Analysis of the Impact of Smartphone on the Environment Using the LCA Method

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Abstract. Today's industrial production has a great impact on the environment all over the world. The constant increase in the world's population has a great impact on the expanding industries in the world. Maintenance, eco-design and life cycle analysis are important concepts related to sus-tainability and environmental protection. Life cycle refers to everything associated with the product at all stages of its life, from the extraction of raw materials to the disposal or recycling of the product. The mobile phone was chosen as a representative in accordance with the global development of the relevant industry and the desire to show its impact on the environment using the LCA (Life cycle assessment) method. The concepts of sustainable development, recyclability and eco-indicators were explained and some concepts and tools were presented to show how can mobile phones industry reduce the impact and con-tribute to the environment and sustainability.

Keywords: eco-design · life cycle analysis · Eco-Indicator 99 · smartphone

1 Introduction

Every product has an impact on the environment during its production, use and at the end of its life cycle. The life cycle refers to everything related to the product at all stages of its life, from the extraction of raw materials to the disposal or recycling of the product. It is necessary to extract the raw material, manufacture, package and distribute the finished product and dispose of it at the end of its life. If the use of the product involves the consumption of materials and/or energy, this phase of the product's life cycle has a significant impact on the environment. In view of today's trend towards large-scale and mass production, and with the emphasis on quality and economy of products, it is necessary to work continuously on the development of tools and equipment [1].

Products can be divided into short-term and durable goods. Short-term goods are products that are intended for one-time use; these are products such as food and beverages that must be consumed within a certain period of time after they are used. Durable goods are products that are intended to last longer than short-lived goods, and most often the manufacturers of such products are required to guarantee the product for a certain period

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of time. These are products such as household appliances, machines, cars, furniture, etc. [2].

As the product and technology, itself evolves for production, as well as the manufacturer, there is an increasing focus on an eco-approach with an environmentally friendly design and a choice of materials that can be reused for different purposes.

However, waste gives an insight into the lives and behaviour of past generations and also reflects the image of the materials that humans have used. For example, materials that did not exist in past centuries have appeared in the waste of our time and have found use in all areas of contemporary life due to their many advantages - plastic and rubber [2].

Maintenance, ecological design and life cycle assessment are all important concepts related to sustainability and environmental protection. Maintenance refers to procedures and activities carried out to maintain the quality and functionality of a product or system during its lifetime. This may include regular repairs, replacement of parts, cleaning and maintenance to ensure that the product or system continues to perform its function without creating additional waste or undesirable environmental impacts. Ecodesign refers to the way in which products and systems are designed to minimise their negative impact on the environment throughout their life cycle. Life cycle assessment is a process that analyses the overall environmental impact of a product or system, from raw materials to waste disposal. It includes an assessment of all stages of production, use and disposal to identify the main factors that influence environmental impacts and to identify opportunities to improve sustainability. All three concepts are important to achieve sustainability and environmental protection. They are used to develop products and systems that are sustainable and have a minimal impact on the environment.

2 Materials and Methods

2.1 Ecological Desing

Nowadays, designers, constructors and importers of products are expected to contribute to the reduction of energy consumption and pollution and to strive for energy efficiency in all phases of their activities. Ecological design as such means creating "smarter" products that contribute to environmental protection.

All products have an impact on the environment during their life cycle, which includes all phases from "cradle to grave". These stages include the use of raw materials and natural resources, production, packaging, transport, disposal and recycling. However, more than 80% of the environmental impact is determined in the design phase itself.

Ecological design means that all impacts of products on the environment are considered at the earliest stages of design. This avoids, in particular, uncoordinated product design (of the type of removal of toxic substances, which should not be accompanied by increased energy consumption, which can also have a negative impact on the environment).

The "Eco-Directive" provides a coherent and integrated framework that allows the establishment of mandatory requirements for some products in the field of ecological design. For example, the "Standby Regulation' requires that many electrical and electronic household appliances such as washing machines, televisions or PCs consume no more than 0.5 W in the so-called 'off' state since 2013." [2].

However, the ecological design requirements must not compromise the functionality of the product or its safety, or have a negative impact on its availability and consumer health. The methodology has been developed to provide practical guidance to the Committee on how and when to assess which requirements and design approaches are appropriate for a particular product (Fig. 1).

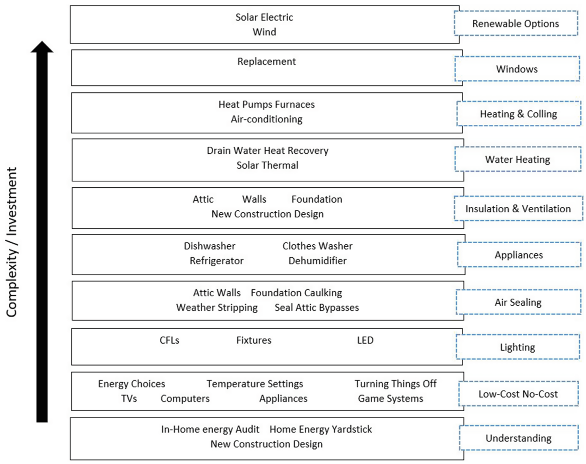

Fig. 1. Extensive impact on the environment depending on investment and complexity

Requirements for ecological design: [3].

– are set separately for each individual product
– set the minimum requirements for the performance of the product in order to reduce its impact on the environment
– are mandatory for all products sold in the EU
– are based on the environmental impact throughout the life cycle of the product (design, production, distribution and disposal).

2.2 Recycling

Recycling or recovery, the process of processing waste materials and used products with the aim of obtaining raw materials and energy for reuse and use [4].

The complete waste management system combines waste streams, their collection and recovery with environmental benefits, economic optimisation and social acceptability. This system includes different materials (paper, plastic, glass, wood, metal, rubber), waste from different sources (households, industry) and different applications (packaging waste). In recycling, the aim is to use as much of the product as possible at the end of its life as a finished form or as a raw material to be returned to the production process of the same or a new product. At the same time, the unusable part of the product must be reduced to the smallest possible size.

Product-oriented production seeks to influence the environment through the most efficient, "ecological" product design possible and considers the impact on the environment throughout the life cycle. The emission of pollutants is monitored from the extraction of the raw material to the disposal of the used product. Some of the methods used are:

- eco-design
- eco-efficiency
- LCA - life cycle assessment (product life cycle assessment)
- LCM - life cycle management.

According to [4], the circular economy system is based on the use of already used materials that can be renewed and used in new and different ways, which at the same time ensures a reduction in the exploitation of natural resources. Therefore, in 2015, the European Commission adopted a Circular Economy Package, which includes legislative proposals on waste, long-term targets to reduce disposal and increase recycling and reuse. The plan includes working on all parts of the chain, from production to reuse, and returning secondary raw materials and materials to the cycle [5].

2.3 LCA – Life Cycle Assessment

The life cycle of a product includes everything associated with the product in all phases of its life, i.e. from the extraction of raw materials to disposal or recycling. The methodology of life cycle assessment has the task of evaluating all components and environmental impacts associated with the product, process or activities during their lifetime [1].

The 5 Steps of a Product Life Cycle which can been seen on Fig. 2: [6].

1. Raw Material Extraction
2. Manufacturing & Processing
3. Transportation
4. Usage & Retail
5. Waste Disposal

LCA is a systematic approach consisting of four important steps which can been seen on Fig. 3: [6].

1. Definition of the objective and scope - defining and describing products, processes and activities, determining the context and boundaries in which the assessment will be carried out.
2. Life Cycle Inventory (LCI) - identification and quantification of energy, water and materials consumed and pollution generation (air emissions, waste generation, …)
3. Life Cycle Impact Assessment (LCIA) - assessment of the potential ecological impact on the environment
4. Interpretation (explanation) of results - evaluation of results and impacts to select products, processes and services, clearly considering the uncertainties and predictions that affect the results.

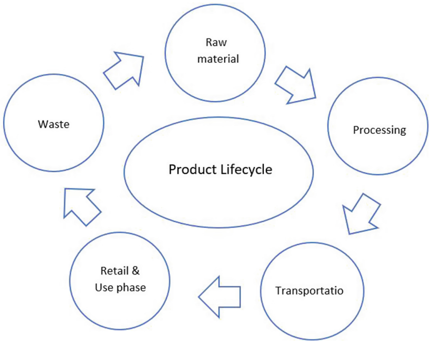

Fig. 2. The 5 Steps of a Product Life Cycle

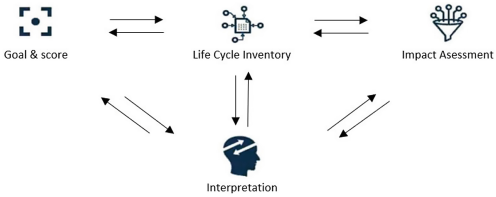

Fig. 3. Four key steps of the LCA method

LCA analyses of some products show that they have a significantly greater impact on the environment during use than during production.

Various methods are used to assess the environmental impact of products. The best known and most widely used is the Eco-indicator 99, which is merely an extension of the LCA method, but not its simplification. LCA is by far the most reliable method for calculating environmental impact, but it also has its limitations.

2.4 Eco-Indicators

Eco-indicators can be defined as numbers that express the overall impact of a product or process on the environment. These figures are derived from life cycle assessment data.

The values of the eco-indicators are "considered" as dimensionless quantities, but the term point is used by common consent. It is also important to mention the scale of values, which was chosen so that 1 Pt (point) corresponds to one thousandth of the annual environmental impact of an average European inhabitant.

The idea of an eco-indicator for a product's impact on the environment was developed with the intention of promoting awareness of the totality of the material and living world, of which humans are a biological part. Incorporating the environment into the product design process is complex and long-term in every respect. Methods and programmes have been developed to simplify the process itself. The Eco-Indicator 99 has been the most widely used, as it shows the link between the impact of substances and harm to human health [2].

In order to calculate the Eco-indicator score, three steps are needed: [7].

1. Inventory of all relevant emissions, resource extractions and land-use in all processe that form the life cycle of a product. This is a standard procedure in Life Cycle Assessment (LCA)
2. Calculation of the damages these flows case to Human Health, Ecosystem Quality and Resources
3. Weighting of these three damage categories

Three steps are illustrated (Fig 4.).

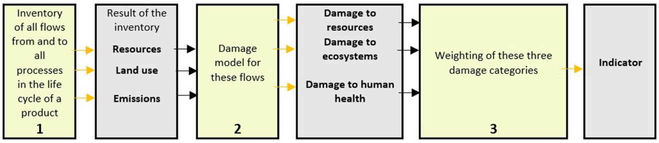

Fig. 4. General procedure for the calculation of Eco-indicator

It is important to emphasize that the disassembling procedure was done by the assessment and the free will of the authors. No disassembling procedure was followed or owned by the phone manufacturer. Similar approach was carried out in [8]. It is necessary to emphasize that the work focuses solely on the Eco Indicator 99 method.

The Eco-Indicator 99 method was developed as a further development of the Eco-Indicator 95 method. Based on the Eco-Indicator 95 method, improvements have been developed that allow a more accurate analysis of the environmental impact of a product or system. These include the updating of parameters, the introduction of new concepts such as toxicology indicator points (TIP) to assess toxicity, weighting factors that reflect current environmental priorities, and other improvements that have enabled a more comprehensive and accurate analysis of environmental impacts. The Eco-Indicator 99 method has become a useful tool for understanding and reducing the environmental footprint of a product or system and has surpassed its predecessor in its ability to assess environmental impact [9].

3 Example of the Application of the Eco-Indicator 99 Method

The smartphone iPhone 4 was chosen as an example for the application of the Eco-indicator 99 method. The selected representative is chosen on the basis of its availability. The device is classified as electronic waste and it is recommended not to classify it as other waste.

The device is assumed to be used several hours a day and its estimated lifetime is 4 years. It is assumed that it will then be recycled as electronic waste.

For the analysis, it was necessary to separate all the parts of the device, then determine their mass and define the material. The mass was determined with a digital scale with an accuracy of 0.1 g. The parts of the smartphone can be seen in Fig. 5.

Smartphone parts with a certain mass and material can be found in Table 1.

Fig. 5. Parts of the device Apple iPhone 4

Table 1. iPhone 4 mobile phone parts with masses and materials

Name of the part	Mass [g]	Material	Pieces
Front housing (screen)	34,9	Glass	1
Central frame	37,2	Aluminum	1
Back cover	22,1	Glass	1
Battery	26,9	Lithium	1
Motherboard	13,9	Silicon	1
Speaker housing	2,5	PVC	1
Camera	1,2	Aluminum + Glass	1
Protective sheets (total mass of all)	1,1	Aluminum	1
SIM card slot	0,7	Aluminum	1
Vibration	0,7	Aluminum	1
3.5 mm headphone jack	0,4	PVC	1

However, some parts could not be weighed with a digital scale, such as screws. All the screws together have a mass of less than 0.1 g, so these parts are ignored.

Once all the necessary data had been obtained, it was entered into the SimaPro 8.0.5 program [10], the desired eco-indicator was selected and the analysis started. The results obtained are presented in tables and diagrams.

3.1 Developing a Life Cycle Tree Using SimaPro 8.0.5

In developing the product life cycle tree, which shows the materials used in the product, the electricity consumed by the product, the production processes used to make the parts and the type of waste disposal, it was necessary to enter the type of material and the mass for each part.

The upper part of the life cycle tree of the appliance can been sean in Fig. 6.

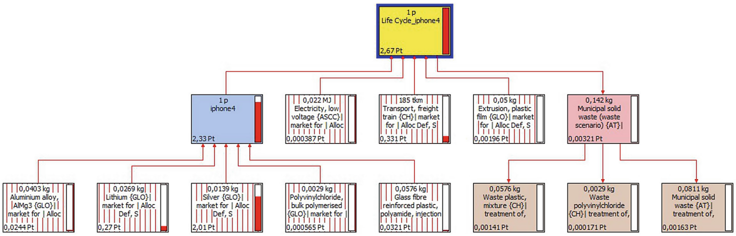

Fig. 6. Life cycle tree with eco-indicator values

3.2 Results of Product Life Cycle Assessment (LCA)

As a result of the assessment of the life cycle of the product, a table was obtained in which the following are listed:

- all substances contained in the materials of the device
- substances required for the production of raw materials
- substances used in the manufacture of parts
- all forms of energy used in all phases of the life cycle of the product
- radioactive radiation from certain substances
- occupies the earth's surface

Part of the results of the LCA of the appliance in Fig. 7.

No	Substance	Compartment	Unit	Total	iphone4	Electricity, low voltage {ASCC}|	Transport, freight train {CH}| market	Extrusion, plastic film {GLO}| market	Municipal solid waste (waste
1	1-Butanol	Air	ng	126	89,9	0,00104	35,6	0,214	0,0249
2	1-Butanol	Water	µg	41,5	31,6	0,00159	9,75	0,0374	0,118
3	1-Pentanol	Air	ng	53,6	44,3	0,000472	9,14	0,145	0,0118
4	1-Pentanol	Water	ng	129	106	0,00113	21,9	0,347	0,0284
5	1-Pentene	Air	ng	113	89,8	0,00144	22,8	0,249	0,0404
6	1-Pentene	Water	ng	97,3	80,4	0,000856	16,6	0,262	0,0215
7	1-Propanol	Air	mg	292	291	1,71E-5	0,47	0,000238	0,000101
8	1-Propanol	Water	ng	389	310	0,0034	77,8	0,998	0,0912
9	1,4-Butanediol	Air	µg	1,02	0,615	1,15E-5	0,406	0,000763	0,000198
10	1,4-Butanediol	Water	µg	1,78	1,02	2,04E-5	0,75	0,00106	0,000372
11	2-Aminopropanol	Air	ng	46,3	35,9	0,000407	10,3	0,0977	0,0109
12	2-Aminopropanol	Water	ng	111	86,2	0,000978	24,8	0,235	0,0262
13	2-Butene, 2-methyl-	Air	µg	149	149	1,03E-7	0,00208	1,48E-6	6,07E-6
14	2-Butene, 2-methyl-	Water	µg	357	357	2,47E-7	0,00498	3,54E-6	1,46E-5
15	2-Methyl-1-propanol	Air	ng	120	97,2	0,00105	22,8	0,3	0,0277
16	2-Methyl-1-propanol	Water	ng	289	233	0,00252	54,7	0,72	0,0665
17	2-Methyl-4-chlorophenoxyacetic acid	Soil	ng	452	428	0,00474	24,4	0,202	0,0247
18	2-Nitrobenzoic acid	Air	ng	66,2	50,9	0,000532	15,2	0,138	0,0172
19	2-Propanol	Air	mg	18,9	18,8	3,91E-6	0,0732	0,0189	0,00077
20	2-Propanol	Water	µg	1,36	1,13	1,09E-5	0,219	0,00265	0,000481
21	2,4-D	Air	ng	849	186	0,0121	661	1,23	0,0742
22	2,4-D	Soil	µg	533	303	0,00564	229	1,15	0,105
23	4-Methyl-2-pentanone	Water	µg	3,45	3,11	0,00796	0,324	0,00849	0,00147
24	Acenaphthene	Air	ng	265	245	0,117	19,2	0,568	0,0861
25	Acenaphthene	Water	ng	317	195	0,106	121	0,283	0,171
26	Acenaphthylene	Air	ng	32,2	3,64	0,000673	28,5	0,00612	0,0556
27	Acenaphthylene	Water	ng	19,8	12,2	0,00665	7,58	0,0177	0,0107
28	Acephate	Air	ng	90,2	19,8	0,00129	70,3	0,131	0,00789
29	Acephate	Soil	µg	39,4	32,6	0,000345	6,67	0,109	0,00977
30	Acetaldehyde	Air	mg	10,9	4,8	0,00325	6,07	0,0145	0,00742
31	Acetaldehyde	Water	µg	167	111	0,00552	55,8	0,149	0,404
32	Acetamide	Air	ng	22,2	4,87	0,000317	17,3	0,0323	0,00194
33	Acetamide	Soil	µg	5,71	4,75	5,06E-5	0,944	0,0154	0,00138
34	Acetic acid	Air	mg	18,6	15,6	0,018	2,93	0,0391	0,0181
35	Acetic acid	Water	µg	818	452	0,011	365	0,606	0,653

Fig. 7. The results of the life cycle assessment of the appliance

3.3 Product Impact on the Environment by Catogory

The impact of devices on three basic categories - human health, ecosystem quality and resources - is shown in Fig. 8.

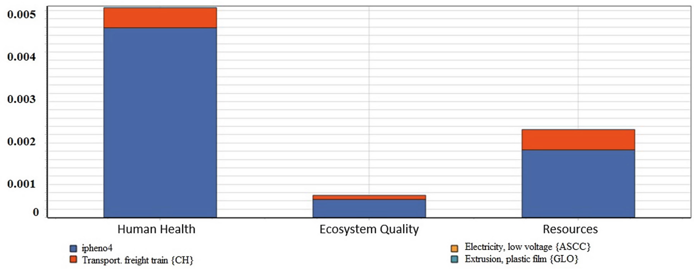

Fig. 8. The environmental impact of device in three basic categories

The results are also presented according to the effects in more precisely defined categories. This definition includes: carcinogenic effects, respiratory effects, climate change, radiation effects, ozone layer effects, ecotoxicity, eutrophication, depletion of the earth's surface and fossil fuel consumption effects. The above results can be seen in Fig. 9.

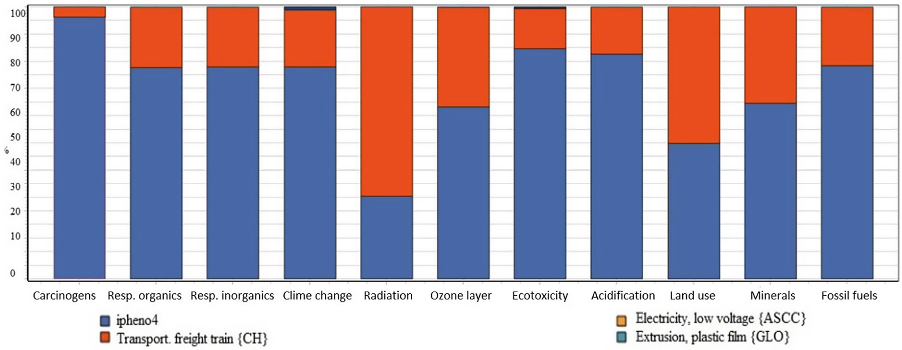

Fig. 9. The environmental impact of device

In the diagrams, the individual categories are scaled with 100%. The blue colour shows the percentages indicating the impact of materials that are stored, i.e. disposed of in landfill. In addition to considering the entire assembly, the impact of individual materials and production processes can also be considered, as shown in Fig. 10.

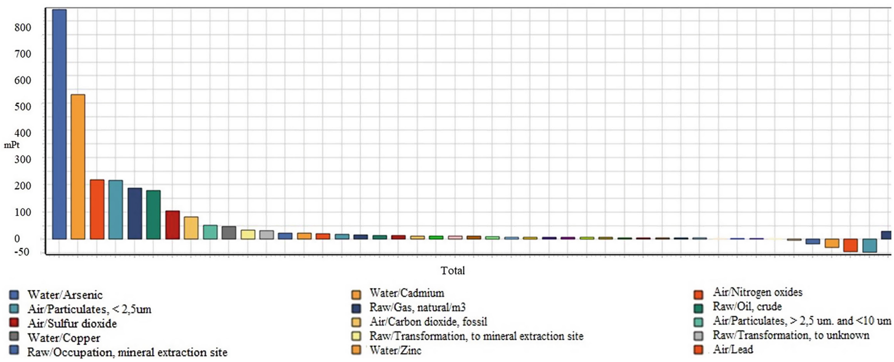

Fig. 10. The environmental impact of the materials (used for the appliance)

3.4 Normalization of Results

Since in the previous diagrams all categories are scaled to 100%, it is difficult to determine which material or technological process related to the product has the greatest impact on the environment. To get a better representation of the product's impact on the environment, it was necessary to perform normalisation. This is an evaluation procedure that makes the individual impacts comparable. Figure 11 shows the normalised results in a diagram.

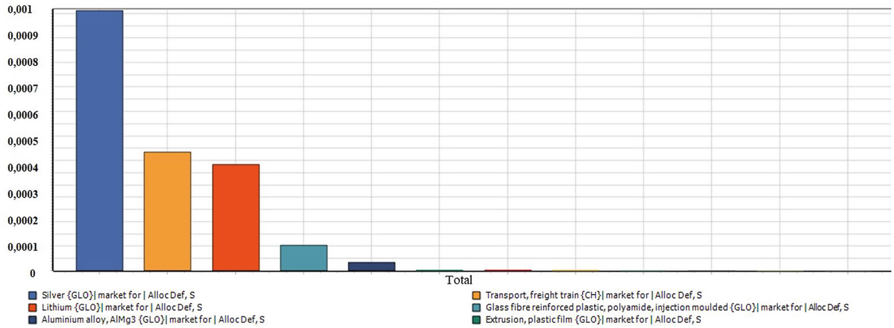

Fig. 11. Normalized results in a diagram

3.5 Scoring of Results

Relatively comparable results obtained by normalisation do not show the importance of individual influences, so that the results obtained so far for two different products were not comparable. By applying weighting factors to the normalised results, we obtain diagrams in which the environmental impacts are expressed in points (Pt). 1 Pt represents one thousandth of the environmental impact of an average European during one year.

The following figures show the impact of the device with the corresponding points. Figure 12. Shows the assessed categories and the assessed results, while Fig. 13. Shows the assessed materials by specific categories.

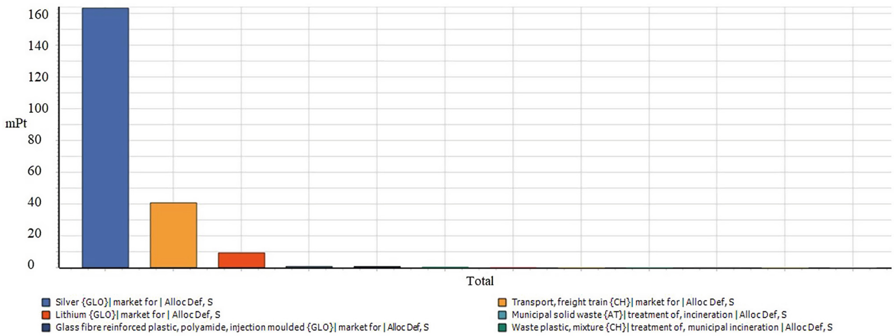

Fig. 12. Assessed categories and the assessed results

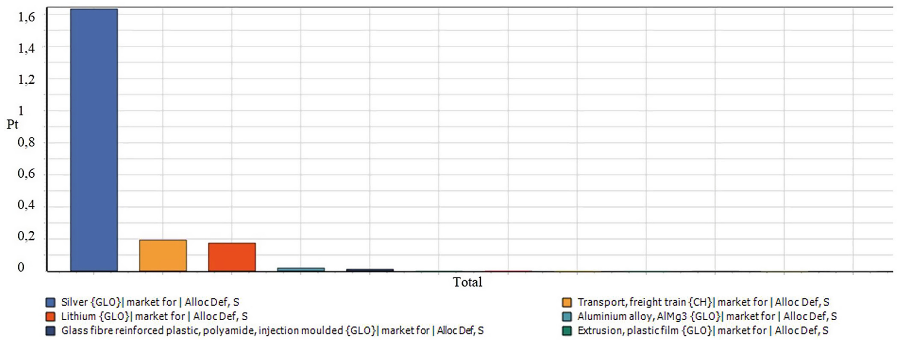

Fig. 13. Impact of materials on the environment - scored results

4 Conclusion

The multitude of different demands placed on production or other units are the main reason for the negative impact on the environment. Nevertheless, proper consideration and investigation of the existing problem provide greater opportunities for a comprehensive and proper analysis of the problem that needs to be solved.

A detailed analysis using the SimaPro software can be used to easily determine the results of the environmental impact of the mobile devices mentioned above. Every product has a greater or lesser impact on the environment and it is of great importance to consider the materials from which it is made, the possibilities of recycling and the impact of production on the environment. According to the life cycle tree, it is obvious that silver has the greatest impact on the environment. Therefore, recycling should be a solution for the disposal of those types of compounds that may affect the human habitat in some way. The final result of the whole life cycle is 2.67 pt. Since this result includes the whole process, from the impact of each material, the electricity consumption, the way each part is produced, to the disposal in the designated places, it can be concluded that the device does not have an excessive impact on the environment.

From the diagrams obtained, it is possible to identify the shortcomings of the design and technical solutions of the existing product. Recycling of the entire product would reduce the impact on the environment as opposed to the assumed disposal in household waste. From the point of view of suitability for material recycling, the number of different types of materials is minimised. The incompatibility of materials is a kind of measure of the imperfection of the available recycling processes. In conclusion, it is very difficult, if not impossible, to answer the question of which criteria are most important and which should be the focus of the whole process.

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References

1. Marijić, J., Vilić, M., Grgić, I., Karakašić, M., Ivandić, Ž.: Development, structure and design od stamping tool. In: Glavaš, H., Hadzima-Nyarko, M., Karakašić, M., Ademović, N., Avdaković, S. (eds.) 30th International Conference on Organization and Technology of Maintenance (OTO 2021). OTO 2021. LNNS, vol. 369, pp. 50–70. Springer, Cham (2022). https://doi.org/10.1007/978-3-030-92851-3_4
2. Kljajin, M., Opalić, M., Pintarić, A.: Recycling of electrical and electronic products. Faculty of Mechanical Engineering in Slavonski Brod, Slavonski Brod (2006)
3. Your Europe Homepage. https://europa.eu/youreurope/business/product-requirements/compliance/ecodesign/index_hr.htm. Accessed 28 Apr 2023
4. Croatian encyclopedia Homepage. https://enciklopedija.hr/Natuknica.aspx?ID=52144. Accessed 28 Apr 2023
5. Vrbek, M.: Ecological Product Design: The Foundation of Circular Waste Management. Master's thesis. University of Zagreb, Faculty of Economics and Business, Zagrab (2020). https://urn.nsk.hr/urn:nbn:hr:148:410383
6. Ecochain Homepage. https://ecochain.com/knowledge/life-cycle-assessment-lca-guide/. Accessed 28 Apr 2023
7. Goedkoop, M., Spriensma, R.: Eco-indicator 99 Manual for Designers, A damage-oriented method for Life Cycle Impact Assessment. Ministry of housing, Spatial Planning and the Environment, The Hague (2000)
8. Vukašinović, J., Grgić, I., Marijić, J., Karakašić, M.: Reverse engineering and 3D printing of the spinning reel: from maintenance to the new product design. In: Blažević, D., Ademović, N., Barić, T., Cumin, J., Desnica, E. (eds.) 31st International Conference on Organization and Technology of Maintenance (OTO 2022). OTO 2022. LNNS, vol. 592, pp. 106–117. Springer, Cham (2022). https://doi.org/10.1007/978-3-031-21429-5_10
9. The Eco-indicator 95 Final Repoer Homepage. https://pre-sustainability.com/legacy/download/EI95FinalReport.pdf. Accessed 04 Sep 2023
10. SimaPro 8.0.5 For Education Homepage. https://simapro.com/. Accessed 28 Apr 2023