Matilainen Anu
Huschauer Kaja
Lazarov Valentin
Clouard Robin

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Task 3: Product Life Cycle

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Introduction

This report includes the life cycle assessments of the original bicycle helmet, the improved version and the comparison between them. First, the life cycle assessment of the original product was made and based on that, then the factors causing most of the impacts were selected to be improved. Finally, the life cycle assessment of the improved version was made and the most important impacts were compared to the original product.

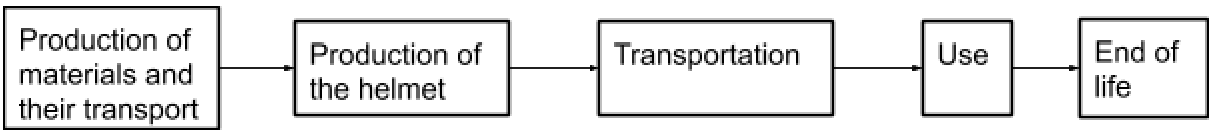
Functional Unit Definition

The functional unit of the life cycle assessment is the lifetime of the bicycle helmet as the bicycle helmets are advised to be replaced after a certain time of use even if they are not crashed or otherwise damaged ([1] and [2]). Functional unit based on active usage time of the helmet was not found reasonable as helmets are not really wearing items (different e.g. from clothes) and using of the helmet does not cause any impacts (different e.g. from energy consuming devices).

In the calculations, the lifetime is expected to be three years as the helmet manufacturer Giro recommends replacing the helmet every three years]1] and the helmet manufacturer Bell every three to five years [2].

Inventory analysis

We made the following life cycle scenario:

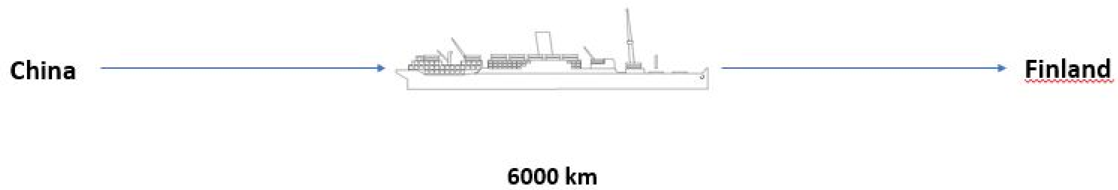


1. Production of raw materials and their transportation to the helmet factory
    - Polycarbonate
    - EPS (expanded polystyrene)
    - PA (polyamide)
    - PUR (polyurethane)
    - PP (polypropylene)
    - POM (polyoxymethylene)

    This part of the scenario was not developed more as the manufacturing process is not a major source of environmental impact.

2. Production of the bicycle helmet: Most of the materials are extruded to their shape of parts, PUR is molded and PP fibres are fabricated by textile technologies. The different parts are assembled together mechanically.

3. Transportation from the helmet factory located in China to Finland
    - 6000 km by ferry (the most typical transportation method)

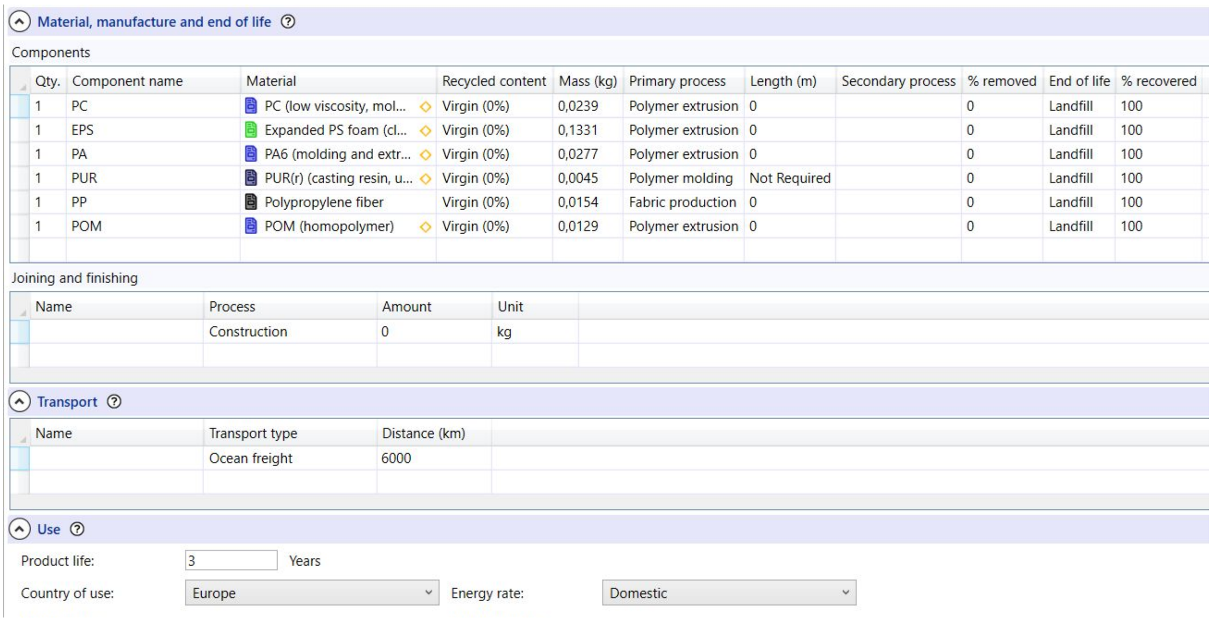


4. Use of the helmet
    - No effects during the use.

5. End of life
    - Two possible scenarios taken into account:
        - Landfill
        - Recycling

We entered these different parameters on Granta EduPack. This software was selected because of its detailed information about different polymers, especially on level 3. Open LCA does not include the database for all the polymers, which are used in this product. The Eco Audit tool of Granta EduPack was used to calculate the ecological and economical impacts.

Here is a screenshot of the inputs on the Eco Audit tool:


Material, manufacture and end of life

Components

Qty.	Component name	Material	Recycled content	Mass (kg)	Primary process	Length (m)	Secondary process	% removed	End of life	% recovered
1	PC	PC (low viscosity, mol...	Virgin (0%)	0,0239	Polymer extrusion	0		0	Landfill	100
1	EPS	Expanded PS foam (cl...	Virgin (0%)	0,1331	Polymer extrusion	0		0	Landfill	100
1	PA	PA6 (molding and extr...	Virgin (0%)	0,0277	Polymer extrusion	0		0	Landfill	100
1	PUR	PUR(r) (casting resin, u...	Virgin (0%)	0,0045	Polymer molding	Not Required		0	Landfill	100
1	PP	Polypropylene fiber	Virgin (0%)	0,0154	Fabric production	0		0	Landfill	100
1	POM	POM (homopolymer)	Virgin (0%)	0,0129	Polymer extrusion	0		0	Landfill	100

Joining and finishing

Name	Process	Amount	Unit
	Construction	0	kg

Transport

Name	Transport type	Distance (km)
	Ocean freight	6000

Use

Product life: 3 Years

Country of use: Europe Energy rate: Domestic

These inputs and outputs of the analysis are listed below:

Inputs	Outputs
-Method of transportation of the bicycle helmet (ferry) -Number of kilometers (6000km) -Years of use (3 years) -Materials (mass, manufacturing process, end of life)	-CO2 footprint, embodied energy and cost resulting from the: ● Material ● Manufacture ● Transport ● Use ● Disposal ● End of life -Percentage and impact (respectively in MJ, kg and EU) of the different materials

Goal and Scope Definition

The material properties, which were found from GRANTA Edupack, are listed as an overview over the product and were used to define goal and scope of the greener version.

Material	**weight [g]**	**Density [g/cm3]**	**Price [€/kg]**	**Embodied energy [MJ/kg]**	**CO2-footprint [kg/kg]**	**Water usage [l/kg]**	**Heat of combustion [MJ/kg]**
Polycarbonate (PC), low viscosity (shell)	**23.9**	1.20	2.06-2.85	100-111	4.53-4.99	165-182	30.3-31.8
Expanded polystyrene (EPS), closed cell (inner part)	**133.1**	0.012-0.050	2.49-2.57	90 (83.5-92.1)	2.25-2.49	433-479	39.9-42
Polyamide (PA) 6, unfilled (size adj mech)	**27.7**	1.13-1.15	1.88-2.22	129-143	7.26-8	178-194	30.1-31.6
Polyurethane (PUR), casting resin/ unsaturated (pads)	**4.5**	1.04-1.06	2.10-2.27	78.1-86.1	3.05-3.37	93.5-103	21.8-22.9
Polypropylene (PP) (fibre, straps)	**15.4**	0.946 (0.91-0.92)	1.65-2.36	66-72	2.8-3.3	38-45	42.7
Polyoxymethylene (POM), homopolymer (buckles)	**12.9**	1.39-1.41	1.41-1.58	81.8-90.2	3.04-3.36	240-265	15.8-16.6

source: GRANTA Edupack 2020

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i) Which improvement ?

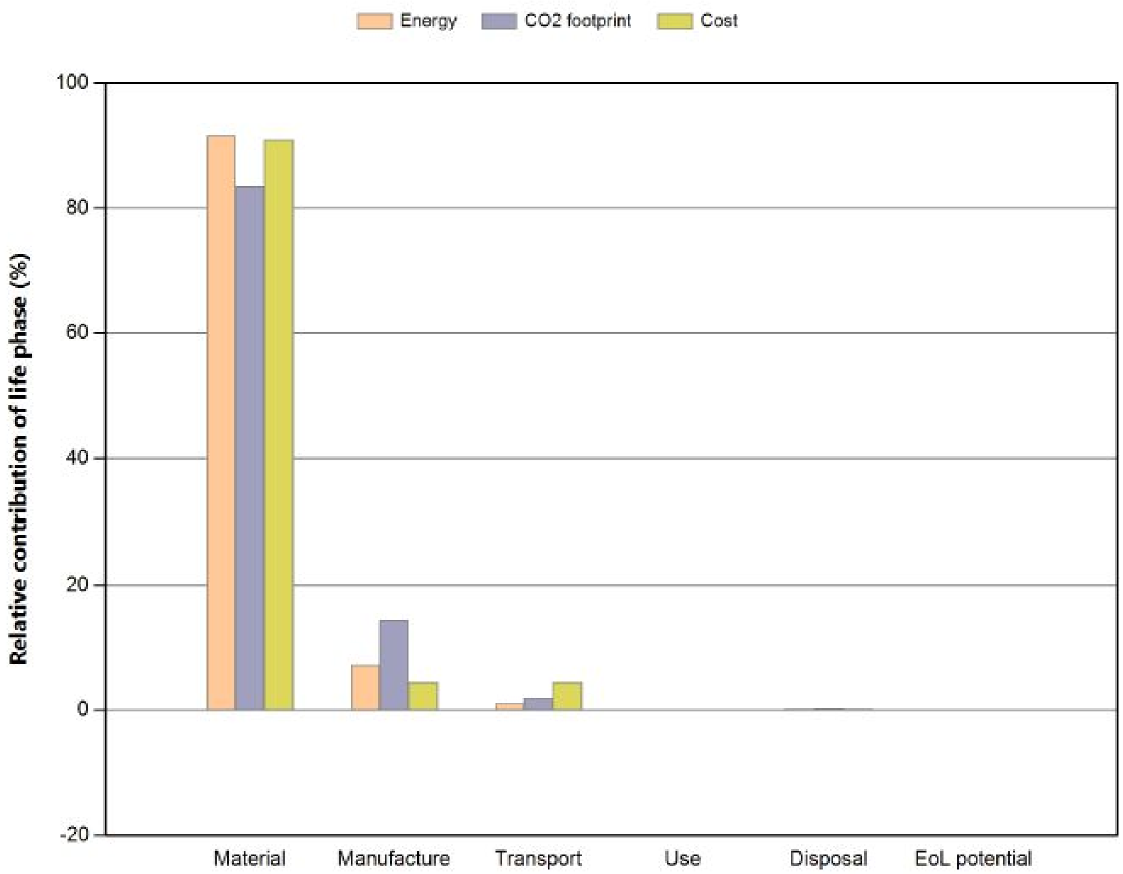
We decided to focus on the material impact itself as we assume it is the main impactor in an environmental point of view (verifications of this assumption will be done in ii) Why these choices). Changes shall be done in EPS, which builds the inner part of the helmet, and for PC, which builds the outer layer and for polypropylene fibre, which the straps are made of.

It shall be used recycled EPS and PP instead of virgin one. Additionally, PC is replaced by recycled PET (rPET).

Picture 1: Improvements made to the product

ii) Why these choices ?

First, it is important to point out that the assumption to make improvements on the material has been verified: It is indeed the main contributor of the different impacts that we took into account, which are the CO2 footprint, the embodied energy and the price.



We can see that the material represents more than 80% of the impact in each category.

Phase	Energy (MJ)	Energy (%)	CO2 footprint (kg)	CO2 footprint (%)	Cost (EUR)	Cost (%)
Material	20,5	91,5	0,742	83,4	0,589	90,9
Manufacture	1,62	7,2	0,128	14,3	0,0287	4,42
Transport	0,235	1,0	0,0169	1,9	0,0288	4,44
Use	0	0,0	0	0,0	0	0
Disposal	0,0435	0,2	0,00305	0,3	0,00125	0,193
Total (for first life)	**22,4**	**100**	**0,89**	**100**	**0,648**	**100**
End of life potential	0		0			

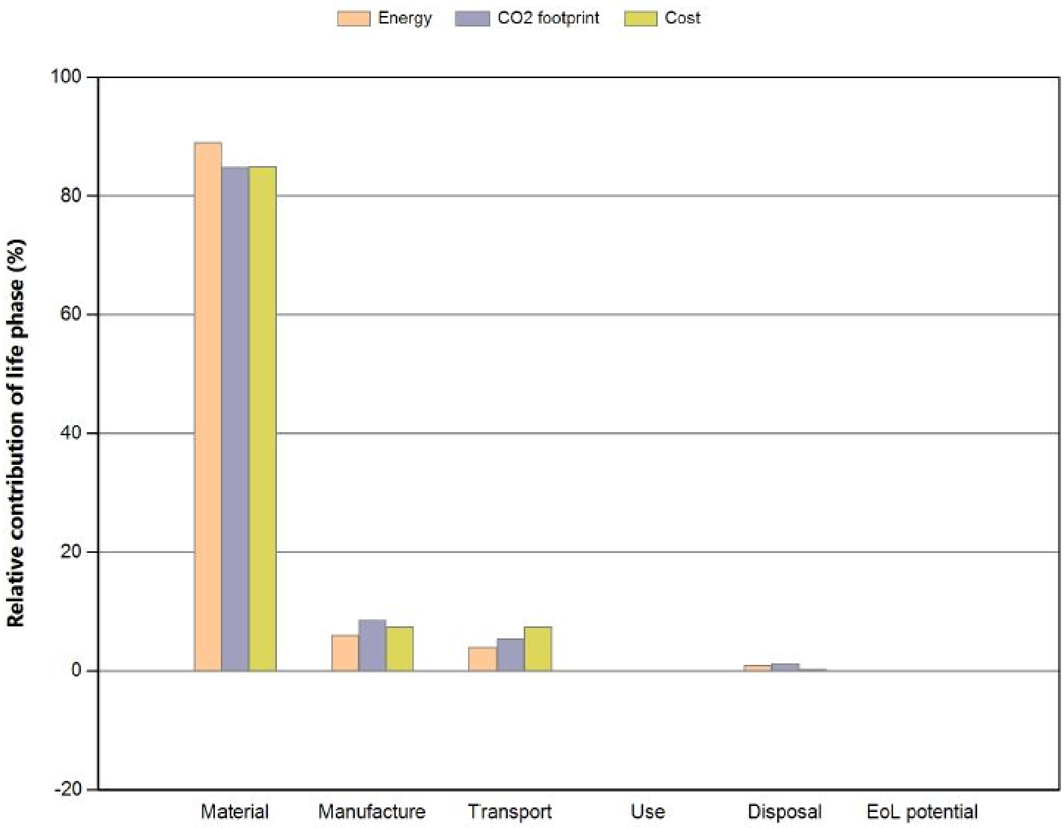
We did not consider other categories like water use or ozon impact for a simple reason: Indeed, most of the materials in a bicycle helmet are different polymers, but they are all basically different kinds of plastics, which is anyway made of petrol. Thus, they have approximately the same method of extraction and manufacturing.

So for the same amount of material, the different polymers will have a similar impact, no matter the parameter. But since EPS is in a far larger amount than the other materials, it will have the biggest impact. Indeed, it weighs 130 g which represents 60,6 % of the total weight. Regarding the embodied energy, the CO2 footprint and even the cost, the EPS shows that it has the biggest impact in all cases:

Component	Material	Recycled content* (%)	Part mass (kg)	Qty.	Total mass processed ** (kg)	Energy (MJ)	%	CO2 foot print (kg)	%	Cost (EUR)	%
PC	PC (low viscosity, molding and extrusion)	Virgin (0%)	0,024	1	0,024	2,5	12,3	0,11	15,3	0,058	9,9
EPS	Expanded PS foam (closed cell, 0.025)	Virgin (0%)	0,13	1	0,13	12	57,0	0,32	42,4	0,41	69,6
PA	PA6 (molding and extrusion)	Virgin (0%)	0,028	1	0,028	3,8	18,4	0,21	28,4	0,057	9,7
PUR	PUR(r) (casting resin, unsaturated)	Virgin (0%)	0,0045	1	0,0045	0,37	1,8	0,014	1,9	0,011	1,9
PP	Polypropylene fiber	Virgin (0%)	0,015	1	0,015	1,1	5,2	0,047	6,3	0,032	5,4
POM	POM (homopolymer)	Virgin (0%)	0,013	1	0,013	1,1	5,4	0,041	5,6	0,021	3,6
Total				**6**	**0,22**	**20**	**100**	**0,74**	**100**	**0,59**	**100**

By using recycled materials, also the use of resources and water decreases. All the materials are skin-friendly and non-toxic, in its virgin form as well as the recycled form [3].

In the following, the Eco Audit of the greener product is shown. Still the material has the most impact on energy, CO2 and costs, but the overall impact is lower.



Phase	Energy (MJ)	Energy (%)	CO2 footprint (kg)	CO2 footprint (%)	Cost (EUR)	Cost (%)
Material	5,24	89,1	0,267	84,8	0,331	84,9
Manufacture	0,354	6,0	0,027	8,6	0,0287	7,35
Transport	0,235	4,0	0,0169	5,4	0,0288	7,38
Use	0	0,0	0	0,0	0	0
Disposal	0,0555	0,9	0,00388	1,2	0,00125	0,321
Total (for first life)	**5,88**	**100**	**0,315**	**100**	**0,39**	**100**
End of life potential	0		0			

The component-wise changes of energy, CO2 footprint and cost are shown in the table below.

Component	Material	Recycled content* (%)	Part mass (kg)	Qty.	Total mass processed ** (kg)	Energy (MJ)	%	CO2 footprint (kg)	%	Cost (EUR)	%
PC	PET (unfilled, amorphous)	Reused part	0,024	1	0,024	0	0,0	0	0,0	0,015	4,6
EPS	Expanded PS foam (closed cell, 0.025)	Reused part	0,13	1	0,13	0	0,0	0	0,0	0,21	62,9
PA	PA6 (molding and extrusion)	Virgin (0%)	0,028	1	0,028	3,8	71,8	0,21	79,1	0,057	17,2
PUR	PUR(r) (casting resin, unsaturated)	Virgin (0%)	0,0045	1	0,0045	0,37	7,0	0,014	5,4	0,011	3,4
PP	Polypropylene fiber	Reused part	0,015	1	0,015	0	0,0	0	0,0	0,018	5,5
POM	POM (homopolymer)	Virgin (0%)	0,013	1	0,013	1,1	21,1	0,041	15,5	0,021	6,4
Total				**6**	**0,22**	**5,2**	**100**	**0,27**	**100**	**0,33**	**100**

One may wonder why we chose to use recycled EPS instead of something that is based on renewable materials such as wood. Indeed the Finnish VTT has recently developed a foam-formed cellulose-based material that could replace EPS in some applications [4]. It is 100% based on wood and can be easily recycled in a way similar to cardboard. Unfortunately for now it remains difficult to compete with some of the properties that plastics are able to offer. For example, EPS is both lightweight and has the ability to absorb mechanical energy on impact quite well. The other problem with many “exotic” materials is their current availability, as in the case with the foam-formed cellulose-based material proposed by VTT.

Picture 2: EPS used in packaging

iii) How much lower impact?

By using recycled materials for inner (EPS) and outer layer (recycled PET instead of PC) the shell as well as stripes (PP), CO2 footprint and embodied energy of the whole product can be lowered. Also the price will decrease.

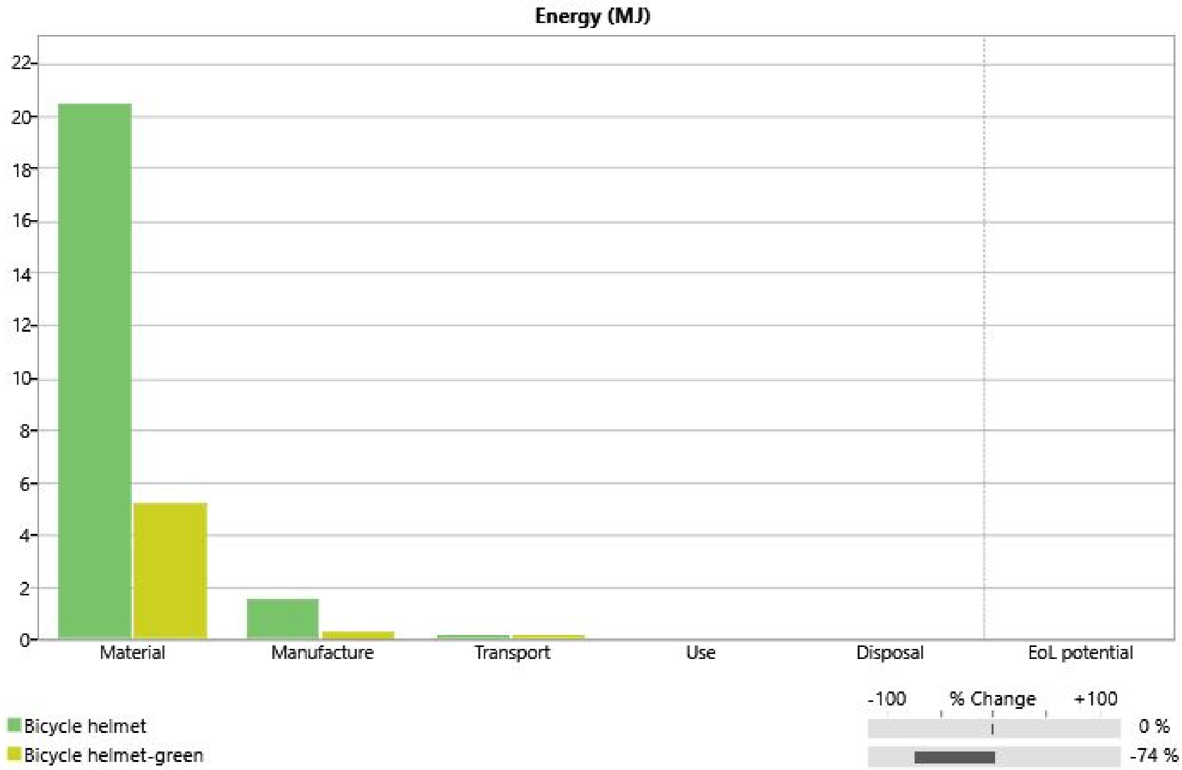
The material's impact on the Eco Audit is changed as followed:

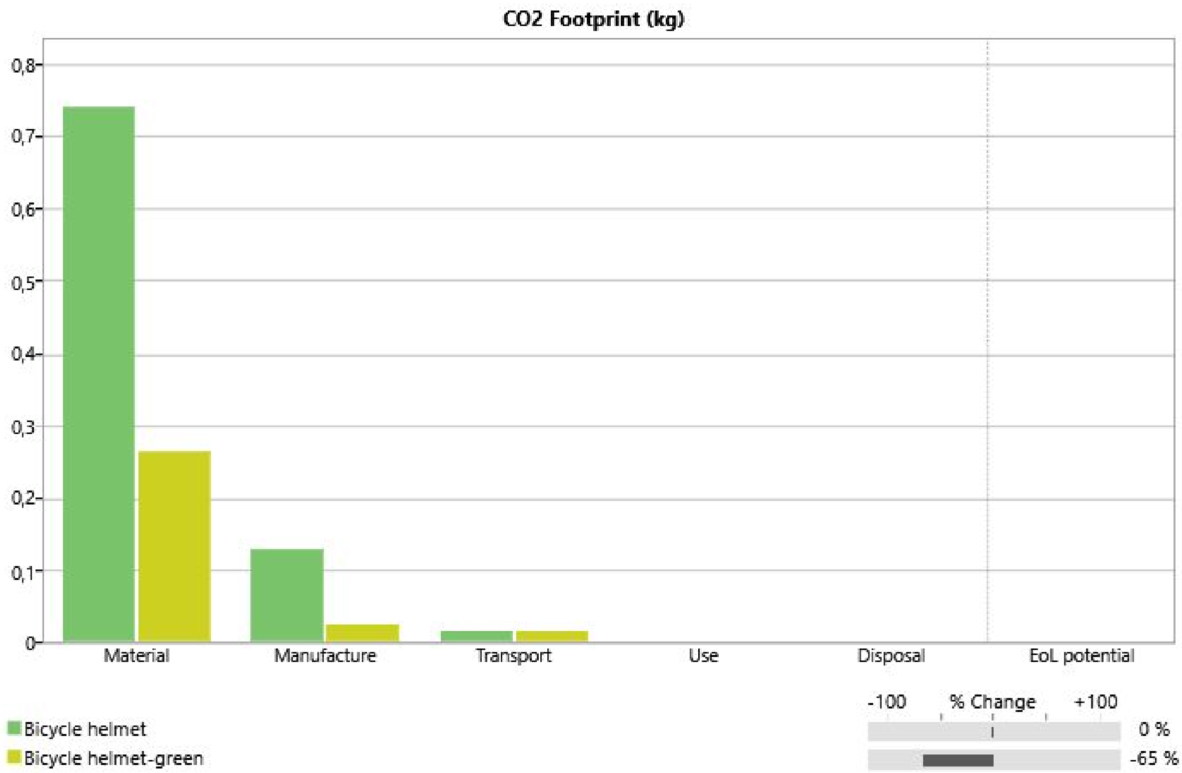
	Energy [MJ]	**CO2 [kg]**	**cost [€]**
original version	20	0,74	0,59
green version	5,2	0,27	0,33

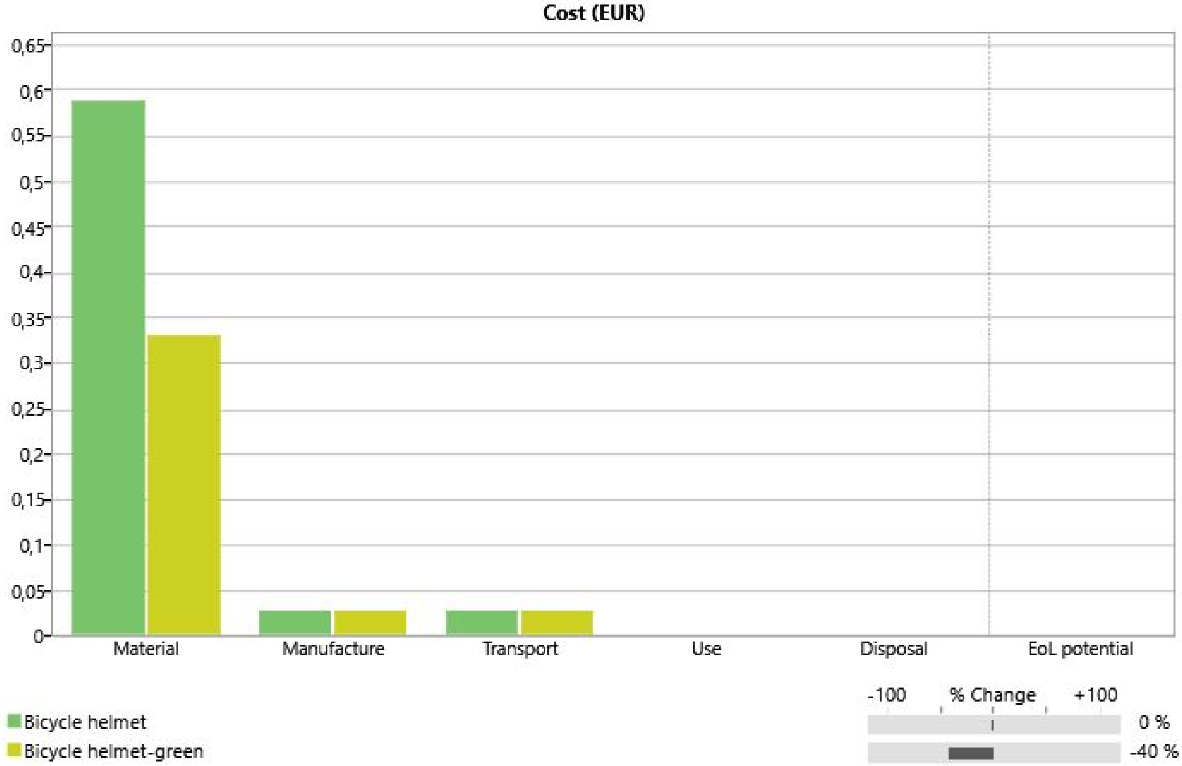
Thus, overall impact changes also:

	Energy [MJ]	**CO2 [kg]**	**cost [€]**
original version	22,4	0,89	0,648
green version	5,88	0,315	0,39

Lower impact of energy, CO2 footprint and cost are shown in detail in the following graphs.







Impact assessment

By replacing virgin materials by their recycled ones, the helmet gets more sustainable: Energy consumption and CO2 footprint decrease significantly and it is assumed that the use of resources and water will decrease by recycling, too. Also downcycling or even recycling at the end of use should be possible for the recyclable parts of the helmet. To ensure the safety of the helmet, no huge changes in material are done and the strength of the materials are still at the same level and should therefore hold the standards of safety. It is hoped that consumers will not be afraid of these small changes, as they may be, if biological resources were used.

Also the density and prices of the materials don't change significantly to stay in the same overall level of weight and price for the product. Still the end product could not be tested yet, as it wasn't built by now. Manufacturing processes can be assumed, but safety and comfort can only be tested by the existing end product.

Transportation is not included in the analysis, assuming that in both cases (recycled and original version of the helmet) the overall impact of transportation remains the same: Indeed, these two versions have the same size and weight.

Interpretation and conclusion

Two of the key parameters targeted during the design of our helmet were the CO2 footprint and the embodied energy during all phases of manufacturing and transportation. By focusing solely on the materials used we were able to achieve overall 73.8% reduction in the embodied energy and 64.6% reduction in the CO2 footprint for every new helmet being manufactured and delivered to a buyer. These numbers are based on the data provided above and originally sourced from Granta EduPack software. It's very important to mention that an original material was altered only if it didn't compromise the overall level of safety for our product. We had no means to build a prototype and crush test it, therefore we had to rely on the mechanical properties of selected materials like ultimate tensile strength and elongation at break.

We believe that only accessible and affordable products can effectively be "green". According to our estimations as well as the data provided by Granta EduPack - the total cost of materials should drop roughly by 50%. This is only a rough estimation and some unforeseen spendings may arise during the manufacturing process but in any case the price of the final product should be comparable or lower than that of existing solutions.

References:

[1] http://pdfstream.manualsonline.com/a/a6b135da-0a20-48d9-838b-46be8e8e8cec.pdf

[2]https://www.bellhelmets.com/on/demandware.static/-/Sites-bellhelmets-Library/default/dwe73f933e/manuals/Bell-Helmets-Bike-Helmet-Manual-B5000433-F-INT.pdf

[3]: http://www.petresin.org/faq.asp

[4]: VTT wood based EPS alternative:
https://www.vttresearch.com/en/news-and-ideas/packaging-doesnt-cost-earth#:~:text=An%20eco-friendly%20alternative%20is,and%20similar%20performance%20to%20EPS