granulate (pc)	767.2	€ 0.0008
	Glass fibres	328.8	€ 0.0002
	Stainless steel cold rolled coil (304)	1199	€ 0.0045
Total price			€ 0.0089

B.4. SketchAndCalc pictures of Fairphone 2 motherboard.

B.4.1. Surface benchmark with bottom module



B.4.2. Total surface of Fairphone 2 motherboard



B.5. Fairphone 2 motherboard teardown

Part	Price	Source
Complete motherboard	**€ 325.00**	
Samsung KLMBG4WEBC 32 GB eMMC NAND Flash	€ 34.99	[38]
Qualcomm WCN3680B Wi-Fi 802.11ac Bluetooth Combo (Based on information from the Fairphone team!)	€ 16.50	[39]
STMicroelectronics LSM330DLC 6-Axis Accelerometer + Gyroscope	€ 6.38	[40]

AKM Semiconductor AKM8963C 3-axis Electronic Compass	€ 24.95	[40]
Texas Instruments DRV2603 Haptic Driver	€ 3.34	[41]
Qorvo Antenna Switch	€ 1.75	[42]
Samsung K3QF2F20EM-QGCF 2 GB LPDDR3 RAM, layered on top of the Qualcomm Snapdragon 801 MSM8974AB	€ 43.98	[43]
Andere MSM8939 1VV Cpu Processor Bga Pakket Qualcomm Originele Qualcomm Processor	€ 51.49	[44]
Qualcomm WTR1625L RF Receiver (similar to iPhone 6)	€ 5.62	[45]
RF Micro Device RF7389EU Multimode Multiband Power Amplifier Module	€ 12.84	[46]
Qualcomm QFE1100 Envelope Tracking Power Management	€ 17.38	[47]
Qualcomm PM8841 PMIC	€ 16.50	[48]
Qualcomm WCD9320 Audio Codec	€ 17.00	[49]
Plain motherboard	**€ 72.28**	

B.6. Modular design and the costs of the iPhones and Galaxys

B.6.1. Modular design and the costs of the iPhone 6S

Parts	Price
Battery	**€ 12.50**
Display	**€ 46.29**
Display	€ 27.95
Home button	€ 7.95
PCB Display	€ 10.39
Top module (headphone jack in bottom module)	**€ 28.95**
Front camera and sensor cable	€ 7.95
Wi-Fi antenna	€ 4.95
Earpiece speaker	€ 4.95
Sub housing	€ 0.02
PCB Top Module	€ 11.08
Bottom module	**€ 25.64**
Lightning connector and headphone jack	€ 8.95
Loudspeaker	€ 6.95
Vibrator	€ 6.95
Sub housing	€ 0.02
PCB Bottom Module	€ 2.77
Camera module (flashlight in top module	**€ 21.62**
Rear camera 12 MP	€ 15.95
Sub housing	€ 0.01
PCB Camera Module	€ 5.66
Back Cover	**€ 45.67**
Back Cover	€ 29.95
Size increase	€ 15.72
Motherboard	**€ 52.90**
Motherboard	€ 14.95
PCB Mainboard	€ 37.95

B.6.2. Modular design and the costs of the iPhone 11

Parts	Price
Battery	**€ 29.95**
Display	**€ 100.34**
Display	€ 89.95
PCB Display	€ 10.39
Loudspeaker	**€ 31.69**
Loudspeaker	€ 14.95
Vibrator	€ 13.95
PCB Top Module	€ 2.77
Sub housing	€ 0.02
Rear camera module	**€ 100.85**
Rear camera	€ 65.95
Wi-Fi antenna	€ 19.95
Right-side antenna	€ 14.95
Sensor cable	€ 19.95
PCB Camera Module	€ 5.66
Sub Housing	€ 0.02
Earpiece	**€ 16.73**
Earpiece	€ 13.95
PCB Bottom Module	€ 2.77
Sub housing	€ 0.01
Selfie camera	**€ 37.72**
Selfie camera	€ 34.95
PCB Bottom Module	€ 2.77
Port	**€ 32.73**
Dock connector	€ 29.95
PCB Bottom Module	€ 2.77
Sub Housing	€ 0.01
Back cover	**€ 60.92**
Back cover	€ 39.95
Size increase	€ 20.97

B.6.3. Modular design and the costs of the Galaxy S6

Parts	Price
Battery	**€ 24.95**
Display	**€ 148.29**
Display	€ 129.95
Home button	€ 7.95
PCB Display	€ 10.39
Top module	**€ 26.00**
Front camera	€ 7.95
Earpiece speaker	€ 6.95
Sub housing	€ 0.02
PCB Top Module	€ 11.08
Bottom module	**€ 28.64**
Dock connector + headphone jack	€ 9.95
Loudspeaker	€ 8.95
Vibrator	€ 6.95
Sub housing	€ 0.02
PCB Bottom module	€ 2.77
Camera module	**€ 20.62**
Rear camera	€ 14.95
Sub housing	€ 0.01
PCB Camera Module	€ 5.66
Back Cover	**€ 45.67**
Back Cover	€ 29.95
Size increase	€ 15.72
Motherboard	**€ 74.94**
Motherboard	€ 36.99
PCB Mainboard	€ 37.95

B.6.4. Modular design and the costs of the Galaxy S10

Parts	Price
Battery	€ 22.95
Display	€ 240.34
Display	€ 229.95
PCB Display	€ 10.39
Loudspeaker	**€ 30.69**
Loudspeaker	€ 14.95
Vibrator	€ 12.95
PCB Top Module	€ 2.77
Sub housing	€ 0.02
Rear camera	**€ 50.57**
Rear cameras	€ 26.99
Wi-Fi antenna	€ 5.95
Antenna	€ 11.95
PCB Camera Module	€ 5.66
Sub housing	€ 0.02
Earpiece	**€ 12.73**
Earpiece	€ 9.95
PCB Bottom module	€ 2.77
Sub housing	€ 0.01
Selfie camera	**€ 13.72**
Selfie camera	€ 10.95
PCB Bottom module	€ 2.77
Port	**€ 28.67**
Port	€ 12.95
Headphone jack	€ 12.95
PCB Bottom module	€ 2.77
Sub housing	€ 0.01
Back cover	**€ 38.05**
Back cover	€ 24.95
size increase	€ 13.10

C. Component replacement

C.2. Component replacement chance and corresponding exponential base

Component	Replacement percentage in five years	Exponential base
Display	0.674	0.99344615129792
Back cover	0.5	0.9885140203529
Battery	0.339	0.98213230175932
Charging port	0.07	0.95664682396131
Earphone jack connector	0.09	0.96066221329523
Camera	0.079	0.95857725123616

D. Economic effect

D.1. Replacement costs by ordinary smartphones

Component	iPhone 6S	iPhone 11	Galaxy S6	Galaxy S10
Display	€ 59.00 [50]	€ 109.00 [51]	€ 179.00 [52]	€ 270.00 [51]
Battery	€ 39.00 [50]	€ 59.00 [51]	€ 65.00 [52]	€ 75.00 [51]
Housing	€ 100.00 [50]	€ 139.00 [51]	€ 50.00 [52]	€ 75.00 [51]
Camera	€ 40.00 [50]	€ 125.00 [51]	€ 85.00 [52]	€ 89.00 [50]
Earphone jack	€ 40.00 [50]	-	€ 69.00 [52]	€ 49.00 [53]
Dock connector	€ 40.00 [50]	€ 75.00 [51]	€ 65.00 [52]	€ 190.00 [51]

Appendix E. Ecological effect

E.1. Co_2e emission of Fairphone 2

Fairphone 2	**Emission (kg CO_2e)**
Production modular	**35.98**
Assembly	4.81
Battery module	1.96
Display module	2.68
Packaging	0.2
camera module	1.93
Top module	1.29
Back cover	0.09
Bottom module	0.53
Core module	22.48

E.2. CO_2e emission of iPhone 6S ordinary

Part	**Emission (kg CO_2e)**
Overall total ordinary	**54**
Production total	**43.2**
Assembly	5.78
Battery	2.35
Display	3.22
Packaging	0.24
Camera	2.32
Headphone jack	0.43
Back cover	0.11
Lightning connector	0.43
Core	26.99
Rest	0.20

D.1. Replacement costs of smartphones

Smartphone	display	back cover	earphone jack	port	port and earphone jack	battery	camera	smartphone2	repair cost over five years
Fairphone 2	€ 130.00	€ 40.00	€ 30.00	€ 25.00	€ -	€ 15.00	€ 45.00	€ 1,045.73	€ 1,330.73
iPhone 6s ordinary	€ 118.00	€ 200.00	€ 40.00	€ 65.00	€ -	€ 39.00	€ 40.00	€ 1,493.83	€ 1,995.83
Galaxy S6 ordinary	€ 358.00	€ 100.00	€ 69.00	€ 65.00	€ -	€ 65.00	€ 40.00	€ 1,392.59	€ 2,089.59
Fairphone 4	€ 159.90	€ 39.90	€ 14.95	€ 29.95	€ -	€ 29.95	€ 79.95	€ 1,153.18	€ 1,507.78
iPhone 11 ordinary	€ 218.00	€ 278.00	€ -	€ 75.00	€ -	€ 59.00	€ 125.00	€ 1,612.91	€ 2,367.91
Galaxy S10 ordinary	€ 540.00	€ 150.00	€ 49.00	€ 190.00	€ -	€ 75.00	€ 89.00	€ 1,790.87	€ 2,883.87
iPhone 6s modular	€ 92.58	€ 91.35	€ -	€ 25.64	€ -	€ 12.50	€ 21.62	€ 1,607.82	€ 1,851.51
Galaxy S6 modular	€ 296.58	€ 91.35	€ 26.00	€ 28.64	€ -	€ 24.95	€ 20.62	€ 1,527.48	€ 2,015.62
iPhone 11 modular	€ 200.68	€ 121.85	€ -	€ 32.73	€ -	€ 29.95	€ 100.85	€ 1,746.86	€ 2,232.92
Galaxy S10 modular	€ 480.68	€ 76.10	€ -	€ -	€ 28.67	€ 22.95	€ 50.57	€ 1,925.67	€ 2,584.64

E.3. CO_2e emission of iPhone 6S modular

Part	Emission (kg CO_2e)
Overall total modular	**56.51**
Production total modular	**45.2**
Assembly	5.78
Battery module	2.35
Display module	3.52
Packaging	0.24
Camera module	2.48
Top module	1.44
Back cover	0.16
Bottom module	1.15
Core module	28.09

E.4. CO_2e emission of iPhone 11 ordinary

Part	Emission (kg CO2e)
Overall total ordinary	72.00
Production total ordinary	56.88
Assembly	3.13
Back cover	0.06
Battery	2.73
Camera	3.13
Core module	40.73
Display	3.41
Packaging	0.06
Speaker	1.28
Selfie camera	1.56
Lightning connector	0.57
Earpiece	0.11
Accessories	0.11

E.5. CO_2e emission of iPhone 11 modular

Part	Emission (kg CO2e)
overall total modular	74.42
production total modular	58.79
Assembly	3.13
Back cover	0.09
Battery	2.73
Camera module	3.29
Core module	41.82
Display module	3.71
Packaging	0.06
Speaker module	1.36
Selfie camera module	1.64
Lightning connector module	0.65
Earpiece module	0.19
Accessories	0.11

E.6. CO_2e emission of Galaxy S6 ordinary

Parts	Emission (kg CO2e)
Production assumption ordinary	**30.49**
Production ordinary	**30.49**
Assembly	4.08
Battery	1.66
Display	2.27
Packaging	0.17
Camera	1.64
Headphone jack	0.30
Back cover	0.08
USB port	0.30
Core module	19.05
Rest	0.94

E.7. CO_2e emission of Galaxy S6 modular

Parts	Emission (kg CO2e)
Production modular	**34.83**
Assembly	4.08
Battery module	1.66
Display module	2.57
Packaging	0.17
Camera module	1.80
Top module	1.41
Back cover	1.60
Bottom module	0.53
Core module	21.01

E.8. Emission of smartphones

Smartphone	**display**	**back cover**	**earphone jack**	**port**	**port and earphone jack**	**battery**	**camera**	**smartphone2**	**Kg CO2e over five years**
Fairphone 2	5.36	0.18	1.29	0.53		1.96	1.93	71.96	83.21
iPhone 6s ordinary	6.44	0.22	0.43	0.43		2.35	2.32	86.40	98.59
iPhone 6s modular	7.04	0.33			1.15	2.35	2.48	86.40	99.75
Galaxy S6 ordinary	4.54	0.15	0.30	0.30		1.66	1.64	60.99	69.59
Galaxy S6 modular	5.14	0.23	1.41	0.53		1.66	1.80	66.70	77.47
Fairphone 4	3.92	0.07		0.33		1.57	1.80	65.39	73.07
iPhone 11 ordinary	6.83	0.11		0.57		2.73	3.13	113.76	127.13
iPhone 11 modular	7.43	0.17		0.65		2.73	3.29	117.58	131.85