TÉCNICO LISBOA

Circular Economy in Electronic Equipment Accessories

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Abstract

Technology has undergone a fast evolution nowadays, generating an increase in the global accessories market. Accessories add value to mobile phones. However, the raw materials and manufacturing processes are very harmful and non-modular, being hard to reuse them. Also, there is a lack of solutions to reduce the waste of electronic equipment accessories.

On this scope, the current dissertation focuses on studying the implementation of product design within a circular economy perspective, developing new sustainable accessories through the understanding of the different tools and frameworks provided in the literature review.

Bearing in mind the problem and using the most advantageous methods presented in the literature review, the methodology proposed in UNLEASH by Delloite (2019) was adopted, which has five steps for the product design process. First, a problem tree and a consumer profile framework were elaborated to understand the causes of the core problem. Then, a brainstorming session and a multicriteria decision analysis allowed the obtention of the best solutions to be pursued. Subsequently, different materials were tested, and their virtual and physical prototypes were created. A focus group was developed to evaluate the prototypes. Finally, a business model for market implementation was elaborated.

The sequence of methods adopted allowed the development of a unique methodology. Its application to a real case study resulted in three fully sustainable final products - charger converter, charger cable, phone case – that promote circular economy and eco-design and are capable of being marketed. Moreover, the products ensure the improvement of the core problem through their modularity, and the recyclability of the materials.

Keywords: Circular Economy, Eco-Design, Electronic Products Accessories

Resumo

A tecnologia está atualmente a passar por uma rápida evolução, originando um aumento no mercado global de acessórios, os quais adicionam valor aos telemóveis. No entanto, as matérias-primas utilizadas e os processos de fabrico são prejudiciais para o ambiente e não-modulares, sendo difícil o seu reaproveitamento. Além disso, faltam soluções para reduzir o desperdício destes acessórios.

Neste âmbito, a presente dissertação centra-se no estudo da implementação do design de produto numa perspetiva de economia circular, desenvolvendo novos acessórios sustentáveis através da compreensão de diferentes ferramentas e enquadramentos disponibilizados na revisão da literatura.

Considerando o problema e utilizando os métodos mais vantajosos apresentados na revisão da literatura, foi adotada a metodologia proposta no UNLEASH pela Delloite (2019), a qual tem cinco etapas para o processo de design. Inicialmente, foram elaboradas uma árvore de problemas e uma análise de perfil do consumidor para obter as causas do problema central. Em seguida, uma sessão de brainstorming e uma análise de decisão multicritério permitiram obter as melhores soluções. Posteriormente, diferentes materiais foram testados, e os seus protótipos virtuais e físicos foram criados. Foi desenvolvido um focus group para avaliar os protótipos desenvolvidos. Por fim, com vista à implementação no mercado, foi elaborado o modelo de negócios. A sequência de métodos adotados permitiu o desenvolvimento de uma metodologia única. A sua aplicação a um caso de estudo real resultou em três produtos finais - transformador do carregador, cabo do carregador, capa para telemóvel - totalmente sustentáveis, que promovem a economia circular e o eco-design, podendo ser colocados no mercado. Além disso, os produtos garantem a melhoria do problema encontrado, através da sua modularidade e da reciclabilidade dos materiais.

Palavras-chave: Economia Circular, Eco Design, Acessórios de Produtos Eletrónicos

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

CAGR: Compound Annual Growth Rate

PC: Polycarbonate

TPU: Thermoplastic Polyurethane

PET: Polyethylene Terephthalate

PVC: Polyvinyl Chloride

PUR: Polyurethane

ABS: Acrylonitrile Butadiene Styrene

PET: Polyethylene Terephthalate

SD: Secure Digital

TF: TransFlash

CF: Compact Flash

Li-ion: Lithium-ion

Li-polymer: Lithium polymer

EEE: Electrical and Electronic Equipment

EU: European Union

WEEE: Waste of Electrical and Electronic Equipment

SDGs: Sustainable Development Goals

MDGs: Millennium Development Goals

TAM: Total Addressable Market

TBS: Traditional Brainstorming

NBS: Nominal Brainstorming

EBS: Electronic Brainstorming

STH: Six Thinking Hats

RWW: Real, Win, Worth it

2D: Two Dimensions

EMF: Ellen MacArthur Foundation

DfE: Design for the Environment

LCA: Life Cycle Assessment

MCA: Multi-Criteria Analysis

EPIs: Environmental Performance Indicators

LiDS: Life Cycle Design Strategy

MPIs: Management Performance Indicators

OPIs: Operational Performance Indicators

ECI: Environmental Condition Indicators

CAD: Computer-Aided Design

UI: Unstructured Interview

SSI: Semi-Structured Interview

SI: Structured Interview

BM: Business Model

CBM: Circular Business Models

1. Introduction

This chapter presents the master's dissertation and is divided into three sections. Section 1.1 presents the context for development of the dissertation and the implicit motivation for it. Section 1.2 shows the objectives of the master's dissertation. Section 1.3 gives the structure of the dissertation, as well as a brief description of each chapter.

1.1. Problem Context

The world is undergoing a constant technological evolution where innovations emerge every second in different areas contributing to society progress (Buchanan, 2020). This continuous innovation and transformation of technology drives the increasing consumption of the electronic equipment market (Statista, 2020a), having registered, in 2017, a total of 9.0 million tonnes of electrical and electronic equipment put on the market in the European Union. Unfortunately, not all EEE sets on the market are collected, treated, reused, or recycled. Several are thrown away with general trash and end up in a trash can, polluting the environment as they are not biodegradable (Eurostat, 2020).

Among the various existing EEE are phones, which emerged, after the industrial revolution, from technological advances in electricity. Almost four decades after the insertion of mobile phones in the market, developed countries register at least 90% of this product penetration (Delloitte, 2017). In 2019, phones accounted for 48.3% of the total electronics market, becoming increasingly pervasive and indispensable, with consumers all over the world enthusiastically embracing its potential (Statista, 2020a). These devices are no longer mere tools. They became intimate and personal objects, making people feel inadequate and uncomfortable without them (Ventä et al., 2008). The potential life span of a mobile phone (excluding batteries) is over ten years, but most users upgrade their phones around four times during this period. This consumer behaviour has resulted in the present situation where replacement phones represent approximately 80% of the new mobile phone purchases (Osibanjo, 2008).

All electronic equipment, including mobile phones, requires charging, protection, and even add-ons such as headphones or power banks. These products represent the electronic equipment accessories market that grows with the increase of the mobile phone market. Several types of accessories are part of the electronic equipment accessories market, namely cable chargers, phone cases, earphones, memory cards, power banks, among others (Delloitte, 2019a). To consumers, accessories are beneficial products that add value to mobile phones and increase their usage time. Besides, for the same equipment, each user has several types of accessories and more than one accessory of each type, which exponentially increases the number of accessories sold. However, the raw materials used to manufacture these accessories are very harmful to the environment and are not biodegradable. Furthermore, it is hard to fix or exchange some parts and put them back on the market since most of them are built using non-modular processes.

Accordingly, this research aims to adopt the methodology proposed by Delloitte (2019) and the United Nations, the UNLEASH Innovation process, which involves five steps, to create a sustainable design for these accessories, studying which materials are most suitable and their respective impact on the environment. The new design for these products is crucial to replace the need for generating more waste in this industry. For a proper understanding of the matters involved, extended research has been conducted in the following chapters. Furthermore, a thorough literature review on steps, tools and frameworks that can be used has been conducted.

1.2. Dissertation Goal

This master's dissertation has an ultimate goal that is develop a marketable product that is based on circular economy and eco-design strategies and that promotes the reduction of waste generated. In order to achieve this goal there are six main objectives: (1) properly introduce, contextualize and characterize the market for electronic equipment accessories, allowing a clear problem characterization, (2) develop a comprehensive and relevant scientific literature review taking into account the five phases proposed by the UNLEASH design process, (3) present, within the scope of the literature review carried out, the most appropriate methodologies to be adopted in the master's dissertation so that the research problem can be properly addressed, (4) Define the scope of the problem, and the design and materials of the product to be developed, (5) Develop a virtual and a physical prototype that can be presented to potential customers, and (6) Analyse possible improvements and develop a business plan capable of supporting the product's market introduction.

1.3. Structure of the Dissertation

This dissertation consists of six sections described below. The first section corresponds to an introduction to the dissertation with a brief context and motivation that led to the problem, and the objectives to be developed. Chapter 2 presents a contextualization of the problem, providing an overview of the electronic products market, followed by the characterization of the accessories market and a detailed presentation of the market and solutions in the five most consumed accessories. Chapter 3 comprises an extensive review of the literature on the available methods which are integrated in the five steps of the UNLEASH design process. Different methodologies that can be implemented are presented, as well as their advantages and disadvantages. Also, a characterization of the concept of circular economy is presented, followed by an introduction to eco-design. Chapter 4 presents the methodology with detailed guidelines, methods, and different processes to be applied at each stage, along with the theoretical basis corresponding to fulfil the objectives defined. Chapter 5 includes the results of all the steps presented in the methodology and their respective discussion. Chapter 6 presents the main conclusions drawn from the study and some recommendations for future research.

2. The Mobile Phone Accessories Market

This chapter is divided into four sections. Section 2.1 provides an overview of the market of electronic products including mobile phones and high sales growth. Section 2.2 presents the primary mobile phone accessories, as well as their consumption and the most used manufacturing materials. Furthermore, subsections 2.2.1 to 2.2.5 specify the characteristics of the accessories with the highest percentage of use. Lastly, section 2.3 characterizes the problem, which will be the focus of this work.

2.1. Characterization of Electronic Products

The continuous innovation and transformation of technology in the world and recently the introduction of technologies such as 5G, drives the consumption of the electronic equipment market. In 2019, consumer electronics generated US$ 1.032 billion in revenue, with a sales volume of 7.6 billion pieces worldwide. These values were expected to grow to US$ 1.160 billion by 2025. However, in 2020, with Covid-19, the estimated revenues had to be adjusted as the pandemic generated a 6% drop in worldwide electronic consumption income (Statista, 2020a). This market is divided into five segments as observed in **Figure 1**.

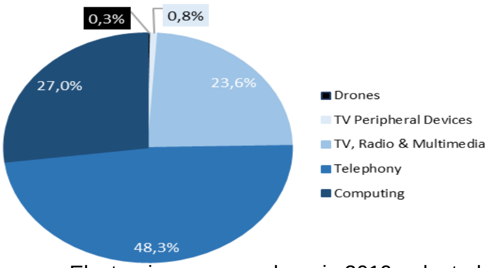


Figure 1: Worldwide Consumer Electronics revenue share in 2019, adapted from (Statista,2020)

The first segment is Telephony, which represents 48.3% of the total market and includes Mobile Phones and Landline Phones. The second, with a representation of 27%, is Computing, including devices such as Laptops and Tablets, Desktop PCs, PC Monitors and Projectors, Keyboards, Printers and Copiers, and Storage Units. In third place appears the TV, Radio and Multimedia segment, comprising devices such as Televisions, Radios, Digital Cameras, Speakers and Headphones, representing 23.6% of the total global market. The last two positions are taken by the TV Peripheral Devices and Drones categories, which represent 0.8% and 0.3% of the total market, respectively. Between 2019 and 2025, it was expected that the two last segments grew more than 30%. On the other hand, the other three should expect an increase of less than 15% (Statista, 2020a).

Nonetheless, the faster development of nowadays technology promotes obsolescence of electronic equipment, making it outdated and uninteresting even when it is still efficient, leading to its immediate replacement by a new version (Osibanjo, 2008).

As mentioned, it is in the first segment that mobile phones are included. Almost four decades after the introduction of the first mobile phone, nearly every developed country has at least 90% of mobile phone penetration rate. The mobile phone has become increasingly pervasive and indispensable, with consumers all over the world enthusiastically embracing its potential (Delloitte, 2017). These devices are no longer just tools, they have become intimate and personal, causing people to feel inadequate and uncomfortable without them (Ventä et al., 2008).

The global mobile phone market size was valued USD 18.49 billion in 2018, growing at a Compound Annual Growth Rate (CAGR) of 12.7% from 2015 to 2025 (Grandviewresearch, 2019). Furthermore, in 2019, the world had 1.52 billion mobile phones sold, corresponding to an increase from the 680 million units in 2012. This growth of smartphones sold to end users represents that more than 19% of the worldwide population owned a smart device in 2019, a value that is expected to reach 37% in 2021 (Gartner, 2020). Thus, it is expected that in 2021 there will be 3.8 billion smartphone users worldwide (Gu, 2019).

Europe, despite not being the region with the largest number of mobile phone users, in 2019, had 593.7 million users. This number is projected to reach 698.2 million by 2025(Statista, 2020b). The percentage of mobile web traffic generated by devices between 2013 and 2018, during Q1 2019 in European countries is on average 30.97%, of which Poland holds the highest one with 36.37% (DeviceAtlas, 2019).

Regarding this market, in Portugal the percentage of mobile web traffic generated by devices between 2013 and 2018 is shown in **Figure 2**. The progressive increase in the use of mobile phones is notable, with 2017 being the year with the highest percentage (32.36%). In 2018, there is an evident reduction in web traffic generated by devices, which is justified not by lower usage, but because it is a year with a lower number of new mobile phone launches (DeviceAtlas, 2019).

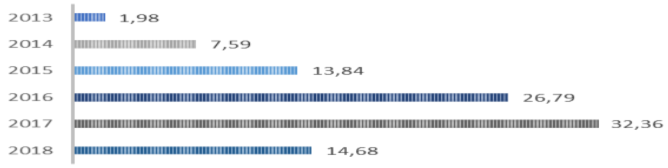


Figure 2: Percentage of overall mobile web traffic generated by devices, adapted from (Device Atlas,2019)

The potential life span of a mobile phone (excluding batteries) is over ten years, but due to the previously mentioned facts, most of the users upgrade their phones around four times during this period. This consumer behaviour has resulted in the present situation where replacement phones represent approximately 80% of the new mobile phone purchases (Osibanjo, 2008). Considering the years between 2016 and 2018, it is noticeable that there is an 18-24-month delay, on average, between an updated version of a device becoming available and the user taking the plunge and upgrading (DeviceAtlas, 2019).

After this time, the mobile phones are thrown into a closet or drawer and finally discarded with the household garbage. Fast innovations lead to a further decrease in average product lifetime, which aggravates the waste issue. Besides, mobile phones are composed of components harmful to the environment, illustrated in **Figure 3**, increasing pollution, and decreasing sustainability (Osibanjo, 2008).

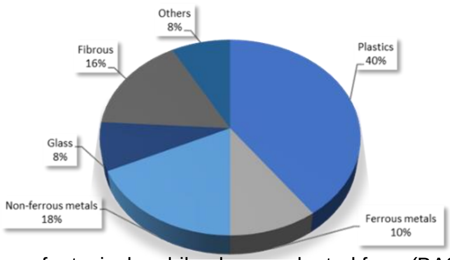


Figure 3: Composition of a typical mobile phone, adapted from (BASEL/MPPI, 2004)

As mobile technology reaches new levels of sophistication, the mobile phone behaviour of consumers follows. However, different generations have different numbers of connected devices, which include any desktop computer, laptop, netbook, tablet, or smartphone. As represented in **Figure 4**, the Gen Z – ages 18 to 22 - are the ones that are living their social lives through multiple devices having, on average, more connected devices – two (Sverdlov, 2011).

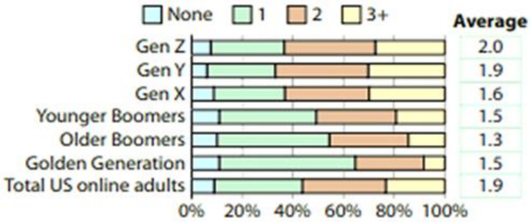


Figure 4: Number of connected devices by generation (Sverdlov, 2011)

The growing demand for mobile phones, drives the growth in demand for another market the accessories market. Any of the products mentioned above requires charging, protection, and even add-ons such as headphones. Therefore, the focus is increasingly on buying equipment that is part of the smartphone ecosystem, in other words, smartphone accessories.

2.2. Mobile phone accessories market

The global mobile phone accessory market size was valued at US$221.4 billion in 2020 and it was estimated to expand to US$251 Billion by 2027, growing at a Compound Annual Growth Rate (CAGR) of 1.8% from 2020 to 2027 (Global Industry Analysts, 2020). This same market can be segmented into four types. The first one is by price range in which three categories, premium, mid, and low, stand out. It is worth to mention that the last two previously mentioned are expected to exhibit strong growth. The second segmentation is by geographic region, where it can be highlighted North America, Europe, Asia-Pacific, Latin America, Middle East, and Africa (MEA) or even by different countries. The third one is by distribution channel, according to which accessories market is split into online stores and offline stores. Finally, it is possible to segment this market by product type, from which the categories represented in **Figure 5** arise (Acumen research and consulting, 2020).

As it is possible to observe in this **Figure 5**, the global accessories market is divided into fifteen categories, of which the five with the highest percentage of consumption stand out: cable charger (99%), phone case (76%), wired earphones (65%), memory cards (57%) and power bank (50%) (Delloitte, 2019a).

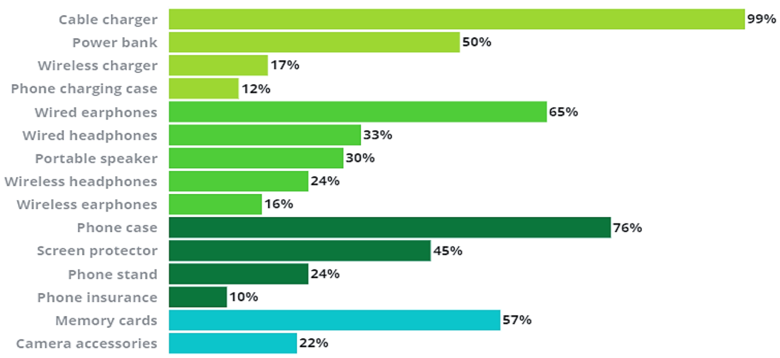


Figure 5: Mobile accessories segmentation (Delloitte, 2019a)

Furthermore, accessory owners can be divided into two major groups: iPhone owners and Android owners. In **Figure 6**, it is possible to observe that the first one's own more accessories in almost all categories. However, Android owners are more likely to own memory cards, with more than half of Android owners purchasing these separately (Delloitte, 2019a).

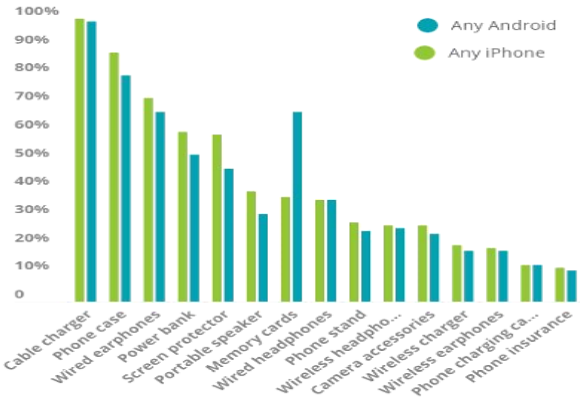


Figure 6: iPhone vs Android accessories ownership (Delloitte, 2019a)

This difference between iPhone and Android users is due not only to the type of ecosystem developed by Apple that is much more coherent and allows for a high connection between all accessories and wearables, but also because of the greater willingness to spend. On the other hand, Android users are more likely to have memory cards reflecting the lesser storage capacity of these devices (Delloitte, 2019a).

Concerning the distribution of accessories consumption by age group, youngers' own an average of eight different types of mobile phone accessories, while 65 to 75-year-olds have an average of four. Among younger ages, 43% own wireless headphones, while 32% own wireless earbuds. Meanwhile, 58% own a portable speaker and 35% own camera accessories (Delloitte, 2019c).

So far, an analysis of the high consumption of mobile phones, as well as, all the elements of its ecosystem, wearables technology, or accessories, has been presented above. At this point, it is essential to understand not only the behaviour of each accessory with a higher percentage of use, as well as the materials used in its manufacture.

2.2.1. Cable Charger

At the present moment, the purchase of a mobile phone implies the acquisition of a charger, and, in some brands, wired earphones. Within a percentage of 98% of smartphone owners that have a charger, 92% of those chargers came with the phone. On the other hand, because the mobile phone has a battery which it is not eternal, it becomes crucial to buy a charger. These are more than valid justifications for the high percentage of consumption (99%) of these accessories (Delloitte, 2019d). The majority of chargers consist of an electrical part composed of metals such as copper and aluminium and a plastic coating, more specifically polycarbonate (PC) (UNEP, 2013).

Polycarbonate is a translucent thermoplastic characterized by its strength, rigidity at temperatures above 140ºC, resistance, and hardness. Moreover, it is a material that maintains its mechanical characteristics and dimensional stability when subjected to different forces and temperatures, and is therefore called amorphous (British plastic federation, 2020). Hence, it can be considered a perfect material for the manufacture of chargers, especially for the most recent ones called fast charging, which tend to reach higher temperatures when used, since they operate at 40 watts compared to the usual 2.5 watts (Paul Lee et al., 2019). In general, the manufacturing process of the exterior of a charger is done by injection, extrusion, or blow moulding, which corroborate the non-modularity of these accessories (British plastic federation, 2020).

As an effort to combat the high consumption of these accessories, ensuring the company's sustainability, Apple announced that its latest version of the iPhone will be sold without the charger, thus contributing to the reduction of carbon emissions (Apple, 2020). Similarly, Nimble, a new technology accessory company, has also created a line of chargers and cables made from plants and a mix of recycled plastic bottles, as shown in **Figure 7** (Bonnington, 2018). Besides, they use packaging made from 100% recycled scrap paper pulp and do not use harmful inks or dyes to make it biodegradable and cheaper to produce, as illustrated in **Figure 8** (Nimble, 2020).

Figure 7: Ultimate iPhone Fast Charge Upgrade Kit from Nimble (Nimble, 2020)

Figure 8: Clean Packaging from Nimble (Nimble, 2020)

2.2.2. Phone Case

There are many different types of mobile phone cases. Depending on the user's preference, it is possible to obtain a cover that is more, or less rigid, softer, or harder to the touch, of different colours and even with animations. For users, the covers are no longer just a protective element, but a decorative and fashionable accessory that allows you to change your phone, looking like a new device (TransparencyMarketResearch, 2020).

During 2019 around 1 billion mobile phone cases were sold, most of them made of plastic or more specifically polycarbonate (PC) (Coolectiva, 2019). When these are damaged or are no longer compatible with the equipment model, they are discarded, usually in the ordinary waste. Polycarbonate (PC), as mentioned for chargers, has characteristics of high strength and rigidity which allows high protection of mobile phones. The covers made of this material have not only high durability, flexibility, and resistance to different environments, but are also affordable (British plastic federation, 2020). However, this material is not biodegradable, taking more than 1000 years to decompose in landfills and thus contributing to environmental pollution (TAPAN, 2019). Furthermore, other materials such as silicone or thermoplastic Polyurethane (TPU) can also be used, which provide greater flexibility and adherence to the material and increase shock absorption. Silicone is an expensive material since the process of transforming sand into it, is time consuming and does not allow economies of scale. Also, its manufacture emits gases that are harmful to the environment. TPU is a type of plastic similar to PC (Hau, 2019).

Generally, the production of mobile phone cases is made by injection moulding, which, once again, refers to the non-modularity of this accessory. Thus, when it is damaged or no longer used it becomes another piece of garbage that pollutes the environment.

To tackle this this problem and to reduce the amount of plastic in the oceans and nature, the PelaCase brand created protective case of 100% compostable and equally resistant materials. Compostable material is one capable of decomposing into carbon dioxide, water, and biomass, leaving no toxic compound (PelaCase, 2018).
These innovative covers are made from plant-based materials with a percentage always higher than 45% of this base. The remaining 55% is derived from non-renewable resources, used to provide added durability to the product (PelaCase, 2018). In 2018, Pela Case sales resulted in more than 19,000 kg of plastic taken from the ocean and donations above € 170,000 that helped protect biodiversity, the ocean, and the coast (Coolectiva, 2019). Some examples of the Pela cases are illustrated in **Figure 9**.

Figure 9: Phone Cases made by PelaCase (PelaCase, 2018)

The big question related to these covers refers to their price since buying only the cover can cost between $ 29.95-49.95 and adding the screen saver the value increases to between $ 60 - $ 80 (Ames, 2020). Also, the use of bioplastics can be a controversial issue since its ability to biodegrade is always in doubt. PelaCase remains open and transparent about its proprietary, Flaxstic material. Through a study by the LCA, it was realized that the greatest impact of these cases is the carbon footprint of transportation, with a value of 46%. This impact includes both transportation of raw goods to manufacturing facilities, as well as the finished product to distribution centres, and from distribution centres to the customer (Greenstep Solutions Inc and Ecobase Solutions Inc, 2019).

2.2.3. Headphones

There are several types of headphones identified in **Figure 5**. The wired earphones (65%) and the wired headphones (33%) are connected by a wire, while wireless headphones (24%) and wireless earphones (16%) are connected by Bluetooth. Currently, wired headphones/earphones predominate among smartphone owners, especially wired earphones/earbuds, which represent 64% of the total, as illustrated in **Figure 10**, since they are the ones that usually come with the mobile phone (Delloitte, 2019b).

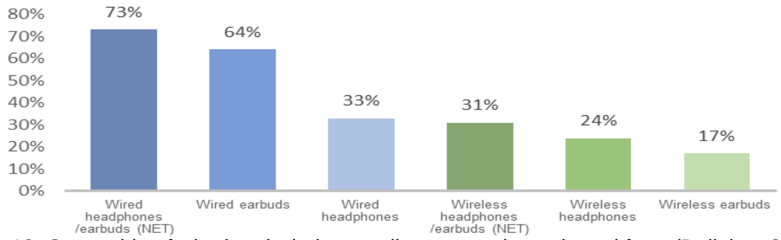


Figure 10: Ownership of wired and wireless audio accessories, adapted from (Delloitte, 2019b)

Although still represent the minority, the trend towards migration to wireless versions has been accentuating in recent years and even the possession of multiple versions depending on the context such as office, physical exercise, or travel (Lee et al., 2019).

However, the biggest concern lies in wired earphones that have a higher percentage of ownership and can be easily thrown away. Besides, they are not possible to fix when damaged, again referring to the non-modularity of these accessories. The materials used in the manufacture of these accessories are numerous, as illustrated in **Table 1**, highlighted foam, vinyl, silicone, synthetic leather, advanced plastic, textile, and many others (Bechstein, 2018).

Table 1: Material identification in headphones and earphones (adapted from Schmidt et al., 2008)

Material	Type
Silicone	Earphones/Earbuds
Foam	Headphones
Leather-effect	Headphones
PVC	Headphones; Earphones/Earbuds
PUR	Headphones; Earphones/Earbuds
PC	Earphones/Earbuds
Artificial Leather	Headphones
Rubber	Earphones/Earbuds
Textile	Earphones/Earbuds (around-ear)
"Slow-memory material"	Earphones/Earbuds (around-ear)
Polyethylene Terephthalate (PET)	Headphones

Synthetic leather and Polyvinyl Chloride (PVC) are the most often used materials for wired and wireless headphones, while textile and leather are used only for high-quality products. Foam is assumed to include foam rubber made of polyurethane (PUR) or PVC. Earphones/earbuds are mainly from plastic types like PVC, Polycarbonate (PC), or Acrylonitrile Butadiene Styrene (ABS). In all of these accessories, there is an outer layer of foamed plastic usually made from PUR or PVC (Schmidt et al., 2008).

House of Marley is an example of sustainable production of accessories, using bamboo, composite wood, recycled paper, and a combination of fabric made from recycled cotton and recycled Polyethylene Terephthalate (PET) as raw materials (Bonnington, 2018). Founded in honour of Bob Marley, this company seeks to manufacture audio products sustainably, ensuring reforestation and the preservation of the oceans. They produce headphones, speakers, and turntables, as noted in **Figure 11** (The House of Marley, 2020).

Figure 11: Accessories produced by The House of Marley (The House of Marley, 2020)

2.2.4. Memory Cards

Memory cards are small devices that allow storing data conveniently. They are generally used to store images, music, texts, or videos, increasing the storage capacity of mobile phones (Advanced Market

Analytics, 2019). **Figure 5** shows that 57% of smartphone owners have these accessories. It was observed, in **Figure 6**, that consumers who have Android buy more memory cards since most Apple smartphones do not have slots that allow their use.

The market for these accessories can be divided into SD (Secure Digital) cards, TF (TransFlash) or Micro SD Cards, CF (Compact Flash) cards, and others. However, currently, the most used in the mobile phone market are Micro SD cards because they are a very tiny device and reach a capacity of up to 512Gb (CDN Newswire, 2020).

The materials used in the manufacture of these small accessories are plastic and some metals for the coating, and an electrical circuit inside, that contains precious and not precious metals. Furthermore, the recycling of memory cards is essential because they include metals such as gold and steel that can and should be recycled, and the plastic that they are made of is harmful to the environment and not biodegradable (Bennett, 2015). In addition to being recycled, these accessories can be reuse, as most of the time, they are replaced because users have bought a new mobile phone or want to purchase a memory card with more space. On the other hand, these are accessories that leave a lot to be desired about their reuse since studies reveal that even when the user thinks that he has erased all the data on the memory card, there are remaining data that generate conflicts of confidentiality (Jones, 2019).

2.2.5. Power Bank

The global power bank market alone was valued at $ 16.3 billion in 2017 and is expected to rise to $ 19.4 billion by 2025. As seen in **Figure 5**, 50% of smartphone owners have this accessory. Also, it is estimated that 40% have been purchased separately from the phone (Delloitte, 2019b).

Power banks are nothing more than external batteries that allow the charging of mobile phones when it is not possible to access a charging point. However, these batteries lose capacity in a short time which involves a regular replacement and generates large amounts of electronic waste. Furthermore, the change to USB-C standard means that consumers want to upgrade existing power banks to faster and more powerful ones (Lee et al., 2019).

There are three types of power banks in terms of charging method. Universal or standard power banks charged through a common USB with a LED battery status indicator light, solar power banks that can use sunlight to charge through small photovoltaic panels, and wireless power banks that apply a wireless system in contact with a power plug (Electronics Notes, 2020). Although the universal one's account for a larger percentage of the market, offering benefits such as easy availability, lower prices, and smaller sizes, it is expected a growth of 19.5% per year, from 2020 to 2027, in solar power banks. The explanation of the expansion of the sector is not only in the popularity of adopting more environmentally friendly alternatives, but also because this type is the most suitable for travel given its ability to recharge without electricity.

There are also power banks with different capacities from 3000mAh to more than 20000mAh. The growing use of mobile phones connected to the internet makes the battery capacity of the device insufficient for daily use. That is the key to the growth of this market segment, namely power banks with greater capacity (Grandviewresearch, 2020).

The materials used for manufacturing these accessories can be diverse. It is necessary to point out that batteries are categorized into Lithium-ion (Li-ion) and Lithium polymer (Li-polymer). The first ones held 80% of the market in 2019 for having low self-discharge, high energy density, and low maintenance. On the other hand, the second category will have higher annual growth in the coming years as they are viewed as safer, lighter, and more mouldable, allowing the acquisition of more compact and elegant models (Grandviewresearch, 2020). Regarding the exterior, the most common material is plastic. However, it is also possible to find aluminium or silicone. The problem with these materials is the same as described for the previous accessories. Nevertheless, these accessories have some modularity that most of the time is not used. Although power banks are considered to be reusable accessories since it is possible to achieve more than one charge with the same device, when their battery is no longer efficient, its destination is disposal and not the exchange of components and reuse.

2.3. Problem Characterization

The fast advancement of technology has brought several advantages worldwide. However, this comes with an environmental price. The consumption of Electrical and Electronic Equipment (EEE) has been increasing over the years. Between 2010 and 2017, the number of EEE put on the market in the European Union (EU) rose from 7.9 million tonnes to 9 million tonnes, representing an increase of 13.9% (Eurostat, 2020). Unfortunately, not all EEE put on the market are collected, treated, reused, or recycled as observed in **Figure 12**.

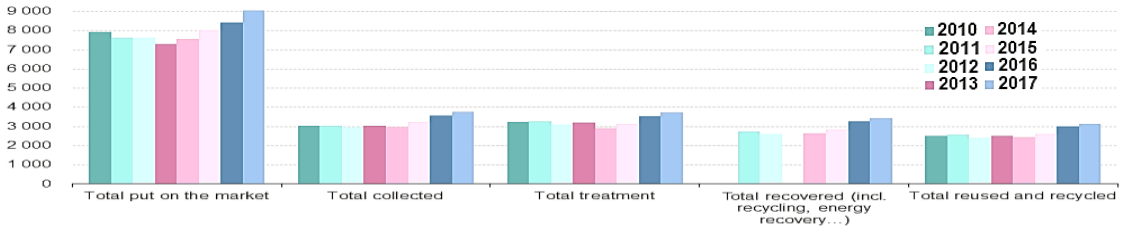


Figure 12: EEE put on the market and WEEE collected and treated between 2010 and 2017 (Eurostat,2020)

In 2017, in the EU, the rate of Waste of Electrical and Electronic Equipment (WEEE) collected was 47% of the total EEE placed on the market between 2014 and 2016, which means that the remaining 53% were just thrown away with usual garbage and ended up in a garbage can, polluting the environment as they are not biodegradable. Regarding to Portugal, in that same year, it was in the fifteenth place of the EU countries with more WEEE, having collected 6.8 kg per inhabitant (Eurostat, 2020).

Considering the five categories that are part of the collected WEEE, IT and telecommunications equipment correspond to 14.6%, as observed in **Figure 13** (Eurostat, 2020). This category includes all mobile phones and devices that are part of the respective ecosystem, such as wearables and accessories.

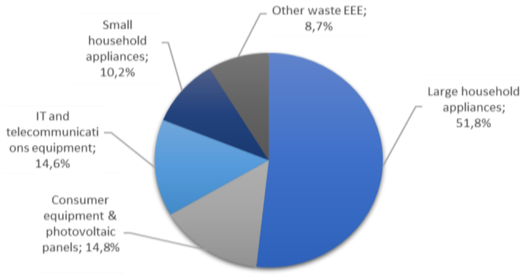


Figure 13: Total WEEE collected, by category, in 2017, adapted from (Eurostat,2020)

These values show that people are increasingly enjoying their mobile phones, giving great importance to more advanced technologies, resulting in decreased time until exchange of the equipment (Delloitte, 2019b). In 2020, around 1 571.22 million of smartphones were sold worldwide (Gartner, 2020).

The increase of e-commerce and online shopping has intensified the demand for smartphones globally and, consequently, the requirement for mobile phone accessories (CredenceResearch, 2016). This market was valued in 2019 at $ 80 947.0 Mn and it was expected to reach US 139 104.2 Mn in 2027 (Coherent Market Insights, 2020). Accessories are viewed as useful products that not only add value to mobile phones, but also increase the time of use. However, the raw materials used to manufacture these accessories are very harmful to the environment and are not biodegradable. Furthermore, it is hard to reuse these products since most of them are built using non-modular processes, implying that they cannot be fixed or exchange some parts to be put back on the market.

To cope with the excessive consumption of mobile phone accessories, it is necessary to analyse them, in detail, to create new eco-designs that increase their sustainability. Therefore, it is essential to understand which materials must be in the manufacturing process, as well as the respective processes to be used so that the new designs have an impact throughout the chain. Accordingly, this research focuses on creating a sustainable design for these accessories, studying which materials are most suitable and their respective impact on the environment. Moreover, it aims to understand the effect that the application of the new design can have on the sustainability of the whole life cycle.

2.4. Conclusion

Technology has undergone a fast evolution nowadays, generating an increase in the consumption of electrical and electronic equipment and its replacement even when they are still in good condition. Besides, the materials used in their production and their manufacturing processes are economically sustainable, but not for the environment. The five categories of accessories for mobile phones with the highest consumption previously described are cable chargers, phone cases, headphones, memory cards, and power banks. Materials such as plastic (mostly PC) and metals are in their manufacturing base as non-modular processes. Every year the WEEE increases, so it is necessary to develop production chains that promote sustainable designs and the circular economy. Concluding, the study of the possible processes to be implemented, as well as the development of a circular economy for mobile phone accessories, will be developed. Accordingly, the problem description has been presented. Next, the literature review will focus on how the concepts of eco-design and circular economy can establish a positive correlation with each other.

3. State of the Art

This chapter presents the theoretical and scientific background to address the problem identified in the previous chapter.

The United Nations has as main objective to promote international cooperation performing on the issues that confront humanity at every moment (United Nations, 2020b). Currently, it is vital to consider sustainable development activities in the 193 Member States of this organization. In 2015, the United Nations developed the 2030 Agenda that provides a shared plan for peace and prosperity for people and the planet (United Nations, 2020a). This document proposes the adoption of 17 Sustainable Development Goals (SDGs), with a total of 169 targets, which must be met by 2030, promoting science, technology, and innovation (Colglazier, 2015). These objectives establish strong indicators to allow countries to highlight their strengths and weaknesses (Gigliotti et al., 2018). Consequently, companies and new ideas must incorporate sustainable development into their business model and produce social and environmental benefits in addition to financial ones (Deloitte, 2019b).

UNLEASH, a global innovation program, was created in 2017 to bring together talented people around the world, in an ecosystem of corporate and institutional partners that aim to form solutions that satisfy the United Nations SDGs (UNLEASH, 2020). In order to achieve its objective, this program proposes the UNLEASH Innovation Process, which promotes the development of ideas and solutions, through an innovation process, that can be implemented in compliance with the SDGs. This process comprises five phases, presented below in **Figure 14**, and each one comprises a set of methodologies that can be used (Deloitte, 2019a).

Figure 14: The five phases of the innovation process, adapted from (Deloitte, 2019a)

Section 3.1 summarizes the possible methods and ways of presenting the problem to develop the first phase which is Problem Framing. Accordingly, Section 3.2 introduces the next phase of the process, ideation and Idea Selection, in which scientific methods are presented to explain ideas that address the problem framing. Moreover, in Section 3.3 distinct methodologies are presented in order to create a tangible prototype so that a potential customer can try the proposed solution. Section 3.4 explores different ways of obtaining feedback from customers, what criteria to use, and their weight in the final decision, representing the testing and refining phase. Finally, Section 3.5 performs an additional literature review having into consideration the implementation phase, focusing on the tools to be used to launch and scale the solution to respond to key activities in the previous phases.

3.1. Problem Framing

Problem framing is one of the most significant activities in solving design problems. It involves different levels and a high capacity for framing and reflection. This process requires searching and transformation, mostly influenced by human memory and external environments (Kvan & Sao, 2006). Despite having arisen within the scope of sociology, the term "frame" is now applied to the broadest areas, representing a pattern used to delimit, identify and make sense of a situation (Bijl-Brouwer, 2019).

It also helps to understand ambiguous problems and define a solution in subsequent stages (Haase & Laursen, 2019).

The problem framing phase was defined by Simon (1984) as the transition from an ill-defined problem to a well-defined and structured one. Usually, it is separated into two tasks, according to Jay and Perkins (1997). The first one defines the area or topic where the problem is inserted, and the second one presents the structure of the problem to generate ideas for solutions. Besides, Coyne (2005) and Kvan & Sao (2006) note that the problem framing allows the construction of scenarios from the imagination following several rules and setting objectives. Kees Dorst (2011) defined a problem frame as a suggestion to deal with a complicated problem, as shown in **Figure 15** (Haase & Laursen, 2019).

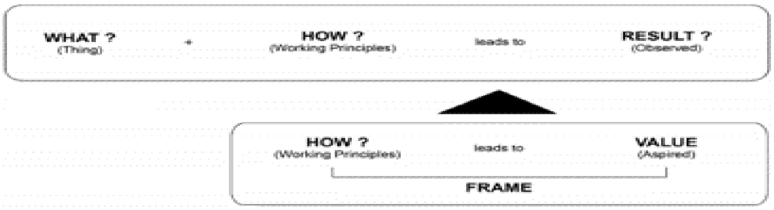


Figure 15: Dorst's definition of a frame (Haase & Laursen, 2019)

Regarding the design process, the framing problem can be identified as coherent statements useful for "think with" creating new and different perspectives on the issue (Haase & Laursen, 2019).

This first phase includes a well-defined problem statement based on a broad debate of the ideas of each one involved in the problem (Buralli et al., 2018). There are other methodologies, namely the one developed by Karl T. Ulrich and Steven D. Eppinger (2016), which gives this phase the name of concept generation. This phase is responsible for identifying consumer needs along with the specifications needed to solve a problem founded (Ulrich; & Eppinger, 2016). According to the UNLEASH Innovation Process, the problem framing phase should be based on what the client/user wants and provide a clear-cut problem statement using insights (Deloitte, 2019a).

Different methodologies and tools can be applied to assist in visualizing and structuring the problem (Madu et al., 2018). Besides, this phase is a creative and iterative moment that requires the use of methods based on the creativity and sensitivity of the actors and not rigid and pre-conceived methodologies (Veselý, 2008). When the problem definition is complex and vague, in order to identify, visualize, and prioritize the problem and its interrelations, a problem tree can be used (Veselý, 2008).

A **problem tree** is a conceptual model that analyses the events that give rise to a problem, allowing the observation and understanding of its consequences (Zimmermann et al., 2008). According to Veselý (2008), the ability to use common sense and a loose set of rules for formulating problems instead of strict logic, allows considering problem trees as a "universal heuristic to identify, prioritize and visualize problems" (Veselý, 2008). It is represented in diagram form and built from the base to the top. So, the base "root" represents the symptom and the roots above the causes for the previous symptom. This process happens cyclically until the key-causes are found at the top of the page (Zimmermann et al., 2008), systematically dividing complex problems into simpler ones (Ammani et al., 2010). Furthermore, it presents, in the branches, a set of effects or consequences of the causes previously introduced. It can offer different versions and shapes, and the higher the quality of the tree, the higher the quality of the problem analysis (Veselý, 2008). However, not all branches are relevant, since it is based on a wide range of information, and therefore it is necessary to identify, which ones require more attention (Zimmermann et al., 2008). Moreover, this tool focused on visualizations, so it involves a correct analysis to understand the causes of a specific problem and find solutions to overcome it (Madu et al., 2018). The problem tree analysis has some advantages and disadvantages described in **Table 2**.

Table 2: Advantages and disadvantages on problem tree analysis

		Reference
Advantages	Enables an easy visualization and understanding of the problem.	(Zimmermann et al., 2008)
	Allows accurate conclusions and effective problem management.	
	Comes up with different parts of the problem and group them according to a couple of characteristics.	(Veselý, 2008)
	Gives perfect differentiation between causes and consequences.	
	Provides several views of the same problem.	
	It is an effective problem approach.	(Madu et al., 2018)
	Considers all aspects regardless of their relevance, avoiding the chances of having a poor plan.	(Mahmoud, 2020)
Disadvantages	Needs multiple participants.	(Wilberforce Walubengo, 2019)
	Based on expectations and irrational ones can lead to mistakes.	
	Result cannot have a sense if the stakeholders are not aligned.	
	Requires a lot of time.	(Dillon, 2012)
	Difficult to identify all the causes and consequences of a problem.	

Similarly, another methodology that can be applied is the **mind map**, which aims to create associations between ideas and concepts based on a central problem. A mind map is a diagram constructed using techniques such as the use of different line thicknesses, colours, and images (Davies, 2010). According to Davies (2010), this technique is a non-linear visual graphic representation since it has no limit on connections and is built freely, promoting creativity. Furthermore, to last in the long term, it has to be reviewed continuously. However, mind maps summarize the main ideas of a topic requiring critical thinking (Noonan, 2012). Mind maps facilitate the organization of content establishing relations in hierarchical levels through lines or arrows (Wette, 2017). The main ideas are connected to a central concept, and the other ideas branch out (Frerichs et al., 2018). The mind map framework has some advantages and disadvantages described in **Table 3**.

Table 3: Advantages and disadvantages on mind maps

		Reference
Advantages	Allows free structure.	(Davies, 2010)
	Requires an unlimited number of ideas and connections.	
	Promotes creativity and brainstorming.	
	Necessary information clustered on one page.	(Noonan, 2012)
Disadvantages	Difficult reading by people other than authors.	(Davies, 2010)
	Limited to more complex problems.	
	Not very formal and structured.	
	Limited to the level of detail you can provide.	(Noonan, 2012)

Along the same line, the **cognitive map** is another method that can be used to structure the problem. First explored by Axelrod in the 1970s (Alipour et al., 2019) cognitive maps are graphs that use concepts and causal links between these concepts to model a problem. Moreover, it is represented by nodes, edges, and symbols of "+" and "-". The nodes symbolize the concepts, the others depict the causal influences between these concepts, obtaining a final value for each node (Aguilar, 2013). Thus, there are two types of causal relationships between concepts, the positive and the negative ones. The first one implies that the first node causally increases the second node, the second means that the first node reduces the second node (Alipour et al., 2019). Furthermore, the relationships and the numerical data are the results of the knowledge of the author. Therefore, these are from imprecise nature and presenting the logic of common sense (Poomagal et al., 2021). The cognitive map framework has some advantages and disadvantages described in **Table 4**.

Table 4: Advantages and disadvantages on cognitive maps

		Reference
Advantages	Usage of quantitative and qualitative data.	(Makarenko, 2018)
	Results in a complete model diagram.	
	Ease of placing and removing concepts.	
	Captures causal knowledge and mental models	(Alipour et al., 2019)
Disadvantages	The nature of the data is inaccurate	(Poomagal et al., 2021)

Therefore, in this stage, it is necessary to understand who is involved in the problem in question. Accordingly, it allows adapting the problem structure and its development, considering the end user (Deloitte, 2019b). Having this objective in mind, it is possible to use the **consumer profile framework**, which allows identifying who experiences the identified problem and, consequently, obtaining information about the needs of a group of individuals. The consumer profile framework makes it possible to fragment the problem according to, not only the content, level, and parameters of the individual's needs, but also according to their expectations (Henezel, 2004). Consumer or user profiles require the collection of reliable information by direct user intervention or by agents who monitor user activity. The required information may include demographic information, such as name, age or country, or information at the level of interests or preferences (Gauch et al., 2007), or other information as depicted in **Figure 16**.

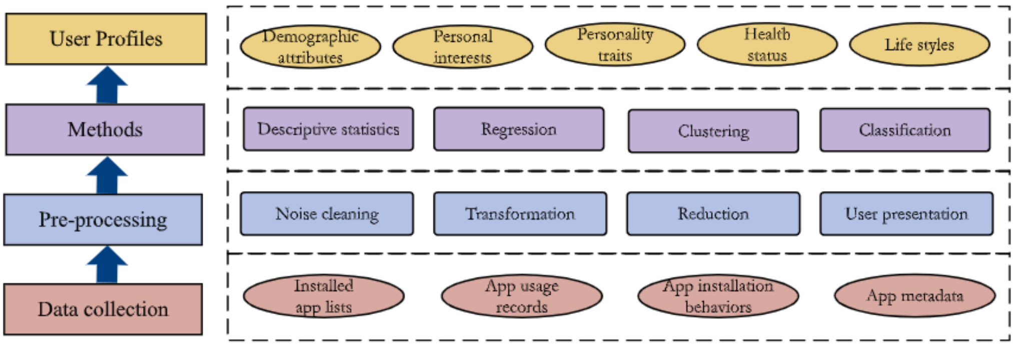


Figure 16: Generic user profiling framework (Zhao et al., 2019)

This methodology allows representation through sets of keywords, semantic networks, or weighted concepts (Gauch et al., 2007), originating a set of labels or generalized characteristics of the user that provides data applied in future analysis (Wang et al., 2019). The information obtained may come from content shared between users by defining their profile type (Francisco & Castro, 2020). There are two types of consumer profiles, those that can be changed, increased, and consider short- and long-term (temporal) interests are called dynamic, and those that use the same information over time are called static (Gauch et al., 2007). The consumer or user profile framework has some advantages and disadvantages described in **Table 5.**

Table 5: Advantages and disadvantages on consumer profile framework

		Reference
Advantages	Ensures maximum relevance to the user.	(Henezel, 2004)
	Provides strategic information.	
Disadvantages	Difficult to apply to a large and complex data set.	(Wang et al., 2019)

In order to have a well-structured problem, it is necessary to understand which individuals or community institutions can contribute to the creation of a possible solution through social, financial, human or knowledge capital. This point of view allows looking at the community as a resource, collaborating in the identification and structuring of a problem. These local resources are called assets. With the purpose of defining these assets, **community asset mapping** can be used (Deloitte, 2019a).

This kind of map allows defining different assets in the target community at three levels: individual assets, citizen's associations, and local institutions (Deloitte, 2019a), involving participatory approaches in the problem development (Crozier & Melchior, 2013). The community asset map is a process that allows registering tangible and intangible resources, i.e., the strengths of the community, through a participatory nature (Cutts, 2016). This tool allows using existing and available resources, avoiding financial assistance to solve a problem (Briggs & Huang, 2017). When there is a problem, it is necessary to make a change, so people and organizations, apart from helping to structure that same problem, can be used as assets to create that change and solve the problem. The process of preparing the community asset map requires choosing, evaluating, and contacting the resources or assets and is, therefore, a longstanding process, but with positive results (Arriero & Griffin, 2018). The community asset mapping process has some advantages and disadvantages described in **Table 6.**

Table 6: Advantages and disadvantages on community asset mapping process

		Reference
Advantages	Allows supporting and solving a problem.	(Briggs & Huang, 2017)
	Provides a comprehensive overview of existing resources.	
Disadvantages	Very time-consuming process.	(Arriero & Griffin, 2018)

Finally, it is necessary to understand how big the problem is, i.e., which market experiences this problem. This dimensioning also allows to understand, in the next phase, the dimension of the solution to be created. Thus, it is necessary to define the target market, which is the group of people who experience the problem, and that if it's possible to use the solution found for that problem. To achieve this, the **total addressable market (TAM) approach** can be used (Deloitte, 2019a). The TAM represents the number of users who experience the problem and can search for the solution (Spitalny et al., 2014). It works as a market forecast depending on the problem and the solution (Artun & Levin, 2015). However, it is not always possible to reach this entire market. Therefore, the serviceable addressable market is defined, which refers to the market with which it is possible to contact. From then on, the defined solution will be addressed to a restricted group of people who form the target market (Deloitte, 2019a). The total addressable market (TAM) approach has some advantages and disadvantages described in **Table 7.**

Table 7: Advantages and disadvantages on total addressable market approach

		Reference
Advantages	Helps to prioritize business opportunities.	(Bowman & Katz, 2015)
	Narrow marketing to people interested in the product.	
	Avoid waste of resources.	
Disadvantages	Poor TAM determination leads to errors in the SAM and, consequently, in the target market.	(Bowman & Katz, 2015)

3.2. Ideation and Idea Selection

Ideation, or idea generation, corresponds to the systematic process of creating ideas or solutions for a problem, following the requirements associated with it. This phase involves high innovation since any innovation process is based on a new idea. In addition, the individual must have some characteristics, including a high level of creativity (Dorow et al., 2015). At the beginning of this phase, there is only one problem that, although well structured, is intangible, qualitative, and subjective, making the ideation a challenging and complex process. The generation of ideas is a rational activity that allows the creation of tangible concepts, i.e., solutions to a problem (Liu et al., 2019). Moreover, after generating ideas, it is necessary to select those that allow an alignment with the mission, vision, and values to be followed so that it is possible to turn an idea into a real solution (Dorow et al., 2015).

The idea selection is more challenging than the idea generation because it requires several filters to obtain a final solution so that the best ideas are developed and not lost, due to uncertainties generated in the process (Dorow et al., 2015). However, the hierarchy effect, that is, the existence of a higher authority, is quite detrimental to ideation but beneficial in idea selection (Fleury et al., 2020).

According to Gonçalves and Cash (2020), ideation in the context of industrial design does not only describe the creation of ideas, but a set of activities that involve the creation and development of ideas, that aim to achieve certain goals through an innovation process. The results obtained from this process can often be conflicting (Gonçalves & Cash, 2020). The ideas obtained must be new and useful. Novelty is defined as ideas that many people failed to have, that are unique and rare. The utility is defined as the viability, effectiveness, or acceptance of an idea (Meslec et al., 2020). Summing up, the second phase includes the creation of ideas that allow establishing solutions to address the problem previously established. Besides, this step requires the selection of a final idea, to be addressed in the following phases, taking into account innovation, feasibility, and impact (Buralli et al., 2018). There are other methodologies, namely the one developed by Karl T. Ulrich and Steven D. Eppinger (2016), which gives this phase the name of concept generation. At this stage, different concepts should be evaluated based on different criteria. The needs of consumers and the relative strengths and weaknesses of the concepts must be taken into account. Finally, one or more concepts must be selected for further investigation or development (Ulrich; & Eppinger, 2016). According to the UNLEASH Innovation Process, the Ideation and Idea Selection phase is defined by the emergence of several ideas that address the problem framing and choose a solution to focus on (Deloitte, 2019a).

Patricia Dorow et al. (2015) presents a summary table of some of the definitions of ideation according to different authors, represented in **Figure 17.**

Authors	Concepts / understanding relating to IDEATION
Dugosh & Paulus (2005)	The process of organizing the ideas for the innovation process.
Björk et al. (2011)	Production and handling of new ideas.
Bocken et al. (2011)	Generation of ideas, complex and contextually specific involving all phases related to process ideas.
Briggs & Reinig (2010)	To generate useful ideas to achieve some desired state or outcome process.
Björk, Boccardelli & Magnusson (2010)	Identification of ideas generation and explicit formulation of ideas.
Briggs & Reinig (2010)	Process to gain a desired result or state.
Cooper & Edgett (2012)	Creation of new process ideas.

Figure 17: Some understandings about ideation (Dorow et al., 2015)

Recently, concerns about environmental impacts have increased. In this sense, the ideation and idea selection phase is dedicated to generating ideas with a reduced environmental impact (Pialot & Millet, 2018). Eco-innovation aims to question and rethink existing products or services in order to create sustainable alternatives. This innovation process starts in an ideation phase or, more specifically, eco-ideation, which aims to generate new ideas taking into account positive environmental impacts (Tyl et al., 2015). Therefore, formal processes must be applied to both ideation and idea selection (Dorow et al., 2015). These creativity tools and methods must be adapted when applied to eco-ideation (Tyl et al., 2015). Regarding idea generation or ideation process, the **brainstorming** tool can be used.

Brainstorming is a technique for idea generation that can be used in groups or individually. The ideas presented must be of low frequency - new - original, and viable, which means that they should have a reasonable potential for application. The three characteristics mentioned that are novelty, originality, and viability, determine the quality of an idea (Putman & Paulus, 2009). According to Barry Matthew Kudrowitz and David Wallace (2013), this is a method of generating ideas in free form or blue sky, which means that it is done without restrictions and, consequently, tends to produce more creative and less useful ideas (Kudrowitz & Wallace, 2013). The first person to introduce group brainstorming was Osborn (1957), who classified it as a way of increasing creativity in corporate environments. However, currently, this technique is applied in the most diverse areas, including product design. For Hosam Al-Samarraie and Shuhaila Hurmuzan (2018), there are three brainstorming techniques. The first is traditional or verbal brainstorming (TBS), according to which in a group environment ideas from each of the elements are verbally shared. This technique allows the creation of a large number of ideas, the removal of criticisms, and even the combination of ideas. Nonetheless, groups produce fewer ideas than the same number of individuals alone. The second, nominal brainstorming (NBS), aims to overcome the disadvantage previously presented, so the members of a group generate ideas individually without communicating, increasing the number of ideas generated. Finally, electronic brainstorming (EBS) promotes group discussion of ideas through digital platforms such as email, chats, or forums (Al-Samarraie & Hurmuzan, 2018).

The brainstorming process is guided by four rules: i) the generation of the largest number of possible solutions; ii) judge only at the end; iii) have original ideas; iv) combine and develop ideas (Bonnardel &

Didier, 2020). This method consists of three phases. The first one is preparation, where the objective is defined, the second is animation, where ideas are generated, and the third capitalization and valorization, where ideas are reformulated and classified and unconvincing ideas are eliminated (Fleury et al., 2020). The brainstorming methodology has some advantages and disadvantages described in **Table 8**.

Table 8: Advantages and disadvantages on brainstorming methodology

		Reference
Advantages	Facilitates creative thinking.	(Al-Samarraie & Hurmuzan, 2018)
	Results in quality ideas.	
	If in a group, promotes discussion and fusion of ideas.	
	Generate a lot of ideas in a short time.	(Kudrowitz & Wallace, 2013)
	If done individually, generate lots of ideas.	(veanu et al., 2019)
Disadvantages	If in a group, the choice of ideas is influenced by previous ones.	(Bonnardel & Didier, 2020)
	If done in groups, produces fewer ideas.	(veanu et al., 2019)

Concerning the creation of ideas, the **six thinking hats** (STH) technique can also be applied. This technique assumes that the individual is placed in different perspectives and forced to leave his comfort zone and to think. Although it was conceived to conduct meetings and change the way stakeholders work and interact, it can also be used to create ideas or solutions, placing the individual in different perspectives when facing a problem. In this way, the individual takes a different direction of thought at a time, depending on the color of the hat that he is wearing (Pinto et al., 2015). Developed by Edward de Bono (1985), this approach promotes critical and parallel thinking, and the output is the unpacking of the dimensions of a complex problem (Payette & Barnes, 2017). The six types of hats fully cover the critical, constructive, and creative aspects of thinking and result in different approaches to thinking and patterns of understanding a problem. However, not all perspectives result in the same level of effectiveness or number of idea generation (Hu et al., 2021). The six colors of the hats are white, yellow, black, red, green, and blue, and their main characteristics are illustrated in **Figure 18** (Pinto et al., 2015).

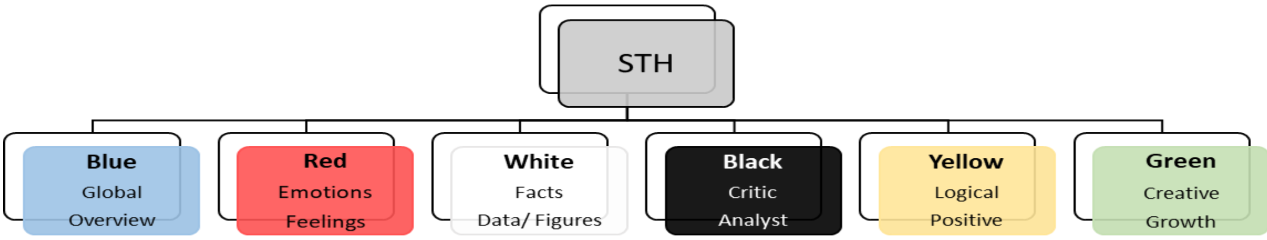


Figure 18: Six thinking hats overview, adapted from (Pinto et al., 2015)

The white hat is the information one, according to which the individual must identify the necessary information, facts to consider, and data to collect to solve the problem. The yellow hat represents possibility, positivity, and optimism. In this situation, the individual should only focus on points of interest and advantages, values , and opportunities of plans, ideas, or scenarios. The black hat takes a sceptical and judgmental stance, in which a cautious position must be adopted, and the risks, weaknesses, disadvantages, and difficulties must be considered. The individual must take note of all errors and points of special attention and doubt any idea. The red hat reveals the individual perspective bringing personal feelings, emotions, and intuitions without a concrete explanation.9 The individual must express self likes and dislikes without a reason and only from personal points of view. The green hat represents creativity, innovative thinking, and the generation of new ideas. The individual must generate new plans and must not make judgments. The blue hat takes on a metacognitive perspective that helps to manage the thought process of the other hats. In this perspective, the individual must determine the direction of the project, which ideas to follow, and summarize the discussions previously presented (Hu et al., 2021; Payette & Barnes, 2017). The six thinking hats technique has some advantages and disadvantages described in **Table 9.**

Table 9: Advantages and disadvantages on six thinking hats technique

		Reference
Advantages	Avoids confrontation of ideas.	(Pinto et al., 2015)
	Increases the speed at which decisions are made	
	Increases originality.	(Göçmen & Coşkun, 2019)
	Promotes critical thinking.	(Payette & Barnes, 2017)
Disadvantages	Not all hats are effective in terms of creativity.	(Göçmen & Coşkun, 2019)
	A moderator is required for the rules to be followed.	(Pinto et al., 2015)

Following the idea creation process, it is necessary to choose those that meet the requirements and, if possible, choose the one that will be the final solution. In the idea selection process, different methods, tools, or frameworks can be applied. Nevertheless, some of these methods are more in-depth and specific than others. In the first stage of selecting ideas, in order to understand whether an idea can be a solution, the **RWW (real, win, worth it) model** can be used. This tool is simple and helps on the idea evaluation based on a succession of questions about the concept or product of innovation. The RWW model helps in solving problems and guides the development of an idea based on three key questions: "Is it real?", "Can we win?" and "Is it worth doing?" (Day, 2008). Afterward, each of the previous questions follows a set of successive questions, as noted in **Figure 19**.

Figure 19: R-W-W framework, adapted from (Day, 2008)

The first question explores the existence of a market and whether the product can satisfy that market. In this way, it is possible to understand the strength of a market avoiding an unnecessary technological impulse. The market is only real if the product or solution responds to a need, or if customers can buy it, or if it is large enough, or if customers are willing to buy the product. The second question results in the assessment of the ability to keep the product on the market, generating profits and ensuring that if there is competition it will not be able to delay the development of the proposed solution and innovation. The third question refers to analysis at a financial and strategic level so that it is possible to determine whether the advantage of moving ahead outweighs the disadvantages that may occur (Day, 2008). The RWW model has some advantages and disadvantages described in **Table 10.**

Table 10: Advantages and disadvantages on RWW model

		Reference
Advantages	Simple tool.	(Day, 2008)
	Decreases the number of acceptable solutions.	
	Corrects problems that hinder a solution.	
Disadvantages	It is not an algorithm for making decisions.	
	It only allows you to evaluate ideas one at a time.	

Concerning the idea selection phase, a methodology that makes it possible to obtain only one solution is the **multicriteria decision analysis (MCDA)** methods. These are tools that assist in decision-making through criteria and their respective relative weights. The multicriteria models allow to compare alternatives and to classify them according to a normalized value obtained through these same criteria (Hermann et al., 2007), and through a set of methodologies that can help in the evaluation of the performance of these alternatives concerning each criterion (Linkov & Moberg, 2012). According to Belton and Stewart (2002), multicriteria approaches can be dissociated into three broad categories: (1) Models of goal, aspiration or reference level: that can be seen as generalized goal programming models (Wierzbicki, 1999), (2) Outranking models: evaluate different courses of action and compare them in pairs. This comparison is made in terms of each criterion, to identify the degree of preference of one alternative over the other. Then, these preferences are aggregated in all relevant criteria in search of evidence that would favor the selection of an alternative over the others (Belton & Stewart, 2002). (3) Value measurement models: based on multiple attribute value theory (MAVT), they aim to develop numerical scores to represent the degree to which one decision option can be preferred over another. Scores are developed initially for each criterion and only after aggregated into higher-level preference models (Belton & Stewart, 2002). Within each of these categories, there are several methods used in the literature. The **ELECTRE (Elimination Et Choix Traduisant la Realité)** method, developed by Bernard Roy in the mid-sixties (Roy & Bouyssou, 1993), can be seen as an example of outranking models. This method is built around binary relationships (Roy, 2013), following two main steps: the construction of overcoming relationships between pairs of actions and the analysis and reasoning, where 29 recommendations are made depending on the type of problem to be solved (Antunes et al., 2016). Preferences are structured based on four elementary binary relationships: indifference, preference, weak preference, and incomparability (Figueira et al., 2013; Roy, 2013). Another model that can be inserted in the outranking models is the **PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations)** model (Guitouni & Martel, 1998a). The first version of this model is based on the same principles as the model mentioned above, but it has six functions to describe the upper limits of the DM in each criterion. It also provides a partial order of alternatives using inbound and outbound flows. The second version, on the other hand, provides a total pre-order of the alternatives using an aggregation of the same input and output flows (Guitouni & Martel, 1998b). The **MACBETH (Measure Attractiveness by Categorical Based Evaluation Technique)**, developed by Bana e Costa, de Corte, and Vansnick in the early 90s (Costa et al., 2005), is an example of a model for measuring value. This method is based on the use of the M-MACBETH software and allows to evaluate the impacts of the alternatives on different criteria, translating them into scores through the Additive Model. It requires the definition of two reference levels, called "neutral" and "good" and the provision of qualitative judgments about the differences in attractiveness between two options by the DM. These judgments are made through a semantic scale with seven categories: null, very weak, weak, moderate, strong, very strong, extreme (Costa et al., 2016). This information will be the basis for solving a specific problem of linear programming, capable of converting qualitative judgments into a numerical scale, and essential for computing the utility/value scales of the criteria performance and the ratio scale for the capacities. Another model that can be inserted in value measurement models is the **AHP (Analytic Hierarchical Process)** developed by Thomas Saaty (1990) (Longaray et al., 2016). This method needs to identify alternatives and evaluate them based on criteria through paired comparisons on a semantic and proportion scale to assess the preference of DM (relative measure scale), to evaluate the performance of each of the options in relation to each criterion. Its score is determined using numerical values taken from the AHP absolute fundamental scale of 1–9 (Saaty, 2016). The multicriteria decision analysis (MCDA) methods have some advantages and disadvantages described in **Table 11.**

Table 11: Advantages and disadvantages on multicriteria decision analysis (MCDA)

	Advantages	**Disadvantages**
MACBETH	Suggests alternatives when judgments are inconsistencies. (Costa et al., 2005)	Necessary to guarantee the independence between criteria. (Angilella et al., 2010)
	Use both quantitative and qualitative criteria. (Carnero & Gómez, 2017)	Different classification of preference change the result. (Guitouni & Martel, 1998b)
	Include an organized view of the problem - value tree. (Carnero & Gómez, 2017)	
ELECTRE	Use qualitative and quantitative scales. (Figueira et al., 2013)	Difficult to use when criteria are only quantitative. (Figueira et al., 2013)
	Use imperfect knowledge and arbitrariness in the criteria. (Figueira et al., 2013)	Not appropriate when a score is required for each action. (Figueira et al., 2013)
	Many DM weightings. (Merad et al., 2004)	Intransitivity can occur. (Figueira et al., 2013)
PROMETHEE	Use qualitative and quantitative scales. (Figueira et al., 2013)	Few applications in the selection of improvement projects. (Kornfeld & Kara, 2011)
	Sensitivity analysis is possible. (Kornfeld & Kara, 2011)	Loss of information in the process of spatial aggregation. (Malczewski & Rinner, 2015)
AHP	Allows for a formal structure to capture the important elements. (Kornfeld & Kara, 2011)	May be inconsistent with the value function approach. (Guitouni & Martel, 1998b)
	Allow consistency check. (Şahin, 2020)	Different classification of preference change the result. (Guitouni & Martel, 1998b)
	Allow verbal judgments. (Şahin, 2020)	Necessary to guarantee the independence between criteria. (Angilella et al., 2010)

Finally, in the idea selection phase, the **Pugh chart or matrix** can be used. The idea of this matrix is to classify, according to selected criteria, the existing alternatives, minimizing the “conceptual vulnerability” (Soban & Upton, 2005). This technique, created by Stuart Pugh (1991), allows for the logical comparison between different options based on predefined criteria and deciding on the most useful solution (Cervone, 2009). However, the quality of the results depends on the experience of the individual who executes the matrix (Burge, 2009). In order to elaborate this matrix, it must be kept in mind that the alternatives or ideas must be in the columns, and the criteria or requirements must be in the lines (Joshi & Dandekar, 2019).

According to Stuart Burge (2009), there are six steps to building a Pugh Matrix. The first step consists of identifying and defining the criteria to be used for the selection. Therefore, an option is selected as a base that meets all the mentioned criteria and functions as a baseline. Then, each alternative is compared with the baseline, for each criterion, by placing a qualitative score, that is, placing an "S" if for this criterion the score is the same as in the base, placing "+" if the score is better or placing " - " if the score is worse. The "++" and "- -" designations can also be used for much better and much worse scores, respectively. The fourth step consists of adding the number of "+" and "-" for each alternative and then sum these values to obtain a score. The highest score reveals the winning idea. The fifth step relates to considering hybrids or combinations with the best of each alternative. Finally, a decision is made and the reasons for the same must be explained (Burge, 2009).

According to Delloite (2019), a Pugh chart is a decision-making tool that allows comparing several alternatives considering a status quo (baseline), highlighting the pros and cons of each alternative, and eliminating weaker ideas. It also allows combinations to be made among alternatives, emphasizing the advantages of each one (Deloitte, 2019a). The Pugh chart or Pugh matrix has some advantages and disadvantages described in **Table 12**.

Table 12: Advantages and disadvantages on Pugh chart

		Reference
Advantages	Allows the selection of the best option.	(Joshi & Dandekar, 2019)
	Simple to understand.	
	Simple to analyse.	
	Allows dealing with many decision criteria.	(Burge, 2009)
Disadvantages	Poor choice of criteria gives rise to bad decisions.	(Burge, 2009)
	The simple scale can give poor results.	
	Requires experience and specialization of the individual.	

3.3. Prototyping and Sketching

After generating ideas and choosing them, it is necessary to design and model the solution in order to be perceivable and tangible to users or stakeholders. The representation of the solution is called a prototype, which is developed in the prototyping phase. Prototyping is essential in developing innovative products, services, or systems and, therefore, must follow well-planned strategies (Camburn et al., 2017). Several authors defend that it is also a learning activity that allows obtaining information and increasing skills. The result from this process, the prototypes, can be physical or virtual if built from 3D modelling software (Erichsen et al., 2019). For the prototyping phase to be successful, a previous activity called sketching is usually used. This tool allows the elaboration of a draw, in two dimensions (2D), which helps not only to better understand the problem or the solution, but also to visual reasoning and to make the solution more viable. When followed by sketching, prototyping allows evaluating the solution quality and the existence of a proof of concept (Bao et al., 2018). Despite being considered physical models, the prototypes can be functional or non-functional depending on the requirements, the context, and the desired solution (Rodriguez-Calero et al., 2020). In short, the third phase includes the creation of a preliminary model that allows viewing the solution taking into account the value for the user, the resources, the cost structure, the partners, the implementation approach, the social impact, the revenue streams, the final objectives, and the SDG indicators (Buralli et al., 2018). According to the UNLEASH

Innovation Process, the Prototyping and Sketching phase requires the production of a tangible prototype so that the potential user can visualize and try the proposed solution (Deloitte, 2019a).

In order to be successful, a sustainable approach must be considered in the development process. The need for a transition from linear business models to circular approaches is increasingly evident. The circular economy is a more sustainable model that allows maintaining the value of products, materials, and resources as long as possible in the economy and minimizing the generation of waste (Sarja et al., 2021). In spite of being a growing topic, there are several definitions of the circular economy that have been improved over time, leading to this being a concept with an indefinite frontier (Goyal et al., 2020). The circular economy is a comprehensive concept that includes reducing the entry of material, minimizing the generation of waste, and promoting the responsible and cyclical use of resources, contributing to sustainable development (Moraga et al., 2019). In a circular economy, the increase of the preservation of the usefulness of products and components enhances the value created. The goal is to eliminate the idea of finite resources and waste from the system (ELLEN MACARTHUR FOUNDATION, 2018). According to Moraga et al. (2019), it is possible to distinguish the definition of circular economy in sensu stricto and sensu latu. The definition in sensu stricto has a narrow focus, distinguishing circular economy from a linear economy by increasing the period of use of products, decreasing the flow and resources, closing the cycle between post-use and production, and transforming flows linear residues in secondary resources. The definition in sensu latu has a broader focus defining the circular economy as an economic model in which planning, resources, acquisition, production, and reprocessing are designed and managed to maximize the functioning of the ecosystem and human well-being (Moraga et al., 2019). Regarding the Ellen MacArthur Foundation (EMF), this has been the one that most explored the concept of the circular economy, defining it as "an industrial economy that is restorative or regenerative by intention and design" (Goyal et al., 2020). On the other hand, Saidani et al. (2019), defined a set of 10 categories of circularity indicators with an impact on the performance of the circular economy at different systemic levels. The defined categories are: (1) levels (micro, meso, macro); (2) loops (maintain, reuse, recycle); (3) performance (intrinsic, impacts); (4) perspective (actual, potential); (5) usages (improvement, benchmarking, communication); (6) transversality (generic, sector-specific); (7) dimension (single, multiple); (8) units (quantitative, qualitative); (9) format (web, formulas, excel); (10) sources (academics, companies, agencies). Grafström & Aasma (2021) also found that the practical implementations of a circular economy can be divided into three levels. For these authors, the micro-level refers to specific company initiatives generally known as the 3R principles (reduction, reuse, and recycling). The meso level includes initiatives related to the collaboration between chains and sectors. Finally, the macro-level refers to implementations made by governments and policymakers.

The innovative approach to the circular economy also reflects a theoretical and practical ambiguity of the concept and its principles. However, the literature review carried out by Sarja et al. (2021) proposes the evolution of the circular economy in three stages. The first stage (1970-1990) is related to the concept of waste treatment, according to which it was necessary to find ways to manage and recycle waste. The second stage (1990-2010) reveals the need to connect the inflow and outflow of resources through strategies that promote eco-efficiency. In this, concepts such as life cycle thinking, industrial ecology, and design for the environment are used. The third stage highlights the approach of closed cycles in supply chains, circular business models, and the consideration of cultural aspects (Sarja et al., 2021). This last approach represents the current one. **Figure 20** illustrates the circular economy process and its components (Grafström & Aasma, 2021).

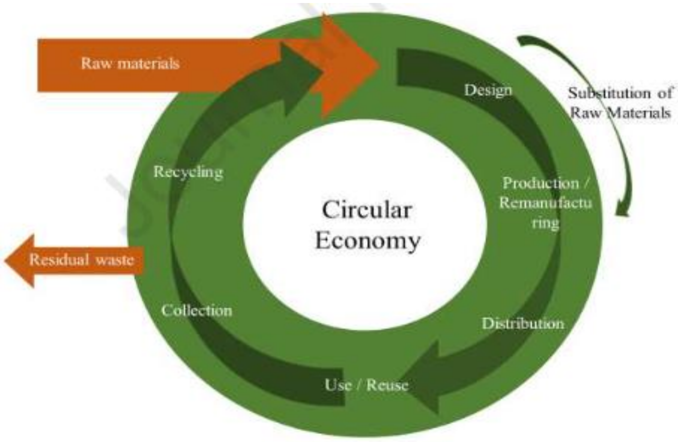


Figure 20: Circular Economy with its different components (Grafström & Aasma, 2021)

Through this, it is possible to observe that design is one of the components that is part of a circular economy approach. The design is primarily responsible for the environmental impacts of a product. Therefore, eco-design seeks to systematically integrate environmental considerations in product and process design (Knight & Jenkins, 2009). Also mentioned as Design for the Environment (DfE), environmentally conscious design, and green design (Lindahl & Ekermann, 2013), eco-design aims to minimize the adverse environmental impacts of products throughout their life cycle, minimizing costs (Knight & Jenkins, 2009). The Design for Environment (DfE) concept includes the product development process considering its entire life cycle and its relationship with the environment to minimize or eliminate the environmental impacts of that product (Ulrich; & Eppinger, 2016). Eco-design involves considering the environmental consequences of a product during the design process (Deutz et al., 2013), including any activity since its initial phase (Bovea & Pérez-Belis, 2012). In order to obtain the best number of benefits, eco-design must be considered and integrated into the initial stages of the product design process (Bovea & Pérez-Belis, 2012). According to Lindahl and Ekermann (2013), the work of Gonza´lez-Benito and Gonza´lez-Benito (2005) identified four principles that should guide the development of environmentally sustainable products: (1) replace polluting and dangerous materials; (2) reduce resource consumption and waste generation at all stages of product development; (3) product design that considers the previous principles; and (4) developing products with a focus on dismantling, reuse, and recycling. These are also principles that eco-design seeks to follow, making it one of the most relevant approaches for organizations (Jugend et al., 2019). Eco-design thus has the potential to contribute to the fulfillment of several of the 17 Sustainable Development Goals (SDGs) declared by the United Nations (Schäfer & Löwer, 2020). As defined by Johansson (2002), eco-design must be concerned with six areas of success factors. These factors must be related to the product development elements. Thus, the success factors are structured in management, relationship with customers, relationship with suppliers, development process, competence, and motivation(Johansson, 2002). Given the application of eco-design practices, Pigosso et al. (2013) classifies them into management practices and operational practices. The first ones are related to product and process development activities and, although generic, can assess the maturity profile of companies in applying eco-design. The second practices describe technical issues of product specification and design. These include more than 480 design options, classified into 35 guidelines and 6 strategies that are grouped according to similar design options. The six strategies that represent the main areas of environmental consideration during product development are: (1) Minimize energy consumption; (2) Minimize the consumption of materials; (3) Extend the Useful Life of the Material; (4) Optimize the product life span; (5) Select Low Impact Resources and Processes; and (6) Facilitate disassembly. In this way, eco-design tools and techniques can support the application of operational and management practices (Pigosso et al., 2013).

Additionally, in this phase, there are specific methodologies that assist in the elaboration of the sketch and the prototype, that are part of eco-design. The impacts of the materials or manufacturing processes to be chosen must be evaluated. Thus, Life Cycle Assessment (LCA), Multi-Criteria Analysis (MCA), Environmental Performance Indicators (EPIs), or Life Cycle Design Strategy (LiDS) wheel can be used. Then, it is possible to elaborate the modelling of the solution by obtaining the first almost tangible prototype, using a CAD system. However, it is first necessary to define which are the **design specifications**. These result from the assumptions made and are presented as the quantitative and qualitative details of the solution. There are several design specifications, as many as the assumptions made, i.e., things that are assumed about the problem, the customer, or the solution that have to be verified on a large scale. According to Delloitte (2019), these specifications are made up of three main characteristics: desirability, business, and technical. The first one refers to the user wishes and needs, the second one refers to operations related to deliveries, and the latter relates to the solution functionalities. The specifications must be measurable in order to guarantee the greatest number of details in the solution prototype (Deloitte, 2019a).

The **Life Cycle Assessment (LCA)** is a tool that allows assessment of the environmental impacts of a product system, which includes its production, distribution, use, and disposal. This process results in the construction of a causal link between the operations carried out. However, it is not always easy to determine the emissions of each product. Therefore, it is possible to divide all existing emissions by the total number of products produced in a period (HERTWICH, 2005). The LCA is a systematic tool that assesses the relative contributions to the environmental impacts of the entire product life cycle, an approach that is called “cradle-to-grave”. This assessment results in a set of environmental scores for some impact categories (Hermann et al., 2007). The International Organization for Standardization (ISO) has a dedicated series of standards for LCA (Muthu, 2015), namely, the ISO 14040 standard, which defines four steps for this process(Ferrari et al., 2021) , represented in **Figure 21**.

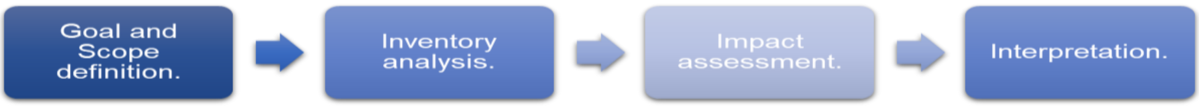


Figure 21: Steps for identifying environmental impacts adapted from (ISO., 2006)

The first stage is the objective and scope definition, followed by the inventory analysis, then the impact assessment, and, finally, the interpretation (Ferrari et al., 2021). The inventory analysis phase includes determining the processes involved in a product life cycle and the environmental pressures produced in each of these processes (HERTWICH, 2005). In this way, this approach is the only systematic and global one, whose objective is to avoid transferring pollution from one stage of life to the next (Rio et al., 2010). Consequently, it is possible to measure environmental impact indicators such as carbon footprint, ecological footprint, water footprint, eutrophication, acidification, and human toxicity (Muthu, 2015). The Life Cycle Assessment (LCA) has some advantages and disadvantages described in **Table 13**.

Table 13: Advantages and disadvantages on Life Cycle Assessment (LCA)

		Reference
Advantages	High comprehensiveness.	(Hermann et al., 2007)
	Avoids problem shifting to other areas.	
	Objective and standardized methodology.	
	Allows reducing environmental impacts before the product is implemented in the market.	(Ramani et al., 2010)
Disadvantages	Requires a lot of data.	(Hermann et al., 2007)
	Very time-consuming.	
	Requires specialized knowledge.	
	Complex processes such as inventory analysis and data structure.	(Ferrari et al., 2021)

The **Life Cycle Design Strategy (LiDS) wheel** is a specific eco-design tool that shows which aspects should be improved when designing a product (Lindahl & Ekermann, 2013). This tool allows a qualitative classification of the environmental qualities of a product, based on the most important criteria through a diagram. Besides, it provides the potential improvements to be made about each of the individual criteria (Tischner, 2001). The LiDS wheel is composed of eight environmental improvement strategies: (1) selection of low impact materials; (2) reducing the use of materials; (3) optimization of production techniques; (4) optimization of the distribution system; (5) reduced impact during use; (6) optimization of the initial useful life; (7) optimization of the end-of-life system; (8) development of new concepts (Byggeth & Hochschorner, 2006; Lindahl & Ekermann, 2013). These strategies and the respective guidelines are depicted in **Figure 22**, as well as the representation scheme of the LiDS wheel.

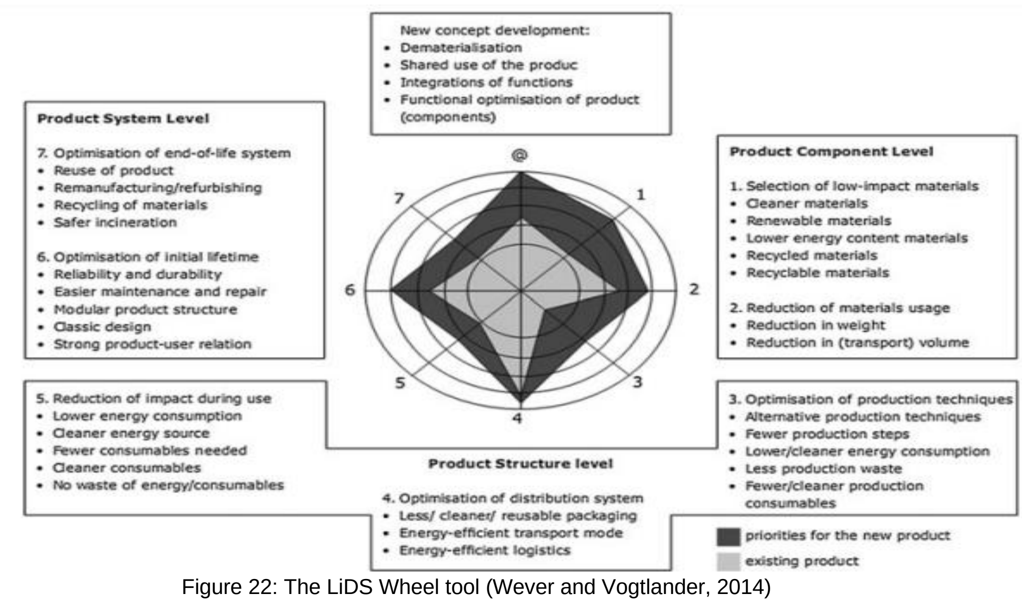


Figure 22: The LiDS Wheel tool (Wever and Vogtlander, 2014)

The Life Cycle Design Strategy (LiDS) wheel tool has some advantages and disadvantages described in **Table 14.**

Table 14: Advantages and disadvantages on Life Cycle Design Strategy (LiDS) wheel

		Reference
Advantages	It allows a life cycle perspective.	(Byggeth & Hochschorner, 2006)
	It is not time consuming.	(Lindahl & Ekermann, 2013)
	Easy to do.	
Disadvantages	The scores awarded are subjective.	(Lindahl & Ekermann, 2013)
	The importance of each strategy is unknown, which can easily lead to focus on the wrong aspects.	

Finally, a computer-aided design (CAD) tool can be used to build a 3D prototype so that it is possible to make the solution visual and encompass the environmental interests previously stipulated. The **3D modelling CAD tools** currently allow the integration of non-geometric information in a purely geometric model. This tool allows the integration of characteristics from sustainable methods used and the extraction of some information to carry out an environmental assessment. Thus, modelling in current CAD systems, combined with other methods of environmental assessment, allows achieving a product that promotes eco-design (Gaha et al., 2013). A 3D CAD modelling involves making decisions in proportion to the scale and the manufacturing and assembly process. In this way, the result is perceived by the viewer as real, ensuring that the product can be evaluated as if it were tangible (Ranscombe & Bissett-Johnson, 2017). The design of CAD models is described as the translation of knowledge into form features (Geromin et al., 2018), a knowledge that should be used in the improvement and development of the final product (Zhang & Zhou, 2019). The 3D modelling CAD tools have some advantages and disadvantages described in **Table 15.**

Table 15: Advantages and disadvantages on 3D modelling - CAD tools

		Reference
Advantages	Enables design automation.	(Nyamsuren et al., 2014)
	Increase the viability of the design.	
	Improve the overall quality of the design process.	
	It has a simple user interface.	(Jayakiran Reddy et al., 2018)
Disadvantages	Need a skilled developer.	(Jayakiran Reddy et al., 2018)
	Time-consuming process.	

3.4. Testing and Refining

Following the solution prototyping, the stakeholders must accept the solution or propose some aspects to change it in order to achieve maximum efficiency (Camburn et al., 2017). The fourth phase comprises the validation of ideas and prototypes created based on experts and community feedback (Buralli et al., 2018). This phase consists not only of testing the prototype achieved, but also subjecting it to a process of successive improvements to the design and the refining process(Camburn et al., 2017). According to the UNLEASH Innovation Process, the Testing and Refining phase requires obtaining feedback and re-evaluating the proposed solution(Deloitte, 2019a).

To obtain feedback from stakeholders, interview methods can be applied. Among them, two types stand out: the interview and the focus group. **Interviews** can be unstructured (UI), semi-structured (SSI), or structured (SI). These strategies allow to collect, generally, qualitative data. However, they can also produce quantitative data in the case of structured interviews (DiCicco-Bloom & Crabtree, 2006). Structured interviews are verbal questionnaires limited to a script and a fixed set of questions. The interviewer uses questions whose answer must be chosen from a number range or a fixed set, i.e., closed questions. This type of interview allows to assess knowledge about a subject, obtain general information, collect uniform data, or compare results from different groups of users (Wilson, 2014). Semi-structured interviews use predetermined open-ended questions, which may add other ones throughout the interview, that may arise related to the stipulated subject (DiCicco-Bloom & Crabtree, 2006). The interviewer must follow a set of main topics and can broaden the range of questions asked. In this type of interview, there should be knowledge of the topics on both parts. They can provide quantitative and qualitative data and allows to obtain personal opinions on a topic, understand the users objectives, or gather information about any activity related to the user (Wilson, 2014). Lastly, the unstructured interviews have no limit to the questions asked and can be seen as conversations guided by the interviewer. The interviewer must identify relevant topics during the interview and write down opinions and behaviours while questioning (DiCicco-Bloom & Crabtree, 2006). In these, the interviewer must be open to unforeseen topics while ensuring that it does not become repetitive. Unstructured interviews allow the collection of data on general topics and information on sensitive or emotional topics, develop new points of view on a subject, or obtain first impressions about a new product (Wilson, 2014). According to Deloitte (2019), an interview is "a conversation where the interviewer asks questions to elicit perceptions, opinions and personal experiences from the interviewee" (Deloitte, 2019a). The interviews has some advantages and disadvantages described in **Table 16**.

Table 16:Advantages and disadvantages on interviews

		Reference
Advantages	Little experience is needed; Answers are comparable; Easy data analysis. (SI)	(Wilson, 2014)
	Reveal previously unknown issues; Provides some flexibility; Requires less training time. (SSI)	
	Direct experience; Provides important insights for the project. (UI)	
Disadvantages	Interviewers must be consistent, Difficulty of harmony between interviewer and participant. (SI)	(Wilson, 2014)
	Results take time to analyse and are difficult to generalize. (SSI)	
	It requires time and practice; Time-consuming data analysis and interpretation; Large amounts of data require expensive and complicated qualitative analysis software. (UI)	

The **Focus group approach** involves the gathering of groups of people with similar backgrounds or experiences, to address a specific issue (Seal et al., 1998). Focus groups are group interviews that allow collecting qualitative data by discussing a predetermined topic provided by a moderator. This type of study is usually carried out in several successive events in order to ascertain whether there is any common and divergent pattern or theme. Concerning participants in this type of approach, they are chosen because they were involved with a particular product or because they share characteristics relevant to the topic in question (Wilson, 2014). The focus group can also be defined as an informal discussion on a given topic among a group of individuals with similar characteristics (Samfira & Raţă, 2015). According to Deloitte (2019), the focus group is a group session where people discuss their perceptions, opinions, beliefs, and attitudes towards a new solution (Deloitte, 2019a). The focus group approach has some advantages and disadvantages described in **Table 17**.

Table 17: Advantages and disadvantages on focus group approach

		Reference
Advantages	Allows generating information quickly and at a low cost.	(Seal et al., 1998)
	Flexible approach to data collection.	(Wilson, 2014)
	Promotes collaborative group dynamics to obtain new ideas.	(Deloitte, 2019a)
Disadvantages	Responses influenced by social pressures.	(Seal et al., 1998)
	The sample may not be representative of the general population.	(Wilson, 2014)
	Does not allow extrapolation of any quantitative data.	

In addition to the interview methods, **scenario analysis** can also be used to obtain feedback from users exposing them to a specific situation. Scenario analysis is a technique that allows the creation of hypothetical scenarios in which the user will have to make a specific type of decision. This tool encourages critical thinking and the exercise of analysis and decision making in the face of assumptions and multiple perspectives (Brookfield, 1997). Scenario analysis is a qualitative way of describing future situations, not in terms of predictions, but in terms of results that can be obtained. This type of consideration makes it possible to take advantage of opportunities and avoid potential threats in the development of a solution (Buytendijk et al., 2010). The scenarios, in addition to allowing an improvement in the decisions to be taken, also allow increasing the flexibility and innovation of a product (Amer et al., 2013). In view of a prototype analysis, this type of tool allows an understanding of the impacts of possible future events in that same solution. The scenario analysis generally adopts a theoretical scenario of the best case (optimistic) and another of the worst case (pessimistic) to determine the best strategy to adopt (Balaman, 2019). Usually, the development of this strategy involves five stages for the construction of scenarios. The first is the identification of the scope of the scenario. The second assumes the identification of key factors, that is, the main trend parameters, followed by their intuitive and numerical analysis. The fourth stage is the generation of the scenario. Finally, this scenario is presented to stakeholders to obtain feedback (Batrouni et al., 2018). Summing up, scenarios are verbal situations that are presented to the user to assess their reaction, contributing to the refining of the solution (Deloitte, 2019a). Scenario analysis has some advantages and disadvantages described in **Table 18**.

Table 18: Advantages and disadvantages on scenario analysis

		Reference
Advantages	Allows the reduction of the risk of uncertainties and explore opportunities.	(Buytendijk et al., 2010)
	Considers qualitative and quantitative data.	
	Requires the participation of several groups of stakeholders, increasing the validity and robustness of the solution.	
Disadvantages	May give rise to imaginative assumptions.	
	Future conditions can be confused with current conditions.	

3.5. Implementing

The fifth phase includes the planning for implementation in the market and the definition of the milestones and main expected obstacles (Buralli et al., 2018). According to the UNLEASH Innovation Process, the Implementing phase requires the production, dissemination, distribution, sale/ commercialization of the solution defined for real customers (Deloitte, 2019a). Regarding this phase, two methodologies can evaluate the viability of the implementation of the product. Those are the business model and the risk management plan.

The **business model approach** involves drawing up a plan responsible for the success or failure of a company. A business model (BM) is considered a plan for creating value, stipulating resources, and determining mechanisms for capturing and delivering value. This model is built on a multi-actor basis according to which a company interacts with customers, mediators, suppliers, and others, sharing with them the need to create an appropriate value. According to Costa Climent and Haftor (2021), there are two broad views to classify the business model. The first one considers that a BM integrates the properties and performance of a company, its context, and the drivers of performance. The second one classifies a BM as a cognitive scheme or pattern of thought that is maintained by the managers of a company and that includes its decision making (Costa Climent & Haftor, 2021). Business models can also be seen as the interconnected and interdependent company activities that are created to satisfy the needs of stakeholders, the underlying value proposition, and the delivery, creation, and capture of value. In this way, the Business Model Canvas was suggested with nine building blocks: value proposition, customer segments, customer relationships, channels, key partners, key activities, key resources, cost structure, and revenue streams (Haaker et al., 2021).

However, the innovation factor of the business models is crucial for the viability of the business guaranteeing its competitive advantage. Changing customer expectations and technological advances are the two main drivers of innovation reflected in the value proposition (value to be delivered to a chosen target customer segment), the delivery of value, the creation of value (repairing or reengineering assets and skills to generate use-value) and the value capture. Thus, it is possible to adapt business models to changing environments (Haaker et al., 2021). This logic of innovation and the concept of circular economy are the base of circular business models (CBM). These are defined as a model according to which the company creates, delivers, and captures value in a closed material loop (Lewandowski, 2016). According to Geissdoerfer et al. (2020), there are four generic strategies in CBM: (1) cycling, which reveals that materials and energy are recycled within the system through reuse, remanufacturing, reconditioning, and recycling; (2) extending, which means increasing the products use phase; (3) intensifying, which implies intensifying the use of the product; (4) dematerializing, which means renewing the utility of the product by replacing components (Geissdoerfer et al., 2020). Bocken, De Pauw, Bakker, and Van Der Grinten (2016) suggested three fundamental strategies for achieving CBM: reducing the use of resources or improving their efficiency, slowing resource consumption by extending product life, and closing the cycle through recycling (Mostaghel & Chirumalla, 2021). Nevertheless, the circular business model has some advantages and disadvantages described in **Table 19**.

Table 19: Advantages and disadvantages on circular business model

		Reference
Advantages	Ensures the application of circularity to all components.	(Lewandowski, 2016)
	Identifies the crucial components for the circular economy.	
	Allows the creation of sustainable business models.	
	Increases the SC efficiency, productivity, and greening.	
Disadvantages	Actual usability has not been tested empirically.	
	It has a more complex structure.	

The **risk management plan** has as main objectives the identification of potential risks in the solution implementation process and the description of strategies to mitigate that same risks (Deloitte, 2019a). Several types of risks can be associated with the development of a solution, so in addition to the plan, risk management must be carried out systematically by companies. Concerning the systematic management of risks, was developed the ISO 31000 (2009) standard. This standard allows the integration of risk management into the general management system of a company. Also, suggests principles and guidelines on how to manage complex issues that are sometimes poorly understood or dealt with in a restricted way (Lalonde & Boiral, 2012). Usually, the risk management plan is divided into four phases. The first step is to establish the context (Oduoza, 2020) through which it is possible to define an interval for the remaining risk management process (Guo, 2015). The second stage is the risk assessment, which involves three steps: risk identification, risk analysis, and risk evaluation (Oduoza, 2020). Several methods can be used to identify risks, such as audits, brainstorming, informal discussions, group discussions, analysis of current and previous data, accident reports, causal identification, and the development of a list of risks (Guo, 2015). This process makes it possible to identify all threats that may inhibit the business from reaching its objectives (Wan Husin et al., 2019). The risk analysis implies the classification of each risk in terms of impact and probability on a scale of 1 to 5. This classification is made from a risk matrix that allows the categorization in low, moderate, or high by multiplying the score assigned to each of the two previous parameters (Guo, 2015). The risk evaluation determines whether the risks are acceptable or need to be eliminated. Risks that are classified as low are usually acceptable and need only to be checked regularly, the remaining ones must be eliminated (Guo, 2015). The third step is the treatment of the risk, which involves the elaboration of strategic options and the definition of the person responsible for them (Wan Husin et al., 2019). These strategies can be to reduce, avoid, transfer, mitigate or retain the risk or, if it is an opportunity, to explore, share, improve or ignore the risk. Finally, the fourth step is to monitor and review the risk plan (Oduoza, 2020). This process should be a continuous and updating one (Wan Husin et al., 2019) allowing communication between the various departments and ensuring that any new risks are added to the plan (Guo, 2015). The risk management plan has some advantages and disadvantages described in **Table 20**.

Table 20: Advantages and disadvantages on risk management plan

		Reference
Advantages	Allows increasing the efficiency of the product implementation.	(Lalonde & Boiral, 2012)
	Allows the elimination of risks on time.	
	Promotes risk awareness.	
	Allows improving business performance.	(Oduoza, 2020)
Disadvantages	It does not allow the rules to be applied generically.	(Renn, 1985)
	When done poorly, it may not allow dealing with risks.	
	Qualitative risk assessment is subjective and lacks consistency.	

3.6. Conclusion

The increasing use of unsustainable materials in the manufacture of mobile phone accessories is a major concern for companies in the sector. Therefore, methodologies that promote a more sustainable design process, that promote the approach to SDGs, and that are based on circular economy and eco-design must be considered. The literature review was conducted to understand which strategies and methodologies can be used in each of the phases of the design process defined by UNLEASH. The five phases inherent to this process are problem framing, ideation and idea selection, prototyping and sketching, testing and refining, and implementing. This chapter develops the research carried out on the main topics that must be explored in each of these phases, reveals some of the methodologies and tools to be used and the main advantages and disadvantages of the individual. Moreover, it is necessary to combine the methodologies and tools presented that guarantee a greater number of advantages to obtain a product development process that promotes sustainability in the mobile phone accessories sector.

4. Methodology

This chapter defines the methodology to be followed throughout the master's dissertation, based on the presented literature review. This methodology will be based on the design process proposed by the UNLEASH Innovation process, developed by Delloitte (2019) and the United Nations. This chapter is divided into five sections, which correspond to the five phases described by that process. In each of these phases different methods are applied, chosen from those described in the literature review regarding their main advantages. The application of different methods allows for better model validation, theory testing and better collection of important information to be considered. Therefore, the methodology to be followed throughout the masters' dissertation is illustrated in **Figure 23**. Each step is explained in more detail.

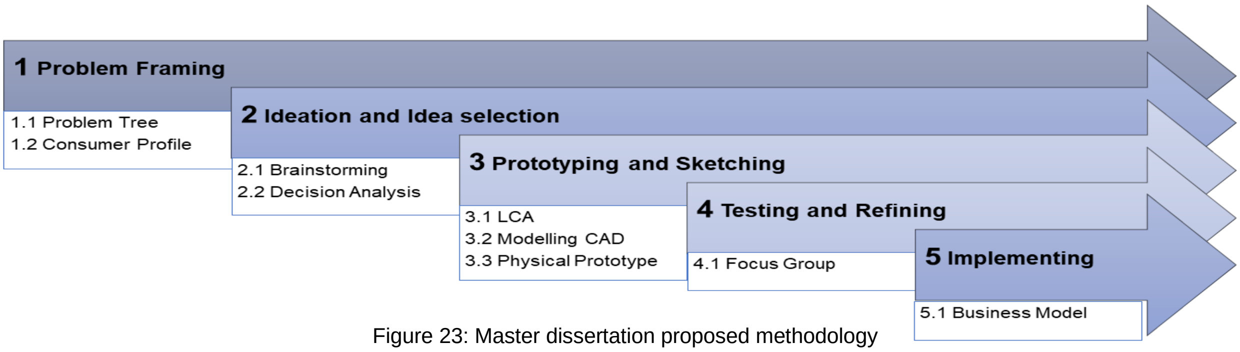


Figure 23: Master dissertation proposed methodology

Step 1 – Problem Framing

At this stage the main objective is to define the problem in a well-structured way, taking into account what the client/user wants. To accomplish this, step 1.1 aims to develop a problem tree and step 1.2 establishes a consumer profile framework.

The problem tree tool allows to depict the issues associated with the main problem, using a diagram. Explored by several authors (Zimmermann et al. (2008), Veselý (2008), Madu et al. (2018), Mahmoud (2020)), this tool allows a clear visualization and understanding of the problem, guaranteeing a perfect distinction between causes and consequences. In contrast, mind maps are not very formal and structured and are difficult to use in complex problems. The cognitive maps are most used in the treatment of quantitative and qualitative data and result in a very complex diagram that is difficult for others to read. In order to formulate the problem tree, five steps result from the development of the research by Ammani et al. (2010), Madu et al. (2018), and UNLEASH by Deloitte (2019):

- **1.1- I-** Identify the topic of the problem tree.
- **1.1- II-** Identify the existing problems concerning that same topic and select the main problem. This problem is the beginning of the problem tree, it must be specific and clear, and it must be placed on top of it. There may also be inherent problems that should be placed on other branches of the tree.
- **1.1- III-** Discuss the causes of the problem and build the respective relationships.
- **1.1- IV-** Review the entire tree, verifying its validity and integrity, and making necessary adjustments.

1.1- V- Identify the core problem. This is the outcome of the problem tree and must be concise and comprehensible.

A problem tree is represented in **Figure 24**.

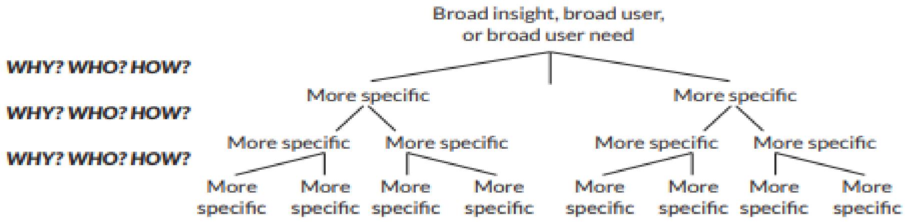


Figure 24: Representation of a problem tree (Deloitte, 2019)

To develop the problem tree, a group with two experts, one in sustainability and the other in circular economy and eco-design, will be created. The process should take five days to complete. First, each participant must record the possible causes for the excessive waste from electronic equipment accessories. Then, the group should discuss these causes and find the causes for the first ones, successively answering questions such as why? who? how? The process ends when it is not possible to further develop the causes and find all the underlying problems associated with the core problem. After the group discussion, the Tree will be organized with causes inherent to the same problem, being organized in the same branch.

Moreover, in this step, the consumer profile framework is applied. As introduced by Zhao et al. (2019), the construction of a user profile consists of four phases:

1.2- I- Data collection: for this step, a survey will be used to collect reliable information. Like any other type of research methodology, surveys are also supported by a theoretical basis and will be carried out in an electronic format using the QuestionPro platform. Based on Rea & Parker (2014) work, the survey should follow the following steps:

- **i-** Identify the focus of the study and the research method: in this step, the goals and objectives of the study must be clearly defined and the data collection format to be used should be identified.
- **ii-** Determine the research chronogram: the time required for data collection must be previously defined. It must be flexible enough to withstand any delays or unforeseen circumstances.
- **iii-** Determine the sample and its respective size: a sample must be selected capable of responding to the questionnaire to be developed, with the knowledge to do so. It must also be stipulated the acceptable value of the number of responses that allow for data processing.
- **iv-** Designing the survey: an impartial questionnaire must be structured to allow the desired content to be systematically obtained. The survey should be easily understood, internally consistent, and useful for an adequate and meaningful data analysis.
- **v-** Test the questionnaire: it is necessary to validate the prepared questionnaire and adjust it so that the implementation can be carried out.

vi- Implement the questionnaire: at this stage, it must be ensured that the determined schedule and sample are respected and be particularly concerned with maintaining privacy and minimizing inconveniences.

vii- Analyze the collected data: the data obtained must be summarized and organized in tables and graphs that allow statistical analysis and determination of conclusions.

The survey was elaborated based on the questionnaire present in the masters' dissertation "Sustainable footwear solutions for the scrap tire sector" (Gomez, 2020) and changed to obtain the required information. Its main objective was to collect data referring to the consumption of mobile phones accessories in general. However, a greater emphasis was placed on one type of accessories: chargers. As shown in Chapter 2, in **Figure 5**, chargers are the accessories with the highest percentage of consumption presenting a value of 99% (Delloitte, 2019a). Furthermore, this is a non-modular accessory and is generally produced from plastic, more specifically, PP (UNEP, 2013). The high consumption and its harmful characteristics make this accessory an environmentally unsustainable product that must have special attention. Finally, it is necessary to understand whether consumers are willing to buy this accessory separately from their equipment and whether it is important that the same charger can be used in various equipment's that they can purchase.

The presented survey begins with an introduction whose main function is to explain the objective of the study and research carried out, as well as the structure of the document. The survey is divided into three sections, with a total of 13 questions. Section 1 aims to understand not only the consumer habits regarding their turnover of mobile phones, but also which are the most used accessories by them. Besides, this section provides an overview of the characteristics and materials that the respondents preferred the most. Finally, it is explored in this section the importance attributed by consumers to habits that promote product sustainability. Section 2 focuses on cable chargers and the importance they have for the consumer. In this section it is possible to understand if the charger is more valued when purchasing the equipment or separately. Furthermore, the cost that can be attributed to a charger is noticeable when its purchase is made individually. Section 3 is about demographic information from respondents. **Table 21** summarizes the main objective of each question that constitute the survey.

Table 21: Survey questions' objective

Question	Objective
1.	Understand the frequency users change their mobile phones.
2.	Realize which of the six most consumed accessories is the most important to consumers.
3.	Understand which materials are most important in mobile phone accessories.
4.	Identify, for each of the mentioned accessories, the most important characteristics.
5.	Understand if it could be other characteristics to be considered.
6.	Understand which of the habits that characterize an environmentally sustainable product is the most important.
7.	Understand the availability of consumers to contribute to sustainable attitudes concerning mobile phone accessories.
8.	Recognize the importance, on a scale of 1 to 5 points of the chargers being sold together with mobile phones or computers.
9.	Recognize the importance, on a scale of 1 to 5 points of being able to repair the charger when it is damaged.
10.	Realize the price range consumers are willing to pay for a charger sold separately with the reduction of the cost of the equipment.
11.12.13.	Associate the choices made in the questions of the first two sections with the gender and the age group to which it belongs, simultaneously characterizing the sample.

The survey is mostly composed by closed responses, providing the respondent with a fixed list of alternative responses in which the best answer must be selected. This type of answer allows to obtain uniform results helping in comparisons, makes the question clearer, remembers alternatives that could not be considered, and increases the probability that the answer rate for the questionnaire is higher. There are also scoring questions in which the respondent must evaluate, on a scale of 1 to 5, the importance given to the accessories (1 being a factor of low importance and 5 a factor of high importance).

Following the definition of the main objectives of the survey, it was determined 15 days to obtain answers. Also, two versions were distributed (an English and a Portuguese one) to increase the number of answers. The survey was distributed online, to different groups of people, through distinct social platforms (WhatsApp, Facebook, and LinkedIn) and private messages.

Having briefly explained the content of the survey, this is fully presented next.

START

---Please read carefully before you start--

This survey supports a Master dissertation titled "Circular Economy in Electronic Equipment Accessories" being pursued at Instituto Superior Técnico - University of Lisbon (Portugal). The main objective of this survey is to create a consumer profile that will support the development of the redesign of electronic equipment accessories, promoting circular economy and eco-design. This consumer profile must be the one that most relates to the problem founded. All the information provided is confidential and only used for the matter of the present study. The survey is divided into 3 sections: (1) General consumption of mobile phones and accessories; (2) Consumer preferences in cable charger; (3) Consumer Data. It should take 6 – 7 minutes to complete.

Thank you for your interest and contribution in answering this survey.

----------------------------Section 1: General consumption of mobile phones and accessories --------------------------------

Q1 – How often do you change your mobile phone?

☐ every 6 months

☐ once a year

☐ every 2 years

☐ more than 3 years

☐ only when there is no fixing

Q2 – Personally, how important is each of the following phone accessories? Consider 1 low importance and 5 high importance.

	1	2	3	4	5
Phone case					
Earphones					
Charger					
Power Bank					
Portable Speakers					
Car Holder					

Q3 – How do you assess the importance of using the following materials in a phone accessory? Consider 1 low importance and 5 high importance.

	1	2	3	4	5
Wood					
Leather					
Metal					
Rubber					
Plastic					
Recycled Material					
Vegan Material					
Biodegradable Material					

Q4 – From the following features choose the two or three most important when purchasing each of the accessories.

	Design	Quality and Durability	User-friendly	Price	Warranty	Brand
Phone case						
Earphones						
Charger						
Power Bank						
Portable Speakers						
Car Holder						

Q5 – Are there other characteristics that you consider relevant that are not in the previous list? Which one(s)?

Regarding the production of a sustainable mobile phone accessory, there are several characteristics that must be privileged and actions that can be taken.

Q6 – From the list of characteristics below, rate the importance that each has for you. Consider 1 low importance and 5 high importance.

	1	2	3	4	5
Use of non-polluting raw materials					
Use of recycled materials					
Use of production processes with low emissions of polluting gases					
Possibility to use in second-hand					
Possibility to recovery components and use it again					
Possibility of recycling					

Q7 – From the list of actions below, which ones are you willing to do. Consider 1 not available and 5 very available.

	1	2	3	4	5
Use accessories made with recycled materials					
Using second-hand accessories					
Reuse accessories from old equipment in a new one					
Take the accessories for repair					
Recycle accessories					
Compost the accessories					

--------------------------------Section 2: Consumer preferences in cable charger ---

As an effort to combat the high consumption of these accessories, ensuring the company's sustainability, Apple announces that its latest version of the iPhone will be sold without the charger, thus contributing to the reduction of carbon emissions.

Q8 – How important it is for you that the chargers are sold together with mobile phones or computers?

	1	2	3	4	5	
Low importance						High importance

Q9 – If you were able to repair the charger when it is damaged, how important would that possibility be to you?

	1	2	3	4	5	
Low importance						High importance

Q10 – Imagine that the charger would be sold separately leading to a reduction in the cost of the equipment. How much would you be willing to pay for a cable charger, under these conditions, that promotes the circular economy?

☐ Less than 5€

☐ From 5€ to 10€

☐ From 10€ to 20€

☐ From 20€ to 30€

☐ More than 30€

--Section 3: Consumer Data---

Q11 - Please indicate your gender.

☐ Male

☐ Female

Q12 – Please state your age gap.

☐ 18 – 22

☐ 23 – 31

☐ 32 – 45

☐ 46 – 55

☐ 56 – 66

☐ +67

Q13 - Please indicate the country you are currently living at.

Thank you for your contribution.

END

1.2- II- Pre-processing: after collecting all the information from the survey, it is treated by removing information that is unnecessary and summarizing it to useful, error-free, and complete data. The objective is descriptive analysis that briefly describe consumer preferences through the primary analysis made by the QuestionPro platform and eliminating incomplete answers.

1.2- III- Aggregation of the information by a pattern: involves grouping information according to similarities in consumer behaviour and choices. In order to obtain a higher number of answers, besides the English version, a Portuguese one will be distributed. In this step, the results of the two versions will be summarized. For each question, a single analysis will be performed.

1.2- IV- User profiles: the different consumer profiles achieved are presented and the one that experience the structured problem is chosen and should, therefore, be the target of the development of the solution.

Step 2 – Ideation and Idea Selection

The ideation and idea selection phase follows next. This step is essential in the generation of several solutions that can solve the described problem and then the choice of the most viable alternative taking into account different criteria. The chosen solution must be new and useful and meet the established criteria. To accomplish this, step 2.1 should be carried out, which includes a brainstorming session with a focus on solutions based on eco-design. Then in step 2.2, to select only one solution, among those obtained, a multi-criteria decision analysis is used to evaluate the different solutions presented and decide on the most feasible one, having in consideration the selected criteria.

Described in the literature review as an idea generation tool explored by several authors, the brainstorming technique will be used to originate new, original, and viable ideas to solve the defined problem. As introduced by Al-Samarraie and Hurmuzan (2018), there are three brainstorming techniques. The one that will be used, as it is simpler and originates a higher number of ideas, will be traditional brainstorming (TBS). According to this technique, in a group environment, ideas from each of the elements are verbally shared. According to Fleury et al. (2020), to perform brainstorming three steps must be followed:

2.1- I- Preparation, where the objective is defined.

2.1- II- Animation, where ideas are generated.

2.1- III- Capitalization and valuation, where ideas are reformulated and classified, and unconvincing ideas are eliminated.

To carry out this step, two groups with clear notions and knowledge on the concepts of eco-design and eco-innovation will be created. In the first brainstorming session, the group will consist of four Engineering and Industrial Management students who have the necessary knowledge. In the second session, the group will consist of three persons and include a sustainability specialist and a product design specialist. Each session will last 2 hours and be moderated by me. The ideas generated in the first session will only be shared with the second group at the end of the brainstorming session.

In step 2.2, the choice of the best solution is made among those suggested above. As suggested by Hermann et al. (2007), a multi-criteria decision analysis is performed. In the literature review, several methods were mentioned that can be used to perform this type of analysis. Thus, the MACBETH method (Measuring Attractiveness by a Categorical Based Evaluation Technique) will be used.

The principle of this approach is to translate the qualitative information provided by the DM into quantitative information that allows to recommend an alternative (Clivillé et al., 2007).

According to Bana e Costa & Chagas (2004), four main steps must be performed:

2.2- I- Definition of the decision context: the different situations to be studied and the criteria to be considered are defined. A value tree is also prepared with the alternatives to be evaluated against the defined criteria.

2.2- II- Quantification of alternatives in parallel: the alternatives are compared two by two, according to the defined criteria, and qualitatively classified on their attractiveness. The scale of attractiveness levels used is null, very weak, weak, moderate, strong, very strong, and extreme.

2.2- III- Determination of criteria weights aims to calculate a weighted arithmetic average for each alternative, considering the relative weights of each of the criteria. After this step, MACBETH provides the aggregate performance associated with different situations.

2.2- IV- Conducting sensitivity and robustness analysis: to guarantee the veracity and robustness of the results obtained, these analyses are carried out. After this step, it is possible to make recommendations on which is the best alternative and, therefore, what should be considered as a solution.

During steps II and III, the answers that are inserted into the MACBETH decision support system are automatically checked for consistency (Bana e Costa & Chagas, 2004) . At the end of this analysis, the best idea must be chosen. The main objective will be to classify the ideas from the brainstorming session according to the criteria defined. Then, that classification will allow obtaining the most favourable alternative that will be the solution to be developed in the following steps.

Step 3 – Prototyping and Sketching

For the prototyping and sketching step to be initiated, all the previous phases must have been successfully completed and a solution must have been selected to be evaluated through the following phases. This phase results in a tangible prototype of the previously proposed solution. Initially, it is necessary to choose materials that should incorporate the final product. This choice is made using the LCA method in step 3.1. Therefore, the construction of a 3D prototype using a CAD system must be carried out to ensure that the dimensions and physiognomy chosen are the most appropriate. After this virtual representation, it is possible, in step 3.3, to create a physical prototype that can later be presented to possible users.

Described in the literature review as a tool used to assess the environmental impacts of a product system and often used in eco-design, the LCA has been studied by several authors. The main objective of this phase is the choice of materials to be used considering their environmental impacts. The professional tool SimaPro will be used, since, as suggested by Starostka-Patyk (2015), it is a very effective IT tool that allows to collect, analyze and monitor the sustainability performance of new products. SimaPro has many resources to support the decision-making process that are extremely useful for design (Starostka-Patyk, 2015). This software allows not only to easily model and analyze complex life cycles but also to measure the environmental impact of the product at all stages of the life cycle. Besides, this process is systematic and transparent and allows identifying the critical points, at an environmental level, of the life cycle of that same product (SimaPro, 2021).

According to ISO (2006) the ISO 14040 standard defined four phases for the LCA process:

3.1- I- Objective and Scope Definition: involves the clear definition of the work to be performed. These definitions determine the data collection and the way the system is modelled and evaluated. For this step to be completed, it is necessary to define three types of boundaries: geographical, temporal, and physical. These boundaries define the places and time of the study and the life cycle to be studied, i.e., which activities and processes are to be included in the analysis to be carried out. Finally, it is necessary to define the functional unit to be used. This unit is a quantitative description of the function for which the assessment is performed and the basis for determining the product reference flow that scales data collection in the next LCA phase, the inventory analysis (Hauschild et al., 2017).

3.1- II- Lifecycle Inventory Analysis (LCI): this phase focuses on the collection of relevant data to the system, such as all inputs (raw materials, water, energy, among others) and outputs (final product, water, air emissions and terrestrial, among others) of it. Initially, a block diagram process should be carried out where the problem, processes, and flows are schematically described. All flows are determined according to the previously defined functional unit. These data are then inserted into SimaPro by creating a computational model and based on the Ecoinvent data provided by the software. Finally, it is necessary to analyse the data report obtained in order to select the relevant data for the selection of the most sustainable materials among the alternatives (Hauschild et al., 2017).

3.1- III- Lifecycle Impact Assessment (LCIA): this step is responsible for generating an environmental impact score for the product system. This information is useful to support the decision on the materials to be used when aggregated with other information such as alternative costs. For this to be possible, there are several methods that follow the methodology described at ISO 14040 standard: (1) The first step is the classification, wherein the elementary flows of the inventory are attributed to the different categories of impact. (2) The second step is characterization, in which scores of specific metrics are assigned to each impact category revealing the environmental contribution of that same category. (3) The third step is the normalization that allows obtaining the scores previously given in a common unit. (4) The fourth step is the weighting that allows the comparison between the impact categories, grouping and possibly classifying them according to their perceived severity. Quantitative weighting allows the aggregation of all scores into a single environmental impact score, the single score (Hauschild et al., 2017).

In this study, the environmental model chosen is ReCiPe because according to Carvalho et al., 2014 is the one that has the most desired characteristics. This model includes midpoint (focus on unique environmental problems) and endpoint (environmental impact at three higher levels of aggregation) analysis.

3.1- IV- Interpretation: this phase aims to verify and evaluate all information obtained from the previous steps and to ensure its consistency. This phase analyses the results keeping in mind the objective and scope defined and the boundaries established. Thus, a set of scenarios are established to improve the current system and support the selection of materials to be used in the final product (Hauschild et al., 2017).

At the end of this analysis, the best materials to produce the solution developed must be selected. These materials will be those with less environmental impact and, therefore, more sustainable. Besides, the LCA analysis will allow verifying which production processes increase the impact of the product and thus it is possible to give recommendations for improvement.

The material selection phase is followed by the creation of a virtual prototype, through a 3D representation using a CAD system. The creation of this prototype is essential to promote eco-design as suggested by Gaha et al. (2013), when combined with methods such as the LCA.

After this virtual representation is completed it is possible to build a physical prototype, which can be presented to potential users. Step 3.3 is completed once the physical prototype is ready and able to be experienced by a possible future user.

Step 4 – Testing and Refining

Once the prototype is completed, it is necessary to obtain feedback from possible users and reassess the proposed solution. In this sense, this phase intends to validate the idea and prototype created based on community feedback, subjecting it to successive design improvements. For this validation to occur, a focus group approach must be used which, as described in section 3.4 of the literature review by Wilson (2014), represents a group interview that allows qualitative data about the product to be collected. Adapting the research carried out by Wilson (2014), step 4.1 must present the following steps:

4.1- I- Choosing a moderator: for a focus group session to be successful, it is necessary to choose a good moderator who has a high level of experience, good memory, and the ability to maintain a neutral approach by not expressing his opinions on the topic.

4.1- II- Dimensioning the groups: the focus group literature recommends three to five individual groups for the data to be more comprehensive. Besides, each of these groups can have between six and eight participants if the objective is to have a small group to be easier to control and have more time for participants to express themselves, or six to twelve in the case of large groups for more comprehensive information.

4.1- III- Develop a guide for the session: the moderator should be provided with a discussion guide that contains the topics, questions, prompts, documents, and exercises that should be covered throughout the session. The script should also contain the duration that each main topic should have.

4.1- IV- Execute the focus group session: the development of the session should consist of an introduction made by the moderator, where the objectives and rules of the focus group session are clearly explained to the participants, the discussion of all topics, and finally a summary of the main ideas discussed.

4.1- V- Treat and analyse the data: decide which relevant information was taken from the session, identifying the suggestions and the "big ideas" given by the participants. This information must be analysed to improve the product initially presented.

Step 5 – Implementing

Finally, the development of step 5 allows obtaining the necessary planning to implement the product in the market. According to UNLEASH by Deloitte (2019) a business model should be created. Since the objective is to introduce the final product within the scope of the circular economy a circular business model canvas (CBM) will be used, as suggested by Lewandowski (2016). This type of business model, developed based on the principles of circular economy referred in the literature review, is an adaptation of the well-known Business Model Canvas (BMC) and consists of eleven building blocks:

5.1- I- Value proposition: this block is the main component of CBM. The products and services offered to the customer must be explicit so that they are circular products that allow the extension of the products useful life. Besides, the product-service system, virtualized services, and collaborative consumption must be mentioned. Finally, the incentives and benefits offered to customers to bring back used products must be referred.

5.1- II- Customer segments: this component must specify all types of customers covered by the product offered. These segments must be entirely related to the value proposal suggested in the previous block.

5.1- III- Channels: this block must highlight all the ways used to sell the value proposition made. Given this model, virtualized channels must be prioritized, i.e., products should be sold through virtual stores, or the communication between the company and the customer must be online.

5.1- IV- Customer relationships: this component must mention which or what types of relationships exist with the customer. Production must be underlying orders to avoid or even eliminate waste. It should also be up to customers to decide social marketing strategies to encourage a move to 2.0 recycling and leverage relationships with community partners.

5.1- V- Revenue Streams: this block must be defined based on the elaborated value proposition and reveals how to generate money. There are four common forms that can be developed in this component. The first is payment for a product called input-based. The second is payment based on small instalments or rental, called availability-based. The third is the one-time payment to use the product called usage-based. The fourth is the payment for contracts called performance-based.

5.1- VI- Key resources: in this block, all necessary suppliers that offer the best materials must be mentioned as well as the materials needed. The resources required to regenerate and restore natural capital, the ones obtained from customers or other members intended to circulate in material cycles should be developed.

5.1- VII- Key activities: this component should refer to all the main activities that, directly or indirectly, contribute to the creation, offer, and delivery of the defined value proposition. These activities should be focused on increasing performance through good maintenance, better control of processes, modification of equipment or technologies, and improvement of product design.

5.1- VIII- Key partnerships: in order to carry out the activities established in the previous block, should be defined which partners along the value chain and the supply chain should cooperate to promote the circular economy. The types of cooperation existing with each of the chosen partners must also be established.

5.1- IX- Cost structure: this block explains the evaluation criteria and principles to be applied to determine the value of incentives for customers, the costs of production, development, or investment.

5.1- X- Take-Back system: this component must explain which channels are involved in the return management system and the existing relationships with the customer related to this system. Besides, the partnerships needed for reverse logistics must also be clarified. This block develops the entire system necessary for the reuse, recycling, and collection of products.

5.1- XI- Adoption factors: in this block the necessary organizational capacities must be developed, as well as the PEST factors (political, economic, social, and technological) that the company must have. The characteristics of human resources, the methods and tools for designing business models and assessment models, and the ability to use technologies to monitor the business must be explained.

A circular business model canvas is represented in **Figure 25**.

<table>
<tr>
<td rowspan="3">Partners
• Cooperative networks
• Types of collaboration</td>
<td>Activities
• Optimising performance
• Product Design
• Lobbying
• Remanufacturing, recycling
• Technology exchange</td>
<td rowspan="3">Value Proposition
• PSS
• Circular Product
• Virtual service
• Incentives for customers in Take-Back System</td>
<td>Customer Relations
• Produce on order
• Customer vote (design)
• Social-marketing strategies and relationships with community partners in Recycling 2.0</td>
<td rowspan="3">Customer Segments
• Customer types</td>
</tr>
<tr>
<td rowspan="2">Key Resources
• Better-performing materials
• Regeneration and restoring of natural capital
• Virtualization of materials
• Retrieved Resources (products, components, materials)</td>
<td>Channels
• Virtualization</td>
</tr>
<tr>
<td>Take-Back System
• Take-back management
• Channels
• Customer relations</td>
</tr>
<tr>
<td colspan="3">Cost Structure
• Evaluation criteria
• Value of incentives for customers
• Guidelines to account the costs of material flow</td>
<td colspan="2">Revenue Streams
• Input-based
• Availability-based
• Usage-based
• Performance-based
• Value of retrieved resources</td>
</tr>
<tr>
<td colspan="5">Adoption Factors
• Organizational capabilities
• PEST factors</td>
</tr>
</table>

Figure 25: Circular business model canvas framework

5. Results and Discussion

This chapter is divided into five sections, each of which is responsible for the results obtained in the steps presented in the methodology. Section 5.1 presents the results obtained in the problem framing phase. Section 5.2 presents the main ideas discussed and the selection of the final solution. Section 5.3 presents the prototyping phase, as well as the selection of materials for the final product. Section 5.4 presents the testing and refining phase. Finally, section 5.5 presents the business model development for the implementation of the product in the market.

5.1. Problem Framing

This phase consists in the elaboration of a problem tree and of a consumer profile. The problem tree intends to explore the main problems related to the core problem. These problems are the target for resolution. Furthermore, the consumer profile aims to define the type of consumer that's most related to the postulated problem. In this section, the results obtained are presented along with the respective considerations and relevant information.

5.1.1. Problem Tree

The development of the tree branches was obtained from knowledge acquired in the literature and a brainstorming process. The different possible causes for the excess of electronic equipment accessories were discussed, successively. Accordingly, the elaboration of the problem tree provided valuable insights to reach the central elements of the problem in question. **Figure 26** shows a representation of the developed problem tree.

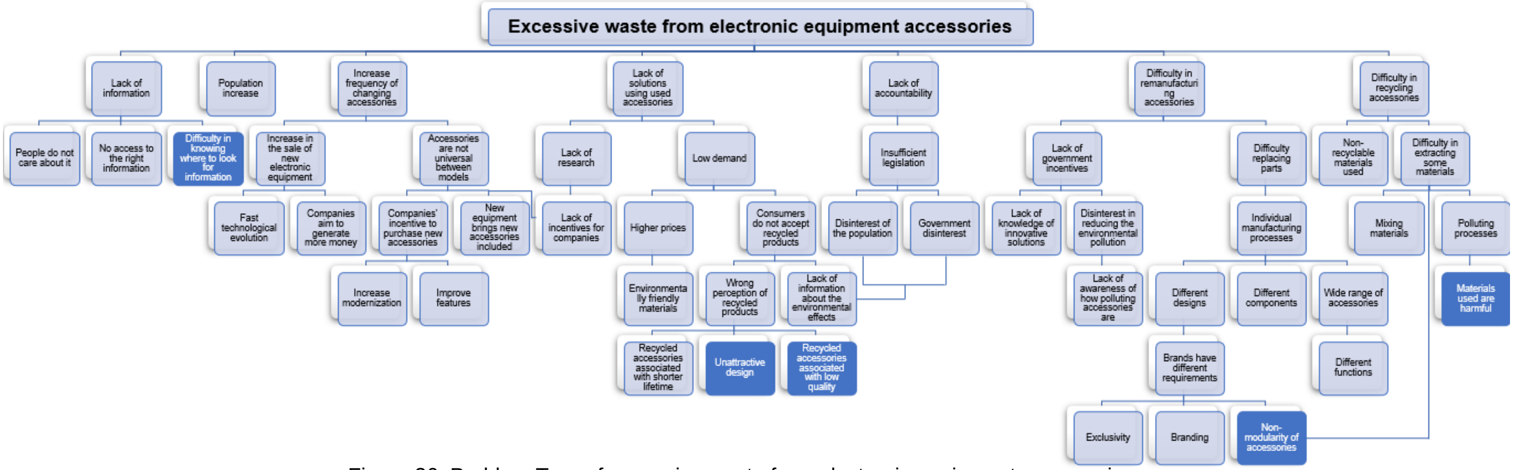


Figure 26: Problem Tree of excessive waste from electronic equipment accessories

In **Figure 26**, it is possible to distinguish seven direct causes for the excessive waste of electronic equipment accessories. Furthermore, the tree is comprised by seven levels of causes associated with the previously mentioned core problem, being the first level of this core problem. The remaining causes are at the following levels and detailed next from left to right based on **Figure 26**.

Emerging from the first level, one of the main causes for the excess waste of these accessories was the lack of information about this excess and its high consumption (level 2). This lack of information may occur not because there is no information about the harmful effects caused by the waste of accessories, but because of the lack of interest of some people in understanding it, or the difficulty in accessing the correct information, or knowing where to look for that information for other people (level 3).

Regarding population growth, this results in the increase of waste from electronic equipment accessories, since the increase in population results in more people having electronic equipment and, subsequently, accessories (level 2).

Third, it is possible to observe an increased frequency of turnover in these accessories, either through the purchase of new equipment or because the accessories are easily damaged or considered outdated (level 2). Two causes were pointed out for this increase. First, the increase in the sale of new electronic equipment, and second, the accessories are not universal, meaning they are not compatible with electronic equipment of different brands and, within the same brand, the same occurs between models (level 3). Regarding the increase in the sale of new electronic equipment, this is justified by the fast technological evolution and the need for companies to generate more money by encouraging new purchases. In addition, the non-universality of accessories is due not only to the increase in incentives by companies for the purchase of new accessories, but also because the new equipment brings new accessories included (level 4). The main reasons for companies to encourage the purchase of new accessories are the increase in modernization and the improvement of their characteristics (level 5).

Another identified cause was the lack of solutions for using used accessories. It is known that few or no options incorporate used accessories in their production (level 2). This lack of solutions is justified by the lack of research in this area and the low demand for products that promote these solutions (level 3). Regarding the lack of research, this has a common cause with the non-universality of accessories, which is the lack of incentives by the government for the companies. Also, solutions using used accessories are in low demand not only because they are usually more expensive but also because consumers do not accept recycled products (level 4). The solutions that incorporate used accessories are expensive due to the use of environmentally friendly materials. On the consumer side, there is a wrong perception on recycled products and a lack of information about the environmental effects that make it difficult to accept recycled products (level 5). The wrong perception on recycled products by the consumers is because they are strongly associated with a shorter lifespan, unattractive design, and low quality (level 6).

At the governmental level, the lack of accountability for this waste is evident, i.e., when an accessory is thrown away no law holds companies and the population accountable (level 2). The level of lack of accountability is attributed to insufficient legislation (level 3). The lack of legislation in this area of accessories comes from the disinterest of both the government and the population which falls on the lack of incentives for remanufacturing (level 4). The lack of information mentioned is also the cause for the government and the population lack of interest in creating laws for this problem and in reducing environmental pollution (level 5).

An additional cause for the increase of excessive waste from electronic equipment accessories is the difficulty in remanufacturing these accessories (level 2). This challenge is due to a lack of government incentives for companies and difficulty replacing parts of the accessories when damaged (level 3). Concerning the lack of government incentives for companies, there are two main causes. The first is the lack of knowledge of innovative solutions that allow remanufacturing and increase the interest of the government entities. The second is the lack of interest in reducing the environmental pollution. In terms of difficulty in replacing parts for remanufacturing it is mainly due to the individual manufacturing processes of the accessories (level 4). In terms of the lack of interest in reducing the environmental pollution is mainly due to the lack of awareness of how polluent accessories are. Regarding the accessory production processes, there are three main causes for the existence of individual manufacturing processes, which are the different designs and components and the wide range of accessories on the market (level 5). The wide range of accessories derives from the different functionalities that each of them presents. On the other hand, the different designs that exist are justified by the different requirements of the brands (level 6). Brands have different requirements because there is a need for exclusivity and branding. Also, the non-modularity of accessories is the main cause for the different requirements of the brands (level 7).

Finally, the last cause founded for the excessive waste of electronic equipment accessories is the difficulty in recycling accessories (level 2). This issue is due to the non-recyclable materials used in their production and the difficulty in extracting some materials so that they can be recycled separately (level 3). Concerning the difficulty in extracting some materials, this is not only because these products contain mixed materials but also because they present polluting processes. Also, the non-modularity of accessories is a cause for the difficulty in extracting some materials to recycle accessories (level 4). About the polluting processes, the basic problem is the use of harmful materials (level 5).

Having detailed all levels of the problem tree, it is noticeable that there are five causes that must be solved to reach the core problem (level 1). These causes selected in blue in **Figure 26** are more specific (less generic) and easier to solve. The causes presented are: (1) Difficulty in knowing where to look for information about the waste of accessories; (2) Unattractive design of recycled accessories (3) Recycled accessories associated with low quality; (4) Materials used in accessories production are harmful; (5) Non-modularity of accessories.

Taking into account the aforementioned causes, it is possible to observe that the majority converge into the lack of government incentives for companies to develop more sustainable products and the low market demand for reused or recycled accessories. These causes can be solved with the creation of a product to be marketed that uses sustainable materials, that is modular, and that allows consumers to stop associating products made with recycled materials with low quality, shorter lifespan, and unattractive design. In addition, the product to be developed must contain in its label the necessary information for the consumer to understand not only the materials used, but also the environmental problems that its use can avoid since it should be more sustainable than the existing on the market. In conclusion, the solution to be developed will consider the tree branches highlighted in blue.

After concluding the problem tree and finding the essential problems, it is necessary to develop the consumer profile that identifies who experiences the problem and, consequently, obtaining information about the needs of a group of individuals.

5.1.2. Consumer Profile

Regarding the definition of the consumer profiles for mobile phone accessories consumption, a survey was prepared for data collection. Since the objective was to understand the consumption characteristics of the largest number of people, a sample was selected for convenience, therefore, not representative of any region or group. The questionnaire was designed, validated by four persons – one expert and three possible consumers – and implemented. Despite the established timeframe, it was necessary to extend the time for answering to 17 days to obtain a higher number of responses. In this way, it was possible to achieve a total of 271 responses. However, only 261 responses were considered as the remaining 10 were incomplete. The collected data were subsequently processed, summarized, and organized in the graphs and tables that follow.

Despite only being requested in the last section, demographic information allows to characterize the sample and therefore is presented in the first place. **Figures 27 and 28** show the age, gender, and region of the respondents, respectively.

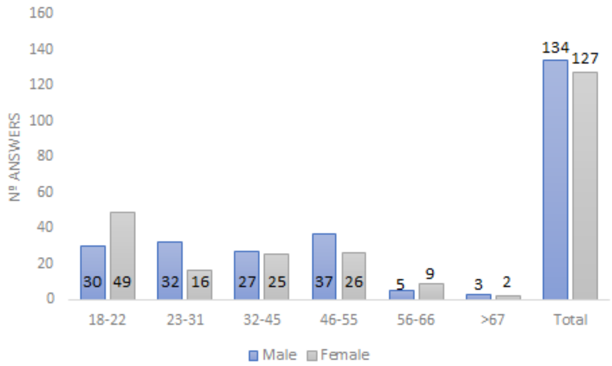


Figure 27: Age and Gender of the survey respondents

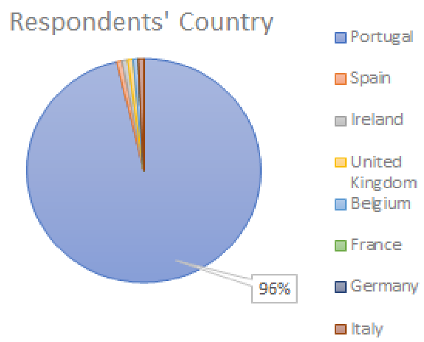


Figure 28: Country of the survey respondents

Analyzing **Figures 27 and 28,** it is possible to conclude that the majority of respondents are male (134), belong to the 18-22 (79) age group, and currently live in Portugal (96%), respectively. Concerning the male gender, it is possible to see in **Figure 27** that they belong, mostly, to the age group between 46 and 55. In the female gender, they belong mainly to the 18-22 age group.

Figures 29 and 30 demonstrate the results obtained concerning the frequency that users change their mobile phones and which mobile phone accessories are the most important to consumers, respectively.

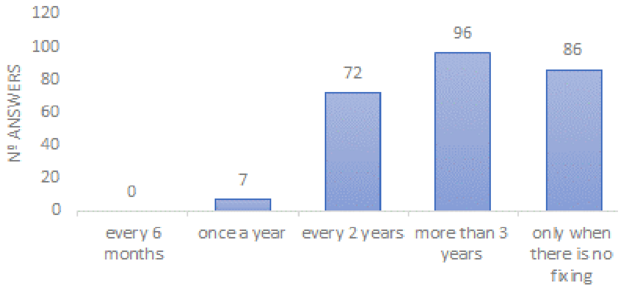


Figure 29: Mobile phone exchange frequency

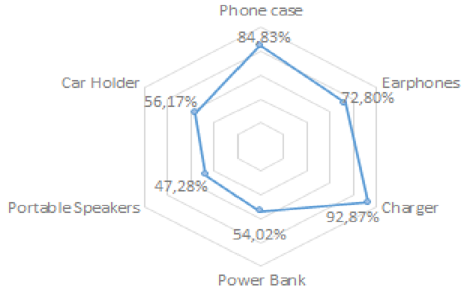


Figure 30: Importance of the six types of accessories for respondents

Most respondents stated that they switch their mobile phones every three or more years (96). However, there is a high number of people that switch mobile phones every two years (72) and, equally, a high number that switch only when they are damaged (86). Thus, it is possible to confirm a tendency to increase the time between switching mobile phones. The increase in consumption of mobile phones generates the same in accessories. Thus, it is possible to verify through **Figure 29** that there is a gap between the frequency of switching of mobile phones. This could mean a concern about the consumption of equipment and, consequently, of accessories by consumers. It is possible to assume that consumers value the durability of the products purchased. As observed in **Figure 30**, the two most important accessories for respondents are chargers (92.9%) and phone cases (84.8%). These two accessories scored more than 4 points on a scale of 1 to 5 points, attributed by the respondents.

After analyzing the materials and characteristics when purchasing mobile phone accessories, the answers obtained are presented in **Figures 31 and 32**.

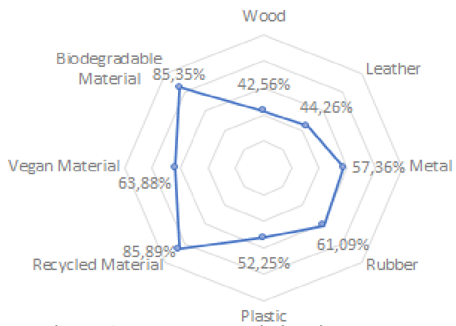


Figure 31: Importance (1 low importance and 5 high importance) of materials when buying a mobile phone accessory

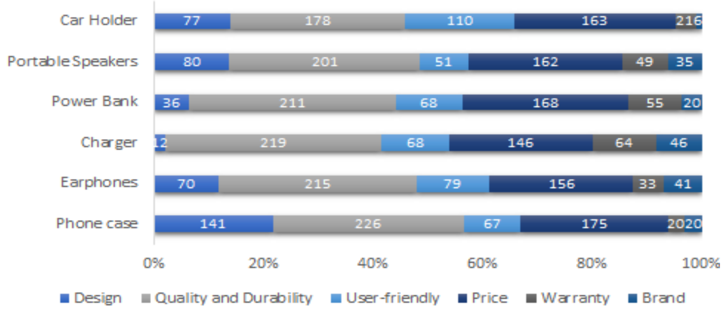


Figure 32: Most important characteristics when buying each mobile phone accessory

As observed in **Figure 31**, the majority of respondents consider recycled materials (85.9%) and biodegradable materials (85.4%) as the most important when purchasing accessories. It is possible to observe high importance attached to more sustainable materials compared to common materials such as plastic, rubber, or metal. Thus, it can be concluded that there is an increase in the preference for more sustainable accessories and, consequently, an increase in the respondents environmental awareness. In **Figure 32**, each line represents one mobile phone accessory, and each color represents a different feature. It is possible to conclude that the most important feature in all accessories is quality and durability followed by price. For phone cases and portable speakers, the third most important feature is design, and for the remaining accessories is to be user-friendly. Considering all the answers, it is possible to verify that the aesthetics of the product is not the primary characteristic considered in the purchase of accessories, but rather the quality and price of the product. With regard to other characteristics not mentioned, there were no relevant responses to consider.

Figures 33 and 34 explores the importance of habits that characterize an environmentally sustainable product and the consumers availability to contribute to sustainable attitudes concerning mobile phone accessories.

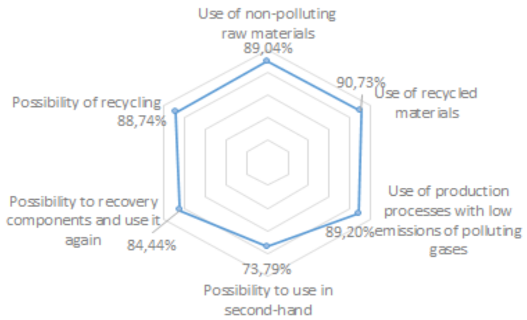


Figure 33: Importance of characteristics within an environmentally sustainable product

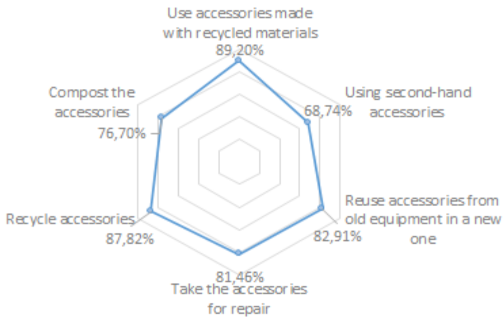


Figure 34: Consumers' willingness to contribute to sustainable attitudes

Most respondents give high importance to the six characteristics presented in **Figure 33**, being the most important the use of recycled materials (90.73%). Regarding the willingness to carry out the actions presented in **Figure 34**, the respondents are available for all of them, with the use of accessories made with recycled materials being the action that they are most willing to do (89.2%). It is concluded that there is a growing concern about the adoption of sustainability measures in the accessories of electronic products.

Finally, section 2 intended to understand consumer preferences regarding cable chargers. The results are represented in **Figures 35** and **36**.

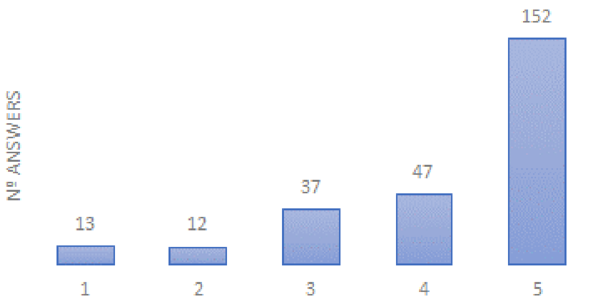


Figure 35: Importance (1 for low importance and 5 for high importance) of the chargers being sold together with mobile phones or computers

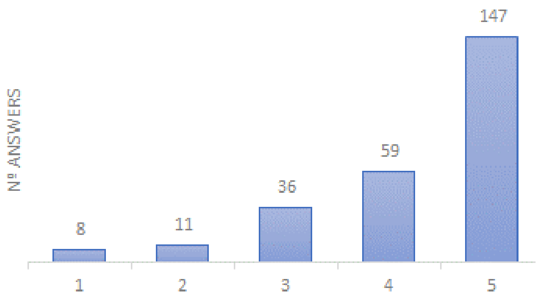


Figure 36: Importance (1 for low importance and 5 for high importance) of being able to repair the charger when it is damaged

In **Figure 35**, it is possible to observe that nearly 58% of the respondents (152) voted with 5 points regarding the importance of chargers sold together with mobile phones or computers. These results reveal the high importance that chargers have for consumers and that they are more valued, when sold together with the equipment. In **Figure 36**, it is possible to observe that for most respondents (147), the option of fixing a charger when it is damaged would be of high importance. The results demonstrate not only the sustainable conscience of the respondents, but also the value of this accessory in ones' life.

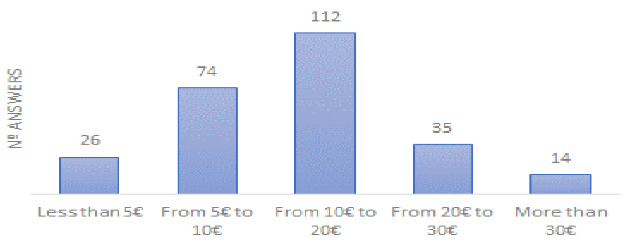


Figure 37: Price range that respondents are willing to pay for a charger sold separately in return for reducing the cost of the equipment

In **Figure 37**, it is possible to observe that the majority of consumers (112 → 42.9%) are willing to pay between 10-20 € for a charger sold separately in return for reducing the cost of the equipment and promoting circular economy. However, several respondents voted for the price range of 5-10 € (74) which, despite being a smaller number, represents 28.4% of the sample.

The results were separated into gender. The first consumer profile was determined considering the male gender and the age between 46 and 55 years old as it is the group with the most respondents. The remaining profile was defined based on the categories with the most answers in each of the survey questions. The second profile was defined regarding the female gender and the age between 18 and 22 years old. In this case, the accessories charger and phone case have similar importance so the two were considered. Data from the survey were used to obtain these two consumer profiles. However, these were from a convenience sample and may therefore be biased. Thus, the consumer profiles obtained are not unique, and there may be others suitable profiles for this market that are not considered here. However, these profiles are good examples of the consumer profiles that can be further identified. Concerning this situation, it would be necessary to carry out a detailed and extensive analysis to determine other profiles. The results allow the definition of the two consumer profiles presented below.

Consumer 1: Portuguese male aged between 46 and 55 years old, who changes the mobile phone only when there is no repair possible. He has high environmental awareness in terms of electronic equipment accessories, and an essential accessory is a charger. This person considers very important that this accessory can be repaired. He is available to use accessories made from recycled materials and to recycle accessories, valuing the production of chargers with recycled materials and their quality and durability. He would be available to purchase a charger sold separately from the equipment that promotes a circular economy for a value between 10€ and 20€ (13.54€).

Consumer 2: Portuguese female aged between 18 and 22 years old who changes the mobile phone only when there is no repair possible. She has high environmental awareness in terms of electronic equipment accessories, and the two significant accessories are a charger and a phone case. She is available to use accessories made from recycled materials and to recycle accessories, valuing the production of accessories with biodegradable and recycled materials and their quality and durability. Also, she considers important the design and the price of the phone case. This person considers very important that the charger can be repaired. She would be available to purchase a charger sold separately from the equipment that promotes a circular economy for a price between 10€ and 20€ (14.53€).

5.2. Ideation and Idea Selection

This phase consists on the elaboration of a brainstorming session and an MCDA project using the M-MACBETH software. In this section, the results obtained are presented along with the respective considerations and relevant information.

5.2.1. Brainstorming

The traditional brainstorming (TBS) sessions were developed by four people in the first one and three in the second, with clear notions and knowledge about the eco-design and eco-innovation concepts. In each session, every element shared its ideas verbally. Following Fleury et al. (2020) steps, it was defined first the main objective of the session and presented to all participants. Accordingly, the established goal for the brainstorming session was: to generate as many alternatives as possible to constitute a sustainable solution for mobile phone accessories. The alternatives should suggest the redesign of any type of accessory in a Eco-Design perspective. Any suggestions should promote the circular economy and the eco-design.

The session resulted in the following ideas:

- **I-** A versatile phone case that allows changing colours through applications.
- **II-** Phone case charged with solar energy increasing battery life.
- **III-** Produce phone case moulds with simpler designs and capable of being applied to different mobile phone models (universal).
- **IV-** Use vegetable inks or vegetable pigments instead of chemicals to colour phone cases.
- **V-** Produce a universal phone case through an expandable system to be compatible with any phone.
- **VI-** Produce charger cables with a malleable and sustainable material such as recycled material or cork or cotton or reused fabric or lianas.
- **VII-** Universal chargers. This type of accessory must have several inputs to meet the needs of consumers with mobile phones of different brands and who, therefore, have distinct charging inputs.
- **VIII-** Use existing surfaces such as lamps, cars, computers, or bedside tables as a base for wireless chargers.
- **IX-** Make charger cables with plastic from the oceans.
- **X-** Develop charger cables using textile products.
- **XI-** Manufacture charger cables using wires and fishing nets.

XII- Manufacture the top of the charger cables with recycled plastic from the oceans.

XIII- Produce a charger with multiple tops to be able to connect to different mobile phones.

XIV- Produce a charger converter with recycled plastic from the oceans.

XV- Produce a charger converter with a slot to allow opening and subsequent recycling.

XVI- Portable speakers produced with plastic from oceans with the front capable of being adapted by an application system with pigmentation in the injection.

XVII- Portable speaker with outer box and fixation system that allows to use the material where it is fixed as a sounding board.

XVIII- Power bank made with recycled plastic from the oceans with an opening system through a slot to allow opening and subsequent recycling.

XIX- Power bank charged with solar energy.

XX- Produce a headphones box charged with solar energy.

XXI- Produce an expandable car holder adaptable to any mobile phone, with a plastic reduction in the main and capable of replacing the sideburns.

Finally, these ideas were reformulated in order to join some suggestions made by the experts who participated in the brainstorming sessions. Thus, it was possible to conclude that the alternatives to be tested in the next stage will be:

[1] Universal phone case adaptable to different models of equipment using an extensible system. This system allows the same phone case to change its dimensions according to the dimensions of the equipment.

[2] Phone case that allows changing colours through a fitting system on the back.

[3] Charger cable with multiple tops to be able to connect to different mobile phones.

[4] Charger converter with a mechanism that allows to open the converter and subsequent recycling its external part.

[5] Portable speakers capable of being adapted through a fitting system at the front side.

[6] Expandable car holder adaptable to any mobile phone, with a plastic reduction in the main and capable of replacing the sideburns.

Having defined the alternatives in the next step, the solution to be developed will be chosen. This process will be done through the evaluation of the alternatives according to the M-MACBETH software and based on criteria to be defined.

5.2.2. Decision Analysis

The choice of the best solution for the core problems diagnosed, plays an important role in the development of the final product. Therefore, using M-MACBETH software it will be possible to determine the most promising solution according to a set of criteria.

To define the criteria, as well as the relationship between them, and classify the alternatives, a group of decision-makers was defined. This group consisted on an eco-design specialist and a sustainability specialist. The decision-makers based on the survey carried out to choose the criteria and their classification.

The first step is to create a value tree, represented in **Figure 38** which is an organised visual overview of the values that are of concern within the decision context. The nodes that are highlighted in red represent the criteria used to evaluate the alternatives in order to choose the most recommended solution.

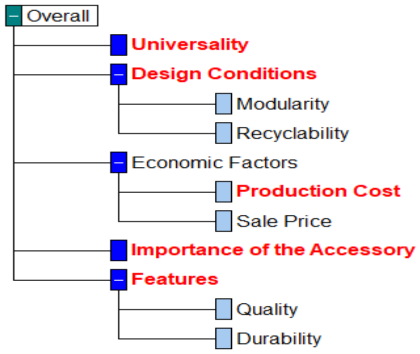
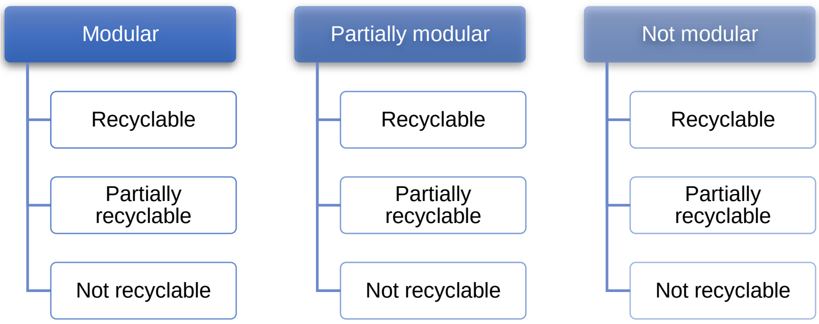


Figure 38:Value tree from M-MACBETH

The criteria chosen were:

- **Universality:** In order to develop a sustainable product, it must be as universal as possible not only to be purchased by more people but also to be adaptable to more equipment, resulting in a more durable product. The universality criterion was defined using "options + 2 references" which allows comparing the options with each other without having to group them into interval levels that would lead to judgment errors. The Good level (100 points) was considered by the decision-makers "an accessory that can be used on any mobile phone" and the Neutral level (0 points) "an exclusive accessory for electronic equipment". Not associating a descriptor of performance to a criterion could be a risk because it does not consider all possible combinations and aspects.
- **Design Conditions:** Due to the problems found in the problem tree, one of the core problems is the non-modularity of the accessories. Moreover, the product must be more sustainable based on eco-design and circular economy and must be recyclable. This criterion classifies through qualitative levels each alternative using the combination of these two characteristics. This performance descriptor results in nine levels of performance:
  The upper reference was considered "Modular and recyclable" and the lower reference "Non-modular and non-recyclable".



- **Production Cost:** Since the price was considered the second most important feature when purchasing an accessory by the survey respondents, the production costs must be as low as possible to guarantee the appropriate profit, and a sale price, which meets customer expectations. Thus, the production cost criterion is defined by six qualitative performance levels determined in conversation with a specialist producer. Level 1 includes costs between 0.20€ and 0.40€ and represents the upper reference. Level 2 corresponds to costs between 0.41€ and 0.60€, level 3 between 0.61€ and 0.80€, level 4 between 0.81€ and 1€, and level 5 between 1.01€ and 1.20€. Finally, level 6 includes costs above 1.20€ and represents the lowest reference.
- **Importance of the accessory:** From the survey, it was possible to determine the most important accessories for the respondents. Regarding the results and the decision-makers opinion, the larger the importance of an accessory, the higher its consumption. This criterion is a quantitative measure of the importance of an accessory will have. The upper reference level (Good) choosen was 100% of importance with 100 points, and the lower (Neutral) reference level was 30% of importance with 0 points.
- **Features:** For most respondents, quality and durability was the most important feature when purchasing all the accessories. For these two characteristics, it is difficult to define the performance levels. Therefore, using the "options + 2 references" we can generalize and compare accessories without the need to define performance levels for each one. The Good level (100 points) was defined as an accessory "used in different equipment for more than three years" and the Neutral level (0 points) an accessory "used with a few equipments and lasting less than one year". This criterion shares the same risks - not considering all possible combinations and aspects - as the ones described in the "Universality" criterion, since the descriptor of performance is not operationalized.

Having all the criteria defined, it is necessary to characterize the options. The options have different characteristics when compared to each other, even if they are very similar. The difference between them is what makes it possible to classify them individually and come up with a single solution. Thus, **Table 22** represents the performance profile of the options in each criteria classified by qualitative and quantitative measures.

Table 22: Performance profile of the options

	Design Conditions	**Production Cost**	**Importance of the Accessory**
Universal phone case	Not modular and recyclable	1,05€	80%
Phone case colours	Partially modular and recyclable	0,50€	80%
Charger cable	Partially modular and partially recyclable	0,35€	90%
Charger converter	Modular and partially recyclable	3€	90%
Portable speaker	Partially modular and recyclable	3,75€	50%
Car holder	Partially modular and partially recyclable	1€	60%

Regarding universality, the universal phone case is the one that can be applied to a higher number of devices, and, therefore, it was considered the most universal accessory. In contrast, the car holder is an accessory that depends on the dimensions of the equipment that the person have. Furthermore, not all cars have the same system to fix this accessory, so this was considered the less universal one, by the decision maker. From the remaining options, the cable charger, the charger converter, and the portable speaker are accessories that can be adapted to different equipments so they were considered in the middle of the first two mentioned. The phone case colors were considered by the decision maker, more universal than the car holder, but less universal than the remaining accessories. Concerning the features, quality and durability, the charger converter is the accessory that is appliable to more equipment and that has higher durability. The car holder is the one that has a shorter use time because in the majority its use is excessive. The remaining options were ordered by the decision maker from the best features to the worst, respectively, portable speaker, universal phone case, cable charger, and phone case colors.

Therefore, for each criterion, the options were evaluated in pairs, using the qualitative semantic scale of M-MACBETH. This scale allows the process to be carried out without losing rigor and scientific consistency and has six levels: very weak, weak, moderate, strong, very strong, and extreme. After the qualitative value judgments, M-MACBETH creates a numerical scale from the set of qualitative judgments found within the matrix of judgments.

Finally, it was necessary to assign weights to the criteria. A semantic judgment on fictitious options and fixed reference levels in each of the criteria has been applied. Thus, it is possible to compare the level of attractiveness between the oscillations of each criterion. After entering these judgments, the software scores each criterion based on the data and calculates the weight scale. **Figure 39** represents the final histogram obtained for the criteria weight.

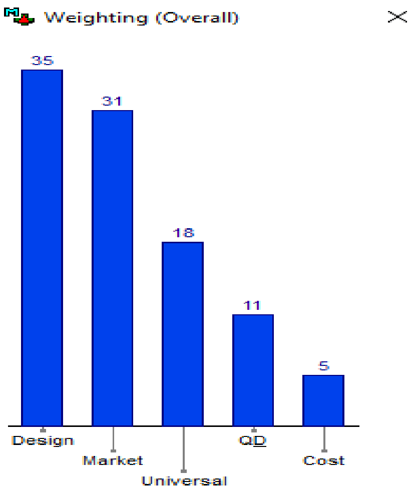


Figure 39: Weighting Judgment's Histogram

This weights scale was built from the weighing matrix of judgements. All the weights were rounded to the unit. Having in consideration all the data provided and inputted in the matrix of judgements, the MACBETH attributed these weights to each criterion.

The global attractiveness value of each option is displayed in **Figure 40**.

Options	Overall	Universal	Design	Cost	Market	QD
Good	100.00	100.00	100.00	100.00	100.00	100.00
Charger converter	82.36	78.36	90.32	0.00	86.67	88.89
Charger cable	71.73	81.72	58.06	100.00	86.67	43.88
Phone case colours	60.11	32.35	74.19	92.02	66.67	27.78
Universal phone case	53.57	96.85	20.97	24.36	66.67	62.82
Portable speaker	51.27	51.89	74.19	0.00	26.67	69.96
Car holder	41.94	25.84	58.06	54.62	40.00	16.67
Neutral	0.00	0.00	0.00	0.00	0.00	0.00
Weights :		0.1800	0.3500	0.0500	0.3100	0.1100

Figure 40: Table of scores

There are eight options represented, of which six are real and two fictitious, the latter ones are [good] and [neutral] respectively representing a global benchmark with criteria performance equal to their superior benchmark and a global benchmark with criteria performance equal to their respective criteria inferior references. The table of scores shows the scores of each option in each criterion, as well as the overall value of each option and criterion weights.

Therefore, the order of preference of the options are:

- Charger converter with 82.36 points;
- Charger cable with 71.73 points;
- Phone case colours with 60.11 points;
- Universal phone case with 53.57 points;
- Portable speaker with 51.27 points;
- Car holder with 41.94 points.

These values were calculated with the partial scores of each option combined with the assigned weights. Changing the values assigned to the criteria weights may lead to a change in the order of preference of the options. Thus, sensitivity analysis was performed to some criteria. In all criteria, except for the "Production Cost" criterion, it was verified that there are no significant changes when changing the weight of the criteria. In these criteria, it was necessary to increase their weight on a high scale for the preferred option to be changed.

The sensitivity analysis performed to the "Production Cost" criterion can be observed in **Figure 41.**

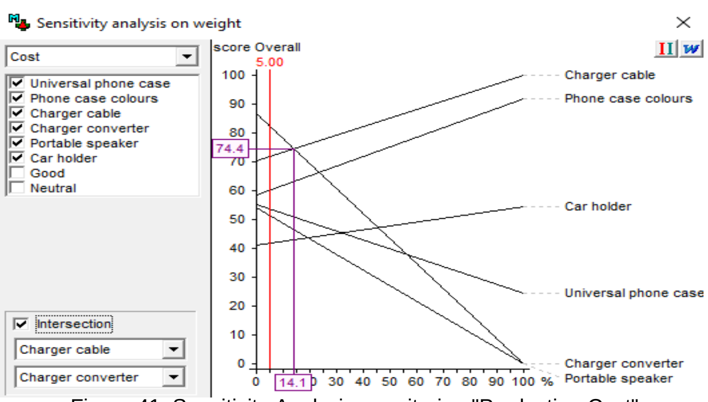


Figure 41: Sensitivity Analysis on criterion "Production Cost"

The red line represents the current weight of the criterion (5%). The preferred option change occurs when the weight of this criterion is 14.1%. As it is possible to see it is necessary only a change of 9.1 percentage points for the preferred option stop being the charger converter and becomes the cable charger. This value is calculated by the difference between the weight at which that change occurs (14.1%) and the current weight of the criterion (5%).

This change is unlikely to occur as it is a high value. Therefore, it is a not significant change. The results of the sensitivity analysis allowed to classify the results as robust, since the modification of the criteria weights have no effect or have a very unlikely effect on the preferred global option.

After obtaining the overall value of each option it is possible to conclude that Charger converter, charger cable and phone case colours are the option with the highest score, and thus the three that are recommended.

Considering the analysis carried out, in the following section the materials of three products will be analyzed - charger converter, cable charger, and phone case colors - and their prototypes will be developed. This process will make it possible to study the feasibility of producing the three products sustainably, promoting circular economy and eco-design.

5.3. Prototyping and Sketching

This phase consists of developing an LCA method, a 3D prototype, and a physical prototype. The LCA intends to define the materials that will be used in the production of the charger converter, the charger cable and the phone case colours. Then, to ensure the dimensions and the physiognomy of the products a 3D prototype was developed using a CAD system. Moreover, the virtual representation allows the creation of a physical prototype. The latter one allows the product to be presented to potential users.

5.3.1. LCA

Having into consideration the ideas from the brainstorming session, and its evaluation through the M-MACBETH software, it is possible to verify that for the same solution different materials can be used. The sustainability of the solution to be developed is crucial. Therefore, it is necessary to evaluate the product's life cycle and produce it from the best materials and processes. These must also promote a circular economy and eco-design. An LCA was performed for the materials that can be used in charger converter, charger cable, and phone case colors. This analysis was executed using the SimaPro software.

This subsection is divided into these four steps – Objective and scope definitions, Lifecycle Inventory Analysis (LCI), Lifecycle Impact assessment (LCIA) and LCA Interpretation. This analysis will allow obtaining a sustainability assessment of each material along with the respective single score to provide a fair basis for comparison.

Step 1 – Objective and scope definition

The goal of this analysis is to compare and select the materials that can be used in the development of the final products. These data should support decision-making and support the development of the following sections. The scope of this study is to design a product made from sustainable materials promoting circular economy and eco-design. The geographical boundary is Europe since the product will be manufactured in Portugal, and the materials to be used must be collected from European suppliers to reduce transport impacts. The temporal boundary is subject to the useful life of the product, which depends on the use of each consumer, but which must be greater than three years because it is the average time between switching a mobile phone. The physical boundary is Gate-to-Gate, which only includes the product manufacture impacts. Therefore, the materials extraction processes were not considered. Only the production of products was considered to allow a fairer comparison between the different materials and to simplify the analysis, since this is a preliminary selection. The information extracted from the software includes the impacts of each product and not of each component, making the analysis objective and efficient in terms of time. Regarding the charger converter and the phone case colors, the impacts between the use of thermoplastic (polypropylene) and recycled plastic from oceans (polypropylene) will be analyzed. In the charger cable, the three materials to be compared are usual thermoplastic (polypropylene), recycled plastic from oceans (polypropylene), and nylon from recycled fishing nets. For any of the products the quantities of materials to be used are the same. In addition, the densities of these materials are similar since the types of plastics used will be equivalent, and most fishing nets are made from some types of plastics (Sicor, 2021). Therefore, the same amount of material will be considered for the analysis and the functional unit to be used will be an arbitrary mass value. The defined functional unit was 1 kg of material.

Step 2 – Lifecycle Inventory Analysis (LCI)

As previously mentioned, the software to be used is the SimaPro, and the corresponding database used was Ecoinvent Database. Having already defined the functional unit, **Table 23** displays the materials used for the analysis along with its SimaPro references.

Table 23: Materials and correspondent SimaPro references

Material	Reference
Thermoplastic (PP)	Polypropylene, granulate {RER}| production | Cut-off, U
Recycled Thermoplastic (PP)	Polypropylene {RER} | maritime plastic, collected, sorted, and reclaimed | Cut-off, U
Nylon	Nylon 6-6 {RER}| production | Cut-off, U

The most used plastic in mobile phone accessories production is PP, so this was the thermoplastic chosen to analyze. In addition, the term “production” includes inputs to produce with the material PP, i.e., the activity of transforming the material into a product (the physical boundary is gate-to-gate). The term "Cut-off" considers the impacts of product manufacture allocated to the first user of the material, i.e., only the environmental impacts of the production process of a product with PP are considered. For these processes, if the material is recycled, the impacts of the initial production are not considered, the impacts of the recycling processes are in this case considered. Finally, the term “RER” represents Europe.

Regarding the recycled thermoplastic (PP) the material was not available in the Ecoinvent database. Therefore, to make the comparison, the data were obtained by adapting the "Life Cycle Impacts for Postconsumer Recycled Resins: PET, HDPE, and PP" report by Franklin Associates (Franklin Associates, 2018). This report provides the inputs in each of the phases considered: collection, classification, and recycling. Polypropylene is collected from drop-off programs and residential curbside, then classified and finally recycled. The impacts considered come from the transport to collect and wash the PP and the electricity used in recycling. However, the recycled PP to be considered must come from the oceans. In this way, the three largest ports in Europe were considered – Rotterdam, Antwerp, and Hamburg (Lotus containers, 2020) – and their average distance to Denmark (where the collection was considered). This distance was used in the transportation from the drop-off programs. The remaining processes were modelled using the previous modelled processes.

Regarding the Recycled Nylon from fishing nets, there is no reference to this material in SimaPro. Furthermore, after extensive research, it was not possible to find any LCA study that reveals the environmental impacts of using recycled Nylon in the production process. Finally, companies were found that use Recycled Nylon in their production and that have LCA studies for this use. However, these companies do not share these studies and results externally. Thus, the Recycled Nylon environmental impacts were estimated. To estimate the value of the Single Score of Recycled Nylon it was assumed that the difference between this value and the value of the Single Score of virgin Nylon would be the average of the differences between the value of the Single Score of virgin and recycled PP, PET, and HDPE. Therefore, the value of the Single Score of the Recycled PP is 56% smaller than the value of the Single Score of the PP. Furthermore, the value of the Single Score of Recycled PET is 38% smaller than the value of the Single Score of PET. Finally, the value of the Single Score of Recycled HDPE is 40% smaller than the value of the Single Score of HDPE. The results of the analyzes carried out in SimaPro, and the representative graphs for the mentioned plastics can be found in Annex B. Thus, it was estimated that the difference between the Single Score of Recycled Nylon and the Single Score of Nylon, was the average of the percentages obtained. Thus, the difference between virgin Nylon and recycled Nylon is given by (56+38+40)/3 which means 45%. From this percentage, it will be assumed that the value of the Single Score of Recycled Nylon is 45% lower than the value of the Single Score of virgin Nylon.

In this way, the materials to be compared are defined. According to Carvalho et al. (2014), the ReCiPe method has the most desired characteristics, including midpoint and endpoint analysis. Therefore, this was the method used to conduct the analysis made.

Step 3 – Lifecycle Impact Assessment (LCIA)

In this step, the environmental impacts of using each material were calculated. Thus, it was possible to choose the materials that will be used to produce each of the three products. The results presented are in characterized values. The characterized values provide the exact values for the impact of the material in the different categories and have less uncertainty. However, these values cannot be compared, as they are not in the same units, they only highlight the performance of the different materials with their actual emission values. The normalized values allow a basis of comparison and allow to obtain a Single Score for each material. It is important to note that the normalized values reveal a higher degree of uncertainty concerning the characterized values. Since the analysis performed for Recycled Nylon was different, the impacts for this material will only be explored in terms of Single Score. **Table 24** shows the characterized midpoint values (focus on unique environmental problems) for PP and recycled PP in the most relevant categories (obtained from the SimaPro software).

Table 24: Midpoint comparison between 1kg of Polypropylene, Recycled Polypropylene

Impact Category	Polypropylene, granulate {RER}| production | Cut-off, U	Polypropylene {RER} | maritime plastic, collected, sorted and reclaimed | Cut-off, U
Global warming	1,911201751 kg CO2 eq	0,926133088 kg CO2 eq
Stratospheric ozone depletion	1,28404E-07 kg CFC11 eq	4,17081E-07 kg CFC11 eq
Ionizing radiation	0,005995725 kBq Co-60 eq	0,009238449 kBq Co-60 eq
Ozone formation, Human health	0,003156285 kg NOx eq	0,000942264 kg NOx eq
Fine particulate matter formation	0,001391192 kg PM2.5 eq	0,001253595 kg PM2.5 eq
Ozone formation, Terrestrial ecosystems	0,003450775 kg NOx eq	0,000970398 kg NOx eq
Terrestrial acidification	0,004102719 kg SO2 eq	0,00128027 kg SO2 eq
Freshwater eutrophication	2,04669E-05 kg P eq	6,35255E-05 kg P eq
Marine eutrophication	6,92557E-06 kg N eq	0,000114323 kg N eq
Terrestrial ecotoxicity	0,190104931 kg 1,4-DCB	4,820650233 kg 1,4-DCB
Freshwater ecotoxicity	0,000487248 kg 1,4-DCB	0,001887223 kg 1,4-DCB
Marine ecotoxicity	0,000768065 kg 1,4-DCB	0,004658555 kg 1,4-DCB
Human carcinogenic toxicity	0,005247544 kg 1,4-DCB	0,004278816 kg 1,4-DCB
Human non-carcinogenic toxicity	0,04925053 kg 1,4-DCB	0,134947694 kg 1,4-DCB
Land use	0,006129545 m2a crop eq	0,011978997 m2a crop eq
Mineral resource scarcity	0,001169194 kg Cu eq	0,000154918 kg Cu eq
Fossil resource scarcity	1,594787182 kg oil eq	0,19249791 kg oil eq
Water consumption	0,019962972 m3	0,00345092 m3

Since the values presented are the midpoint characterization, it cannot be concluded which is the best material. Although, it is possible to compare the values within the same category. The values shown in green correspond to the smallest impact in each category.

As observed in **Table 24**, recycled polypropylene is better in most categories. However, this material has environmental damage in eight categories compared with polypropylene. For instance, in terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, human non-carcinogenic toxicity, and land use, polypropylene performs better than recycled polypropylene.

In order to obtain a comparison between the materials, it is important to present the Single scores. This value allows comparing the materials since the units of the impacts are the same. Also, this analysis decreases the trade-off of the previous results. In this analysis, it is already possible to include the impacts calculated for Recycled Nylon. From the study presented in Annex B, it was possible to conclude that the average percentage of impact difference between plastic material and its recycled one was 45%. The Single Score obtained in the SimaPro software for virgin Nylon was 248.9. Thus, the calculated value for the Single Score of Recycled Nylon is depicted in **Figure 42**, along with the Single Score obtained for Recycled PP and PP.

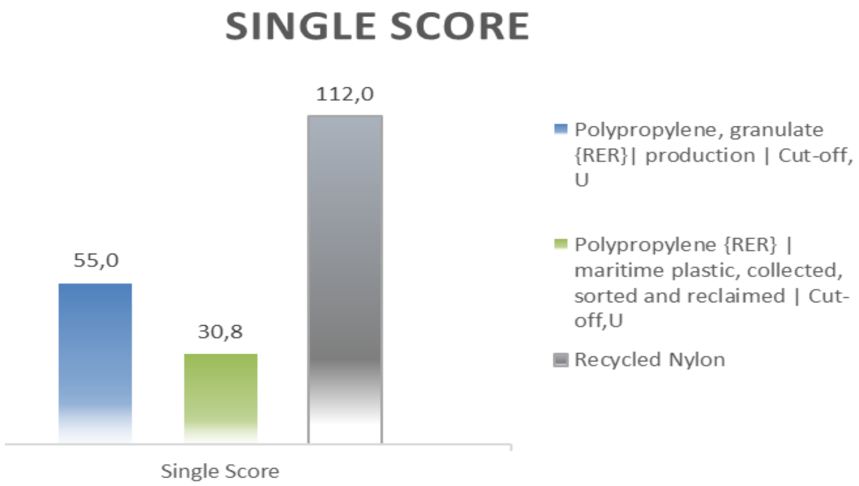


Figure 42: Single Score values for PP, Recycled PP and Recycled Nylon

Single score provide a valuable comparison basis for selecting one material. Regarding these, Recycled PP is the best material with a Single score of less than half the amount of Recycled Nylon single score. Thus, it is possible to conclude that the material that has a less environmental impact is Recycled PP, followed by PP, and finally Recycled Nylon.

Step 4 – LCA Interpretation

In this subsection the last step of the LCA analysis – Interpretation Phase – is included, to complement the conclusions reached from the analysis. Before highlighting the main conclusions of the previous analysis, it is important to mention the two main limitations that can compromise the obtained results. Firstly, due to the lack of Recycled Nylon in the database, it was necessary to obtain data for this material from an approximation of the Single Score difference between some plastics and their recycled versions existing in the program. These data could have been different if an LCA study had been obtained for Recycled Nylon, specifically, the one from recycled fishing nets. To overcome this limitation, it would be necessary to insert Recycled Nylon into the software, which means that all life cycle activities, from the acquisition of fishing nets to the use of Nylon, would have to be mapped and the impacts of each activity would need to be calculated. Secondly, the same density was considered for all materials, which may result in different values for the impact categories. This would be overcome by measuring the mass of the same final product with different materials. Despite these limitations, with the results obtained it is possible to reach a conclusion about the materials.

For the charger converter and phone case colors, either PP or recycled PP could be used. In this case, the most sustainable material is recycled PP. This material must be imported and will have a cost associated with that trip. However, its use promotes the reduction of plastics in the oceans, contributing to a more sustainable and less polluted environment. For the charger cable, the three materials studied could be used. The cable ends could be made from recycled PP or PP. In this case, the conclusion will be the same as for the previous products, Recycled PP should be used as it is more sustainable. For the cable component PP, Recycled PP, or Recycled Nylon could be used. From the analysis made, it is possible to conclude that recycled PP should be used as it is more sustainable than other materials. In short, for all three products, Recycled PP should be used.

Once the analysis and selection of materials are completed products can be materialized and the prototypes can be created with the selected material.

5.3.2. Modelling CAD

In view to present a physical product to potential users, a 3D prototype was developed for each of the three selected products. The virtual design allows idealizing the appearance of products, playing a crucial role in the conceptualization process. To develop the virtual design On Shape software was used, which provided 3D modelling tools for design. **Figure 43** represents the design of the charger converter and its components.

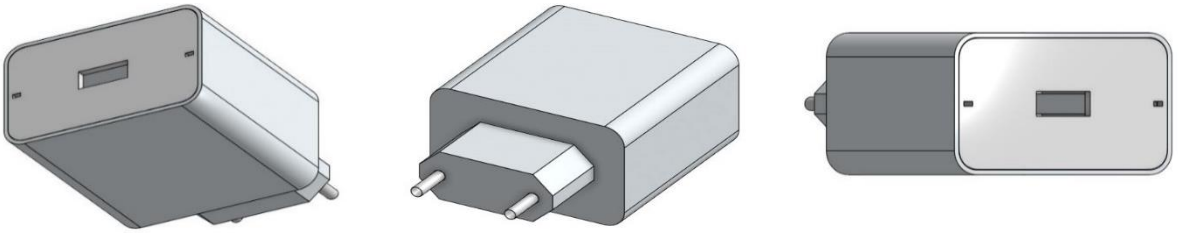


Figure 43: Charger Converter 3D Prototype

The dimensions to develop the charger converter prototype were based on an existent Huawei charger (see Annex C) and considering a fast charger that most of the times has higher dimensions. From the physiognomy and dimensions presented, adaptations were made so that it was possible to obtain a charger converter capable of being opened and recycled, removing the electronics from its interior. In this way, it was possible to obtain a modular charger converter that increases the circularity of the product, facilitating the process of disassembly and recycling of individual parts. Having the components, it was possible to perform a representation of the final design by assigning the materials and their colors determined in the previous step.

Regarding the charger cable, a virtual prototype was also created using the same software. The dimensions considered were determined from an existent cable (Annex D). In this case, the product is composed of one part, which is the product. In addition, the top component has been adapted for three types of mobile phone charging inputs. For this product, the chosen material was Recycled PP. Being plastic-type it is possible to make pigmentation in the injection and therefore the color obtained for this product may change. **Figure 44** represents the virtual prototype obtained.

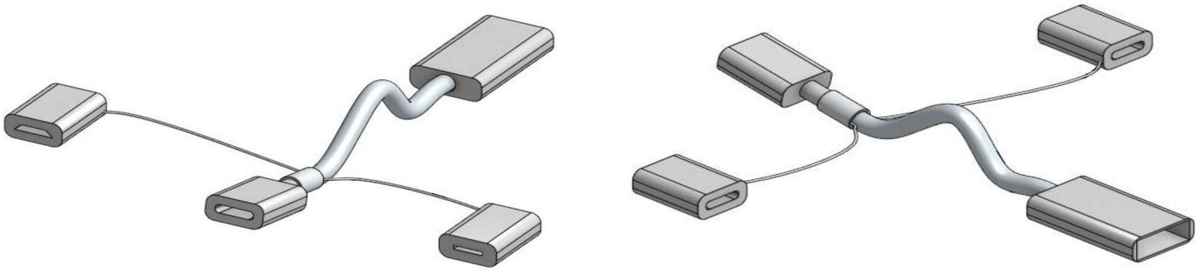


Figure 44: Cable Charger 3D Prototype

Finally, for the phone case colors, a 3D prototype was created using an existing phone case and its dimensions (Annex E). For this product, the main objective was to create the main part that would be the same for any mobile phone model and that could have different colors or images, thus making it possible to customize the phone case. For each equipment, a structure of one color will be manufactured, and a central part of different colors will be adapted. For this product, the material chosen was recycled PP. **Figure 45** represents the virtual prototype obtained. For this example, the chosen color of the central part was red.

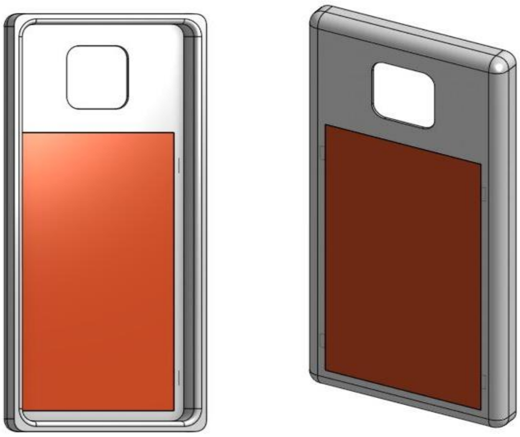


Figure 45: Phone case colors 3D Prototype

Having finished the virtual prototypes, it was possible to produce the physical prototypes.

5.3.3. Physical Prototype

To develop the physical prototypes, 3D printing of the accessories was used. Taking into account the virtual prototypes previously made, in a conversation with an expert it was possible to conclude that the only prototype that could be entirely printed in 3D, was the charger converter. **Figure 46** represents the photographs of the final physical prototype.

Figure 46: Charger Converter physical prototype

Concerning the cable charger, it was concluded that it was only possible to print the new plug-in parts, and these would be adapted to an existing cable charger. The photographs of the final prototype are illustrated in **Figure 47**.

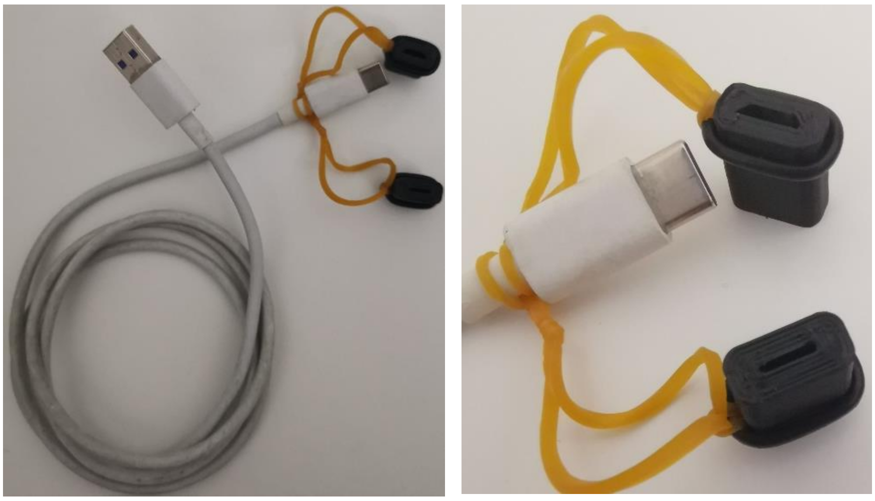


Figure 47: Cable Charger physical prototype

Regarding the phone case colors, it was found that 3D printing was not possible. Therefore, the final prototype would be the virtual one.

Having developed the physical prototypes, a focus group was created to evaluate them. The main insights obtained are presented next.

5.4. Testing and Refining

This phase consists of the development of a focus group to validate the ideas and the products through the physical prototypes created. In this section, the results obtained are presented along with the respective considerations and relevant information.

5.4.1. Focus Group

A focus group session was performed, each with a group of three people. People were selected based on the answers obtained in the questionnaire carried out. To have consistency between the answers provided in the survey and the insights from the focus group, the people chosen needed to be women aged between 18 and 22 years and men aged between 46 and 55 years. The group was made up of potential customers who met the age requirement mentioned.

The activity was divided into three different parts. The first part consisted of the presentation of the three prototypes, two physical and one virtual, along with the introduction of the scope, materials, and objectives of the project. In this part, the rules and structure of the session were also presented. In the second part, the participants received the prototypes to touch and evaluate by experiencing the products for a while. Finally, in the third part, some questions were asked about the three products, and feedback from the participants was obtained.

The script used in each session, as well as the questions asked, and a summary of the responses/feedback are presented below.

"Good afternoon everyone. Thank you for your presence and collaboration. This focus group is part of my master's dissertation entitled "Circular Economy in Electronic Equipment Accessories" and its main objective is to obtain feedback from potential users. In this session, I will present the three prototypes developed: a charger converter, a charger cable, and a mobile phone case. I must mention that all accessories developed are sustainable and were designed based on the principles of eco-design and circular economy. Therefore, the prototypes presented here today are merely figurative of what the final products will be. These physical prototypes were obtained through 3D printing. However, the final products will be manufactured from recycled plastic from the oceans. In this session, I will pass the prototypes to your hands so you can evaluate the experience you have with the products, and then I will ask some questions."

- Questions:
  1. What are the first impressions you get when viewing each of the three products?

Most of the potential consumers assumed they liked the three products highlighting their lightness. In addition, the environmental benefits they present both in terms of the products used and the fact that they are recyclable are also characteristics that are pleasing to consumers. However, there were some doubts regarding the design presented by the phone case.

2. In the case of the two charger components, what was the first thing you thought about when holding them?

Regarding the two components of the charger, the opinions of potential consumers were unanimous. Most reveal, once again, that it is advantageous that the charger converter can be recycled and that it has a low weight. In the case of the charger cable, consumers were particularly pleased with the length of the cable, and with the fact that they could use the same product for different equipment or even be able to keep it even when changing mobile phone brand. However, some consumers considered the design unattractive and questioned the resistance of the products to continuous use.

3. For the mobile phone case, what was your first impression when you saw the prototype?

In the case of the phone case, consumers expressed doubts about the strength and malleability of the product, as they cannot touch it since it is a virtual prototype. However, they found the idea original and were pleased that it was customizable.

4. What are the positive points you identify in each of the products that would make you buy them?

Being recyclable, manufactured from plastic from the oceans, and able to be repaired, are the most outstanding features for the charger converter that would lead consumers to buy this product. Concerning the charger cable, the main positive point was the possibility of adopting the same product for different types of equipment through its three inputs. Finally, for the phone case, the only outstanding advantage was its originality.

5. What would you improve on each of the three products?

Several changes to the final products, were suggested. Regarding the charger converter, potential consumers suggested reducing its size as they considered that even being a fast charger it would be too big. In addition, the design itself should be changed to something more futuristic and attracting consumer attention from among all the other options on the market. Finally, it was even suggested that the same charger converter had more than one USB connection to allow simultaneous charging. Concerning the charger cable, opinions were quite divergent between a longer cable or a shorter cable, taking into account the routine of each consumer. Finally, regarding the phone case, the change of the design was common to all respondents. The design considered did not prove to be very appealing to potential consumers. They suggested several colors for the base part, the application of a non-slip film, or a design that considers taking off the camera part as it occurs in the customizable part. In addition, some respondents only consider phone cases as an element of protection.

6. Considering the design and materials that would be used in the final product, if these products were for sale in the market would you buy them?

Regarding the charger converter and the charger cable, the purchase opinion was unanimous. However, for the phone case, there were many doubts. The decision would be taken considering the price and the change to a more appealing design to stand out among the other phone cases on sale in the market. It should also be noted that most consumers preferred a separate purchase of the charger converter and the charger cable.

7. What price would you be willing to pay for each of these products?

For the values presented by potential consumers, the arithmetic average was calculated to obtain an acceptable value for the sale of the products. Regarding the Charger Converter, consumers would be willing to pay an average of 15,75€. Concerning the Charger Cable, consumers were willing to pay an average of 16,50€. If these two accessories were sold together, consumers revealed that they would be willing to pay 26,40€. Regarding the Phone Case, consumers would be willing to pay 13,00€ and for the customizable part a maximum of 10,00€.

8. If a QR Code containing information on the relationship of the materials used and the environment was displayed on the product packaging, would your decision be changed?

According to potential consumers, this feature would increase the probability of purchasing these accessories. However, they would not change the price they would be willing to pay.

9. If it were possible to obtain a coupon to use when purchasing other accessories of the same type when delivering used accessories, would your decision be changed?

Overall, all respondents agreed that this option would increase the chance of purchasing these accessories. However, the accessories could have a higher price as long as the final price that they should pay did not exceed the one previously mentioned when using the discount.

10. Do you have anything else you would like to add?

Furthermore, it was added that the Charger Converter and Charger Cable could have different colors. Moreover, the change of the design of the Phone Case to a more attractive one was reinforced.

Regarding the answers obtained from the focus group, it is essential to improve the main points addressed. First, the weight of the Charger Converter. Second, the design and colors of the Charger Converter and the Charger Cable. Third, the design of the Phone Case. Thus, most recommendations focus on product design. Although the survey revealed that the most important characteristics for users would be price, quality, and durability, the focus group sessions allowed concluding that design is also an important factor and that it should be used to highlight these products in comparison with the remaining ones on the market. The answers obtained also allowed to conclude that the sustainability of the products is not enough to make them preferable to others.

5.5. Implementing

This phase consists of the elaboration of the business model of the products to be manufactured. In this section, the results obtained for the circular business model canvas of accessories will be presented. Also, the relevant considerations for each building block will be explained.

5.5.1. Business Model

The Circular Business Model Canvas was the model chosen to create the business model of the three electronic equipment accessories developed. The final business model is represented in **Figure 48**, and the detailed information is presented below.

Key Partnerships	Key Activities	Value Proposition	Customer Relationships	Customer Segments
Ocean plastic sellers. Injection factory.	Collection. Production. Investigation and Development. Marketing. Distribution. **Key Resources** Recycled plastic from the oceans. Production facilities. Factory workers. Electronic components. Specialist in environmental sustainability.	Mobile phone accessories whose design promotes the total recycling or reuse of materials used for others manufacturing processes and sustainably produced from recycled plastic from the oceans.	National production. Incentives for returning used accessories. **Channels** Online website. Sustainable and reconditioned items stores. **Take-Back Systems** Accessory collection locations. Delivery scheduled online. Separation of plastic and electronic components. Circular production.	Male consumers of mobile phones and their accessories, specifically aged between 46 and 55 years, and female consumers of mobile phones and their accessories, specifically aged between 18 and 22, both with high environmental awareness.

Cost Structure		Revenue Streams
Purchase of recycled PP.	Workers.	Sale of sustainable mobile phone accessories.
Production.	Distribution.	

Adoption Factors	
Sustainability training.	Regular assessment of materials and processes.
Environmentalist mindset.	Promotion of the circular economy.
Product design evaluation to promote eco-design.	Cost reduction by reusing materials.

Figure 48: Circular Business Model Canvas for Electronic Equipment Accessories

Key Partnerships: To obtain the raw materials to use in the sustainable accessories presented, it is necessary to establish a partnership with an ocean plastic supplier. This supplier must be European and must have high-quality plastic. Concerning the design, there is no partnership needed. Another partnership should be established with a factory for the production of accessories. This factory must use injection as a process and must be chosen nationally.

Key Activities: There are five activities inherent in the process of developing the mobile phone accessories created. The first is the collection of plastic from the oceans so that it can be sorted and treated. The collection of this plastic will take place in the biggest ports in Europe then it will be sorted and processed in Denmark. Finally, the recycled PP should reach Portugal. The second activity will be the production of accessories. The sustainable accessories will be produced, from recycled PP, at appropriate factories. The third activity includes investigation and development. This activity must include the product design that should be changed when more sustainable options exist and product labels that must be developed to contain relevant information for consumers about the benefits of new accessories and the harm of existing ones to the environment. A QR Code must also be developed that sends the consumer to a website where data is mentioned about the excessive waste generated by electronic equipment accessories, how it is possible to reduce this waste and how these new accessories contribute to this reduction. The fourth activity includes a marketing strategy that enables communication about the materials chosen and the processes adopted, promoting the purchase of accessories by more people. The last activity includes the distribution of both production materials and products that will be sold online or in stores.

Value Proposition: The accessories developed are based on the use of recycled materials, eco-design, and circular economy.

Customer Relationships: Although the materials come from other places in Europe, emphasis will be placed on national production. In addition, through the survey, it was possible to see that potential consumers value the possibility to repair the accessories, in particular the charger, and are available either to use accessories made from recycled materials or to recycle accessories. Therefore, it is important to establish incentives for consumers to return damaged or old accessories so they can be recycled. These incentives are given by awarding discount coupons to use when purchasing other accessories made from recycled materials. These coupons are obtained when returning old accessories. For each accessory delivered a 5% discount coupon is given. If the consumer subscribes to the virtual customer card, after 15 returned accessories, a 20% discount coupon is generated on the purchase of recycled accessories.

Customer Segments: Regarding the consumer profiles previously obtained, it is possible to define that the accessories produced are indicated for male consumers aged between 46 and 55 years, and female consumers aged between 18 and 22, both with high environmental awareness. However, the customer segments can be much more extensive and include other consumers. Since these profiles were obtained based on the results of the survey carried out, and this was obtained from a convenience sample, the results may be biased. Thus, the consumer profiles obtained are not unique, and there may be others suitable for this problem that were not considered. Concerning this situation, it would be necessary to carry out a detailed and extensive analysis to determine other customer segments.

Key Resources: Includes all the materials needed for accessories' production. The raw material to be used is recycled plastic from the oceans and that is why this resource is essential. Furthermore, for the products to be manufactured it is necessary to hire a factory and its workers for the manufacturing process to take place. Therefore, these two are key resources. With the market in constant change and evolution, the design needs to be continually updated to be appealing to consumers. However, this design must always allow the circularity of the products through their recycling and reuse, so they can be put back on the market and not end up in a landfill. For the circularity of the product to be viable, it is necessary to have an expert in environmental sustainability who ensures that new designs do not lead to increased impacts on the environment.

Channels: Initially, the products will be launched on the online market to reduce distribution costs and promote environmental sustainability. Then, the accessories should be sold in physical stores based on reconditioned and sustainable accessories and equipment sales.

Take-Back System: In this system, customers are encouraged to return damaged or old accessories. The incentives are given through coupons. These coupons will be given on delivery of used accessories and should be discounted when purchasing new accessories. Also, customers can have a discount of 5% on new accessories when delivering an old accessory or can subscribe a virtual customer card that gives a 20% of discount on a new accessory after they deliver 15 old accessories. The return of accessories will be made through the collection in specific locations whose delivery must be scheduled online. In these accessories, the electronic components must be separated from the plastic components. The first ones are sent to landfills or repaired, and the second ones should be used again in other accessories. Thus, there will be a circular production by recycling the outer plastic or by reusing repaired accessories.

Cost Structure: The costs considered refer not only to obtaining raw materials but also to the entire production and distribution process. There may be costs to obtain the plastic from the supplier chosen for the partnership. In addition, it is necessary to establish a partnership with a factory for production, and here, there will be costs both at the level of production and at the level of workers who will have to be paid. For production costs, an expert was interviewed who determined the production costs of a charger converter of 3€, for a cable charger between 0.20€ and 0.50€ and a phone case colors between 0.30€ and 0.70€. Finally, there will be distribution costs for the consumer's home when the purchase is made online and for stores when there are sales in physical stores.

Revenue Streams: Revenue is generated from the sale of the accessories produced. According to the survey prepared, the average price that consumers are willing to pay for a charger is 14€. According to the focus group, the consumers are willing to pay 15,75€ for a charger converter, 16,50€ for a cable charger, and 13,00€ for a phone case. Also, if the charger converter and the charger cable were sold together, consumers were willing to pay 26,40€ for it. In this way, considering only the production costs, it would be possible to obtain a profit of 12,00€ for a charger converter, 16,00€ for a cable charger, and 12,00€ for a phone case.

Adoption Factors: The human resources involved both at the manufacturing and sales level must have regular training in sustainability and have an environmental mindset. In this way, the processes developed all promote the circular economy and the reduction of environmental impacts. The company must evaluate, permanently, the materials, processes, and design to ensure they promote eco-design and the circular economy. By reusing plastic, there will be a reduction in the costs associated with these accessories production.

6. Conclusion

The world has reached a point where technology is developed at light speed, where new electronic equipment appears every day to satisfy the material needs of human beings. The new generations grow with a very high consumerist mindset and are responsible for the increased production of new technologies. This excessive production has a significant and irreversible environmental impact on our planet, jeopardizing the future generations that will inhabit it. For this reason, now, more than ever, it is extremely important to address the current situation on our planet. The excessive waste caused by mobile phones and their accessories is an urgent problem, which requires extra attention about their environmental impacts, not only because of the waste generated but also because of the amount of plastic used in their production.

In this dissertation, the mobile phone accessories market is studied, and a solution that allows addressing the excessive waste generated by these accessories is presented. This solution uses sustainable materials through the recycling of existing waste materials, namely, plastic from the oceans. Despite this being a pressing and current problem, very little is done to solve it. Thus, to support the development of the final solution, an exhaustive literature review, based on the UNLEASH global innovation program was prepared. The literature review showed that the circular economy is the ideal approach to reduce the waste of materials and close the cycle of over-extraction of these materials. Different authors have suggested distinct ways to incorporate circular economy into product development, being the most innovative approach the one that considers the design as the most responsible for the environmental impacts of a product. Therefore, it is necessary to consider the eco-design concept when developing a product. Although the literature base in this field is far from insufficient, many authors claim that there is still a scant level of implementation of eco-design in the mobile phone accessories industry. However, the benefits of implementing eco-design and the circular economy in product development are undeniable. These practices allow an increase in product usage time and the reduction of natural resources exploitation, bringing economic benefits to companies and the accessories industry.

The creation of the solutions was done based on a unique methodology created through a sequence of tools and frameworks explored in the literature review. The methods were chosen after establishing the advantages and disadvantages and evaluating those that best performed the desired role and fulfilled the main objective of this dissertation. The methodology has five stages, each one linked with the previous steps. Its application to the problem "excess waste generated by electronic equipment accessories" made it possible to obtain three final products - the charger converter, the charger cable, and a phone case - capable of being placed on the market and fully sustainable by promoting the circular economy and eco-design. Moreover, the created products allow addressing the causes founded through the realization of a problem tree. It was possible to verify that the consumers difficulty to find information, the unattractive design and low quality associated with recycled accessories by consumers, the harmful materials used in the production of accessories, and their non-modularity are the causes of excessive waste from electronic equipment accessories. The three products allow to address these causes. Firstly, they are modular, made from recycled materials, and capable of being recycled as well. In this context, the LCA analysis allows to concluded that recycled PP from the oceans would be the indicated material to be used. Secondly, they were developed based on eco-design to be sustainable and have an appealing design. Furthermore, they will be manufactured from recycled ocean plastic supplied by a supplier with high-quality plastic dispelling the idea that recycled accessories have low quality. Third, consumers will be provided with a QR Code on the product packaging with credible information about the excess waste caused by these accessories, and the comparison between the materials normally used and those that will be used in these products. Also, a comparison of the environmental sustainability of these products will be made available, as defined in the business model developed. This dissertation also allows understanding the opinion of potential consumers about the current situation in the mobile phone accessories market and their availability to buy sustainable accessories. It also allows for feedback from potential consumers on the features and design of the final products through a focus group. Finally, products are likely to be implemented in the market if the guidelines provided by the circular business model developed are followed.

At all stages of development, the circular economy strategies and eco-design practices were considered to ensure that the main objectives of the dissertation were met - to develop a solution for electronic product accessories made with sustainable materials, and that promotes a circular economy. The objective of this dissertation was reached, and all the necessary guidelines for future research were outlined. To make these three products marketable and to develop more mobile phone accessories in this perspective, more work needs to be done. This remaining work can be summarized.

First, it is necessary to consider important issues regarding the results obtained, referring to the consumer profile, focus group, and Customer Segments in the Business Model. The results were defined from the survey. Since the sample used for the survey was a convenience sample, the results may be biased. Therefore, it is recommended that, in future research, a broader questionnaire should be designed to obtain results representative of the world population. Second, it is necessary to develop the main pain points obtained in the focus group. The design of the charger converter must be studied, making possible to transform it into a more attractive product with smaller dimensions. This change would allow consumers to buy this accessory and save the amount of material used. In addition, a new design for the phone case should be considered not only to be more attractive but also to take a deeper look at the issue of personalization and the environmental impacts that may result from it. Finally, the addition of one more USB port on the charger converter or change the charger cable to allow simultaneous charging of different equipment should be studied. Third, it is necessary to develop partnerships with key entities so that it is possible to obtain quality plastic from the oceans, to procure a good manufacturer and also that the products are sold at a fair price.

Briefly, the use of available resources and the collaboration of different stakeholders is key to changing the consumption mindset of future generations. There is an increasing need to raise awareness on the environmental benefits of the sustainable use of resources, their reuse, and recycling. The realization of this project could represent an advance in the technological sector in terms of sustainable and circular growth, increasing business opportunities without jeopardizing the environment.

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Annexes

Annex A – Recycled PP LCA

In this annex, the analysis in endpoint categories of PP and Recycled PP is presented. Recycled PP did not exist in the SimaPro Ecoinvent database. For this reason, it was necessary to model this material. This modeling was made from the data present in the report "Life Cycle Impacts for Postconsumer Recycled Resins: PET, HDPE, and PP" (Franklin Associates, 2018). In this way, it was possible to compare the modeled Recycled PP and the existing PP in SimaPro's Ecoinvent database.

Figure 49 presents the weighting results for endpoint categories (environmental impact at three higher levels of aggregation.

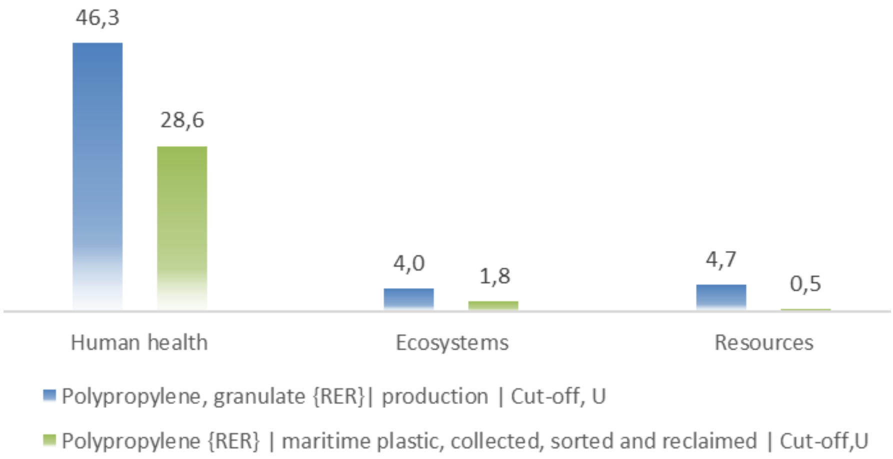

Figure 49: Weighting values for PP and Recycled PP in endpoint categories

The endpoint categories are Human Health, Ecosystems, and Resources. **Figure 49** illustrates that recycled polypropylene performs better in the three categories. Also, both materials appear to cause more damage in human health, which is also the category where there is a higher percentage impact difference between the two materials. Regarding the ecosystems and resources, polypropylene is more harmful than recycled polypropylene. However, the difference between the impacts of the two materials in these categories is not significant.

Endpoint categories can be aggregated in a single value, the Single Score. The analysis made for the PP was presented in section 5.3, and the results for the Single Score of PP and recycled PP are presented in **Figure 50**.

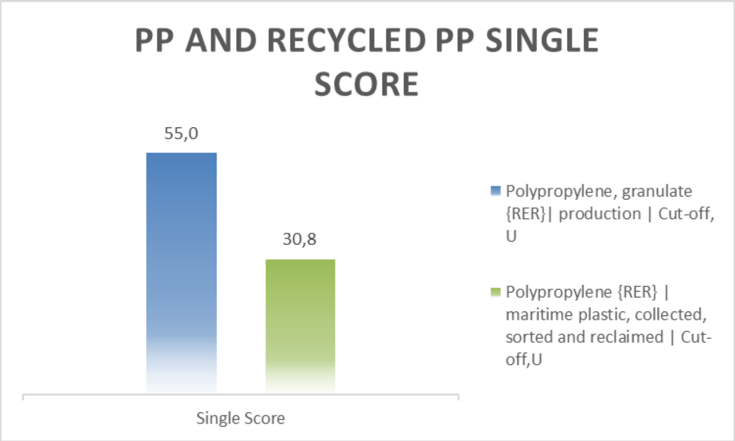

Figure 50: Single Score PP

Figure 50 illustrates that recycled PP has much lower environmental impacts than PP. Thus, it is possible to conclude that recycled PP is a more sustainable material, and therefore should be used.

Annex B – Study of the average percentage of impact difference between plastic material and recycled plastic material

In this annex, the results of the analysis performed to define the calculation of the Single Score of Recycled Nylon are presented. The main objective of this analysis is to obtain a comparison of the Single Score value of the three possible materials to be used in the final products, which are Recycled PP, PP, and Recycled Nylon. However, it was not possible to obtain the Single Score of Recycled Nylon because the material does not exist in SimaPro and no study fits the goal and scope of this dissertation. Thus, it was assumed that the difference between the Single Score of Nylon and Recycled Nylon is the same as the difference between the Single Score of plastics such as PP, PET, and HDPE and their recycled materials.

The analysis performed to calculate the Single Score of PP and Recycled PP was previously presented. Considering the results obtained, and illustrated in **Figure 50**, the difference in percentage between the two Single Score values is given by: (30.8/55.0)*100 and the result obtained was 56%.

To carry out this analysis, the comparison between the LCA of PET and Recycled PET, and between HDPE and Recycled HDPE was performed in the SimaPro software. The SimaPro references used are shown in **Table 25**.

Table 25: SimaPro references for PET and HDPE

Material	Reference
PET	Polyethylene terephthalate, granulate, amorphous {RER} | production | Cut-off, U
Recycled PET	Polyethylene terephthalate, granulate, bottle grade, recycled {RoW} | polyethylene terephthalate production, granulate, bottle grade, recycled | Cut-off, U
HDPE	Polyethylene, high density, granulate {RoW} | production | Cut-off, U
Recycled HDPE	Polyethylene, high density, granulate {RoW} | market for polyethylene, high density, granulate, recycled | Cut-off, U

The results obtained for the Single Score values between PET and its recycled material are shown in **Figure 51**.

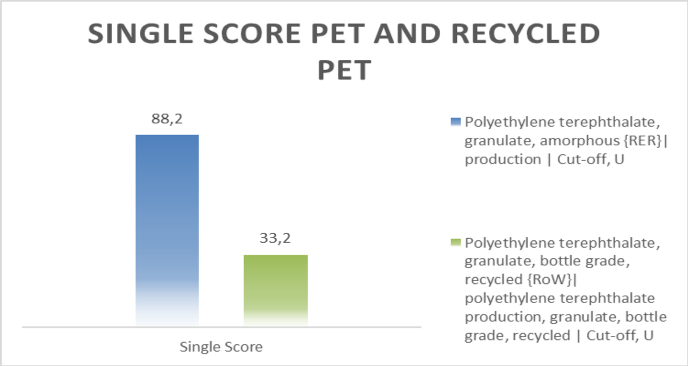

Figure 51: Single Score PET

Considering the results obtained, the difference in percentage between the two Single Score values is given by: (33.2/88.2)*100 and the result obtained was 38%.

As for HDPE and its recycled material, the results obtained for the Single Score values are presented in **Figure 52**.

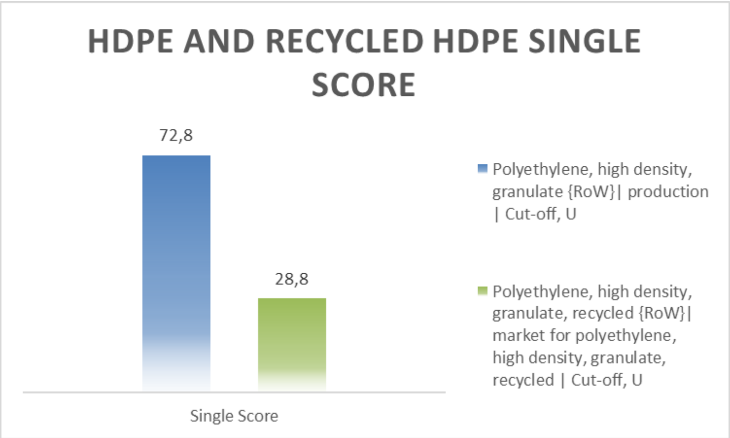

Figure 52: Single Score HDPE

Considering the results obtained, the difference in percentage between the two Single Score values is given by: (28.8/72.8)*100 and the result obtained was 40%.

Finally, having the three percentages of the difference between the two Single Score values for the mentioned plastics and their recycled version, these three values were averaged. The result obtained for this average was 45% ((56+38+40)/3). This percentage was used to calculate the difference between the Nylon Single Score and the Recycled Nylon Single Score.

Annex C – Charger Converter Photographs

This annex gathers the photographs of the charger converter used to design the 3D prototype.

Figure 53: Original Charger Converter

Annex D – Charger Cable Photographs

This annex gathers the photographs of the charger cable used to design the 3D prototype.

Figure 54: Original Charger Cable

Annex E – Phone Case Photographs

This annex gathers the photographs of the phone case used to design the 3D prototype.

Figure 55: Original Phone Case