Product life cycle of a greener backpack

Task 3

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I. Creation Processes of Component Parts

Polymers are most commonly derived from fossil fuels, such as natural gas and coal tar. Both ethane and propane are extracted from natural gas in a process called cryo- liquification, which uses cold temperatures to turn the natural gas into liquid, which then separates into its component gases. Naphtha is a derivative of coal tar distillation, a process using high temperatures to boil off desired or undesired elements from a combined source, such as coal tar. Ethane, propane, and naphtha are all further refined into ethylene and propylene through steam cracking.

Natural gas and coal tar are also made into synthesis gas through steam reforming and coal gasification, respectively. Syngas, as it's often called, is a mixture of primarily hydrogen, carbon monoxide, and some carbon dioxide. Methanol is produced by combining hydrogen and carbon monoxide through catalyst reaction over copper and zinc oxides.
Ethylene is then used in both chain-growth polymerization and an oxidation process to produce (low density)polyethylene and ethyl glycol, respectively. Propylene also undergoes chain-growth polymerization to become polypropylene. Methanol is oxidized similarly to ethylene, but to produce formaldehyde. Oxidation of ethylene along with methanol esterification are used together to produce dimethyl terephthalate through several more complex steps.
Polyoxymethylene is derived from formaldehyde through the steps of anionic catalysis and acetic anhydride stabilization. Ethyl glycol and dimethyl terephthalate are combined through trans-esterification, and then purified by distilling off unwanted byproducts, to produce polyethylene terephthalate.

The mixing of diisocyanate monomer and macro glycol, and the subsequent reaction with diamine creates a prepolymer solution which is then spun through a panel with small holes in it to create elastane thread. Low density polyethylene (LDPE) is extruded into a foam, polypropylene and polyoxymethylene are molded into components, and polyethylene terephthalate is extruded into threads. These component parts are woven or welded to combine into the different elements of the backpack, which are sewn and assembled together to create a finished product.

The metallic zinc zipper tabs are created through a different process line, though some of the steps could possibly be supplied from the fossil fuel processes, such as carbon monoxide use.
Zinc starts as sulfidic ore deposits in the form of sphalerite (ZnS) crystals. Sulfidic ore usually contains many other metallic sulfides, however, so the ore is ground into a fine powder, which is then separated through froth flotation. Lighter elements rise to the top of differently weighted liquids, making it possible to separate each component sulfide out.
The resulting zinc sulfide ore concentrate is roasted, causing both the zinc and sulfur to oxidize in the high temperatures and separate. Sulfur dioxide is catalyzed over vanadium oxide to add another oxygen, creating sulfur trioxide, which is mixed bathed in sulfuric acid to create oleum, also known as fuming sulfuric acid. Oleum is diluted with water to create more sulfuric acid, which can be reused for multiple processes.

Meanwhile, the zinc oxide can either be burned with carbon monoxide from fossil fuels and distilled to create pure zinc and carbon dioxide, or can undergo a process called electrowinning, which uses sulfuric acid and an electrolysis reduction to leach the zinc out of the concentrate. In the end of either process, the result is around 99% pure zinc, known commonly as special high grade (SHG), which can be cast into parts or used in other important processes, such as galvanization.

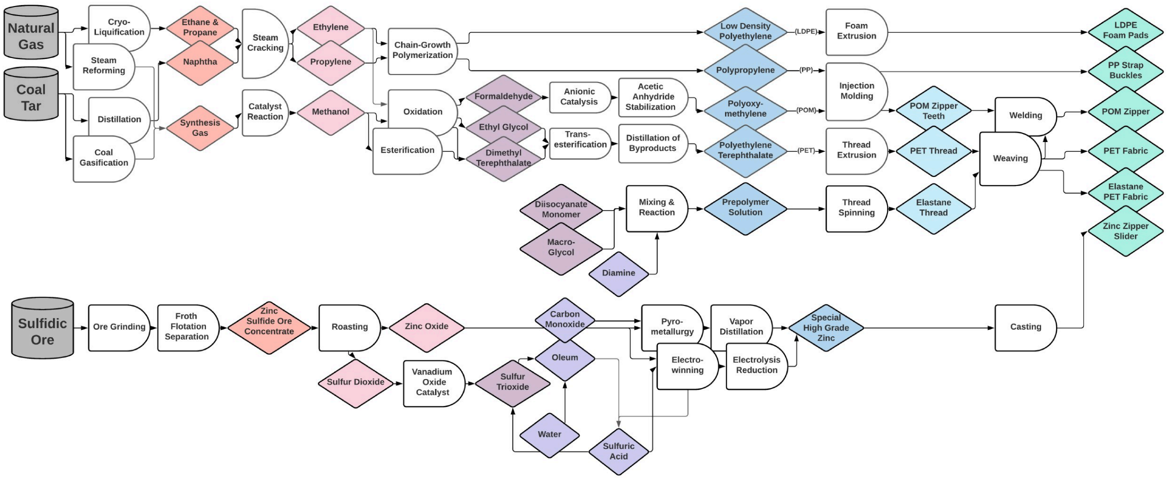

Figure 1: Creation Process Visual Map

II. Functional unit definition

A greener bag doesn't mean less performance. That is why it must meet the specifications of a classic backpack.
Therefore, we will evaluate the lifetime of the materials of the greener bag. The materials of the greener backpack will have to be just as rigid and durable as the classic backpack Then, we will compare the water used and of course the price of the overall production.

III. Goal and scope definition

To make our bag more durable, the objectives are multiple. Through a first study which consists in evaluating the environmental impact of the classic bag we will be able to compare the impact of our greener bag.
Therefore, our study will be based on 4 main areas. The first is the production of our materials, which includes the impact of this extraction. Then we have the assembly, which includes manufacturing and transport. Then we have the use part of the bag. Finally, the end of life which consist of recycling, reusing of the backpack or directly throwing in the trash.

In our comparison, we will only take these parameters into account. In fact, the LCA software does not have the database containing all the materials of our product, we will use both LCA and CES which will allow us to obtain information on the environmental impact, as well as the cost of our product.
By indicating the dimensions of our material, the extraction of the raw material will be given. We will consider that this raw material will be assembled by a process previously defined in the LCA. Thus the impact of the assembly will be evaluated.
Afterwards, we will see the impact in terms of transportation. We will impose a maritime transport and a truck transport.
Finally, in terms of recycling, we will take into account if the bag is directly thrown in the garbage or if it is 100% recycled or reused.

IV. Inventory Analysis

CES do not work in the same as LCA. However, we can define our Inputs as:

Components

Qty.	Component name	Material	Recycled content	Mass (kg)	Primary process	Length (m)	Secondary process	% removed	End of life	% recovered
1	Bottom foam	PE foam (cross-linked,...	Virgin (0%)	0,008	Polymer extrusion	0		0	Landfill	100
1	Size adjustment textile	PE-LD (molding and e...	Virgin (0%)	0,022	Polymer extrusion	0		0	Landfill	100
1	Handle foam	PE foam (cross-linked,...	Virgin (0%)	0,0093	Polymer extrusion	0		0	Landfill	100
1	Side pocket	PE-LD (molding and e...	Virgin (0%)	0,0024	Polymer extrusion	0		0	Landfill	100
1	Metallic ZiP	Zinc-aluminum alloy, All...	Virgin (0%)	0,0265	Casting	Not Required	Fine machining	0	Landfill	100
1	Zip polyoxymethylene	POM (homopolymer,...	Virgin (0%)	0,0225	Polymer extrusion	0	Fine machining	0	Landfill	100

Polyester polyols	Materials production/...	0.11240	kg	none	P Polyes...
Polypropylene (PP) fiber	Materials production/...	0.01040	kg	none	P Polypr...
Polyester		0.01460	kg	none	
Polyether polyols (long chain)	Organic chemicals/nan	0.00220	kg	none	

Figure 2: Inputs of the classic backpack

These inputs are the one of the classic backpack, we will try to replace them by another material which are less polluting. We will reveal their natures only in the following session. Concerning the output, we have only the backpack.

IV. Impact assessment

First we will study all the materials separately to find alternative materials through CES, then later we will use LCA to have a global vision of our classic bag compared to the greener bag. In our case, the environmental impact is evaluated according to the energy consumed, the CO_2 emissions and the cost of materials.

a) PE-LD, PE-Foam, Zinc Aluminium alloy, and POM Analysis

In this first part we will evaluate the impact of PE foam, PE LD, Zinc and POM. To understand and solve our problem, we first need to do a Design Requirements.

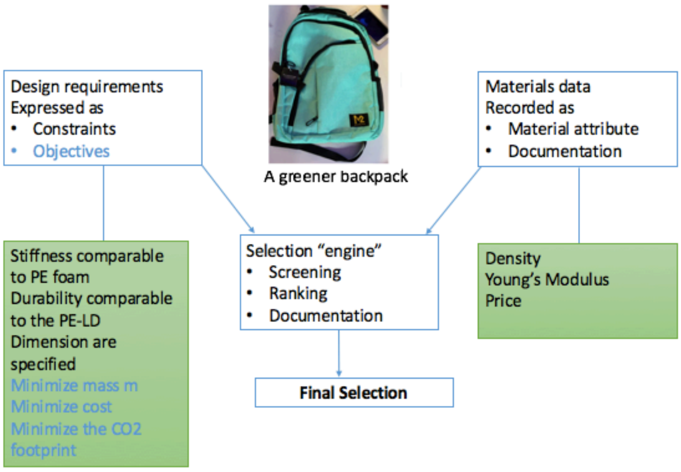

Figure 3: Design requirement for the greener backpack

In figure 4, we notice that in terms of energy consumed, the raw material is the most important. It is then followed by manufacturing and finally, what we least suspected, by transport. Indeed, it is less compared to these two processes. The "backpack" terms take only into account the inputs just mentioned above.

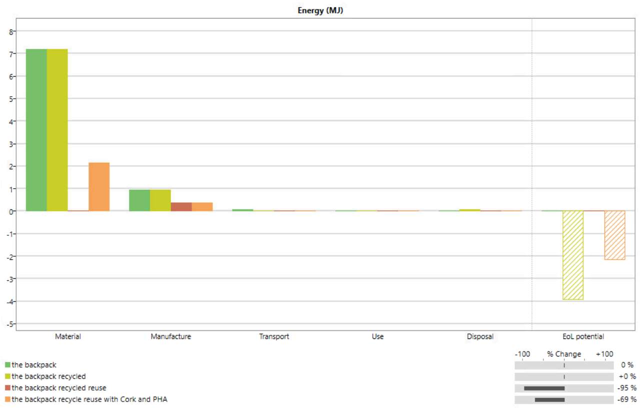

Figure 4: Energy consumed in the production of a backpack, a backpack using recycled materials, a recycled material reused, and a backpack using alternative materials.

According to this first graph, we see that the energy consumed by the material itself is the most important. By common sense, it is therefore necessary to reduce it as much as possible. To do this, we have chosen to replace some of our materials with alternative materials. The materials presented in figure 2, being our reference elements, it is therefore necessary that our alternative materials respect the same criteria as the latter. From the inputs presented in figure 2, we deduce that in terms of mass, PE foams and PE-LD are the most important elements. Furthermore, according to the literature [1], zinc remains one of the most recyclable materials compared to Polyethylene.

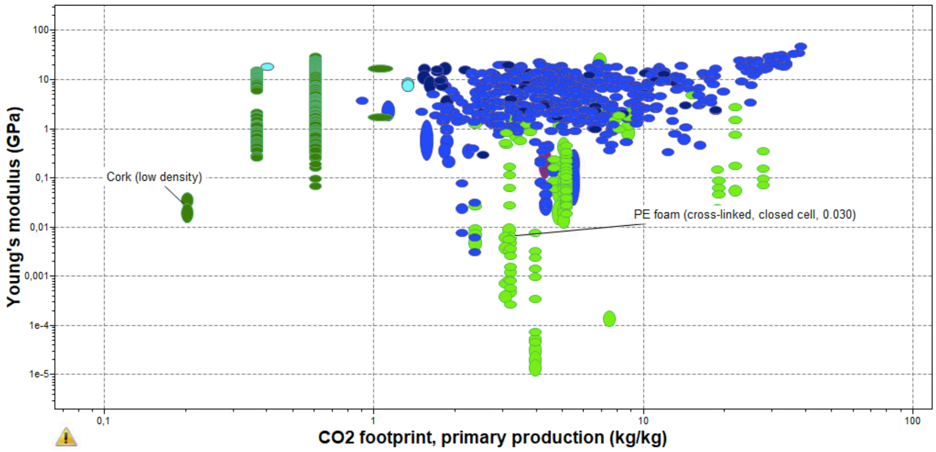

Figure 5: Evolution of the Young's Modulus against the CO_2 footprint for the plastics and hybrids materials (foam and naturals materials)

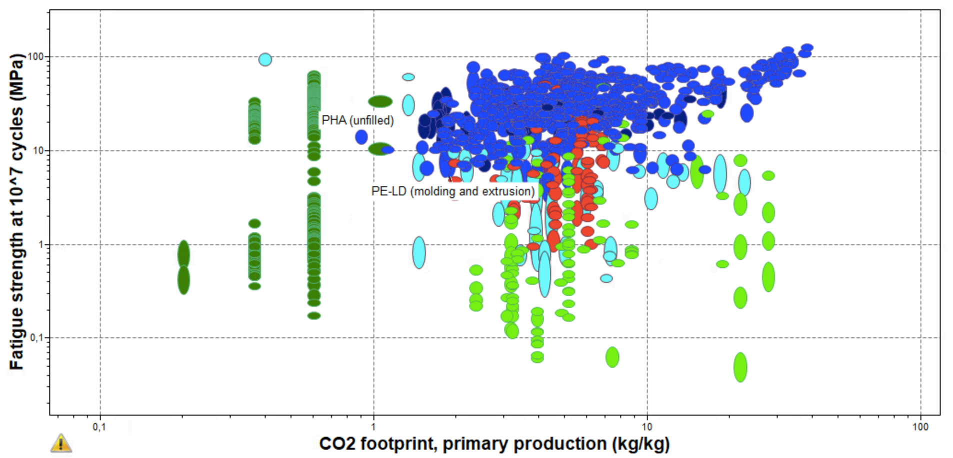

Figure 6: Evolution of the fatigue strength against the CO_2 footprint for the plastics and hybrids materials (foam and naturals materials)

We know that young's modulus refers to the rigidity of our material. Analyzing figure 6, we notice that PE foam can support 0.01GPa, and produces 3kg/kg of CO2.
In our search for an alternative material that respects the rigidity criterion and produces less CO2, we turned to cork, which allows us to support more than 0.01GPa and emits less CO2 (0.2kg/kg) than PE Foam.
Similarly, by comparing the durability of the PE-LD material (figure 6) and its CO2 production, we can find an alternative material. It turns out that PHA is one of the materials that meets our objectives. However, after documentation [2], it seems that this material is still under development. We will take it as a new reference keeping in mind that this material will be one of the future materials that could limit our CO2 production.

Knowing that, we will try to minimize the cost and the weight of our materials. We can define a Penalty function (Z) for this kind of specification.

$$Z = M2 + \alpha M1$$

with

C the cost of the materials α exchange constants m the mass of the structure which can be defined as $\frac{\rho}{E^{\frac{1}{3}}}$ when we suppose to work on a panel structure

The mathematics behind the mass of the structure is explained as follow:
For a beam the mass m can be expressed as: $m = AL\rho = bhL\rho$.

With

A the surface L the length ρ the density b the width

Finally, we get this expression:

$$m = \left(\frac{12S^{*}L^{3}}{Cb}\right)^{\frac{1}{3}}(bL\text{^}2)\left(\frac{\rho}{E^{\frac{1}{3}}}\right).$$

Thus we can see the dependence with the density and the Young's Modulus. We will tried to minimized $M1 = \frac{\rho}{E^{\frac{1}{3}}}$

Concerning the cost, we know that we write the cost as $C = m * Cm$
With

Cm the cost/kg of the material m the mass explained above

Thus we will tried to minimized $M2 = \frac{Cm\,\rho}{E^{\frac{1}{3}}}$

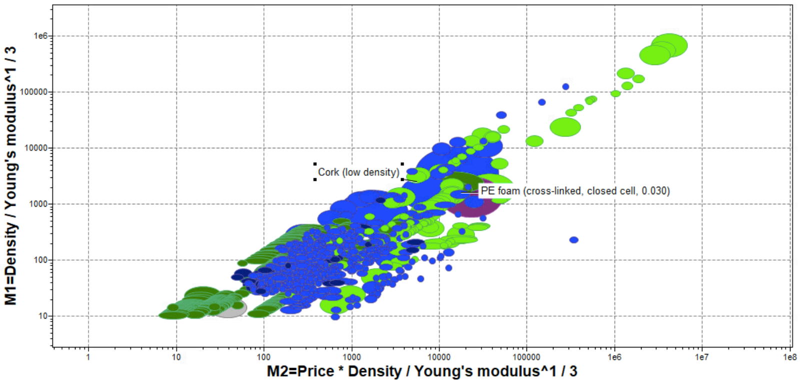

Figure 7: Dependence of the price and density for the PE foam and the Cork.

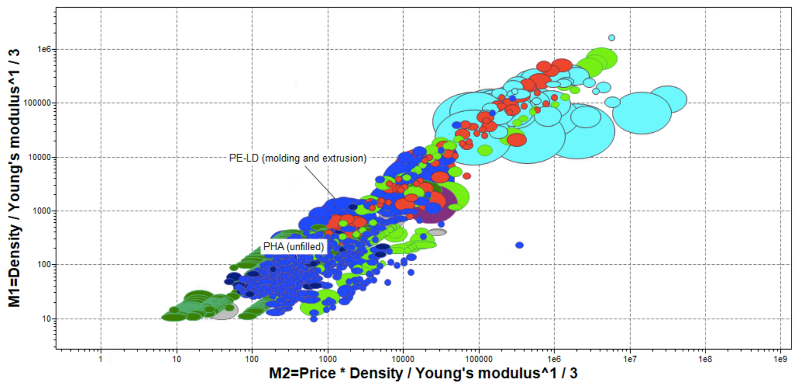

Figure 8: Dependence of the price and density for the PE LD and the PHA

According to figures 7 and 8, we can evaluate the influence of price as a function of the mass of our material. As we can see, in the case of cork it would seem that its price is less important than that of PE Foam, however its weight will be slightly more important. We have to consider that our foam is only a part of our backpack, so we can try to reduce the mass with another part. Therefore, the difference of the CO_2 footprint is considerably non negligible as it was mentioned just above.

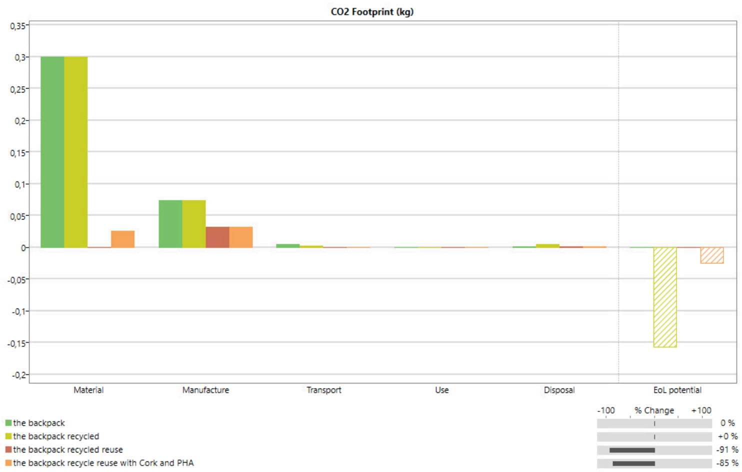

Figure 9: CO_2 footprint in the production of a backpack, a backpack using recycled materials, a recycled material reused, and a backpack using alternative materials

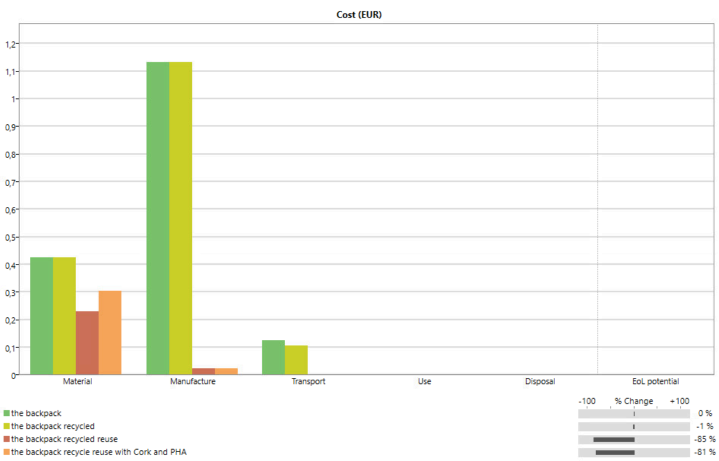

Figure 10: Cost in the production of a backpack, a backpack using recycled materials, a recycled material reused, and a backpack using alternative materials

To confirm our words, the Figure 3, show the energy consumed but it can be support by the CO_2 footprint and the cost. The CO_2 footprint is correlated with our previous analysis. Indeed, the materials are the one which produce the most. Thus by choosing some alternative materials we also reduce the CO_2 footprint. The red and orange block in figure 9, show that.

NB: when our materials are recycled, we can see the potential End Of Life, which offers the possibility to reduce the CO_2 footprint for more than a half (0,3 kg to 0,12 kg). In fact, the hatched green and orange blocks allow us to evaluate the importance of recycling our materials.

In terms of manufacture, figure 10 is much more telling, the cost being much more important for our classic bag. However, it seems that in terms of carbon footprint we can reduce our emissions by 2. By reusing our old materials and simply replacing the parts with cork and PHA we can reduce the impact, but also reduce the cost.
In the same way, we have imposed a constraint of transport in the classic bag. In the worst case, our bag is produced in China and therefore has to be transported by cargo ship. Then delivered to the point of sale by truck. Figure 11 allows us to evaluate this process.

Name	Transport type	Distance (km)
Truck	14 tonne (2 axle) truck	200
Cargo Boat	Ocean freight	2000

Figure 11: Imposing a constraint in term of transport.

In order to reduce this impact, we will assume that in the case of the recycled bag, we will only have the impact related to the truck because we will assume that the bag is already on site. In addition, in the case of reused backpacks, we will assume that the impact of transportation is less due to the fact that all the raw materials are on site and that production will take place directly on site (Ideal case).

b) Elastane and Polyester woven analysis

In this part we will analyse the Life cycle of two materials used in the backpack, namely, Elastane and Polyester.
For both analysis, we made the following assumptions; Electricity from European mix grid, and for transport, we consider road, so trucks, 28-32 tons.

First, let us consider Elastane Life cycle analysis.

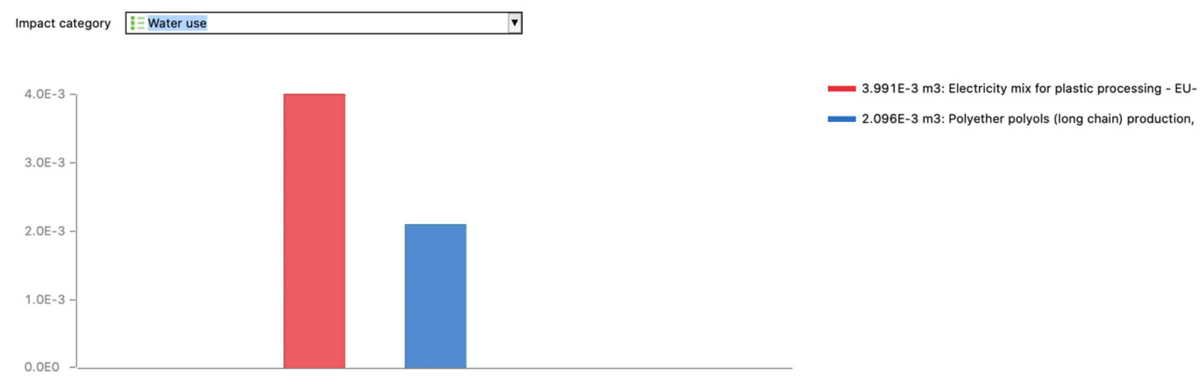

Figure 12: LCA impact analysis for Elastane for water use

To do this LCA, Elastane is a Polyurethane copolymer, and Polyether polyol is a main precursor to produce Elastane material.
As we can see, the life cycle analysis for Elastane production, the main contribution for water use during the process are the electricity needed as well as the proper polyether polyol production process.
As Elastane is a very light contribution to the total mass of the backpack, exactly 1.6 g, we consider not replacing it.

Now let us analyse Polyester material in the next section.

Figure 13: LCA impact analysis for polyester for land use

Here for the polyester part, we clearly see that the main impact in term of energy consumption is the Electricity needed to process the polymer during the fabrication. As seen with the LCA of PET (Polyester), the steps consist mainly of mechanical and chemical actions, thus leading to a high energy consumption.

c) Alternative to Polyester woven analysis

According to some articles Nylon should be more durable and fit our durability goal toward sustainability [3]. Let us consider it and perform analysis.

Replacing PET with Nylon

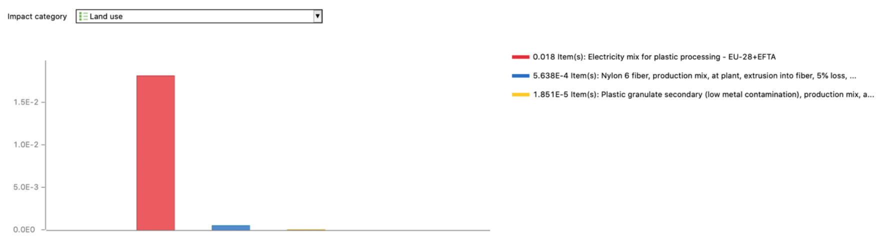

Figure 14 : LCA impact analysis for Nylon for Land use

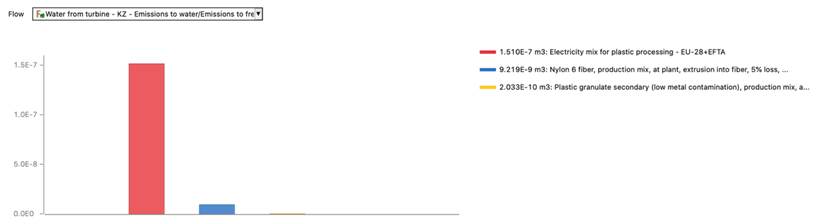

Figure 15 : LCA impact analysis for Nylon for water consumption

The LCA of an alternative to PET which is Nylon. We clearly see here the main impact again is the electricity needed for the processing.
However as a difference from Polyester, for instance the water use is newly added to the fabrication process and the electricity use is nearly decreased by a factor 100.

In order to justify the choice of this material, we proceed to GRANTA analysis of the alternative materials in order to compare the mechanical, economical and environmental aspects.

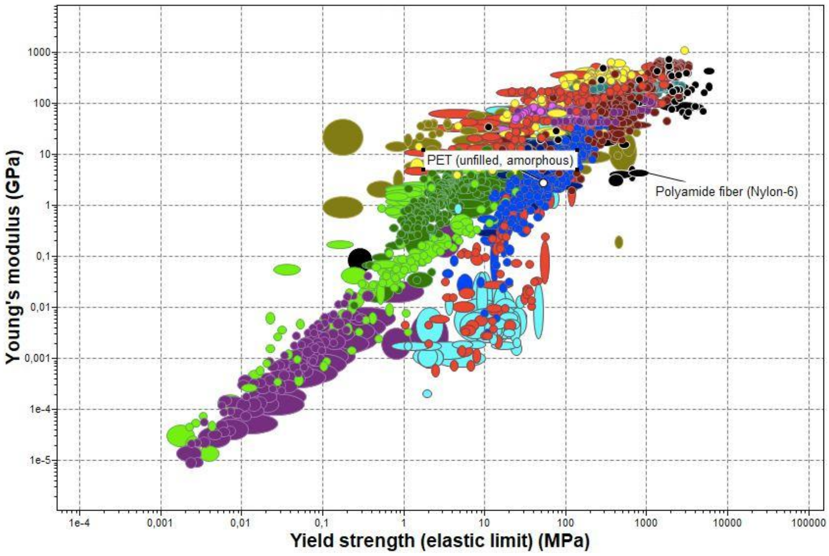

Figure 16: Evolution of the Young's Modulus against the Yield strength for the plastics and hybrids materials (PET & Nylon)

A first alternative material for PET is Nylon. Strictly considering the mechanical properties, we can see that for the Young Modulus, both materials display roughly the same value at 2-3 GPa. On another hand, for the elastic limit, Nylon shows a yield strength close to 10 times higher than PET with 800 MPa instead of 70 MPa. This means clearly that Nylon may be more durable than PET for a same applied stress.

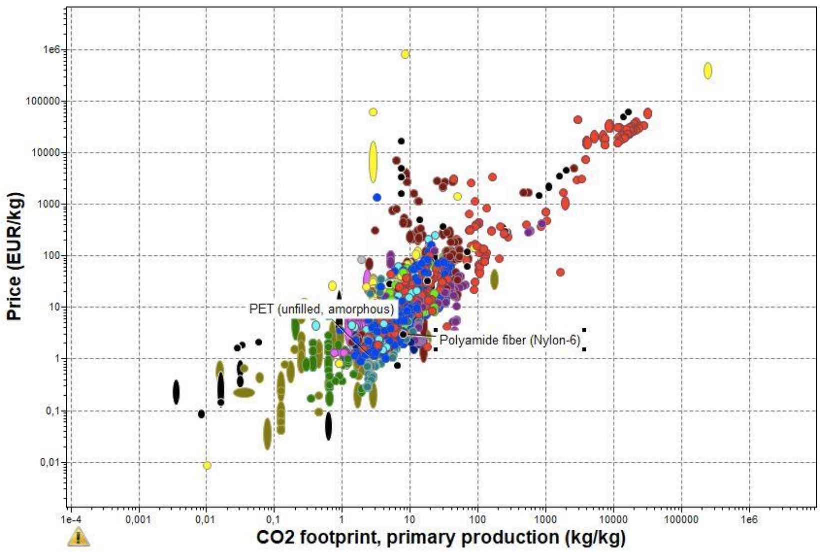

Figure 17: Evolution of the Prices against the CO_2 footprint for the plastics and hybrids materials (PET & Nylon)

In term of price range, PET is about 3 times cheaper at 1 euro/kg whereas Nylon is closer to 3 euros. Then the CO2 footprint, for primary production of Nylon is twice the one of PET at 7kg eqCO2/ kg. So choosing Nylon even if it is more durable may affect the overall CO2 footprint of the backpack.

Replacing PET with EVA:
EVA is also a promising material specially used in running shoes industry. Let us analyse it.

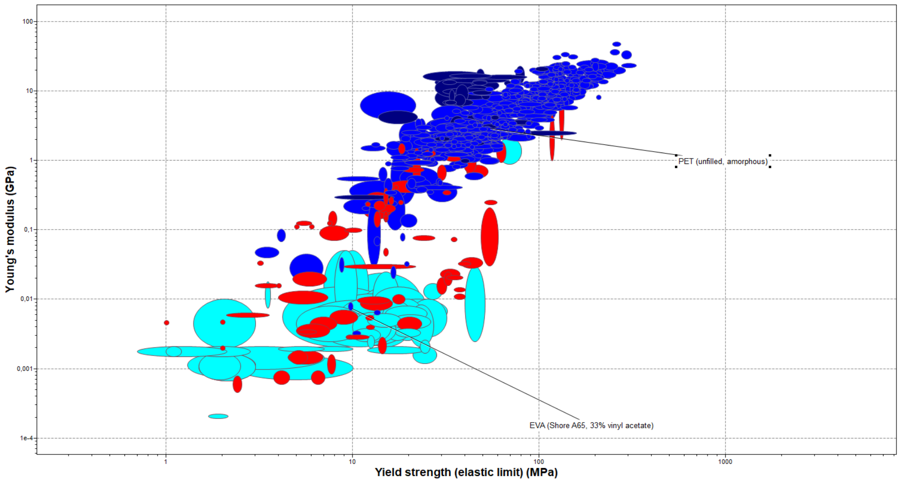

Figure 18 : Evolution of the Young's Modulus against the Yield strength for the plastics and hybrids materials (PET & EVA)

A second material considered to replace PET is EVA (Ethylene-vinyl acetate). In terms of mechanical properties, we can see here that PET (polyester) displays a Young modulus of roughly 3 GPa as well as an elastic limit of roughly 70 MPa. In comparison, EVA shows respectively 0.009 GPa and 10 MPa for the same properties. We clearly see a huge drop in the Young modulus, meaning that for a same constrain, EVA will deform more than PET.
Besides the elastic limit, is significantly lower, meaning that we can reach plastic deformation and thus a loss of elastic behaviour.

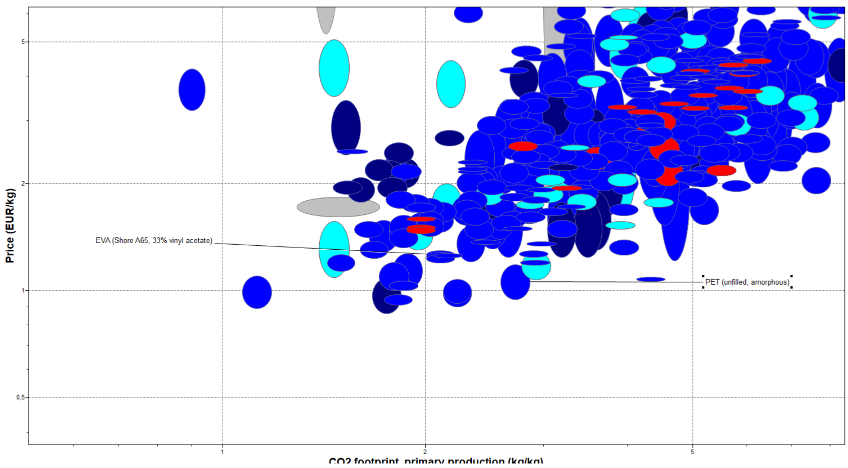

Figure 19: Evolution of the Prices against the CO_2 footprint for the plastics and hybrids materials (PET & EVA)

In term of price, both EVA and PET are in the same range around 1.3 euros/kg so this criteria is not discriminant. For the CO2 footprint, again the same order of magnitude are reached for both materials around 2.2 kg eqCO2/kg.

Replacing PET with Recycled PET.

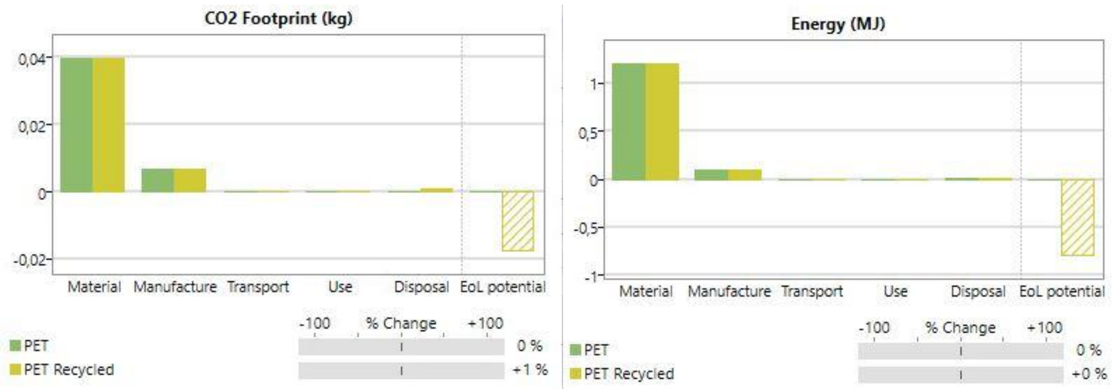

Figure 20: Impact comparative analysis for CO2 footprint and Energy consumption for PET & recycled PET

Considering now a last alternative to PET, which is recycled PET. Due to its nature, recycled PET should display about the same mechanical properties as PET. However, we can see in the figures that for all the early stages of the life cycle, both CO2 footprint and Energy consumption are the same. But the main advantage of using this recycled PET would be the negative impact on land use. In fact, we saw earlier that for PET, the main impact is in the end of life if it is not recycled. Here we see that potentially, by using recycled PET, we could compensate about half of both CO2 footprint and Energy consumption which is a considerable advantage towards the sustainability goal.
However, the mechanical properties of the recycled PET are slightly lower than the ones of normal PET, leading to a shorter use time.

Regarding all the previous option for replacing the use of PET in our backpack, Nylon might be the best option.
In fact, even if its CO2 footprint is slightly higher than the other materials, its mechanical properties ensure a long life time when used. Moreover, the replacement of both the woven PET and the main coated PET part which are the main structure of the backpack contributing with 226.6 g, we might reduce the number of materials used thus leading to a better recyclability.

d) Polypropylene and black layer polyester analysis

In the last part we evaluate the impact of black layer polyester and polypropylene. Therefore, we compared the used material with the alternative one.

A big part of the backpack is made out of black layer polyester. As an alternative material we were thinking to change this with neoprene. The advantage of using neoprene is that it has an additional protective property compared to the polyester. In figure 21 the neoprene has a lower young's modulus than the polyester, but due to the use for the back side of the backpack it does not need so much strength. Therefore, it might be a drawback which we can handle and accept. The CO_2 footprint for the neoprene is a lot lower than for the polyester. However, in figure 22 the neoprene has a slightly higher price. Nevertheless, neoprene is a good alternative to substitute the polyester.

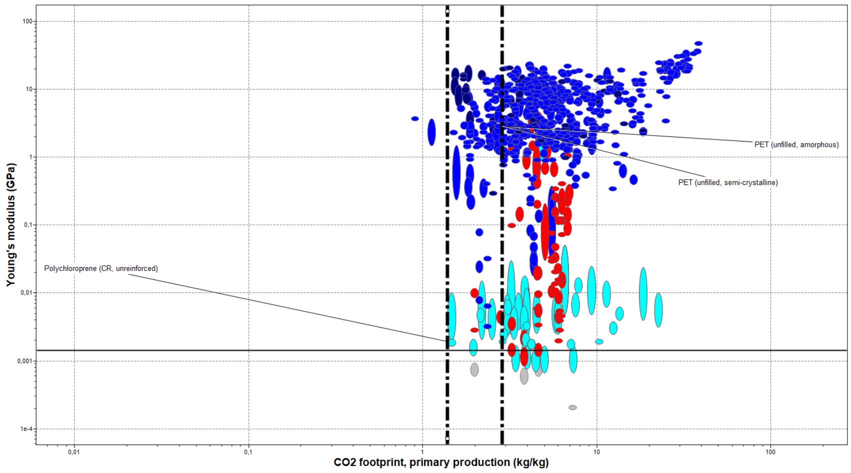

Figure 21: *Evolution of the Young's Modulus against the CO_2 footprint for the plastics and hybrids materials (polyester and alternative materials)*

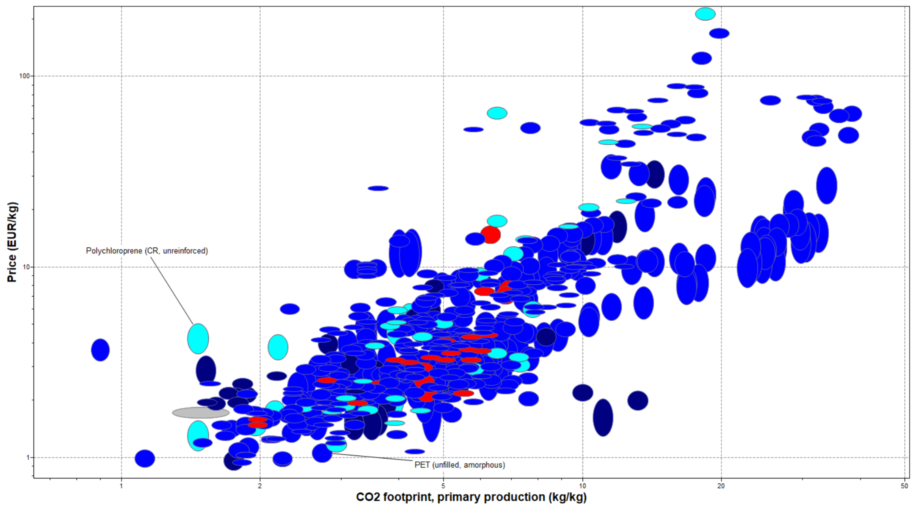

Figure 22: *Evolution of the price against the CO_2 footprint for the plastics and hybrids materials (polyester and alternative materials)*

The backpack has hard plastic clips out of polypropylene to adjust the lengths of the carrier. Those clips have a total weight of 10.4 grams of the whole backpack. The weight of the clips is relatively low and the use of the material exists for a long time without bigger problems. Therefore, it would be more sustainable to obtain this material, also due to the low price, instead of changing it.

V. Interpretation

In the following steps we analyzed the different impacts for the classical and alternative backpack.

a) Impact of classic backpack

In figure 23 the CO_2 impact is plotted for the different procedures. There it can be seen that the CO_2 impact is the highest for the electricity. This is due to the different materials, which are used for the backpack.

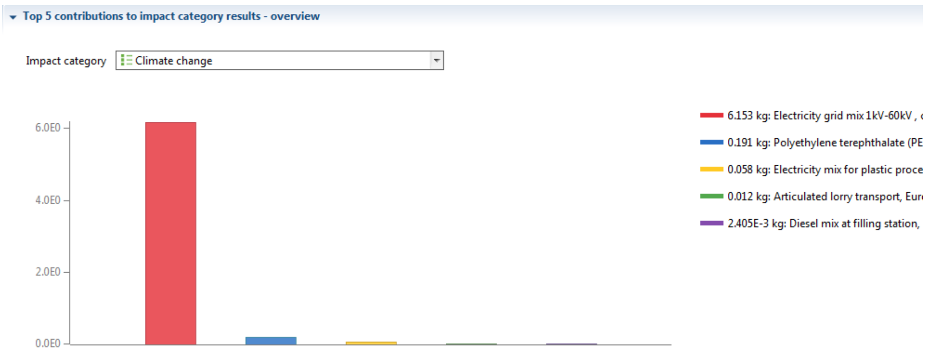

Figure 23: CO2 footprint for the end product for 5 contributions.

The figure 24 show an overview of the classical backpack and make the high amount of the different material clear.

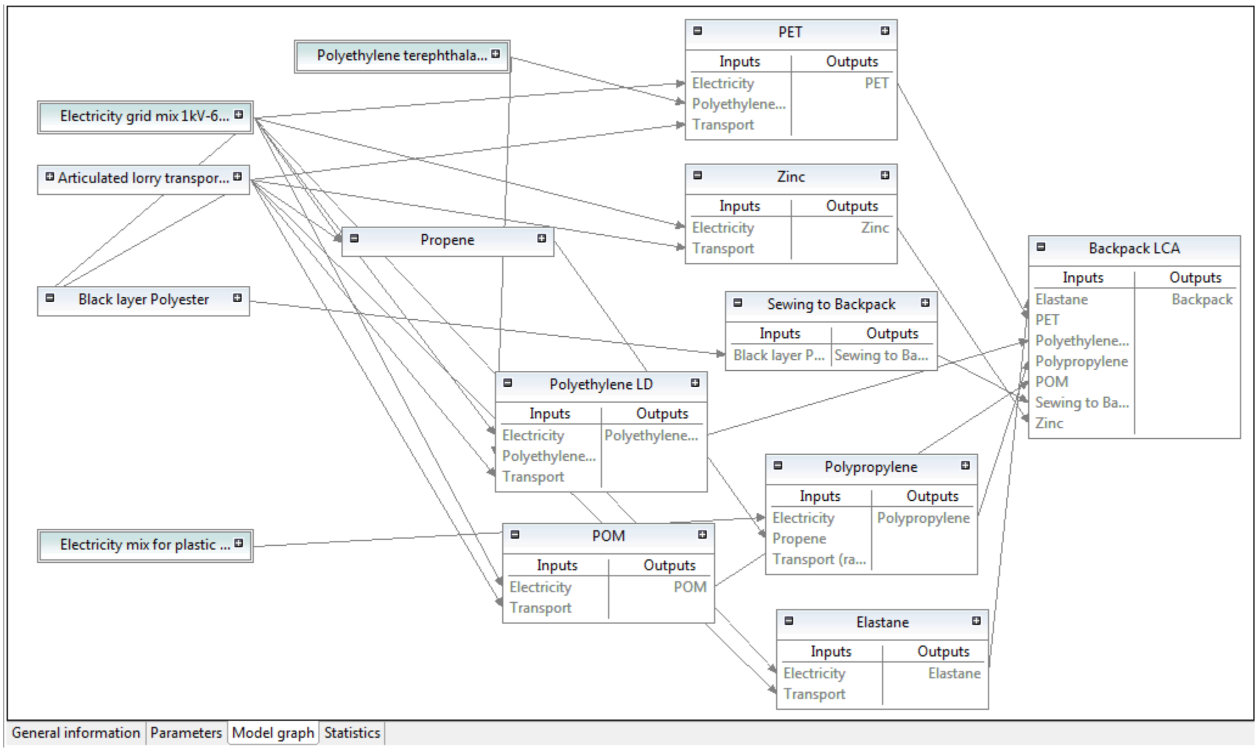

Figure 24: Overview of the LCA for the classical backpack made by OpenLCA.

As reason, for this high use of electricity is that the industries are using few renewable energy sources. During the usage phase, the classical backpack does not have any impact. Considering the end-of-life for the backpack, there are different opportunities. First, the backpack can be

reused in the meaning that it can be resold to other people. Something similar would be to give the bad preserved or broken backpack to a person, which refurbish the product and resell it again.
However, it would be more realistic that the backpacks end up in a landfill instead of getting refurbished. The reason is that it is nearly impossible to split the different used materials of the backpack to recycle all of them properly.
To sum it up, the biggest impact is in the manufacturing of the backpack and a little while the end-of-life, but not for the usage phase.
For the reasons given above, other materials could reduce the impact of the backpack.

b) Impact of the greener backpack

For this LCA the following assumptions has been made:

-Local production of the backpack, thus electricity consumption is from the Finnish electricity grid mix
-Transportation of the raw materials and backpack assembled by truck 28-32 tons, for a distance of 250 km.
-The POM (polyoxymethylene), is approximated by acetaldehyde.

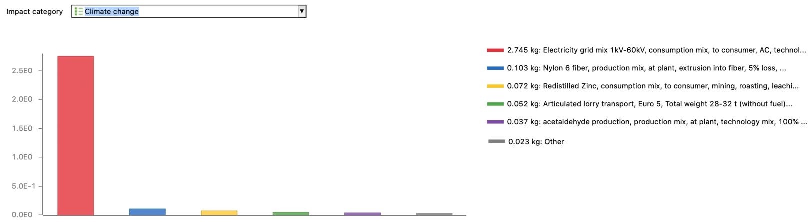

Figure 25: Impact analysis for CO2 footprint for the Green Backpack

In the figure above, we considered the “Climate change impact” as in the Classical backpack part, in order to be able to compare the results. Moreover, we made the same assumptions except for the electricity mix grid, as for the classical backpack we assume it is produced out of Finland.
As we can see, the electricity consumption which is the main impact for the backpack production is decreased nearly by a factor 2.3, from 6.1 to 2.7 kg.

For this greener back pack we also aimed to reduce the number of different materials used for instance PET is used in different forms (woven, coated), so this implies multiple processes. By replacing them all by a unique waterproof material, Nylon we contribute to reduce the overall production impact of the backpack. Also considering the lifetime and durability, by using nylon that have higher mechanical properties, it will last longer than the classical backpack, so we are also reducing the overall impact in this regard.

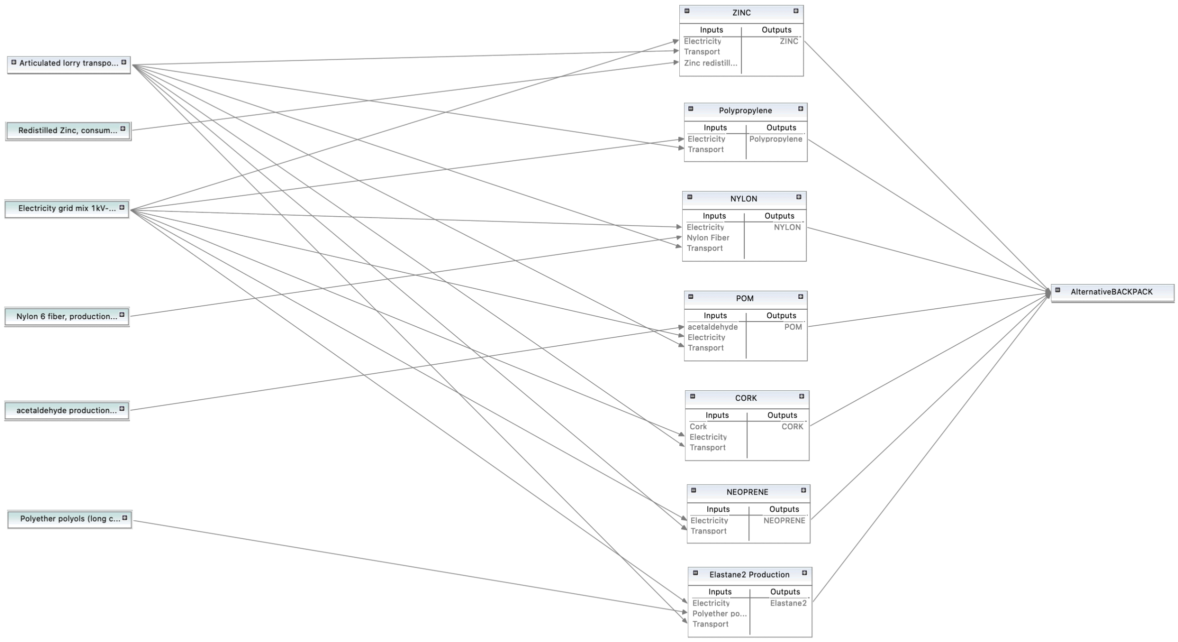

Figure 26: Overview of the LCA for the Green backpack made by OpenLCA.

In the figure above the overall LCA of the green backpack is displayed, we can see, by comparing it we the classical backpack, that we reduced the number of inputs as well as the number of intermediate processes.

VI. Conclusion

In conclusion, reducing the environmental impact of our backpack is a real challenge. It is not insurmountable, but its cost is relatively high.
On the one hand, the choice of material is crucial. It is chosen according to its CO2 footprint but also according to all other parameters that surround it such as its production, transport and usage costs. The reduction of carbon footprint is often linked to the set of raw materials which when combined allows us to evaluate the impact of the whole backpack.
To a certain extent, it is not necessarily necessary to find an alternative material because the quantity of the material is less and therefore it would be more expensive to replace it. In our case, zinc as well as elastane will remain the two original materials.
On the other hand, as far as Polyethylene foams are concerned, according to our analysis it would be preferable to replace it with cork. Since PHA is still in the research and development stage [2], it cannot be considered a viable solution at this time. Another improvement can be made. It turns out that the PET present in our classic backpack can be replaced by different materials depending on the selection criteria. After documentation [3], and in spite of the fact that it produces more CO2 footprint, it seems that Nylon is one of the possibilities to consider. Indeed, it remains one of the most durable materials.
Finally, on the one hand it is preferable to choose an alternative material based on its environmental impact, but on the other hand, it is preferable to choose a material based on its durability.
Our greener bag will try to combine all of these two criteria.

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