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Life cycle assessment (LCA) of the valorisation of waste from apple processing as substitute of polyurethane

Aim

The goal of this LCA (Life Cycle Assessment) study is to identify the potential environmental benefits related to the partial substitution of polyurethane (PU) with processed waste from apple processing (WAP). This substitution non only reduces the consumption of PU but also improves the management of the waste deriving from apple processing because, in a circular economy perspective, a waste is valorised, re-utilised and substitutes another raw material.

Method

The LCA approach was applied according to the standards ISO 14040 and 14044.

In this study, the selected functional unit (i.e., the reference unit for whom all the impacts are calculated) was 1 m^2 of product.

Six products were analysed:

1. Product 1A - MELAVIR,
2. Product 1B - MELAVIR with PU instead of WAP,
3. Product 2A - LORKAPPLE,
4. Product 2B - LORKAPPLE with PU instead of WAP,
5. Product 3A - APPLE UPPER PAM,
6. Product 3B - APPLE UPPER PAM with PU instead of WAP.

Table 1 reports the main composition for the different products using WAP, for the product without WAP (1B, 2B, 3B) the percentage of WAP is replaced by PU. For each product, by comparing the one with WAP with the one without WAP (and with an increased amount of PU), it was possible to quantify the benefit related to the valorisation of WAP for the production of leatherette.

Regarding the system boundary, the analysis includes the impact related to the manufacturing of the different materials required for the different products. Background data about the impact of the different materials were retrieved by the Ecoinvent® v.3 version.

Regarding the WAP, primary data about energy consumption during the processing of apple pomace and waste were achieved by the producer. The transport was included considered the distance between Bolzen and Campi Bisenzio with a freight, lorry (>32 metric ton, EURO 6). For the transport, a full load and an empty return were taken into account.

Table 1 – Composition of the analysed products including WAP (PU = polyurethane, PL = polyester, WAP = waste from apple processing)

<table>
<tr><th rowspan="2">Parameter</th><th rowspan="2">Unit</th><th colspan="4">1A
MELAVIR</th><th colspan="4">2A
LORKAPPLE</th><th colspan="4">3A
APPLE UPPER PAM</th></tr>
<tr><th colspan="4">Value</th><th colspan="4">Value</th><th colspan="4">Value</th></tr>
<tr><td>Mass</td><td>g/m^2</td><td colspan="4">250</td><td colspan="4">350</td><td colspan="4">550</td></tr>
<tr><td>Thickness</td><td>mm</td><td colspan="4">0.68</td><td colspan="4">0.8</td><td colspan="4">1</td></tr>
<tr><td>Width</td><td>cm</td><td colspan="4">140</td><td colspan="4">140</td><td colspan="4">140</td></tr>
<tr><td rowspan="2">Composition</td><td>%</td><td colspan="3">PL</td><td>18%</td><td>PL</td><td>27%</td><td>Cotone</td><td>22%</td><td>PL</td><td>20%</td><td>Cotone</td><td>16%</td></tr>
<tr><td>%</td><td>PU</td><td>43%</td><td>WAP</td><td>39%</td><td>PU</td><td>27%</td><td>WAP</td><td>24%</td><td>PU</td><td>38%</td><td>WAP</td><td>26%</td></tr>
</table>

About the WAP, the carbon content was assumed to be stably incorporated into the product and, consequently, an absorption of carbon dioxide from the atmosphere was considered. This absorption, calculated considering the dry matter content of the material and a 55% of carbon in the dry matter, represents an environmental benefit related to the production of 1A, 2A and 3A.

The consumption of energy and other inputs, as well as the production of wastes (in term of mass and characteristics) was considered similar between the product with and without WAP. Consequently, being the aim of this LCA study comparative, they were excluded in this preliminary assessment.

The following impact categories were evaluated considering the ReCiPe 2016 Midpoint (H) V1.04 / World (2010) H method:

1. Global warming (expressed as kg CO_2 eq);
2. Stratospheric ozone depletion (expressed as kg CFC11 eq);
3. Ionizing radiation (expressed as kBq Co-60 eq);
4. Ozone formation, Human health (expressed as kg NOx eq);
5. Fine particulate matter formation (expressed as kg PM2.5 eq);
6. Ozone formation, Terrestrial ecosystems (expressed as kg NOx eq);
7. Terrestrial acidification (expressed as kg SO_2 eq);
8. Freshwater eutrophication (expressed as kg P eq);
9. Marine eutrophication (expressed as kg N eq);
10. Terrestrial ecotoxicity (expressed as kg 1,4-DCB);
11. Freshwater ecotoxicity (expressed as kg 1,4-DCB);
12. Marine ecotoxicity (expressed as kg 1,4-DCB);
13. Human carcinogenic toxicity (expressed as kg 1,4-DCB);
14. Human non-carcinogenic toxicity (expressed as kg 1,4-DCB);
15. Land use (expressed as m_2a crop eq);

16. Mineral resource scarcity (expressed as kg Cu eq);
17. Fossil resource scarcity (expressed as kg oil eq).

Results

Tables 2 – 4 report the absolute results for the products 1A and 1B (Table 2), for the product 2A and 2B (**Table 3**) and for the product 3A and 3B (**Table 4**). The tables also report the impact reduction achieved thanks to the substitution of PU with WAS. The relative comparison is reported **Figure 1** for product 1A and 1B, in **Figure 2** for product 2A and 2B and in **Figure 3** for product 3A and 3B. In the graph, for the different environmental effects, the product with the higher environmental impact is set equal to 100% while the score for the other product is proportionally scaled.
The results of the contribution analysis with the identification of the environmental hotspots (i.e., processes most contributing to the total impact for the different impact categories) is reported in **Figure 4-5** for products 1A and 1B, in **Figure 6-7** for products 2A and 2B and in **Figure 8-9** for products 3A and 3B. In the graph each column can be read as a cake graph, higher is the contribution to the total impact of the specific material larger is the corresponding bar.

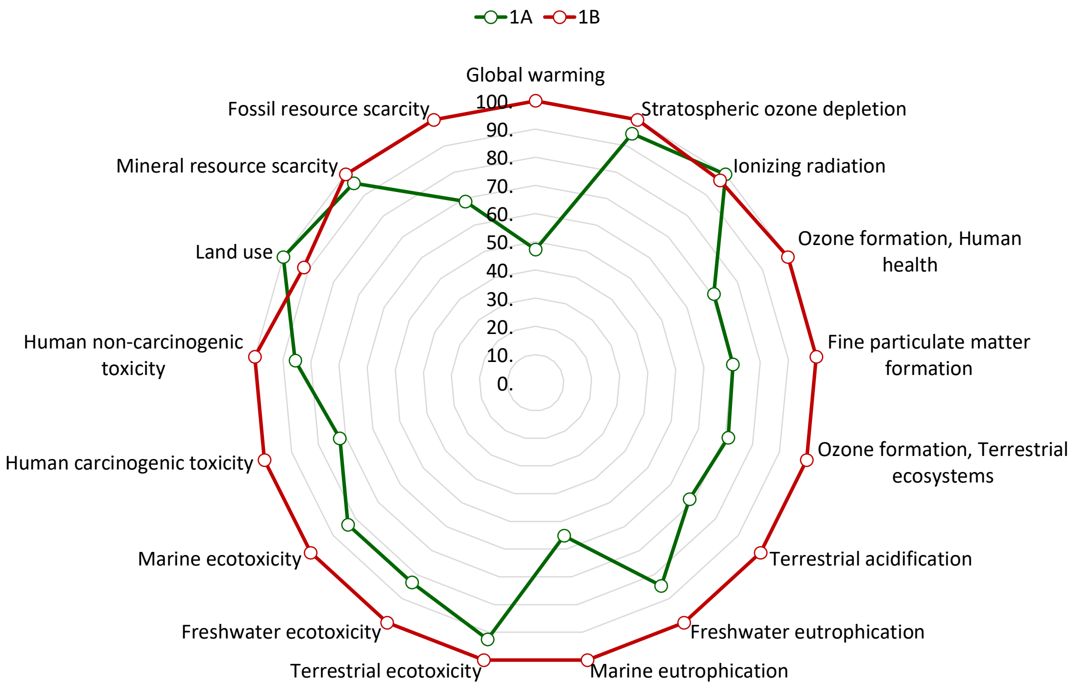

Figure 1 – Relative comparison between product 1a and 1B

Table 2 – Absolute impact 1 m2 of product 1A and 1B (Melavir)

Impact category	**Unit**	**1A**	**1B**	**Δ**
Global warming	kg CO2 eq	0.71574	1.513226	-53%
Stratospheric ozone depletion	kg CFC11 eq	2.53E-07	2.67E-07	-5%
Ionizing radiation	kBq Co-60 eq	0.042645	0.041418	3%
Ozone formation, Human health	kg NOx eq	0.002353	0.003331	-29%
Fine particulate matter formation	kg PM2.5 eq	0.001463	0.002081	-30%
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.002515	0.003539	-29%
Terrestrial acidification	kg SO2 eq	0.003494	0.005104	-32%
Freshwater eutrophication	kg P eq	0.000227	0.000269	-15%
Marine eutrophication	kg N eq	0.000109	0.000198	-45%
Terrestrial ecotoxicity	kg 1,4-DCB	2.530169	2.734314	-7%
Freshwater ecotoxicity	kg 1,4-DCB	0.036681	0.044027	-17%
Marine ecotoxicity	kg 1,4-DCB	0.048332	0.057919	-17%
Human carcinogenic toxicity	kg 1,4-DCB	0.039738	0.055044	-28%
Human non-carcinogenic toxicity	kg 1,4-DCB	0.740048	0.864723	-14%
Land use	m2a crop eq	0.103373	0.094914	9%
Mineral resource scarcity	kg Cu eq	0.008065	0.008428	-4%
Fossil resource scarcity	kg oil eq	0.386636	0.561294	-31%

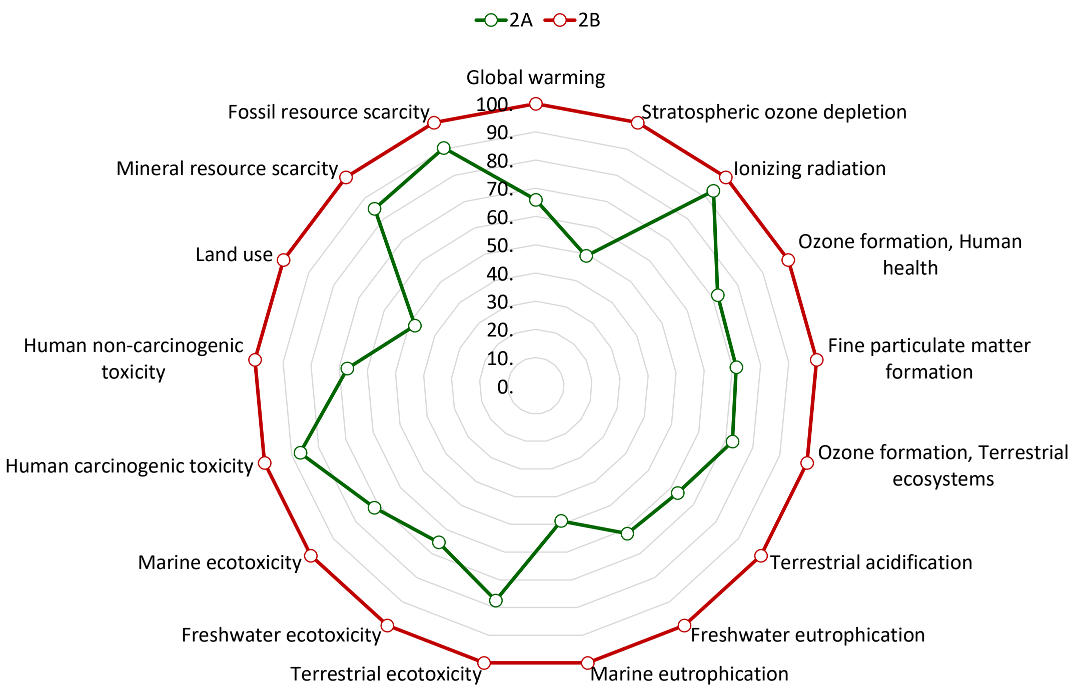

Figure 2 – Relative comparison between product 2A and 2B

Table 3 – Absolute impact 1 m² of product 2A and 2B (LORKAPPLE)

Impact category	**Unit**	**2A**	**2B**	Δ
Global warming	kg CO2 eq	1.18663	1.801034	-34%
Stratospheric ozone depletion	kg CFC11 eq	4.50E-06	9.11E-06	-51%
Ionizing radiation	kBq Co-60 eq	0.045718	0.048911	-7%
Ozone formation, Human health	kg NOx eq	0.003908	0.005422	-28%
Fine particulate matter formation	kg PM2.5 eq	0.002484	0.003479	-29%
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.004114	0.005677	-28%
Terrestrial acidification	kg SO2 eq	0.008308	0.013188	-37%
Freshwater eutrophication	kg P eq	0.000534	0.000865	-38%
Marine eutrophication	kg N eq	0.003446	0.007063	-51%
Terrestrial ecotoxicity	kg 1,4-DCB	3.332844	4.30359	-23%
Freshwater ecotoxicity	kg 1,4-DCB	0.070836	0.108423	-35%
Marine ecotoxicity	kg 1,4-DCB	0.075025	0.104589	-28%
Human carcinogenic toxicity	kg 1,4-DCB	0.048444	0.055783	-13%
Human non-carcinogenic toxicity	kg 1,4-DCB	1.321973	1.970785	-33%
Land use	m2a crop eq	35.97652	75.10714	-52%
Mineral resource scarcity	kg Cu eq	0.008702	0.010249	-15%
Fossil resource scarcity	kg oil eq	0.464416	0.513631	-10%

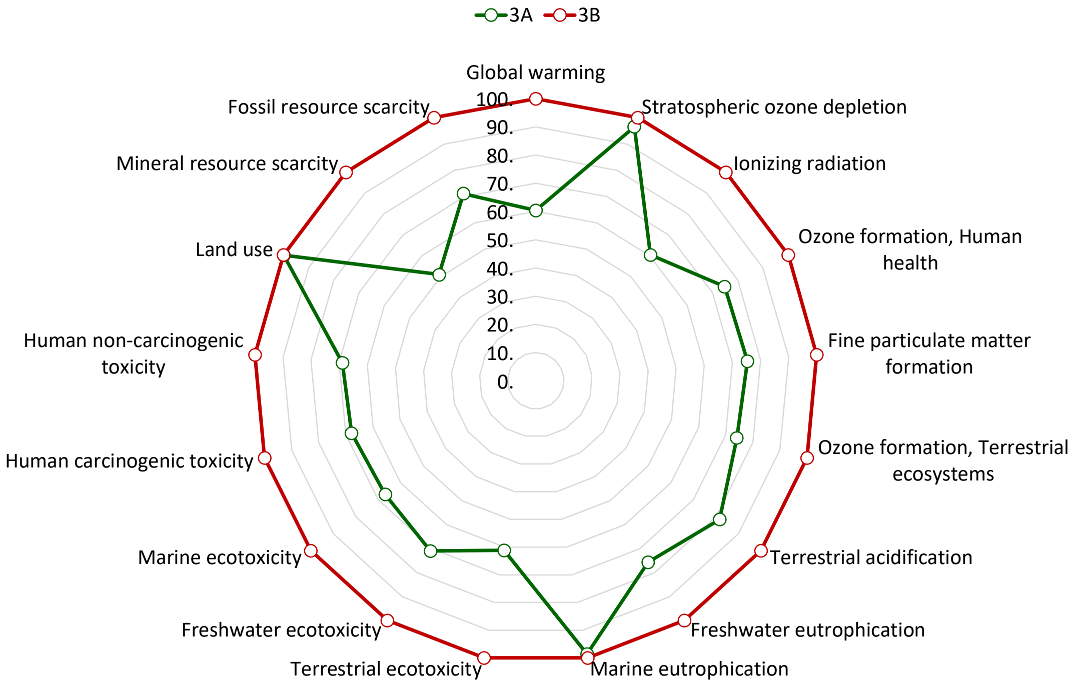

Figure 3 – Relative comparison between product 3A and 3B

Table 4 – Absolute impact 1 m² of product 2A and 2B (APPLE UPPER PAM)

Impact category	**Unit**	**3A**	**3B**	Δ
Global warming	kg CO2 eq	1.800368	2.980818	-40%
Stratospheric ozone depletion	kg CFC11 eq	5.22E-06	5.40E-06	-3%
Ionizing radiation	kBq Co-60 eq	0.059329	0.098325	-40%
Ozone formation, Human health	kg NOx eq	0.00564	0.007545	-25%
Fine particulate matter formation	kg PM2.5 eq	0.00358	0.004752	-25%
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.005928	0.008	-26%
Terrestrial acidification	kg SO2 eq	0.011444	0.014015	-18%
Freshwater eutrophication	kg P eq	0.000675	0.000892	-24%
Marine eutrophication	kg N eq	0.004032	0.004091	-1%
Terrestrial ecotoxicity	kg 1,4-DCB	4.25537	6.956644	-39%
Freshwater ecotoxicity	kg 1,4-DCB	0.091105	0.128253	-29%
Marine ecotoxicity	kg 1,4-DCB	0.099048	0.148014	-33%
Human carcinogenic toxicity	kg 1,4-DCB	0.073423	0.108037	-32%
Human non-carcinogenic toxicity	kg 1,4-DCB	1.693748	2.459297	-31%
Land use	m2a crop eq	41.13419	41.21723	0%
Mineral resource scarcity	kg Cu eq	0.01055	0.020736	-49%
Fossil resource scarcity	kg oil eq	0.738194	1.037734	-29%

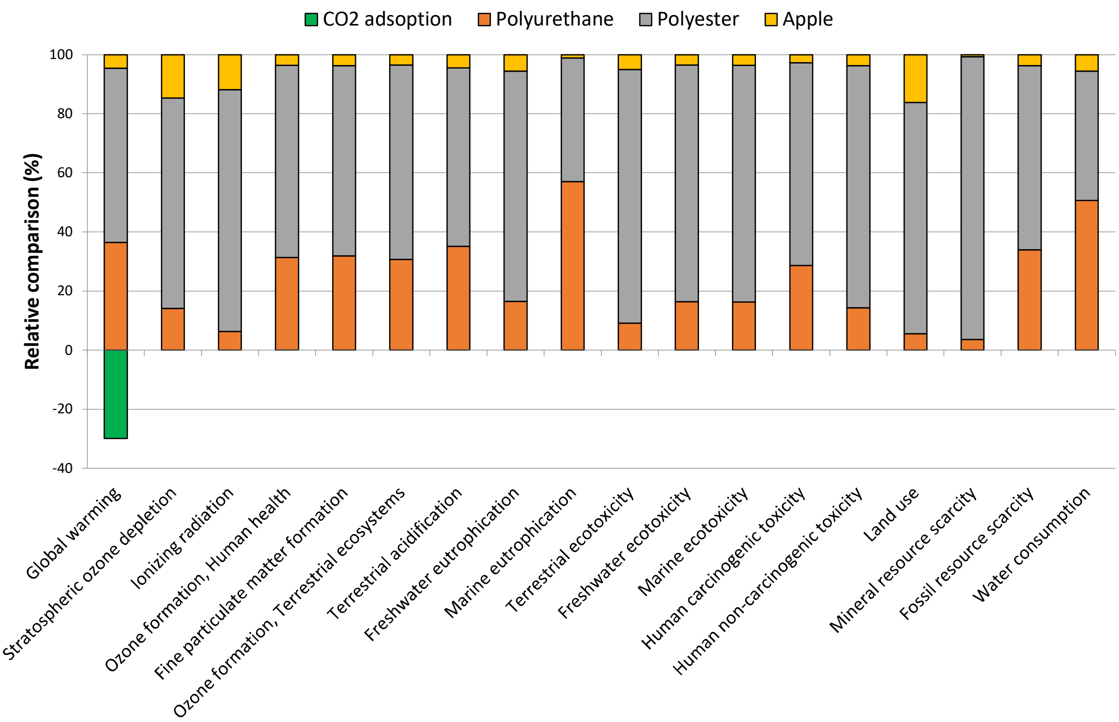

Figure 4 – Contribution analysis for the product 1A

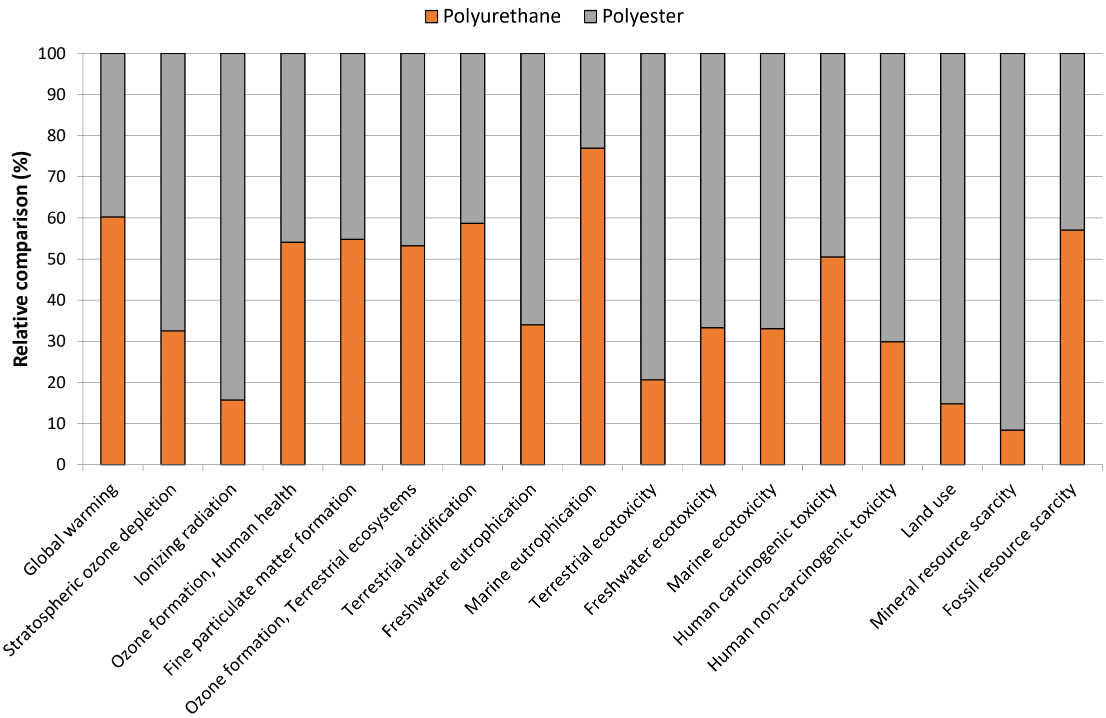

Figure 5 – Contribution analysis for the product 1B

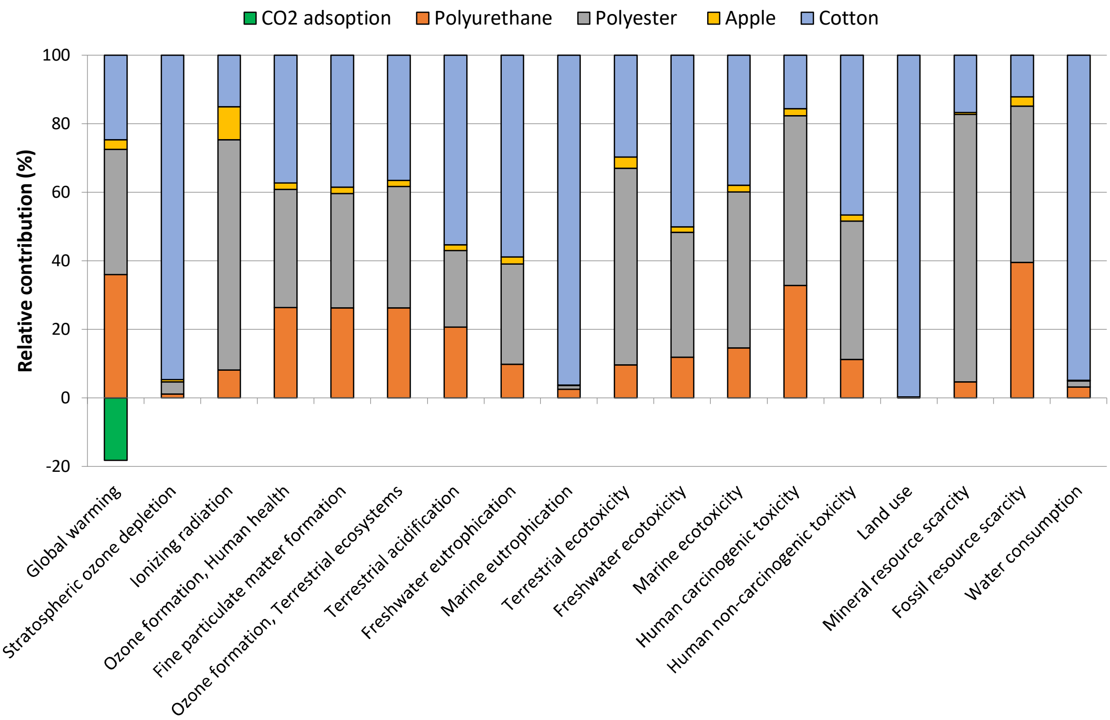

Figure 6 – Contribution analysis for the product 2A

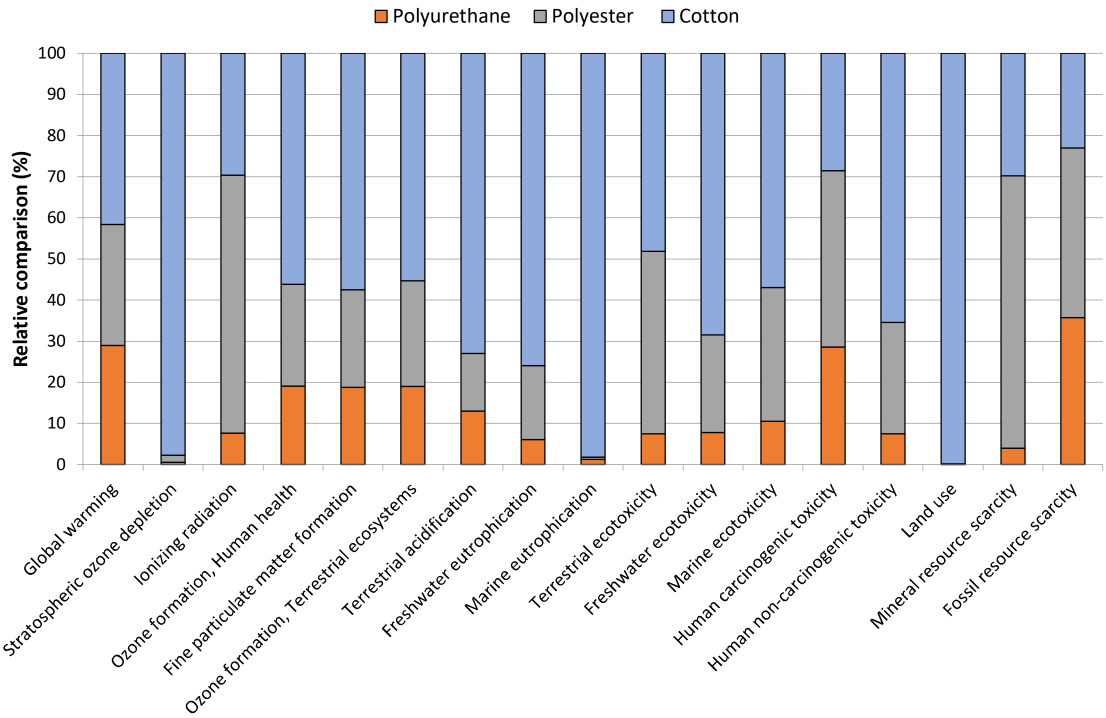

Figure 7 – Contribution analysis for the product 2B

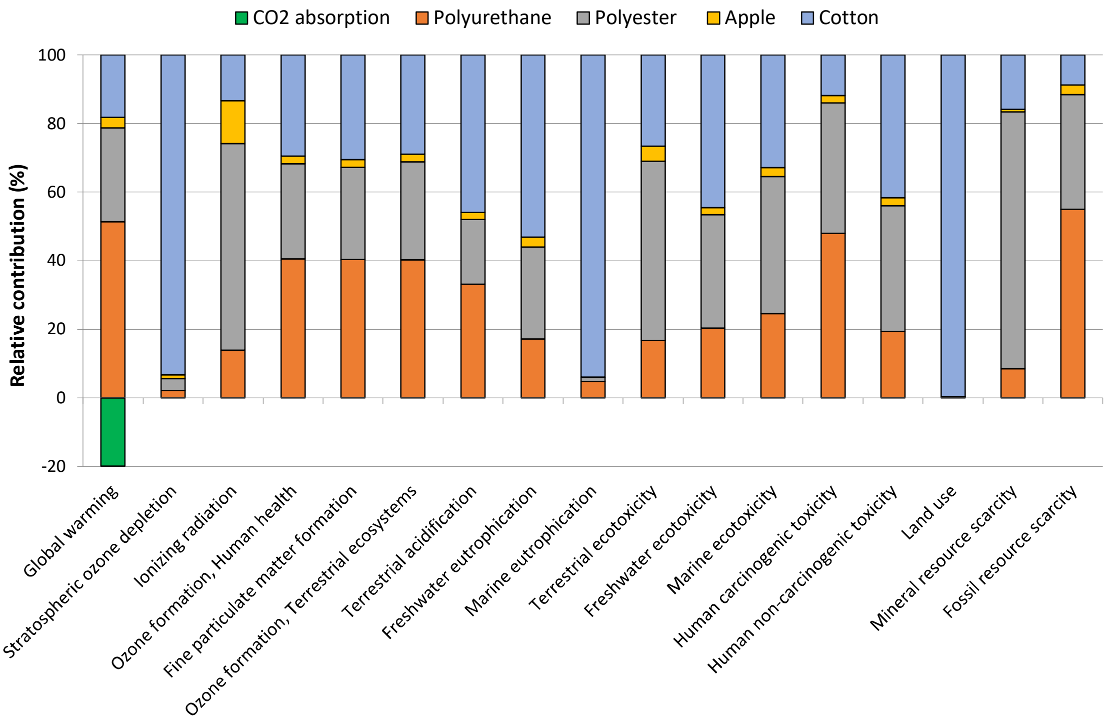

Figure 8 – Contribution analysis for the product 3A

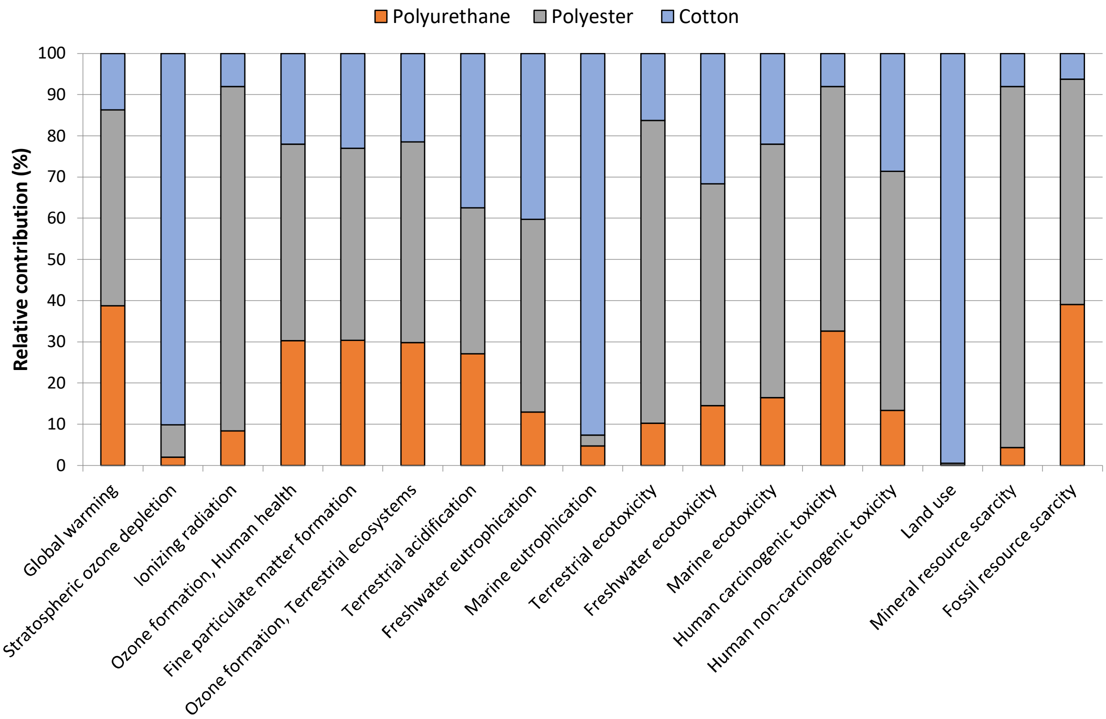

Figure 9 – Contribution analysis for the product 3B