WP5

LCA of selected packaging products

INTRODUCTION

Paper and board in Europe is a very commonly used raw material for packaging. Paper packaging can exist in many different makes and forms and its production process, usage and disposal scenarios can vary significantly. EcoPaperLoop project focuses on the eco-design phase of the packaging from the point of view of recycling, but this does not limit the scope of the environmental considerations just to packaging design and construction. Eco-design and manufacturing solutions of paper products also affect different parameters of the recycling process for the pulp stock preparation and production of new paper products. This can lead to limitations in the possibility of recycling or different levels and efficiency of the recycling process, affecting the environmental performances of the process itself, for instance in terms of emissions or energy consumptions. In order to present this issue a number of LCA of packaging products were prepared within the EcoPaperLoop project. This report presents the results of those studies.
Considered packaging LCA's:

- **PACKAGING LCA 1: SCREENING STUDY**

SHOPPING BAGS - COMPARISON BETWEEN SHOPPING BAGS – Pure paper shopping bag and plastic laminated paper bag

The first presented study is a 'screening LCA', it is based mainly on data obtained by literature or specific LCA databases, like Ecoinvent. The scope of the screening LCA is not to search for new specific data or processes for the LCA, but to evaluate a general category of products to demonstrate issues potentially involving a wide range of stakeholders. This study is intended to compare the life cycle of paper bags manufactured with pure paper and with laminated paper, taking into account the most important phases from the production of the paper to the end of life options.
With respect to highest possible transparency and objectivity, different end of life options and scenarios for the products were assessed, based on their recycling behaviour – this is especially true with regards to laminated paper bags, which can be successfully and fully recycled in a specialised recycling plant. Using already available data and methodology for LCA, the impact of different end of life scenarios was assessed, specifically the differences of recycling in standard or specialized recycling plants and the option of final disposal of the product without any recycling.

- **PACKAGING LCA 2: PILOT CASE STUDY**

CORRUGATED BOARD PACKAGING - COMPARISON OF SIX SECONDARY PACKAGING SOLUTIONS, PRODUCED WITH DIFFERENT TYPES OF CONSTRUCTIONS, INKS AND BINDINGS.

Study performed in cooperation with the packaging producing company – Model Opakowania Sp. z o.o. – Biłgoraj - Poland -

The study is technical LCA, with the scope of assessing the most relevant parameters affecting the recyclability and the most relevant impact categories developed in Work Package 5 during the project. The developed quantitative analysis of the most relevant recycling parameters and related environmental emissions were applied and validated in this case study, considering the selected relevant impact categories for the purpose.

SCREENING STUDY

PURE PAPER SHOPPING BAG AND PLASTIC LAMINATED PAPER BAG LCA (screening study)

The scope of the study is to assess the life cycle of different shopper bags, one made of pure paper and one made of paper plus plastic lamination, taking into account the most important phases from the production of the paper to the end of life options. Regarding the laminated bag, three different options were compared: recycling in a standard plant using an ordinary mix of paper for recycling, recycling in a specialized plant for the treatment of composite and laminated paper grades, disposal without recycling.

Assumptions for the study:

For both product categories, a typical product with standard properties was selected, as well as typical conditions of manufacturing and recycling.

Software used for calculations: SimaPro version 8.0.3 with impact assessment method ReCiPe Endpoint V1.10.

Most of the processes and data for the calculation were taken from Ecoinvent V3 Database.

Functional unit:
The functional unit for the calculation is 1 kg of ready to use bags.

Paper:
Same paper grade was considered for both pure paper bags and plastic laminated bags:
50% kraft bleached cellulose from wood and,
50% recycled fibres.

Lamination:
20% w/w of polypropylene.
The case of 20% plastic lamination can be considered as the maximum level of plastic fraction normally used in high quality bags available on the market. Reference: Information from contacted laminated bags producers.

Other components:
Apart the plastic lamination, the total weight of the bag and all the other properties, like adhesive application, handles and finishing are supposed to be the same.

End-of-Life scenarios:
1. Pure Paper Bag: Recycling of pure paper bag in a standard recycling plant
2. Laminated Paper Bag Scenario A: Recycling of laminated paper bag in a standard recycling plant

3. Laminated Paper Bag Scenario B: Recycling of laminated paper bag in a specialized plant for the treatment of composite and laminated paper grades
4. Laminated Paper Bag Scenario C: Disposal without recycling.

In the case of the “**Pure Paper Bag**”, it’s assumed that all the product is recycled back to the same packaging paper stream, for manufacturing the same paper grade. The recycling yield is assumed to be 100%, that means no coarse reject generated in the recycling process.
It is taken as a reference the real case of a pure paper bag tested at Innovhub within the EcoPaperLoop testing campaign for the assessment of the recyclability of packaging products.

In the case of “**Laminated Paper Bag - Scenario A**”, the end of life option is recycling as mixed packaging paper for recycling in a standard plant, not specifically equipped for managing high amount of composite materials. It is supposed that the coarse reject after the pulping stage is 50%, because not all the cellulose fibres can be recovered and an important part of them is rejected together with the plastic.
The coarse pulping reject is supposed to be disposed as for the MSW, 60% landfill and 40% incineration.

In the case of “**Laminated Paper Bag - Scenario B**”, the end of life option is recycling as selected packaging paper for recycling in a specialized plant, equipped for managing high amount of composite materials. As there are only few of these plants in EU, it is included in the assessment an average transport distance of 500 km by truck from the place where the paper is collected to the mill where it is recycled. It is supposed that the coarse reject after the pulping stage is 25%, some fibres are rejected together with the plastic but most of the paper fraction can be recovered (75%).
The coarse pulping reject is supposed to be disposed as for the MSW, 60% landfill and 40%, as for Scenario A.
Part of the plastic waste (40%) is supposed to be recycled and not disposed, even if it is not accounted any benefit for this as it is not suitable for producing the same polypropylene grade raw material.

In the case of “**Laminated Paper Bag - Scenario C**”, the end of life option is final disposal of the used product, for instance if the local regulation doesn’t allow recycling for this kind of products in the paper fraction. The disposal scenario is supposed to be 60% landfill and 40%, as for MSW.

Closed Loop Approach:
The recycled fibres obtained are supposed to replace the raw material used for bags manufacturing:
50% of recycled fibres replace the recycled raw material,
50% of recycled fibres replace the virgin cellulose pulp.

Quality Factor:
It was considered that the quality of recycled fibres is normally lower than virgin cellulose fibres, so a quality factor was calculated in the recycling loop. The quality factor was set to 75%, which means that only 75% of the original quality and properties can be obtained by

using recycled fibres. In order to include this reducing qulity factor in the LCA calculation, it was considered that only 75% of available recycled pulp is used back into the loop for replacing the virgin pulp fraction (process named “packaging paper recycling q=75”).
The determination of the most suitable value for the quality factor need to be studied more precisely in the possible future update of this study, taking into account new developments of the Product Environmental Footprint rules under discussion in Europe.

Results:
The following figures show the results of the LCA study of paper bags, along with the short commentary beneath them.

How to read the LCA process tree graphs:
Emissions in the environment are shown as red arrows in the process tree (fig.1-8), the wider the arrow the greater is the impact on the environment. The green arrows represent instead the benefits due to recycling, in terms of savings of raw material and all the connected emissions.

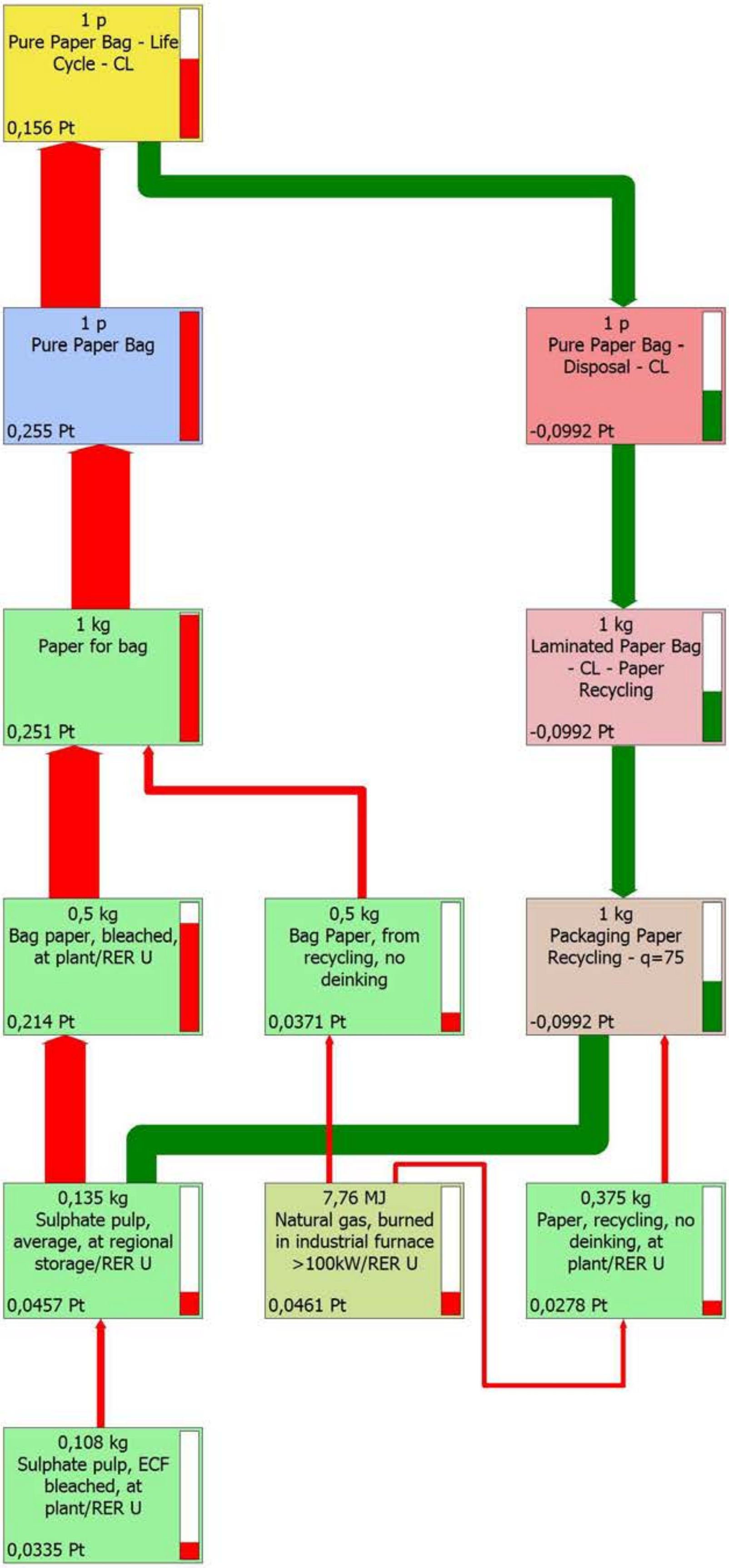

1 p
Pure Paper Bag - Life Cycle - CL
0,156 Pt
1 p
Pure Paper Bag
0,255 Pt
1 p
Pure Paper Bag - Disposal - CL
-0,0992 Pt
1 kg
Paper for bag
0,251 Pt
1 kg
Laminated Paper Bag - CL - Paper Recycling
-0,0992 Pt
0,5 kg
Bag paper, bleached, at plant/RER U
0,214 Pt
0,5 kg
Bag Paper, from recycling, no deinking
0,0371 Pt
1 kg
Packaging Paper Recycling - q=75
-0,0992 Pt
0,135 kg
Sulphate pulp, average, at regional storage/RER U
0,0457 Pt
7,76 MJ
Natural gas, burned in industrial furnace >100kW/RER U
0,0461 Pt
0,375 kg
Paper, recycling, no deinking, at plant/RER U
0,0278 Pt
0,108 kg
Sulphate pulp, ECF bleached, at plant/RER U
0,0335 Pt

Figure 1 – The process tree of the pure paper bag, including recycling into the same loop. The green arrow shows the benefit of recycling into the same loop. Specifically the arrow is linking to the sulphate pulp which production could be avoided with recycling into the same loop. Recycling can avoid the major impact of pulp production from virgin wood, but the environmental impacts of the recycling process and paper formation are still accounted. *Please note – that this graph does not show all processes - only the top influencing processes are shown out of over 9000.*

Method used: ReCiPe Endpoint (H) V1.10 / Europe H/A

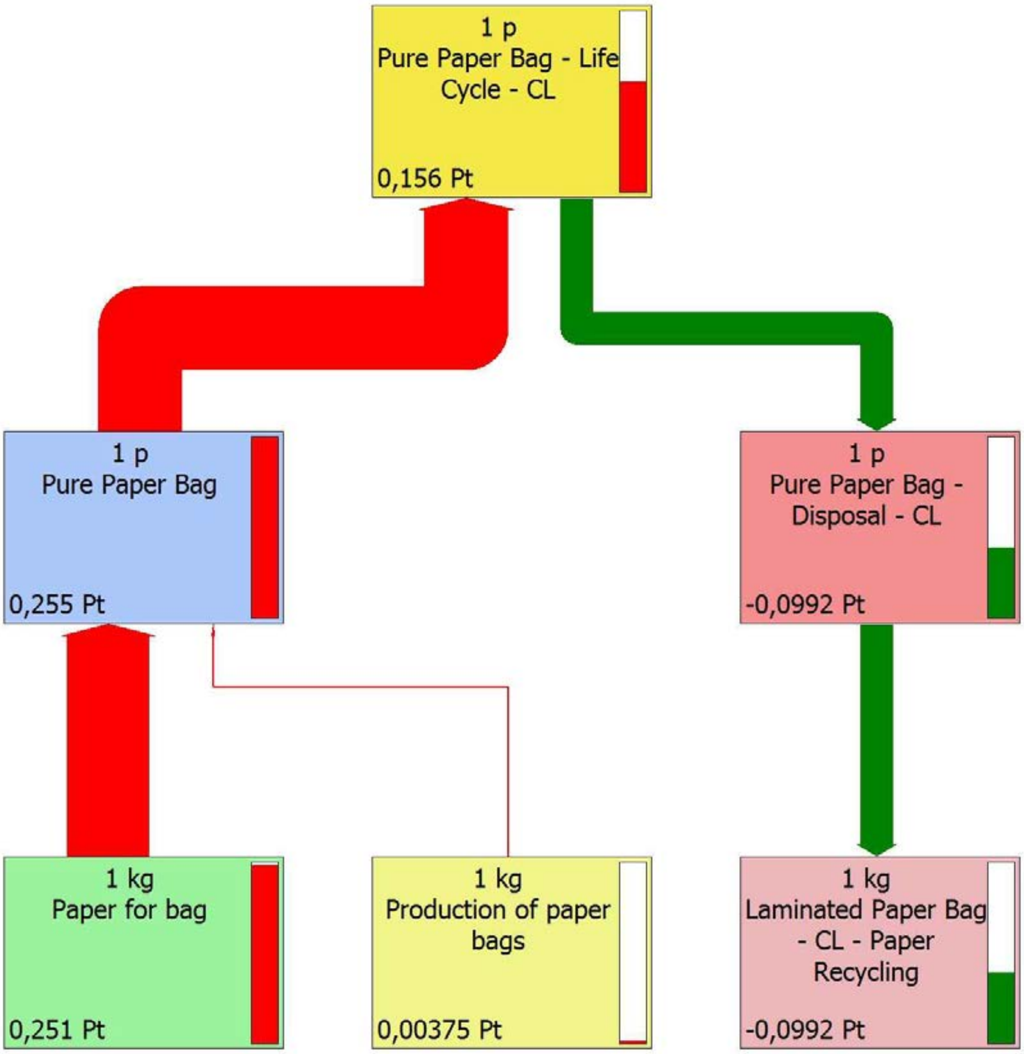


Figure 2 – Simplified process tree of the pure paper bag, including recycling into the same loop.
The figure shows the same results as figure 1, albeit in a simplified form with only top accounting processes shown.

Method used: ReCiPe Endpoint (H) V1.10 / Europe H/A

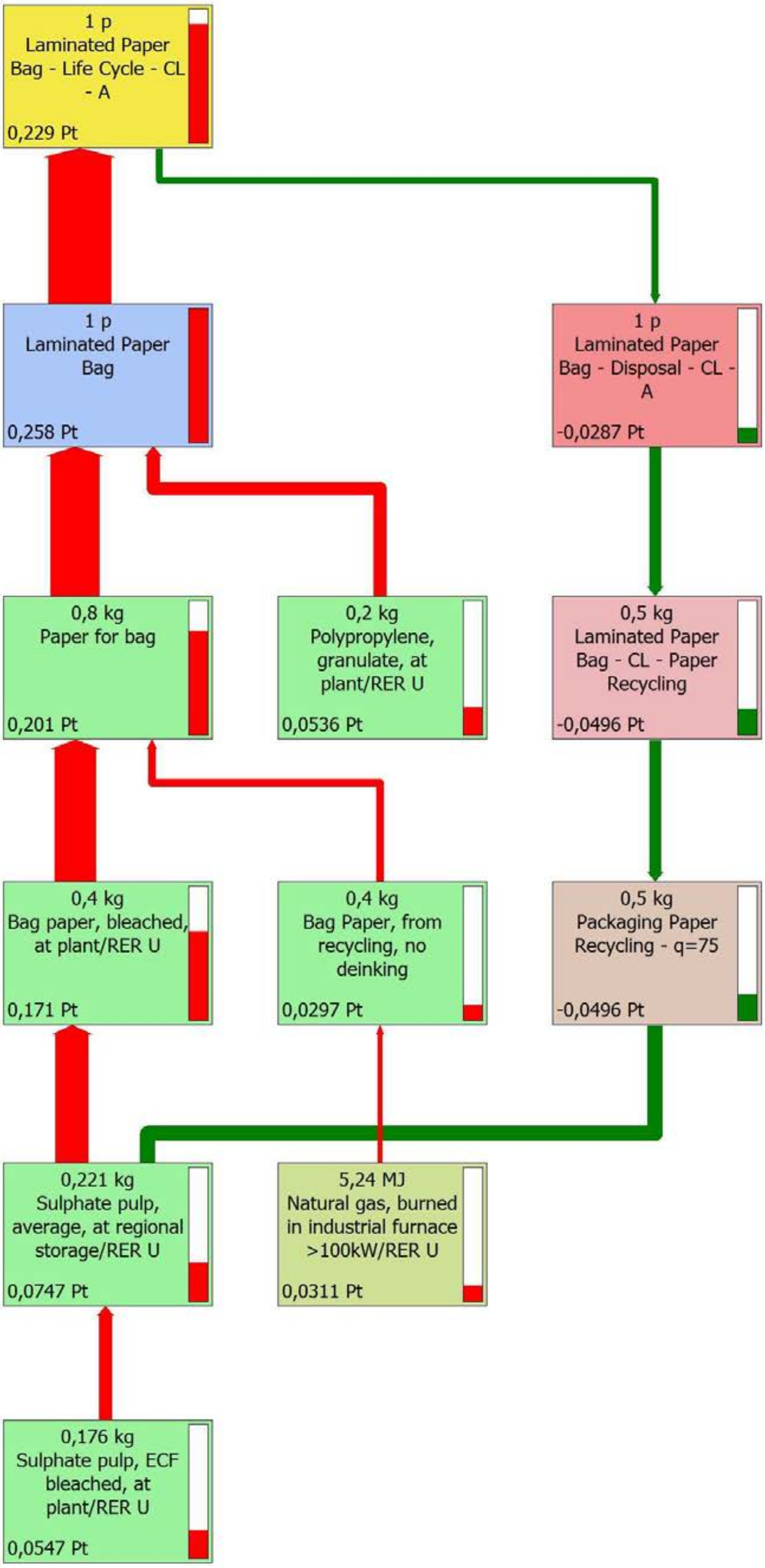


Figure 3 – The process tree of laminated paper bag – scenario A - including recycling into the same loop.

The green arrow shows the benefit of recycling into the same loop. Specifically the arrow is linked to the sulphate pulp which production could be avoided with recycling into the same loop. The benefit of recycling is smaller than the environmental cost (red arrow), due to the recycling process, paper production and reducing quality factor for recycling. Especially the benefit is smaller than in figure 1 due to smaller amount of paper being recycled – in accordance to scenario A of the laminated paper bag case study (recycling in standard plant). The amount of paper recycled is equivalent to 50% of the overall bag weight.
Please note – that this graph does not show all processes - only the top influencing processes are shown out of over 9000.

Method used: ReCiPe Endpoint (H) V1.10 / Europe H/A

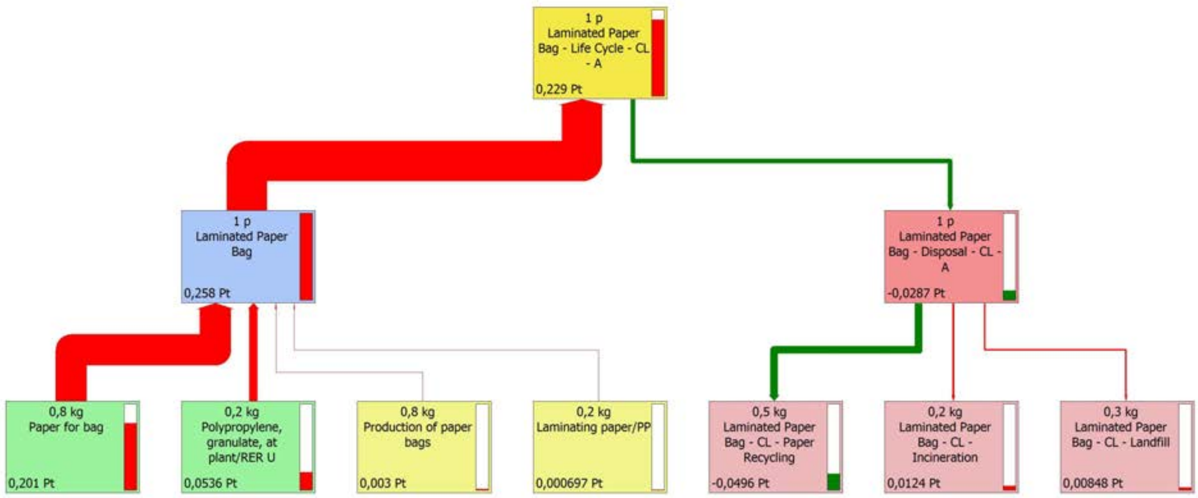


Figure 4 – Simplified process tree of the laminated paper bag – scenario A - including recycling into the same loop.

The figure shows the same results as figure 3, albeit in a simplified form with only top accounting processes shown. However, thanks to this format, environmental impacts from incineration and landfilling are visible, whereas, on figure 3 they were below the cut-off point.

Method used: ReCiPe Endpoint (H) V1.10 / Europe H/A

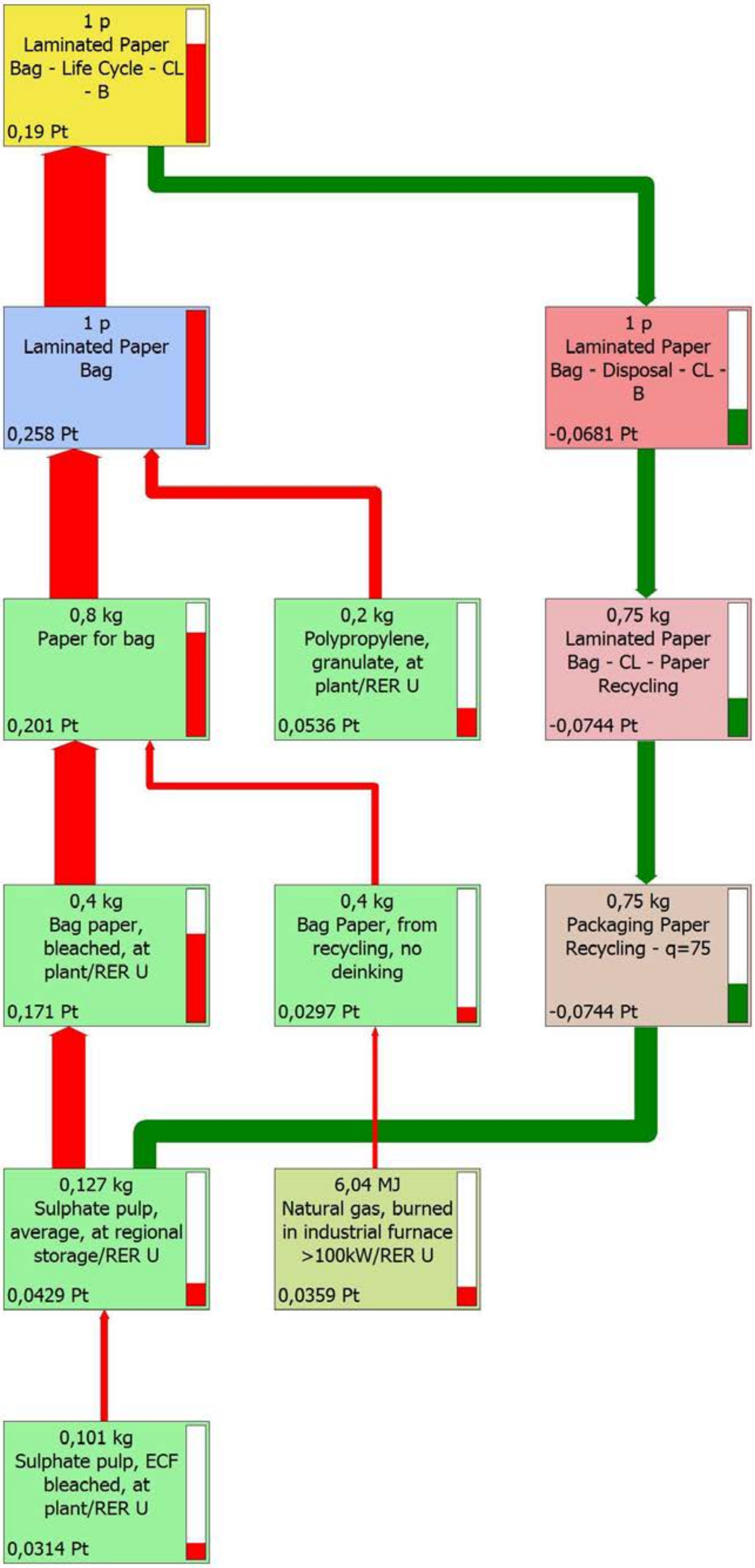


Figure 5 – The process tree of laminated paper bag – scenario B - including recycling into the same loop.

The green arrow shows the benefit of recycling into the same loop. Specifically the arrow is linking to the sulphate pulp which production could be avoided with recycling into the same loop. As in Scenario A, the benefit of recycling is smaller than the environmental cost (red arrow), due to the recycling process, paper production and reducing quality factor for recycling. On the other hand the benefit is bigger than in figure 3 due to larger amount of paper being recycled – in accordance to scenario B of the laminated paper bag case study (recycling in specialised plant). The amount of paper recycled is equivalent to 75% of the overall bag weight.
The recycling process also includes bigger transport environmental costs, due to the fact that there are not many specialised recycling plants in Europe that can successfully recycle laminated paper bags with high efficiency, as written in the introduction.
Please note – that this graph does not show all processes - only the top influencing processes are shown out of over 9000.

Method used: ReCiPe Endpoint (H) V1.10 / Europe H/A

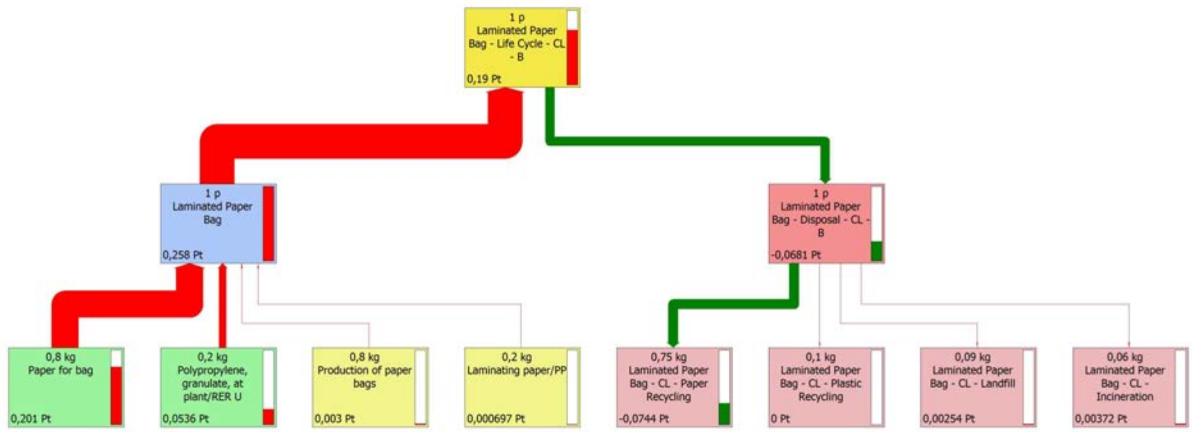


Figure 6 – Simplified process tree of the laminated paper bag – scenario B - including recycling into the same loop.

The figure shows the same results as figure 5, albeit in a simplified form with only top accounting processes shown. However, thanks to this format, environmental impacts from plastic component recycling, incineration and landfilling are visible, whereas, on figure 5 they were below the cut-off point.

Method used: ReCiPe Endpoint (H) V1.10 / Europe H/A

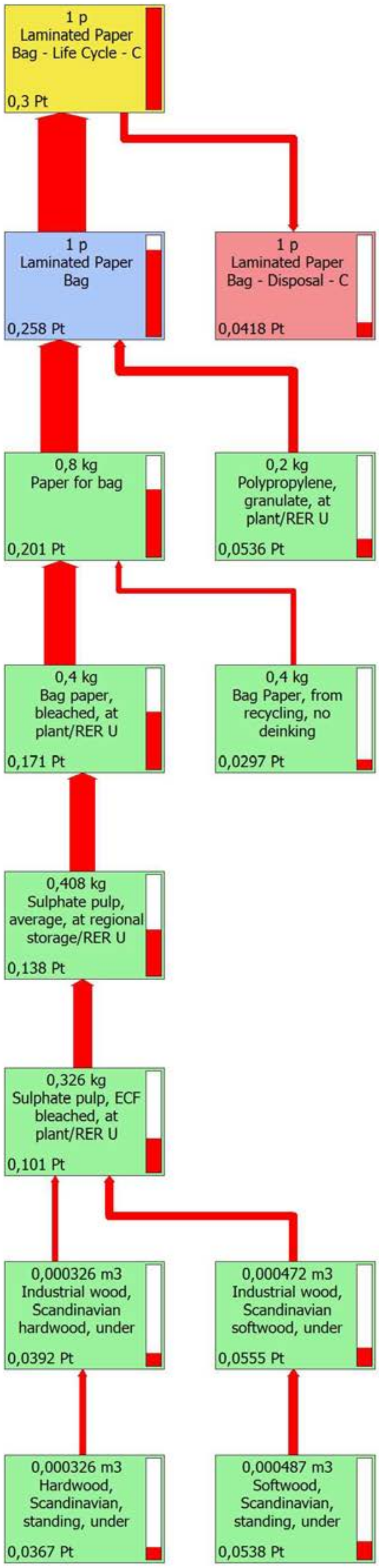


Figure 7 – The process tree of laminated paper bag – scenario C .

In this instance - scenario C – there is no recycling taking place as all of the laminated paper bag is considered as a waste and is disposed in landfill and incineration, in accordance to scenario C of the laminated paper bag case study. This is a scenario specific to countries where laminated paper bags usually do not go to any recycling plant.

Method used: ReCiPe Endpoint (H) V1.10 / Europe H/A

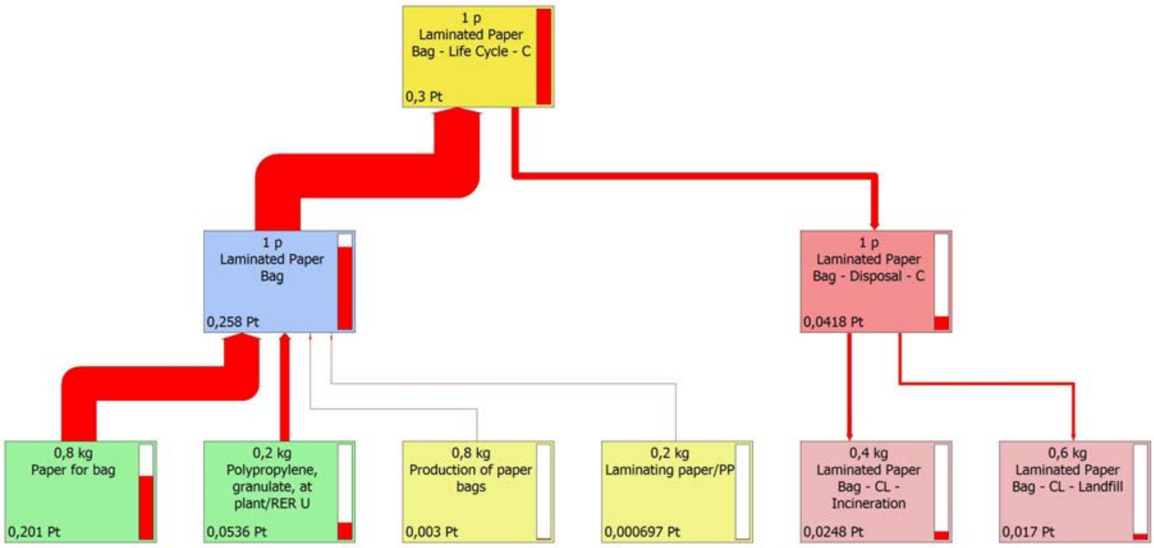


Figure 8 – Simplified process tree of the laminated paper bag – scenario C

The figure shows the same results as figure 7, albeit in a simplified form with only top accounting processes shown. However, thanks to this format, environmental impacts from incineration and landfilling are visible, whereas, on figure 7 they were below the cut-off point.

Method used: ReCiPe Endpoint (H) V1.10 / Europe H/A

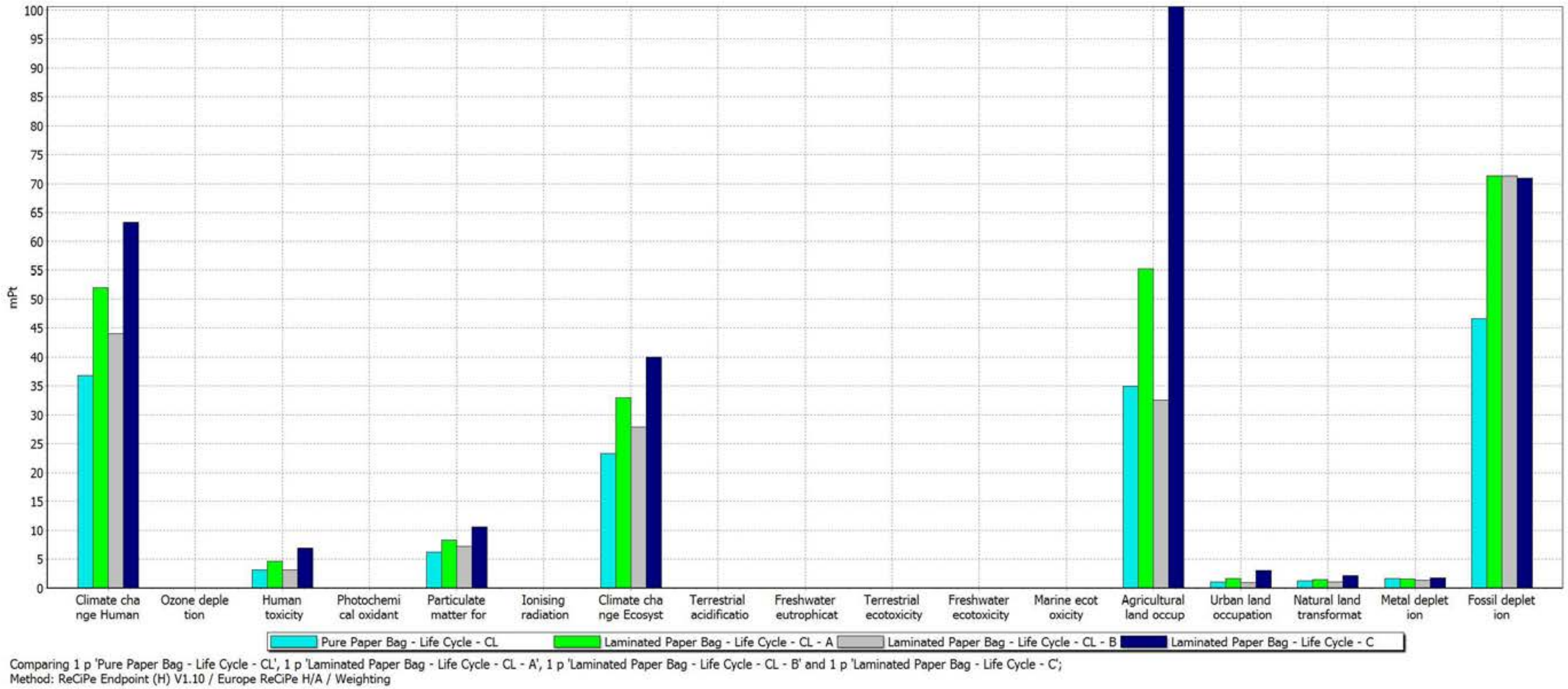


Figure 9 – Impact assessment of full life cycle of pure paper bag and three scenarios of laminated paper bags – per impact category

Pure paper bag shows the lowest environmental impacts in all categories, as 100% of the material is recycled. In scenarios A the level of recycling is 50% and in scenario B raise up to 75%, as described in the scope of the study. For all these scenarios the recycled fibres are used for replacing the cellulose pulp with a quality factor of 75%. Scenario C assumes no recycling at all – all the material goes to waste.

The benefit of recycling is especially prevalent in agricultural land occupation impact category, which is directly linked to the feedstock material of pulp and paper production.

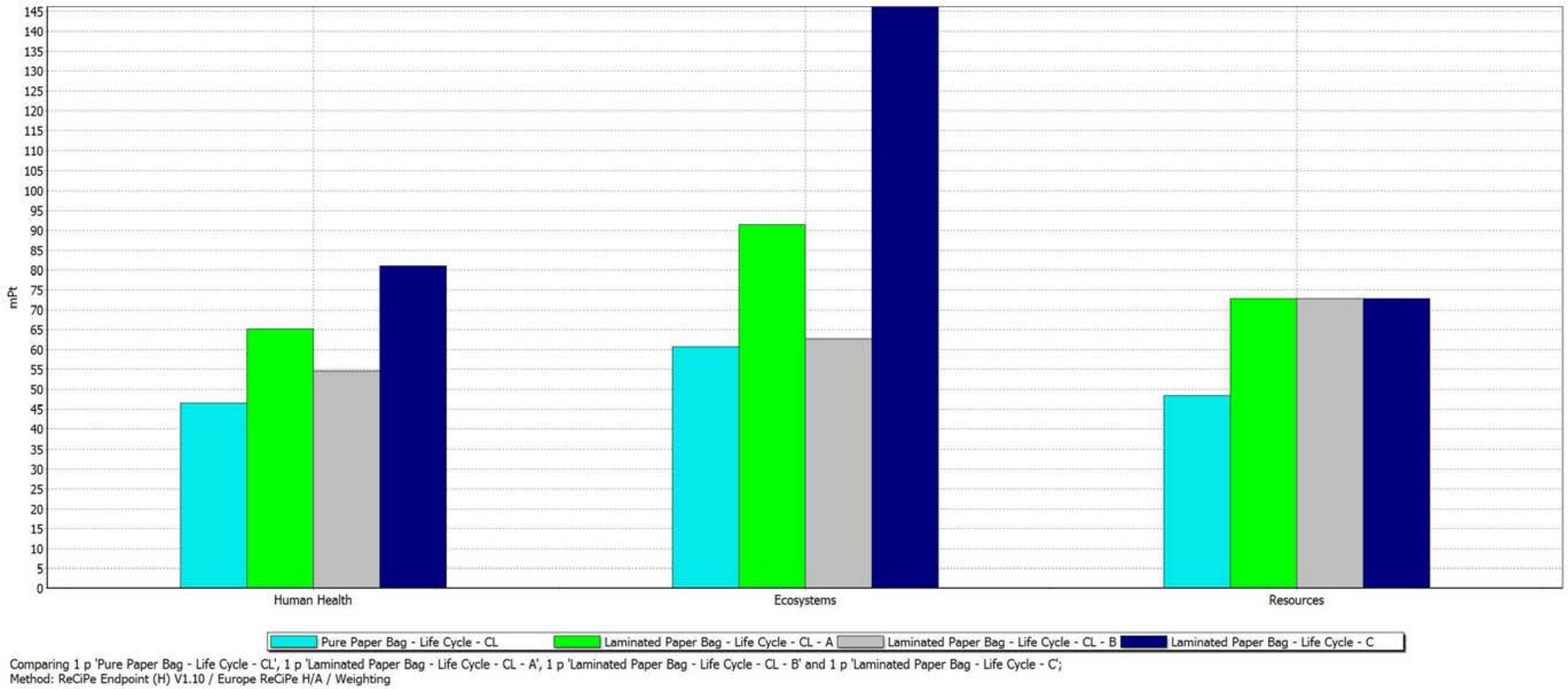


Figure 10 – Impact assessment of full life cycle of pure paper bag and three scenarios of laminated paper bags – per damage category

Similarly to figure 9 pure paper bag shows lowest environmental impacts in all categories because of material recycling. The effect of recycling in a close loop is once again represented in the ecosystems quality damage category; the impact is highest for scenario C – where the loop is not closed and therefore feedstock paper and plastic material is not recovered in any way.

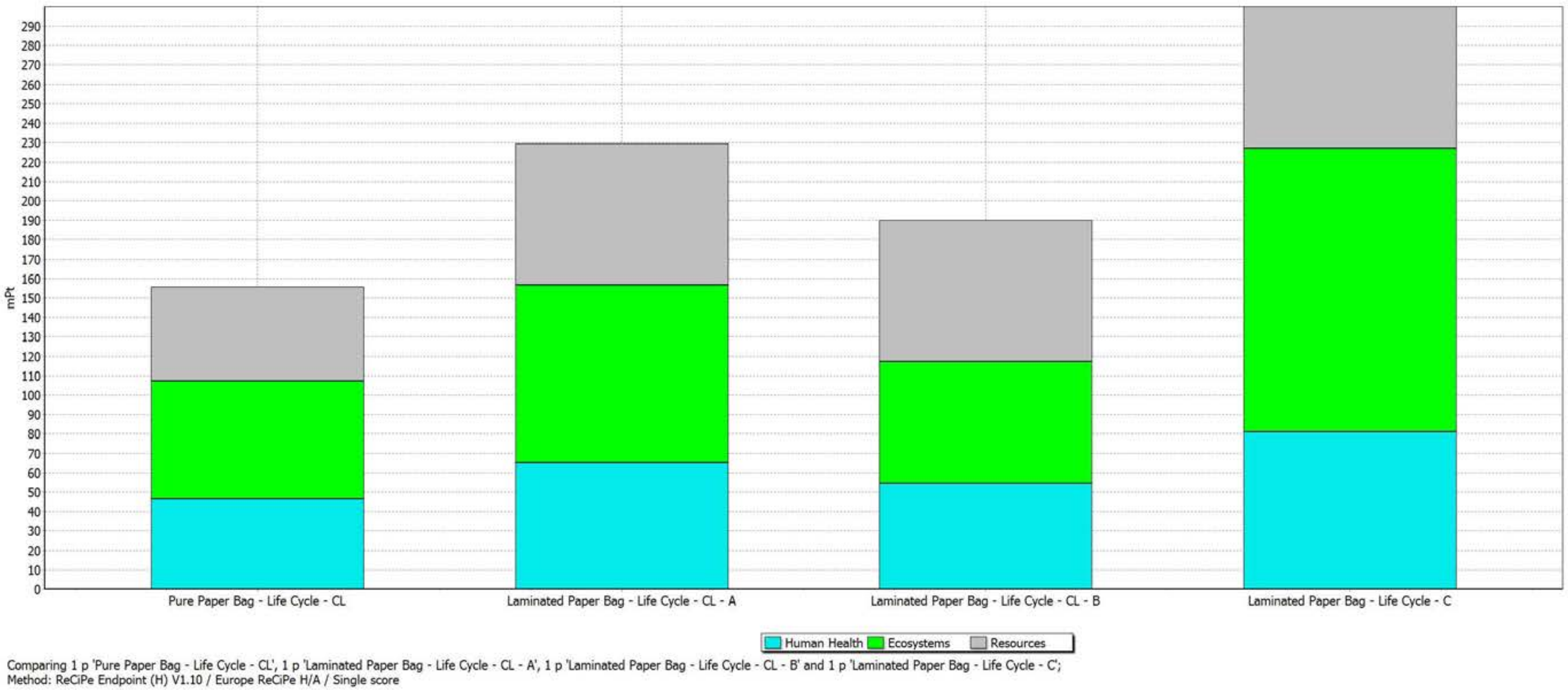


Figure 11 – Impact assessment of full life cycle of pure paper bag and three scenarios of laminated paper bags – Single Score results

The overall impact of pure paper bag and three scenarios of laminated paper bag is accounted for the three damage categories, per tested product. This result format shows the same impacts as figure 10, but in a format where all environmental damages are shown per product.

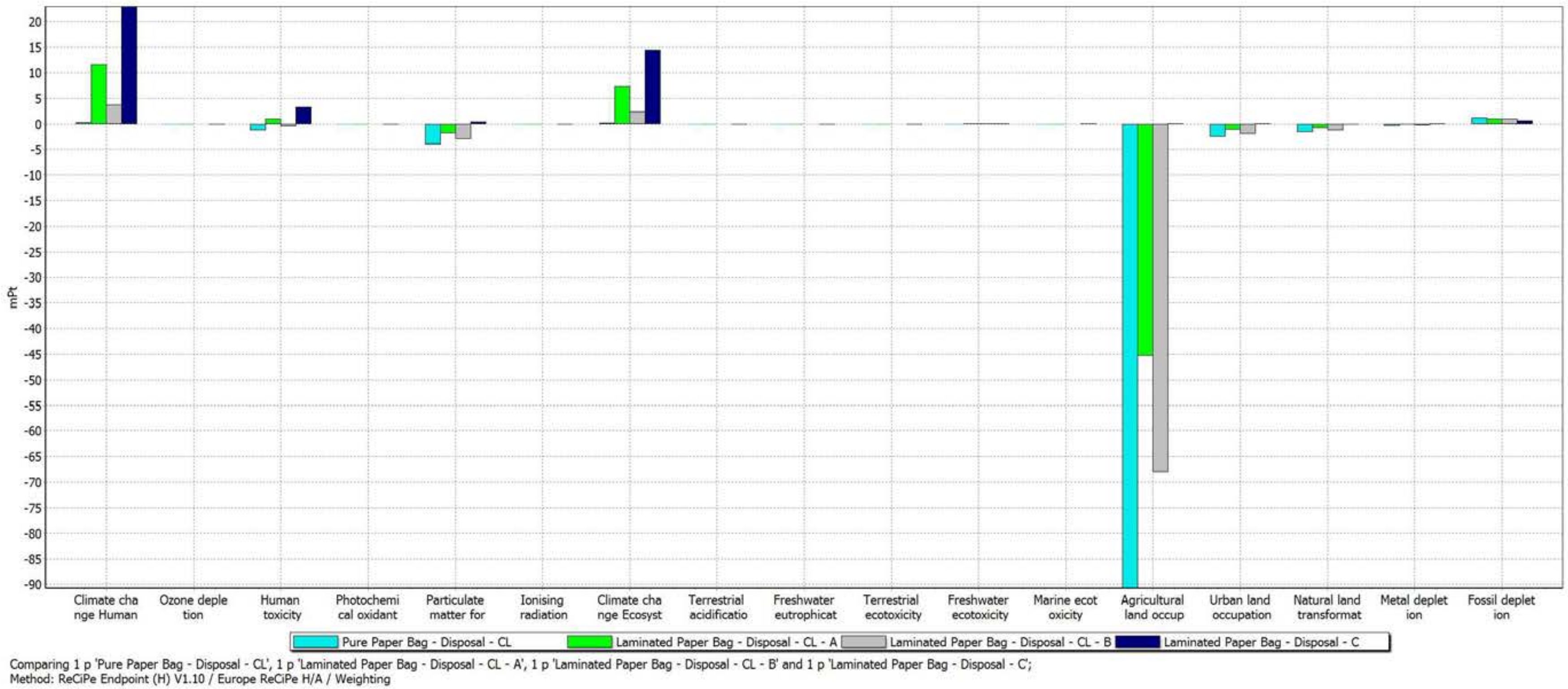


Figure 12 – Impact assessment of disposal scenarios of pure paper bag and three scenarios of laminated paper bags – per impact category

The impact of disposal scenario in the category of agricultural land occupation is in the negative axis for pure paper bag and scenario A and B of laminated paper bag due to recycling processes present, which represents an environmental benefit. For this category recycling is most relevant and crucial aspect in the consideration of disposal scenario processes. In scenario C – as there is no recycling present – the impact of this category is zero.

As this figure shows only disposal options, only the environmental impacts of end-of-life processes and impacts of material waste are presented. Impacts in all other categories of scenario A and B are related to final disposal of recycling waste (polypropylene and fibre fraction) while all the impacts of scenario C, are related to landfill and incineration of the overall laminated paper bag.

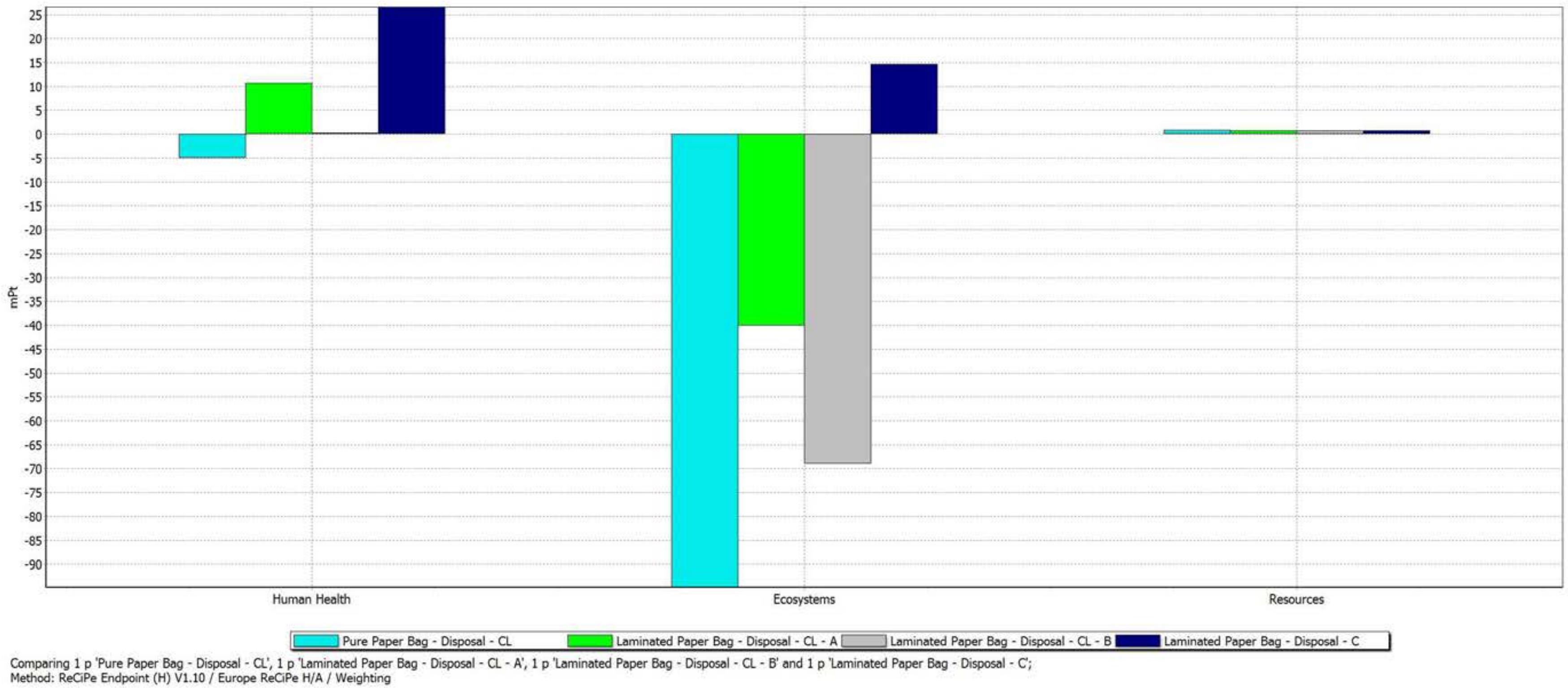


Figure 13 – Impact assessment of disposal scenarios of pure paper bag and three scenarios of laminated paper bags – per damage category

The impact of disposal scenario in the damage category of ecosystems is negative for pure paper bag and scenario A and B of laminated paper bag due to recycling processes present. All other damage categories are related to other disposal options landfill and incineration of laminated paper bag waste. The biggest environmental impact can be attributed to scenario C, where there is no recycling and the overall product is disposed as waste.

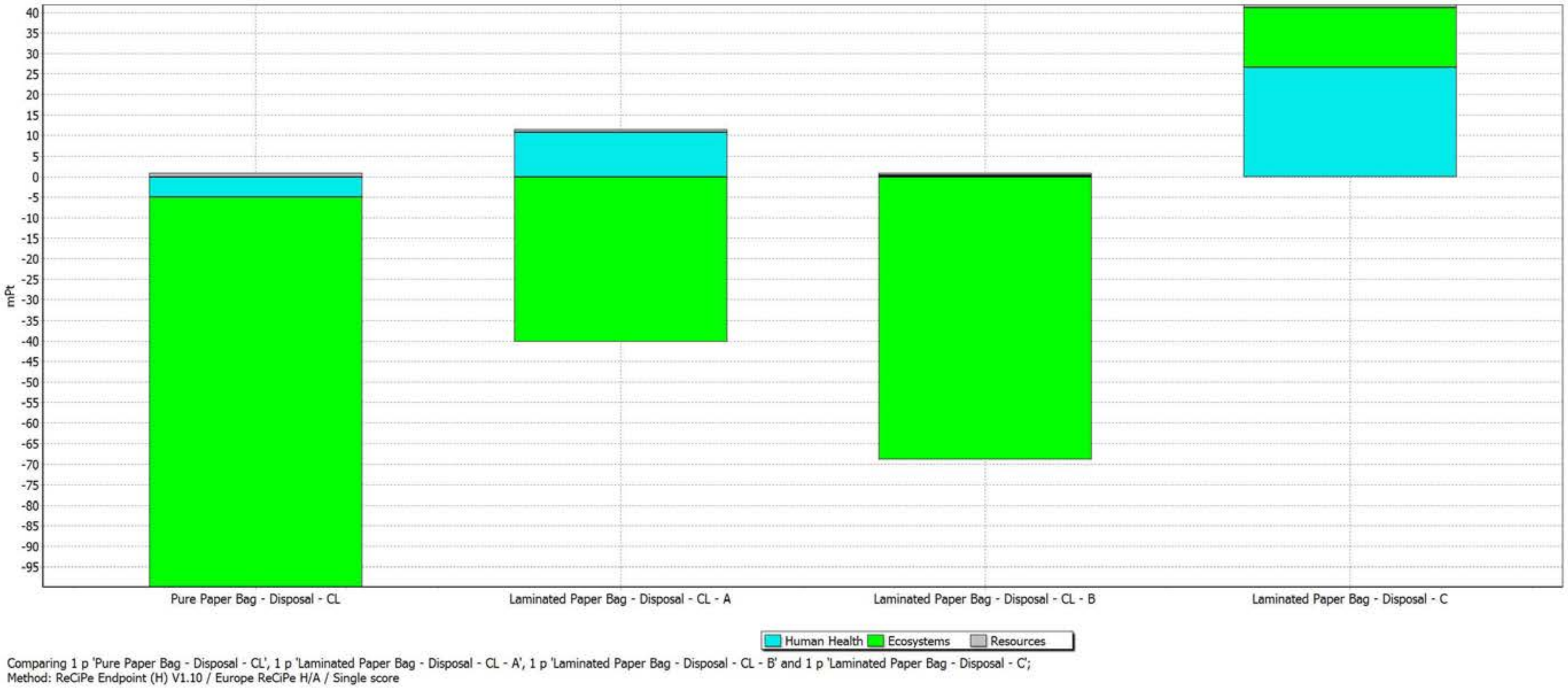


Figure 14 – Impact assessment of disposal scenarios of pure paper bag and three scenarios of laminated paper bags – Single Score results

The overall impact of pure paper bag and 3 scenarios of laminated paper bag is accounted for the three damage categories, per tested product. This result format shows the same impacts as figure 13, but in a format where all environmental damages are shown per product.

Conclusion:

- The main impact for the manufacturing of all bags is due to the pulp and paper production from virgin cellulose fibres.
- The polypropylene accounts for 27 % of the total weighted environmental costs for the laminated paper bag.
- the most important environmental advantage is the possibility of recycling the paper at the end of life in the same production loop, for producing the same paper grade used for the bag.
- This option enable to reduce the amount of virgin raw material pulp for the manufacturing of the bags, although taking into consideration a reducing quality factor of 75%.
- In the case of laminated paper bag - Scenario C , the lack of recycling make it necessary to supply all virgin fibres for the production and to dispose the product at the end of life.
- The case of pure paper bag with complete recycling in the same paper cycle has the best behaviour in all impact categories.
- Laminated paper bag – Scenario A is worse than the pure paper bag, because of the impact of polypropylene and the low amount of recycling rate, 50% of the total bag mass.
- In Scenario B the results for most of the impact categories are better than Scenario A.
- The Scenario C is generally the worse one, especially for agricultural land occupation which is directly linked to the pulp feedstock supply.
- The determination of the most suitable quality factor value need further investigation in the future, taking into account new developments of the Product Environmental Footprint rules under discussion in the EU.

PILOT CASE STUDY

CORRUGATED BOARD PACKAGING - COMPARISON OF SIX SECONDARY PACKAGING SOLUTIONS, PRODUCED WITH DIFFERENT TYPES OF CONSTRUCTIONS, INKS AND BINDINGS.

The scope of the study is to compare the life cycle of corrugated board packaging, produced in the same industrial manufacturing plant, with different technological solution and taking into account the most important phases from the production of the paper to the end of life options.

The study was performed in cooperation with a big Polish paper packaging producer - Model Opakowania Sp. z o.o. Biłgoraj - Poland. The producer was very helpful in securing a very detailed information about their production processes.

This LCA is divided into two distinct parts focusing on different system boundaries:

1. Full life cycle of the corrugated boxes, taking into consideration closed loop recycling
2. End-of-life recycling environmental emissions taking into consideration the recyclability score of the packaging – according to outputs of EcoPaperLoop's WP3.

Full life cycle of the corrugated boxes, taking into consideration closed loop recycling

The system boundaries of the study were limited to the most important aspects regarding the production of the corrugated board boxes and the end of life options.
The study considers the raw material paper for all boxes, inks and varnishes as well as the printing process, regarding the aspects which are different in all considered packaging.

All tested products use the same corrugated board made of recycled fibres – testliner grade. As the feedstock material itself has the greatest environmental impact, in order to provide a reference frame of the LCA the study also takes into consideration scenarios with theoretical different grades that also can be used to manufacture the product without the need of changing the production processes:

1. A standard mixture of testliner and kraftliner made of virgin fibres, taken from the EcoInvent 3 database and,
2. 100% kraftliner grade

Those scenarios enable a grater comparison of eco-design potential and show a reference of recyclability of tested products.

Transport, packaging and use phase of the products were not evaluated, as they don't affect the comparison of the tested boxes

End-of-life recycling environmental emissions taking into consideration the recyclability score of the packaging – according to outputs of EcoPaperLoop's WP3.

In addition to the abovementioned assumptions of the study, the end of life was also specifically investigated for the recycling phase and the quantitative relations between recycling parameters resulting from the recyclability test and the related environmental emission were implemented in the LCA. In the case an open loop recycling approach was selected, as the most important scope of this study is not to assess a possible closure of the loop, replacing the virgin paper by using recycled paper, as for the first system boundary described above. Instead the main scope was the environmental assessment of the different recyclability levels of the products, focusing on specific phases of the recycling process.

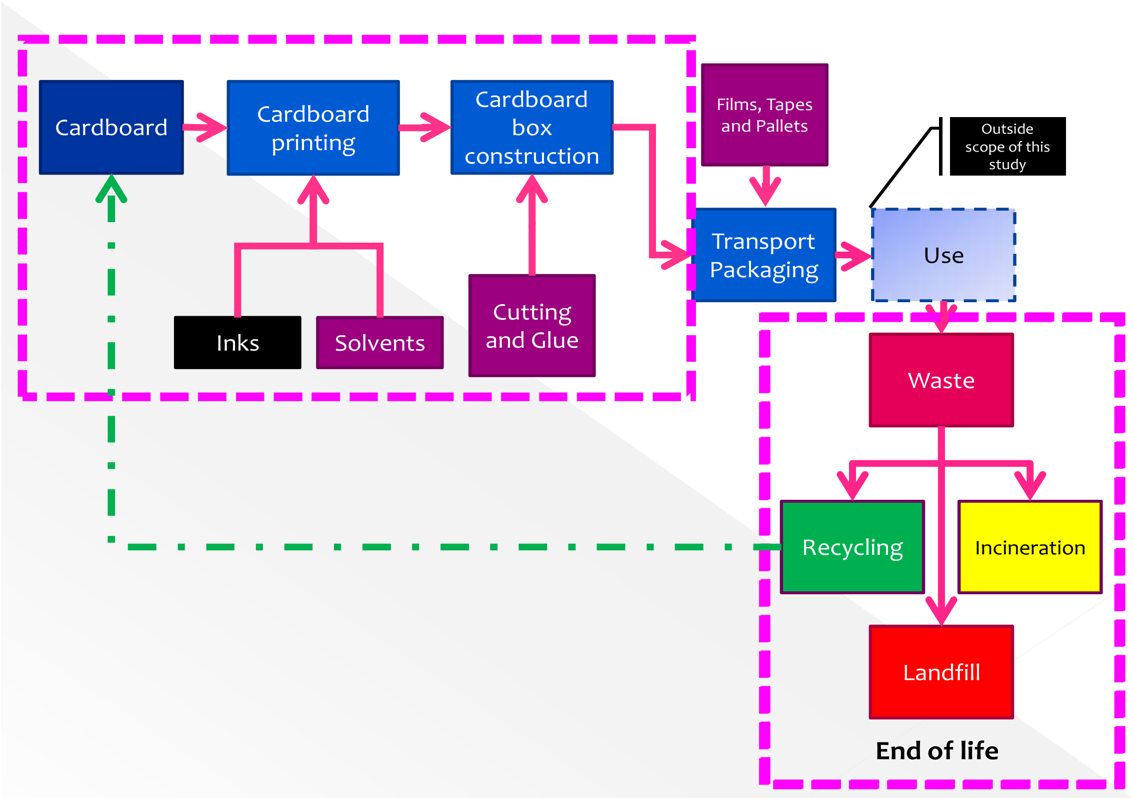


Figure 15: System boundaries of the full LCA study

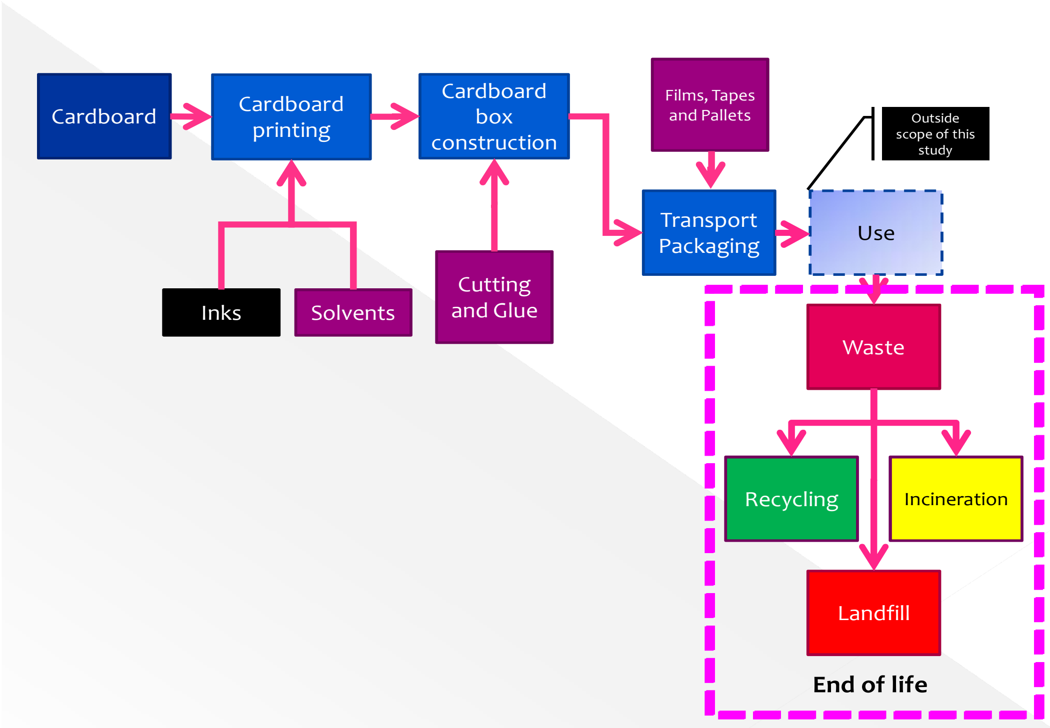


Figure 16: System boundaries of the end-of-life study

The following table presents the tested corrugated board boxes.
Due to their different functions, three pairs of boxes were identified and will be considered separately.

Reference number	Packaging construction	Functional unit	Dimensions
1A	Regular Slotted Box	12 x 700ml bottles	296x221x269
1B	Folder-Type Box (Wrap-around)	12 x 700ml bottles	296x221x269
2A	Regular Slotted Box	12 x 500ml bottles	288x215x269
2B	Folder-Type Box (Wrap-around)	12 x 500ml bottles	288x215x269
3A	Regular Slotted Box	6 x 700ml bottles	246X164X271
3B	Folder-Type Box (Wrap-around)	6 x 700ml bottles	246X164X271

Table 1: Specifications of the tested packaging

Packaging construction was determined according to FEFCO (European Federation of Corrugated Board Manufacturers) International fibreboard case code.

Regular Slotted Box (code family 02) consist of basically one piece with a glued, stitched or taped manufacturers joint and top and bottom flaps. They are shipped flat, ready to use and require closing using the flaps provided.

Folder-type box (code family 04) usually consist of only one piece of board. The bottom of the box is hinged to form two or all side walls and the cover. Locking tabs, handles, display panels etc., can be incorporated in some designs. [5]

Figure 17 and 18 present typical construction forms of Regular Slotted Box box and Folder-type box used by MODEL Packaging in provided samples

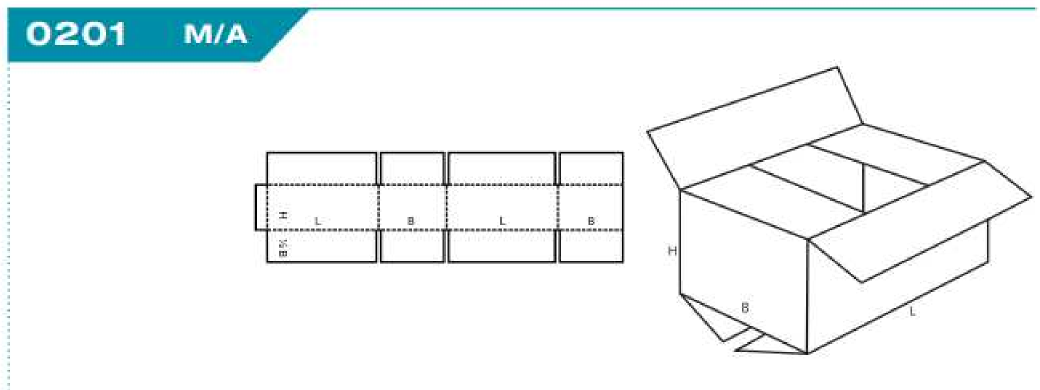


Figure 17: Construction form of a typical Regular Slotted Box used by MODEL Packaging – FEFCO code 0201 [5]

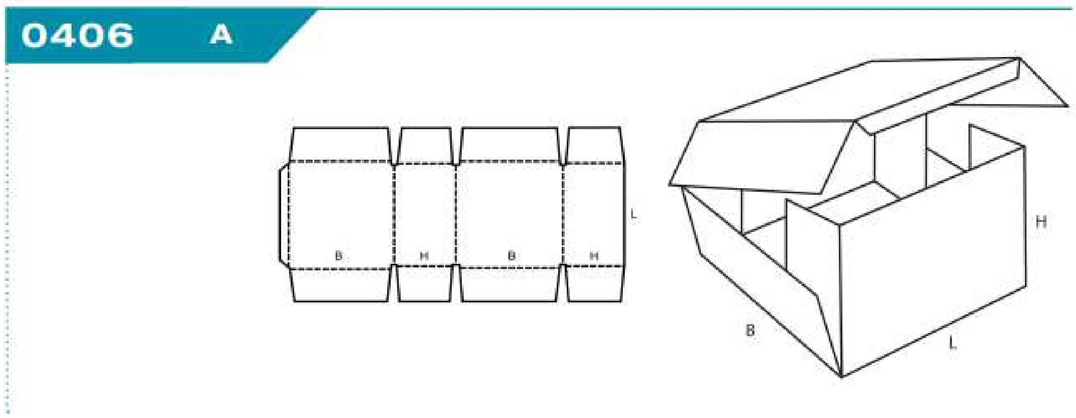


Figure 18: Construction form of a typical Folder-type box (wrap around) – used by MODEL Packaging – FEFCO code 0406 [5]

Assumptions for the study:

Software used for calculations: SimaPro version 8.0.3 with impact assessment method ReCiPe Endpoint V1.10.

Most of the data regarding the packaging were provided by the company, while part of the data regarding different paper grades and recycling process were taken from Ecoinvent V3 Database.

Functional unit:
There are three functional units for the three pairs of products provided by the producer:

1. Secondary packaging of 12 x 700ml bottles
2. Secondary packaging of 12 x 500ml bottles
3. Secondary packaging of 6 x 700ml bottles

Due to non-standard bottles packed in each pair of packaging products, a standardised functional unit for all three pairs would not provide viable and objective results

Paper:
technical data sheets from the paper manufacturer were considered.
Processes about pulp and paper production were taken from Ecoinvent V3.

Type of inks and varnishes:
info and technical data sheet about inks and varnishes were provided by the company.

Printing process and packaging construction:
All data provided by the company as primary data, according to the construction flowchart presented in figure below:

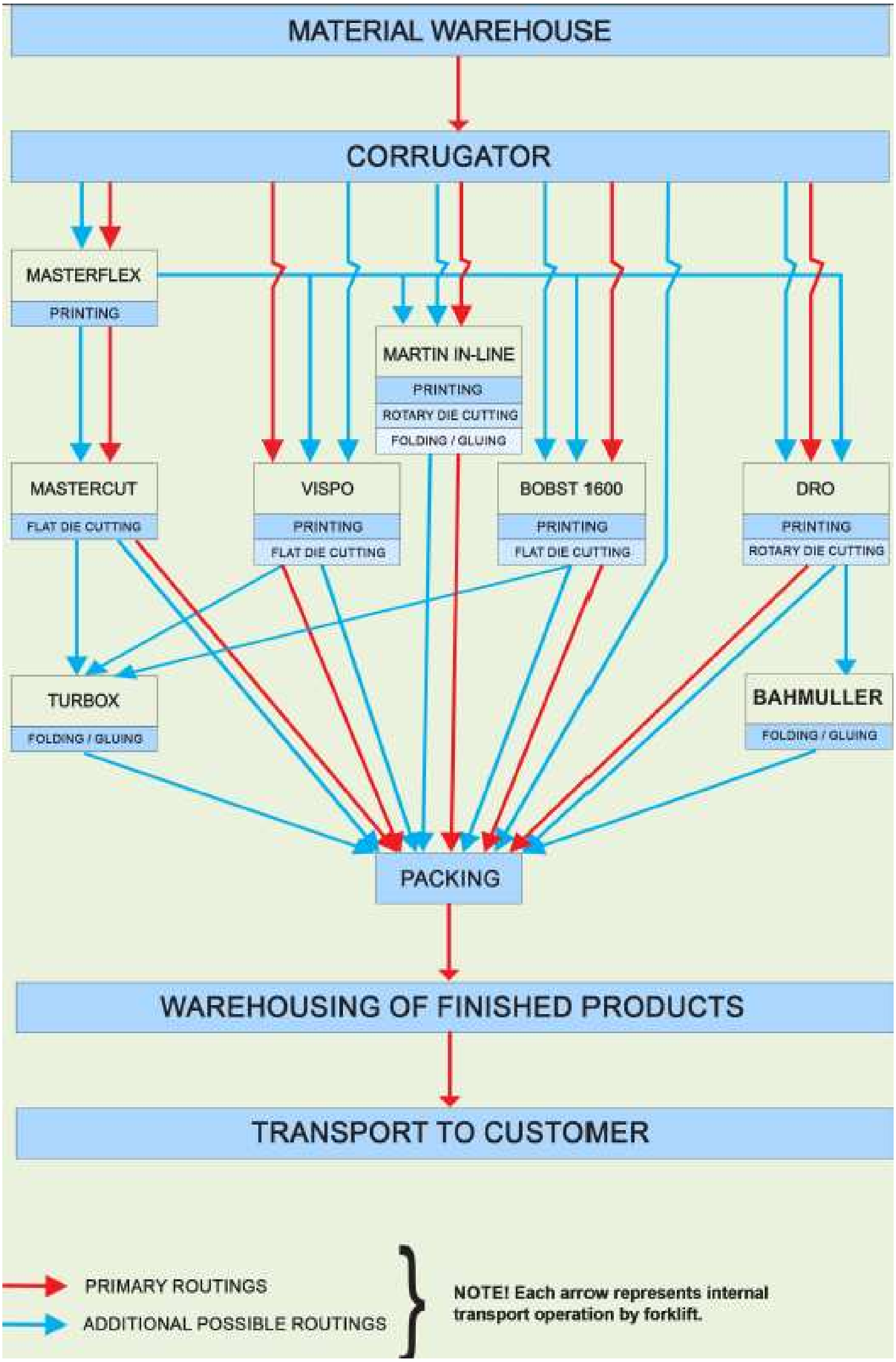


Figure 19. Production map chart representing different possible flows of different printing/construction machines in the company.

End of life-recycling:

The general processes about the end of life disposal scenarios where taken from Ecoinvent V3.

Environmental inputs/outputs used for packaging recycling:

- waste generation – linked to coarse reject score in the Recyclability Test Method for packaging products[1], developed by EcoPaperLoop WP3 (expressed in percentage waste)
- electricity consumption – linked to macrostickies amount in the Recyclability Test Method for packaging products, developed by EcoPaperLoop WP3 (expressed in Macrostickies area <2000 µm per kg of product - mm^2/kg).

Results of the selected parameters measured in the laboratory recycling tests.

Test performed according to EcoPaperLoop Recyclability Test Method for packaging products:

	Box 1A	Box 1B	Box 2A	Box 2B	Box 3A	Box 3B
Coarse reject %	0	0,4	0	0	0	0
Macrosticky area <2000 mm^2/kg	553	710	1706	289	195	901

Table 2: Results of the recyclability parameters to be considered for the LCA

End of life – recycling process

Recycling parameters and related environmental emissions for LCA

In a previous EcoPaperLoop Work Package 5 Deliverable[2], it was reported the study regarding the determination of the most relevant recycling parameters obtained from laboratory recyclability test on packaging products and their main environmental impacts in a standard industry recycling process.

Quantitative relations between recycling parameters and environmental impacts were further developed into a methodology to be included in the LCA.

The established correlation and the methodology is here specifically presented.

According the quoted Deliverable, two parameters were selected as the most important for the analysis of the packaging recyclability and possible consequences on the environmental impacts of the recycling process:

- Coarse Rejects: content of non-paper components or difficult to disintegrate materials, which are separated in the first operation.

- Macro-stickies: content of tacky particles mainly due to adhesive used in the packaging product, with specific attention to the fragmentation behaviour during the recycling process.

If the coarse reject CR of a tested product is higher than the average, an additional amount of reject is accounted as waste production to be disposed.

If the measured value for the coarse reject is lower than the average, a minor amount of reject is accounted as recycling waste to be disposed.

If the amount of Macro-stickies is higher than the average value for the category, the amount of stickies should be reduced. In order to decrease the amount of macro-stickies, there are few options and generally it can be limited to operations intended to better separate the adhesive particles or disperse them if they have small size:
i) to add more effort in the screening stage → higher electricity consumption in the process.
ii) to add a dispersion step → higher electricity consumption in the process.

If the product has a content in Macro-stickies lower than the average level, a possible reduction of the energy for the screening and/or dispersion stage can be assumed → less energy consumption.

CORRUGATED BOXES	Coarse rejects, CR %			
	Low limit: 0,0	**High limit: 20,0**	**20,0 < CR < 30,0**	**CR ≥ 30,0**
energy consumption, electricity, kWh / kg pulp	-	-	Tolerable recyclability, but needs design improvements and/or process adaptations.	Not suitable for use in standard recycling processes, but can possibly be used in specialized processes.
waste production kg waste / kg raw material	**0,0 kg waste/kg** ***(function CB1, fig. 18)***	**0,2 kg waste/kg** ***(function CB1, fig. 18)***		

Table 3: Correlation between Coarse Rejects content and waste production in the recycling process, for corrugated boxes.

CORRUGATED BOXES	Macro-stickies <2000, MSA mm^2/kg				
	Low limit: 0	**Average: 2600**	**High limit: 20000**	**20000 < MSA < 30000**	**MSA ≥ 30000**
energy consumption, electricity, kWh / kg pulp	**0,120 kWh/kg** ***(function CB2, fig. 19)***	**0,140 kWh/kg** ***(function CB3, fig. 20)***	**0,220 kWh/kg** ***(function CB3, fig. 20)***	Tolerable recyclability, but need improved adhesive applications.	Not suitable for use in any recycling processes as individual product.
waste production kg waste / kg raw material	-	-	-		

Table 4: Correlation between Macro-stickies content and electricity consumption in the recycling process, for corrugated boxes.

Average and Limits for Coarse Rejects and Macro-stickies :

Average and limits values included in the previous tables were established on the base of the EcoPaperLoop Recyclability Database developed in WorkPackage 3. The recyclability database includes all the test and results obtained in the project, even if it still needs to be enlarged in the future to set more precise limits for the sustainability assessment.

In principle it was considered as low limit the total lack of corse rejects and therefore no pulp waste production during recycling. The same for Macro-stickies, it was considered as low limit the total lack of macrostickies, as the lowest values in the Recyclability Database are close to zero.

The high limit for Coarse Rejects was set as the Warning Level in the proposed Recyclabiltiy Scorecard, CR=20 %, even if normally the coarse reject is lower for corrugated boxes. The same for Macro-stickies, the high limit is the same as the Warning level in the Recyclabiltiy Scorecard, 20.000 mm^2/kg.

Criteria for determination of waste production and electricity consumption:

Recycling waste production is supposed to be the same as the amount of the measured Coarse Reject.
For Instance: CR = 10% then Waste production = 0,1 kg waste / kg raw material product.
Therefore it was established a linear increase correlation from zero to CR=20%, which correspond to 0,2 kg waste / kg raw material product.

Different values for the typical range of electricity consumption of the stock preparation of a standard recycling process were found in literature, depending on the plant technology, raw material and production. In particular the screening and dispersion processes, which are related to the residual Macrostickies content, are among the most electricity intensive ones and they can have a very broad range of energy consumption.

Here it is reported an estimation of the average values, based on available literature information:
Electricity consumption of the pulp stock preparation (corresponding to average values of Macro-stickies content) = 140 kWh/t or 0,140 kWh/kg pulp (on dry basis).

Additional electricity in case of Macro-stickies values higher then Average:
linear increase till 220 kWh/t or 0,220 kWh/kg pulp when the high limit is reached.
The electricity increase is due to additional or more intensive screening and dispersion stage.
For MSA values higher then high limits, the product is still accepted up to MSA=30.000 mm^2/kg, with recommendation of improving the adhesive application; over this limit value the product is not accepted because additional energy would not be enough or convenient to reduce the amount of macrostickies and even so some problems in the production line could occur.

Literature references:

- *Recycled fibers and deinking, vol.7, ed.2010*[3], pag140-141: specific energy consumption of unit processes.
- *Handbook of paper and board, ed.H.Holik (2013)*[4], pag476: packaging papers: typical specific energy consumption 100-200 kWh/t.

According to the same literature sources, a possible variation in the dispersion stage can be the following:
- *Recycled fibers and deinking, vol.7, ed.2010*, pag140-141: specific energy consumption of unit processes: dispersing: 30-150 kWh/t.
- *Handbook of paper and board, ed.H.Holik (2013)*, pag 356: range of specific energy demand in dispersing: 30-80 (120) kWh/t.
- *Handbook of paper and board, ed.H.Holik (2013),* pag 356: range of specific energy demand in tail screening: 20-40 kWh/t.

Based on literature information and project partner experience, it was supposed a possible max increase of 80 kWh/t electricity related to dispersion and fine screening (therefore from 140 to 220 kWh/t of the overall process).

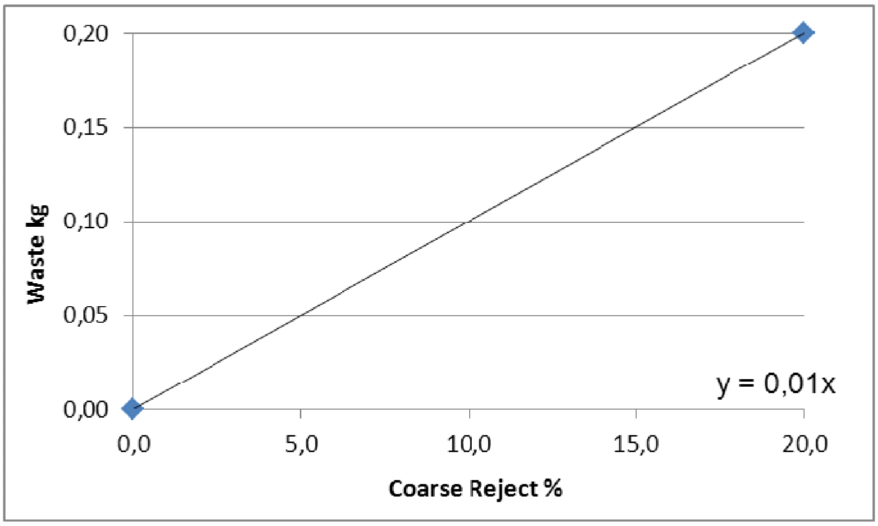
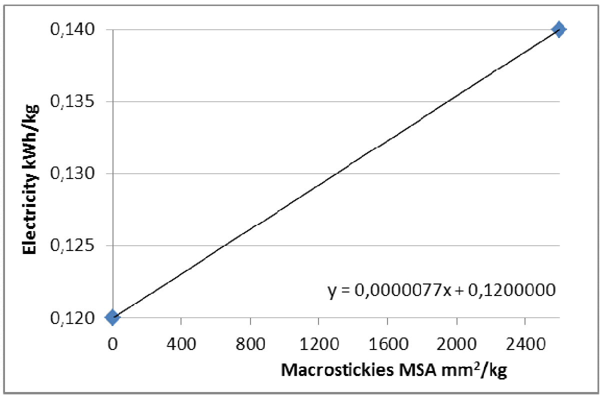


Figure 20: Function CB1

In Fig. 20 it is reported the linear correlation function between Coarse Reject and Waste generated for corrugated board.



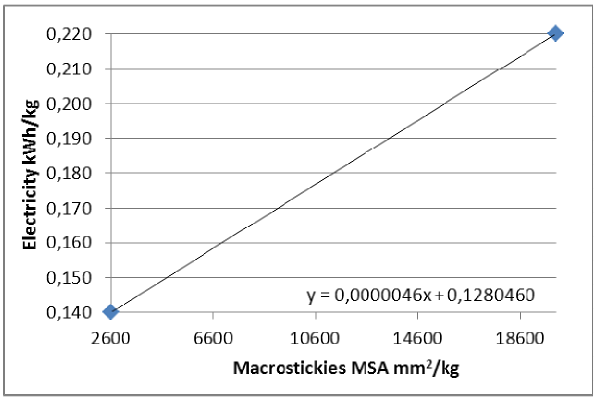


Figure 21: Function CB2

Figure 22: Function CB3

In Fig. 21 and Fig. 22 are reported the linear correlation functions between Macro-stickies and electricity consumption for corrugated board.

LCA results:

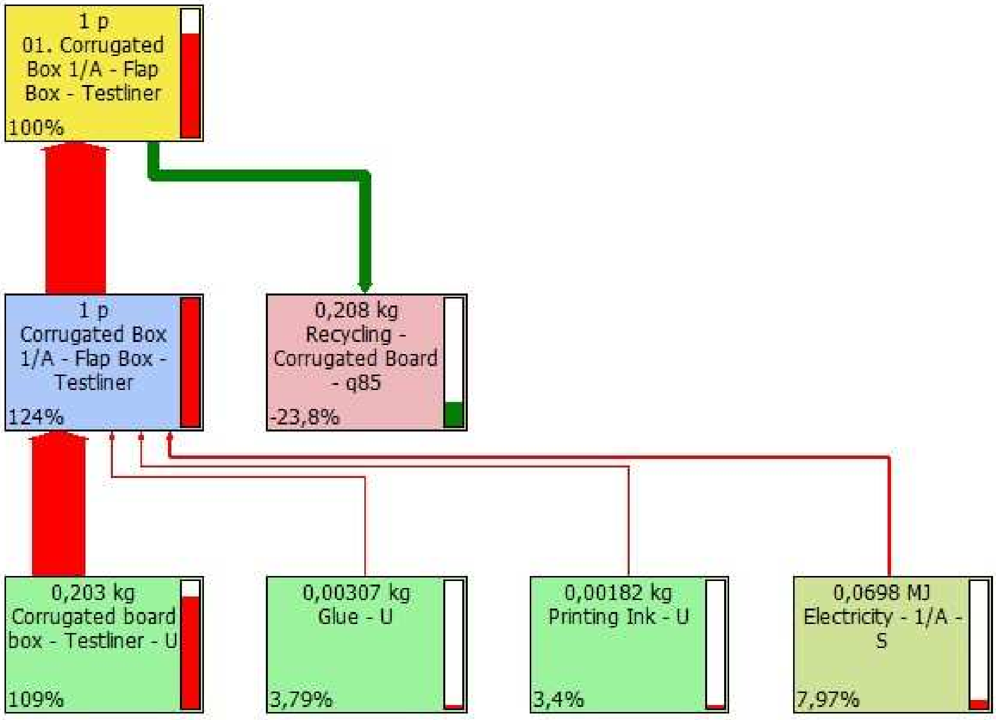


Figure 23. Process tree for packaging 1A – Notice that production of corrugated board constitutes to the majority of environmental impacts.

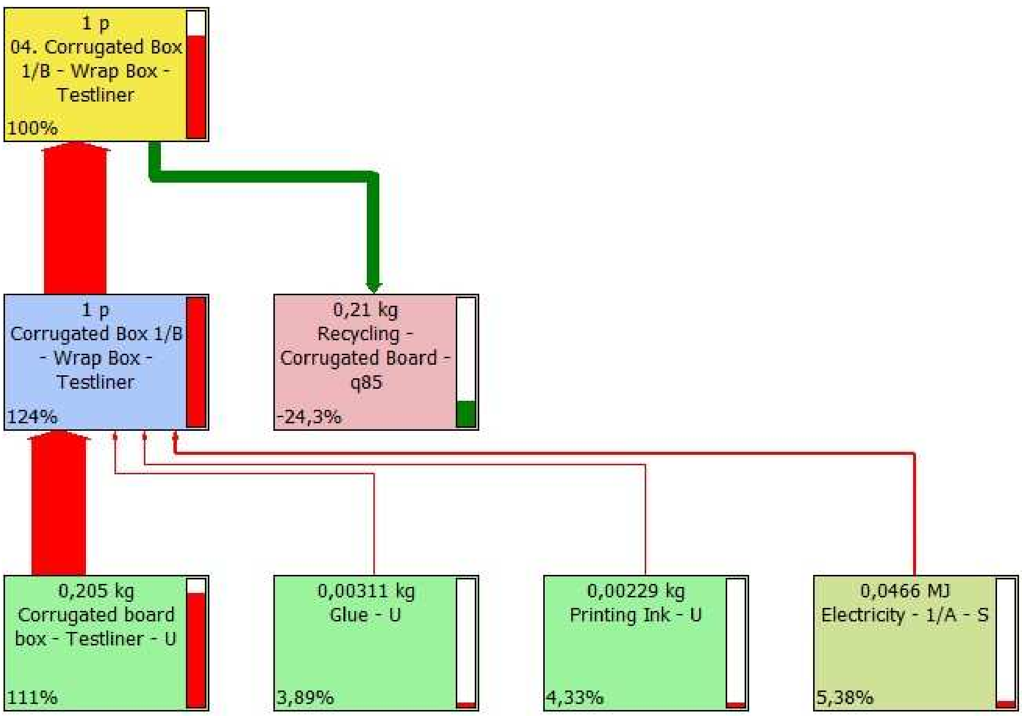


Figure 24. Process tree for packaging 1B – Notice that production of corrugated board constitutes to the majority of environmental impacts.

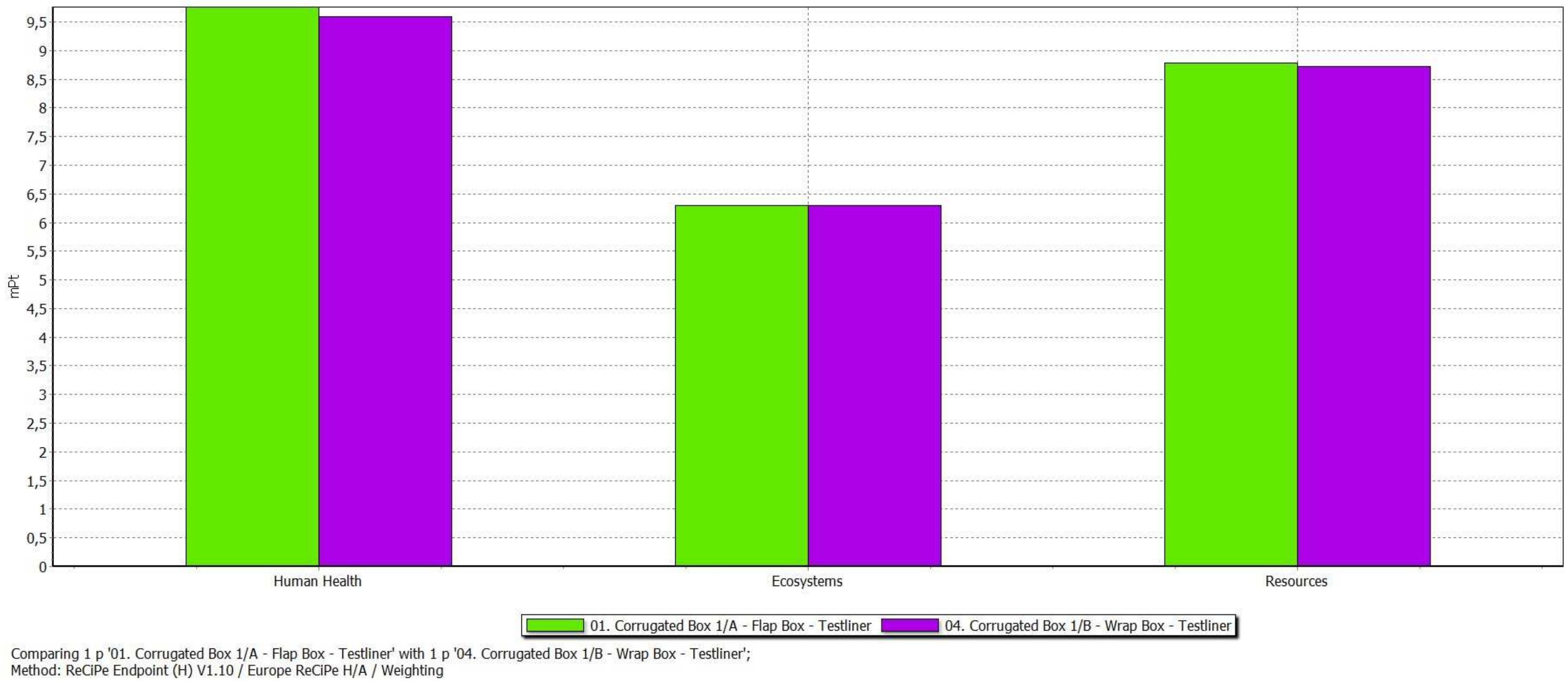


Figure 25. Environmental damages for packaging 1A and 1B. In this instance construction differences of this pair tested packaging have little difference on environmental damages

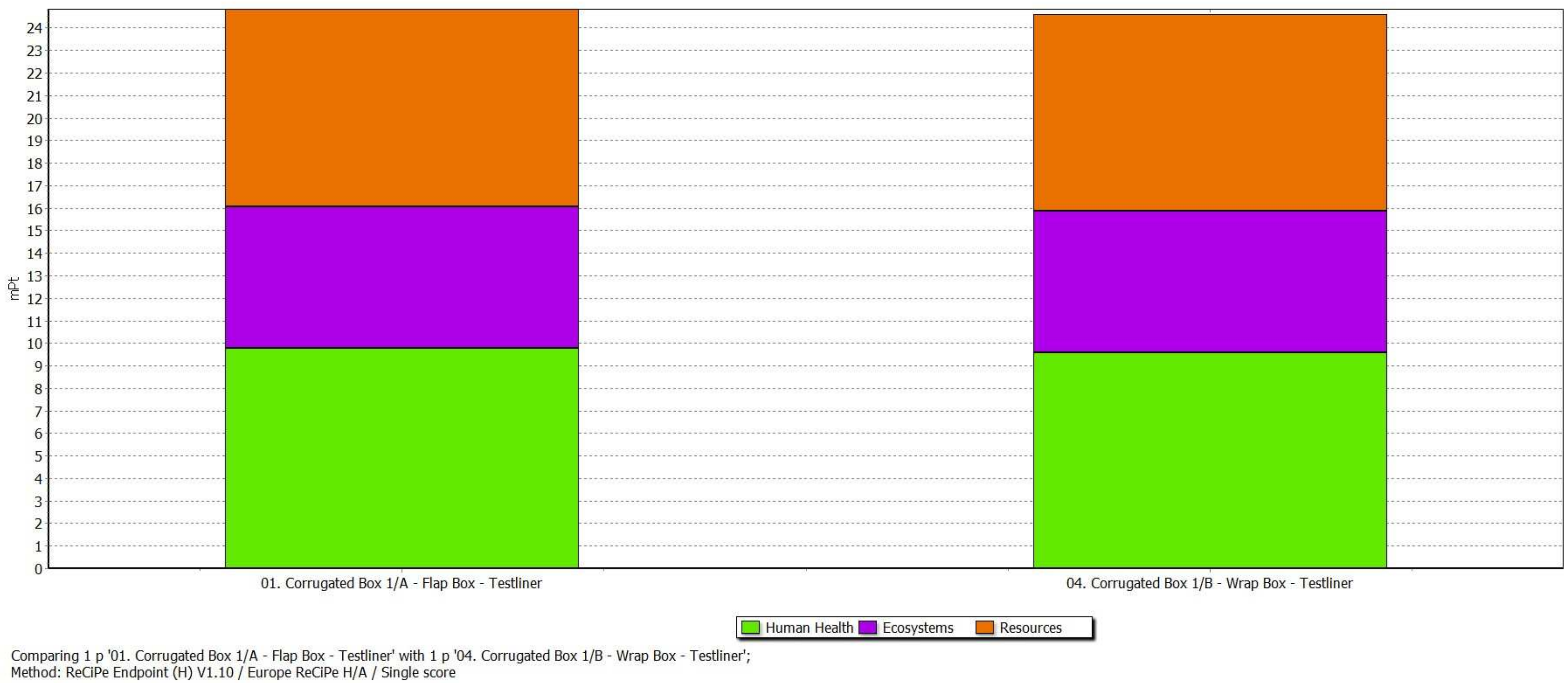


Figure 26. Environmental damages for packaging 1A and 1B expressed as a single score. In this instance construction differences of this pair tested packaging have little difference on environmental damages

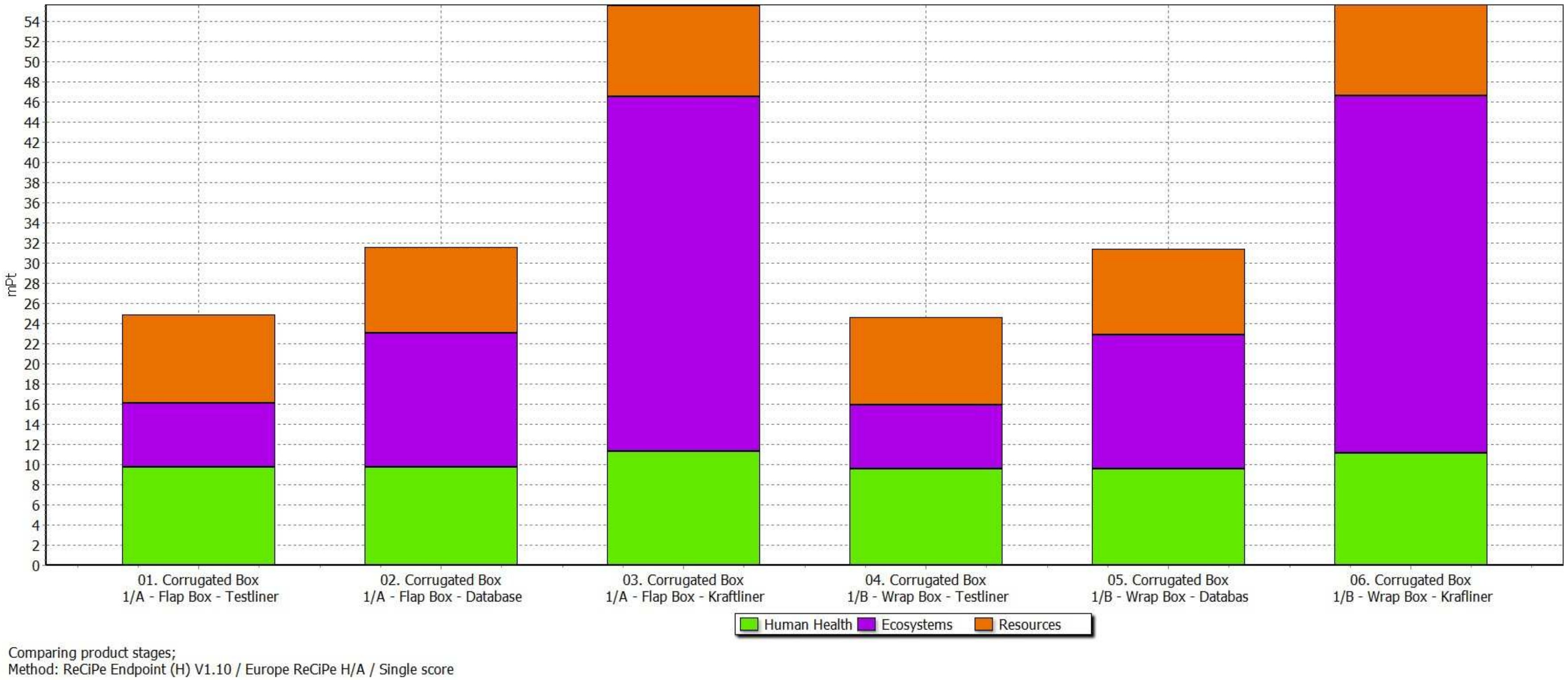


Figure 27. Environmental damages for packaging 1A and 1B expressed as a single score – taking into account different feedstock materials – recycled testliner and simulated corrugated board from Ecoinvent v3 database, and example of what the impact of packaging would be if kraftliner corrugated board is used instead of testliner. It can be clearly seen that corrugated board used by the company has the lowest environmental impact, due to recycled raw material instead of virgin fibres, recyclability of the feedstock material and ability to close the recycling loop.

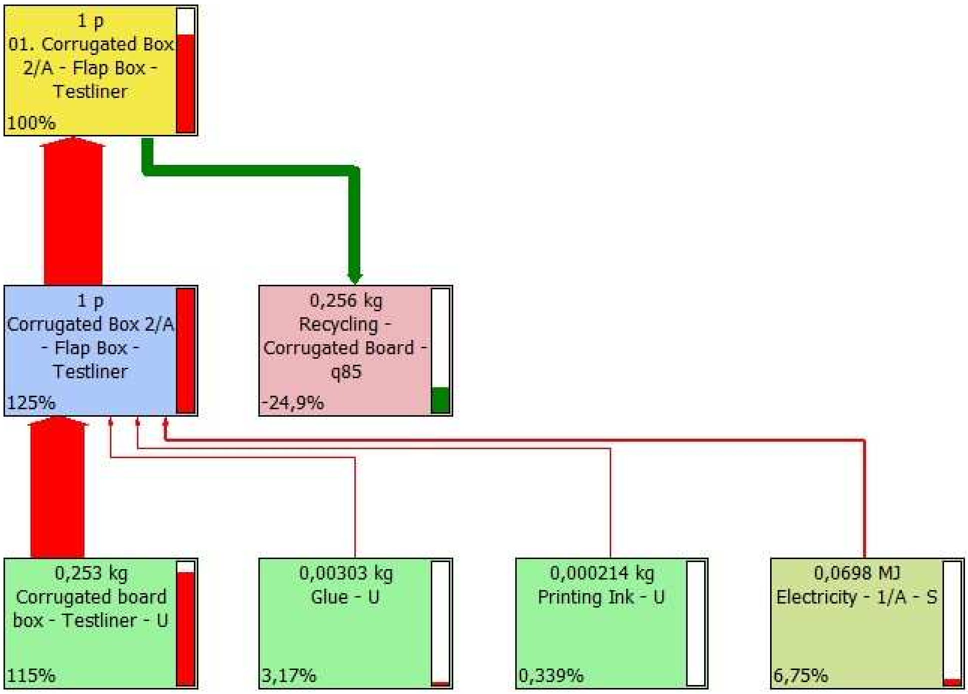


Figure 28. Process tree for packaging 2A – Notice that production of corrugated board constitutes to the majority of environmental impacts.

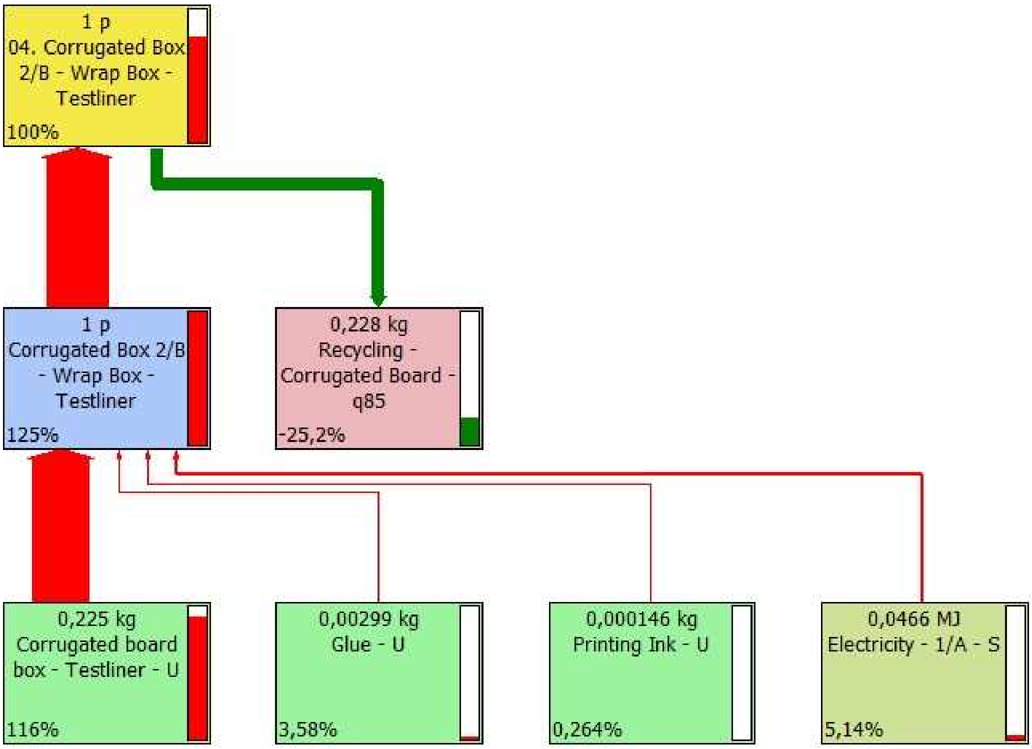


Figure 29. Process tree for packaging 2B – Notice that production of corrugated board constitutes to the majority of environmental impacts.

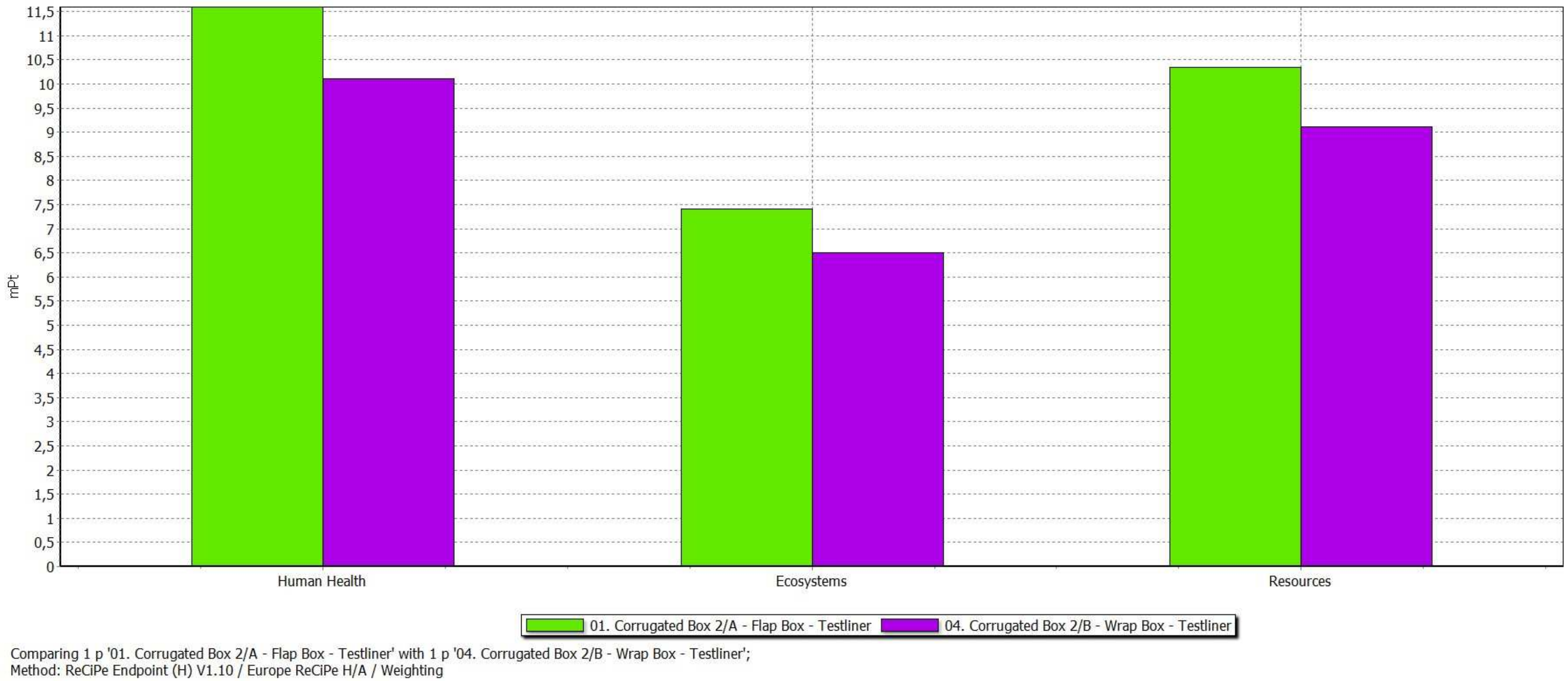


Figure 30. Environmental damages for packaging 2A and 2B. In this instance construction differences of this pair tested show that construction 2B have lower environmental impacts than construction 2A.

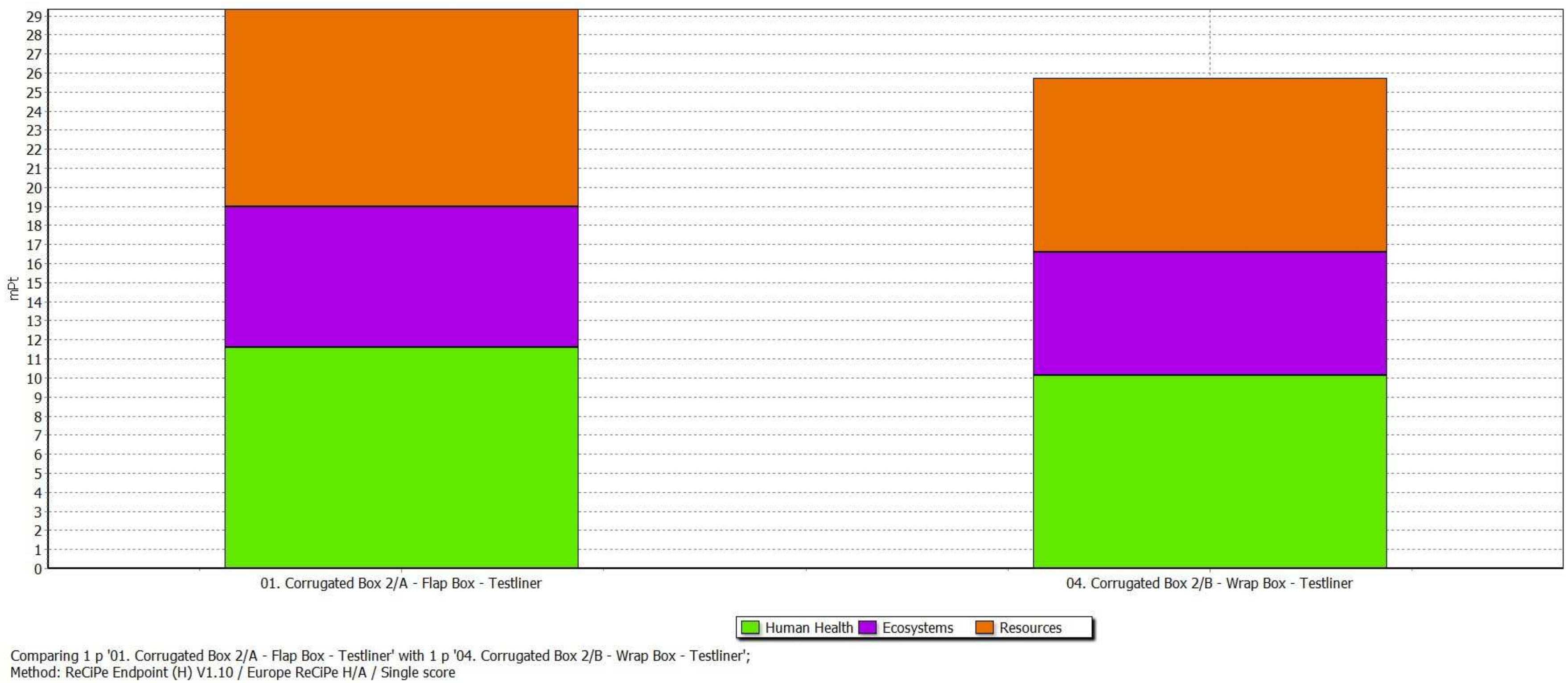


Figure 31. Environmental damages for packaging 2A and 2B expressed as a single score result. In this instance construction differences of this pair tested show that construction 2B have lower environmental impacts than construction 2A.

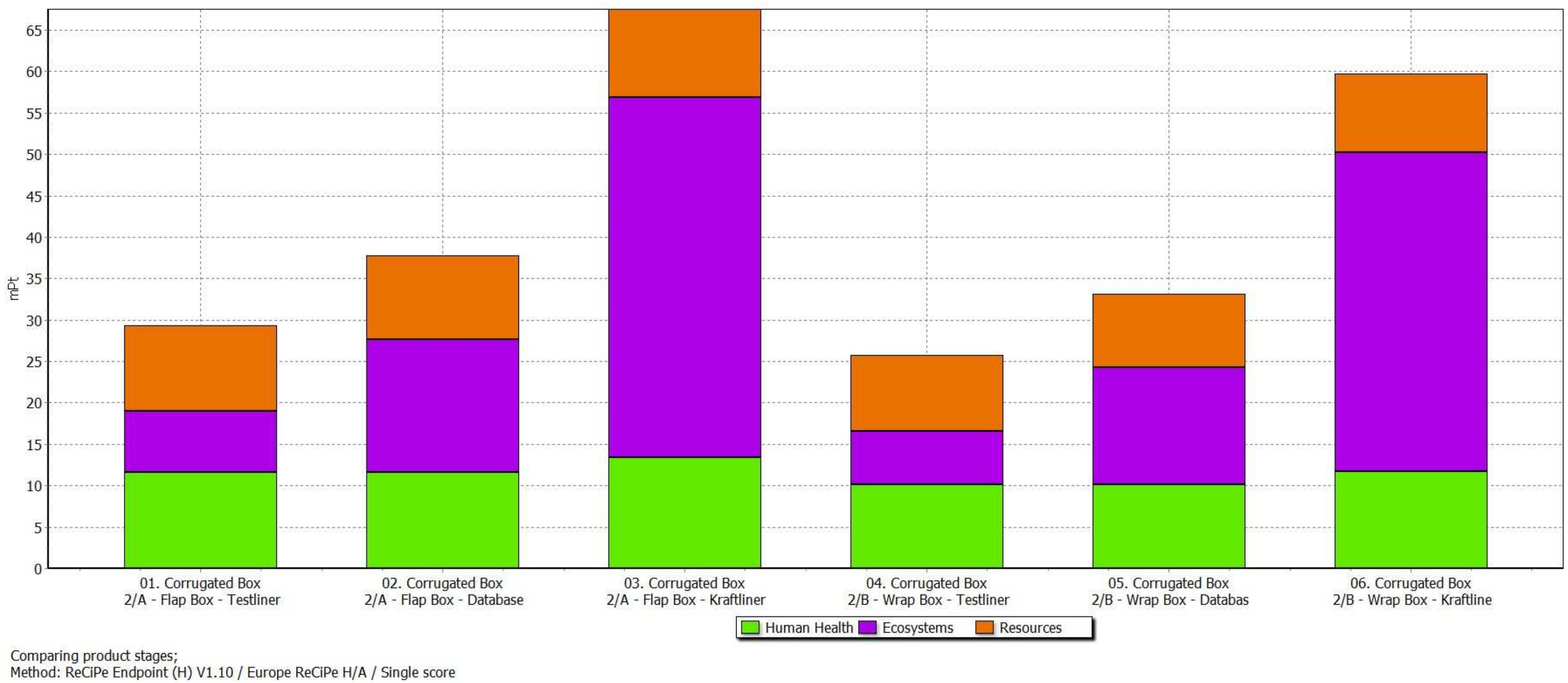


Figure 32. Environmental damages for packaging 2A and 2B expressed as a single score – taking into account different feedstock materials – used testliner and simulated corrugated board from Ecoinvent v3 database, and example of what the impact of packaging would be if kraftliner corrugated board is used instead of testliner. Similarly to figure 25, it can be clearly seen that corrugated board used by the company has the lowest environmental impact, due to recyclability of the feedstock material, and ability to close the recycling loop. See revision figure 23

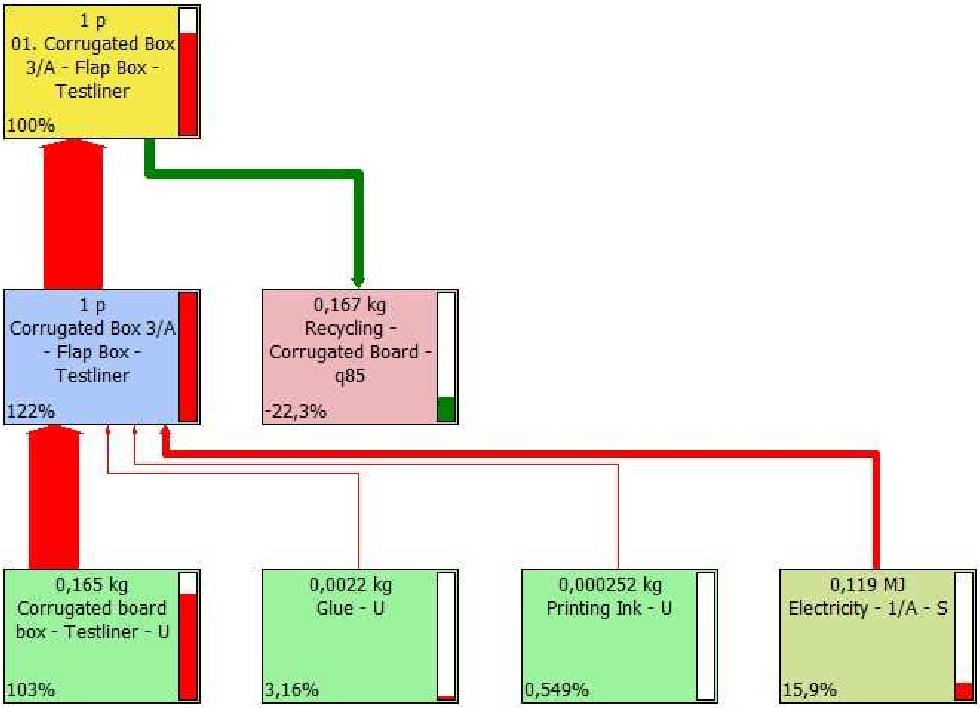


Figure 33. Process tree for packaging 3A – Notice that production of corrugated board constitutes to the majority of environmental impacts.

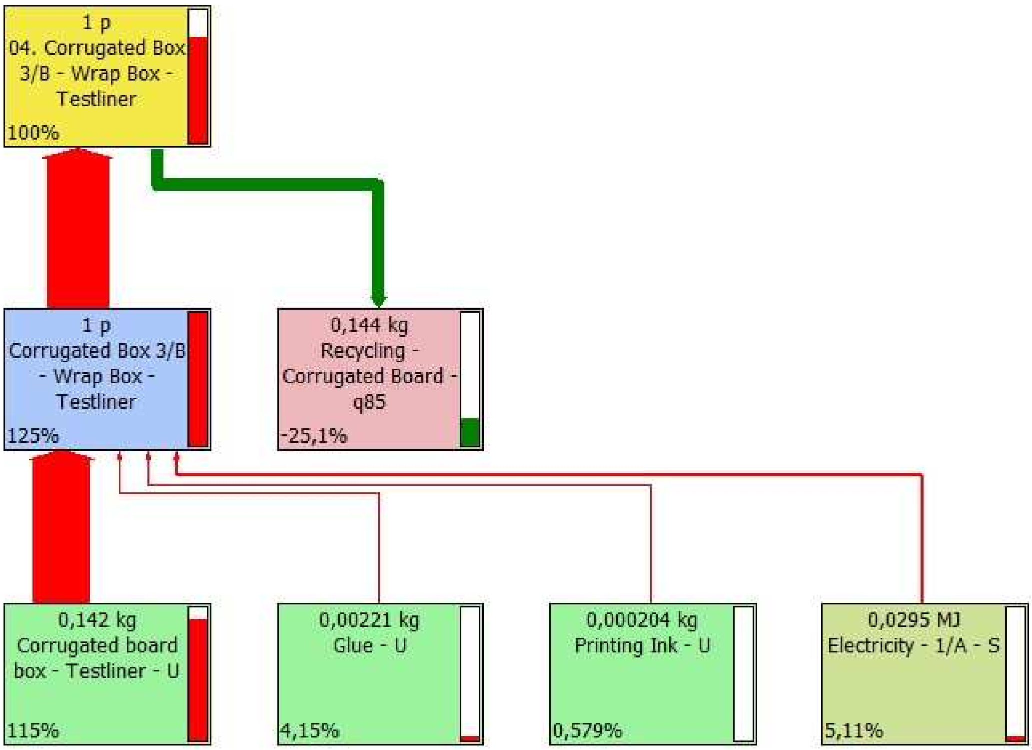


Figure 34. Process tree for packaging 2B – Notice that production of corrugated board constitutes to the majority of environmental impacts.

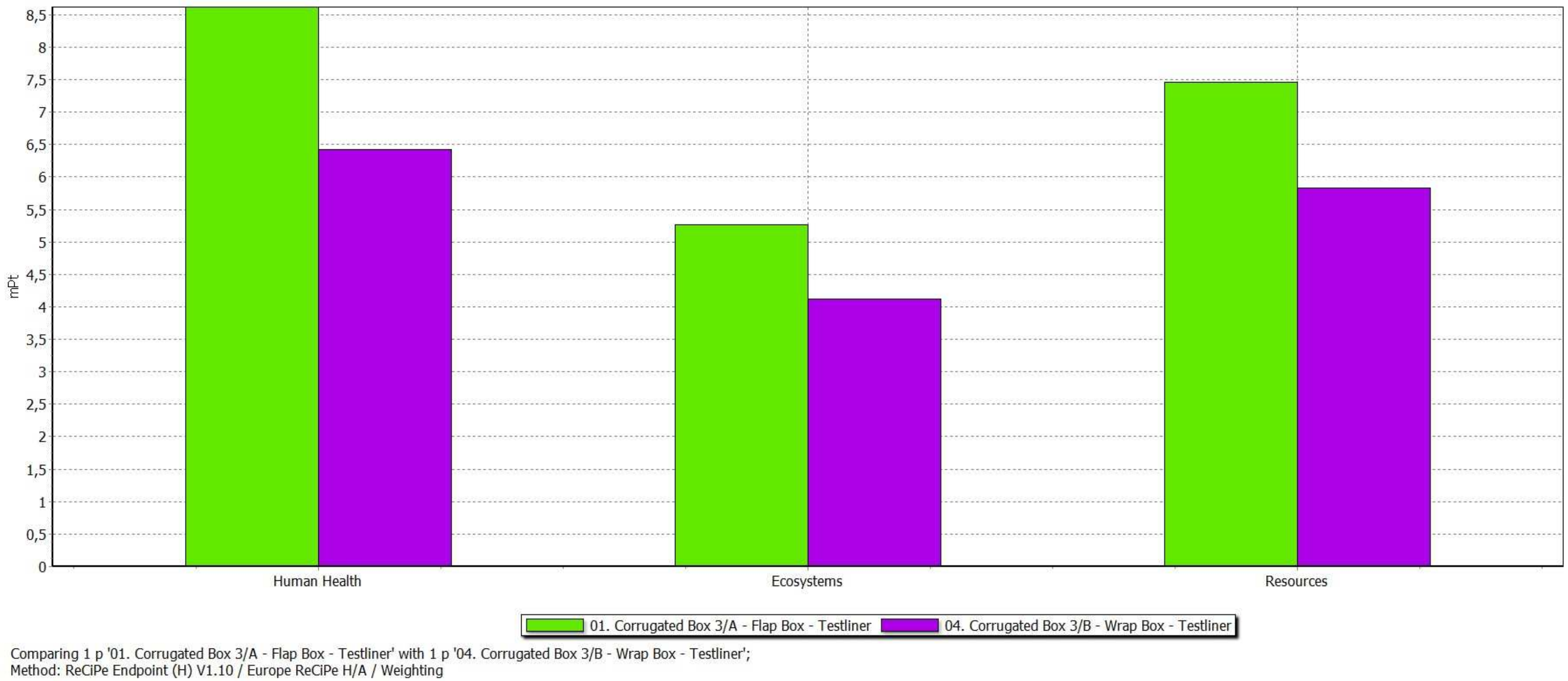


Figure 35. Environmental damages for packaging 3A and 3B. In this instance construction differences of this pair tested show that construction 3B have significantly lower environmental impacts than construction 3A.

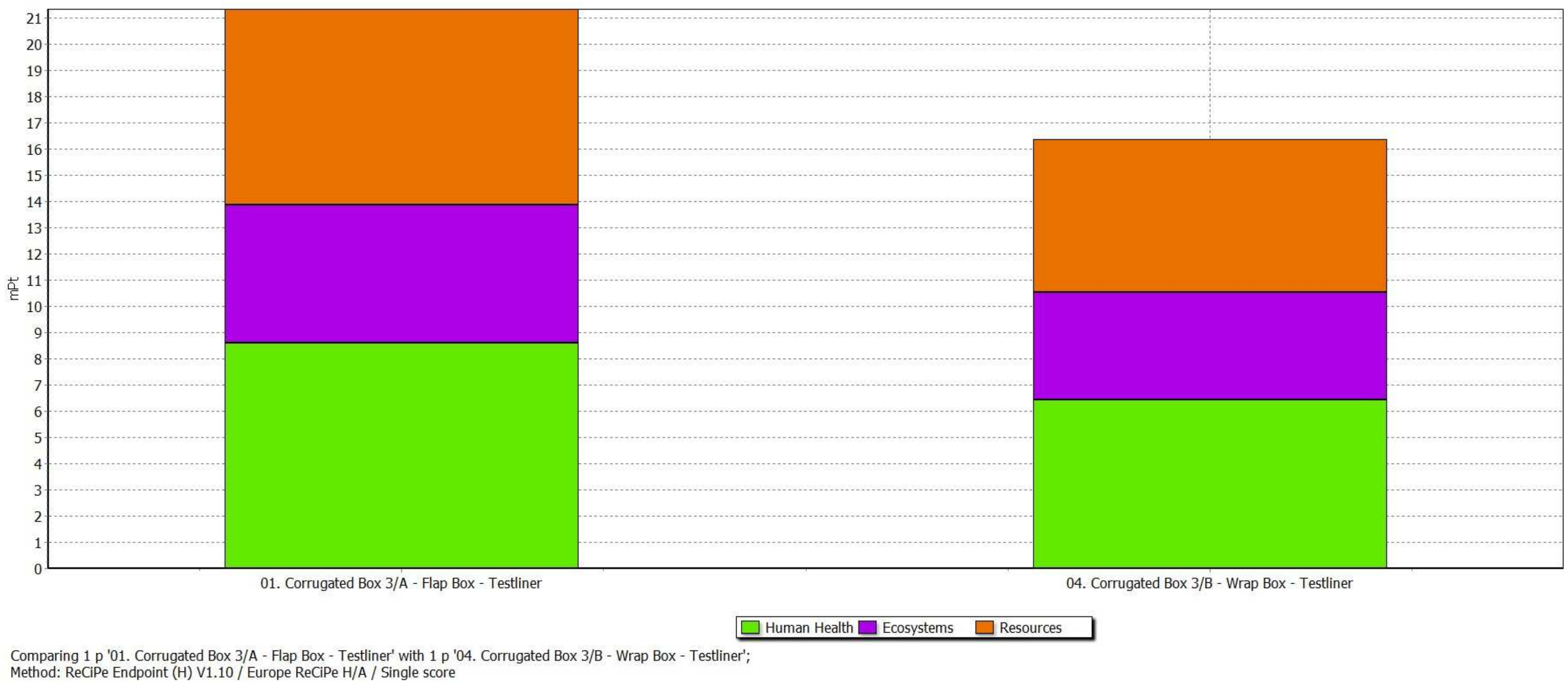


Figure 36. Environmental damages for packaging 3A and 3B expressed as a single score. In this instance construction differences of this pair tested show that construction 3B have significantly lower environmental impacts than construction 3A.

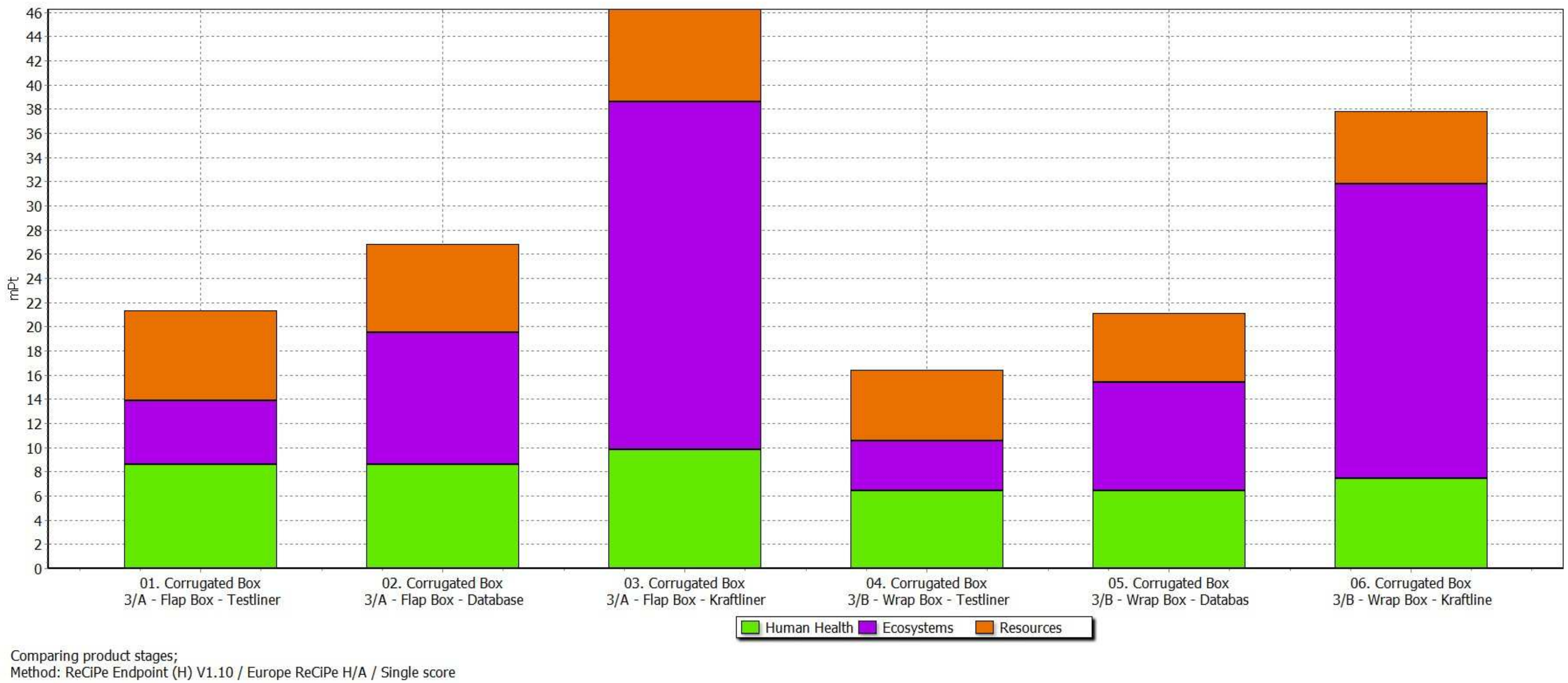


Figure 37. Environmental damages for packaging 3A and 3B expressed as a single score – taking into account different feedstock materials – used testliner and simulated corrugated board from Ecoinvent v3 database, and example of what the impact of packaging would be if kraftliner corrugated board is used instead of testliner. Similarly to figure 30, it can be clearly seen that corrugated board used by the company has the lowest environmental impact, due to recyclability of the feedstock material, and ability to close the recycling loop. One can also observe the differences between packaging 3A and 3B in different feedstock material scenarios vary more significantly. See revision figure 27

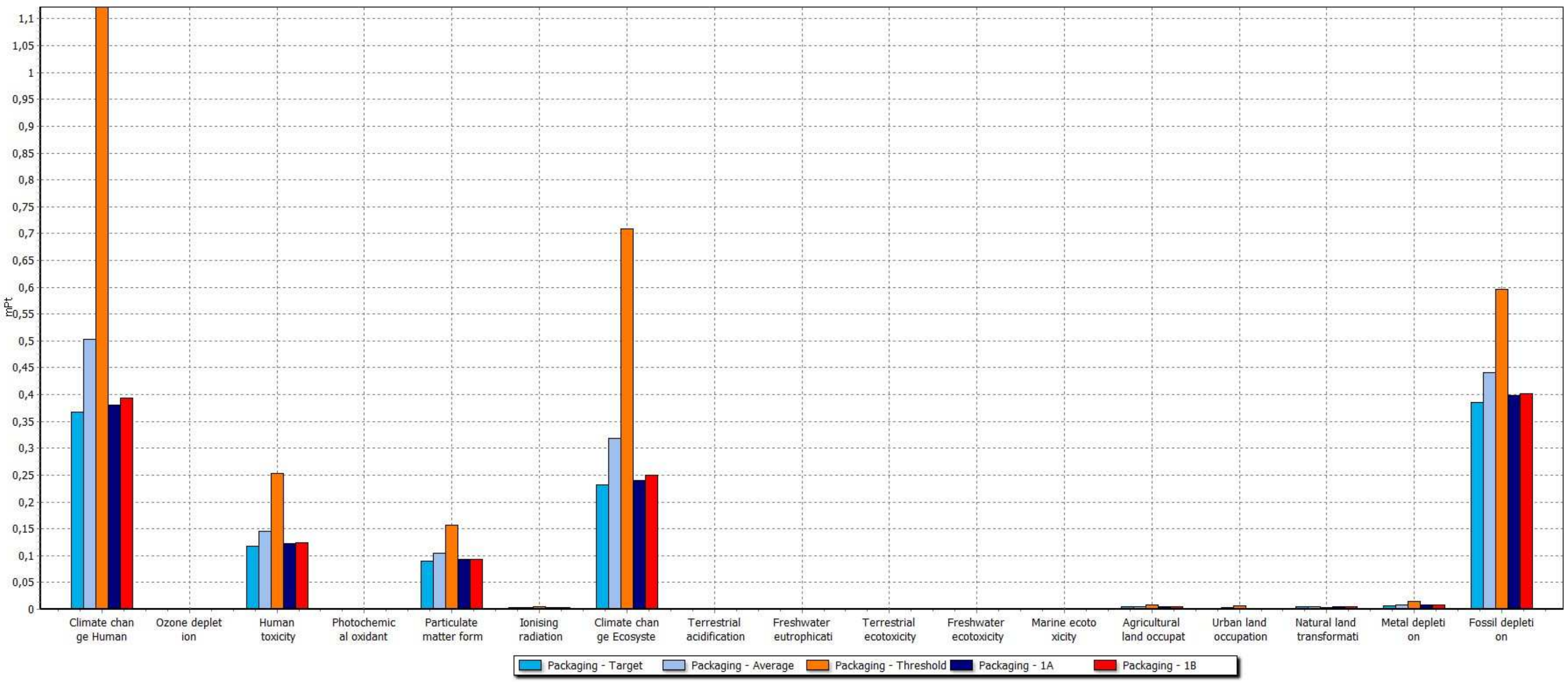


Figure 38. Impact assessment categories of recycling process of packaging 1A (dark blue) and 1B (red). Figure also presents the theoretical cases of target and threshold results of recycling parameters that can be obtained in the EcoPaperLoop recyclability score for corrugated boxes. As can be seen, the recyclability of packaging 1A and 1B is slightly above the target value, and much below the average value from the recyclability benchmark database. Environmental impact categories that are relevant in packaging recycling are: climate change from human health and ecosystem perspective, human toxicity, particulate matter formation and fossil depletion. Those categories are related to amount of waste and electricity generated in recycling process based on the recyclability scores of EcoPaperLoop method.

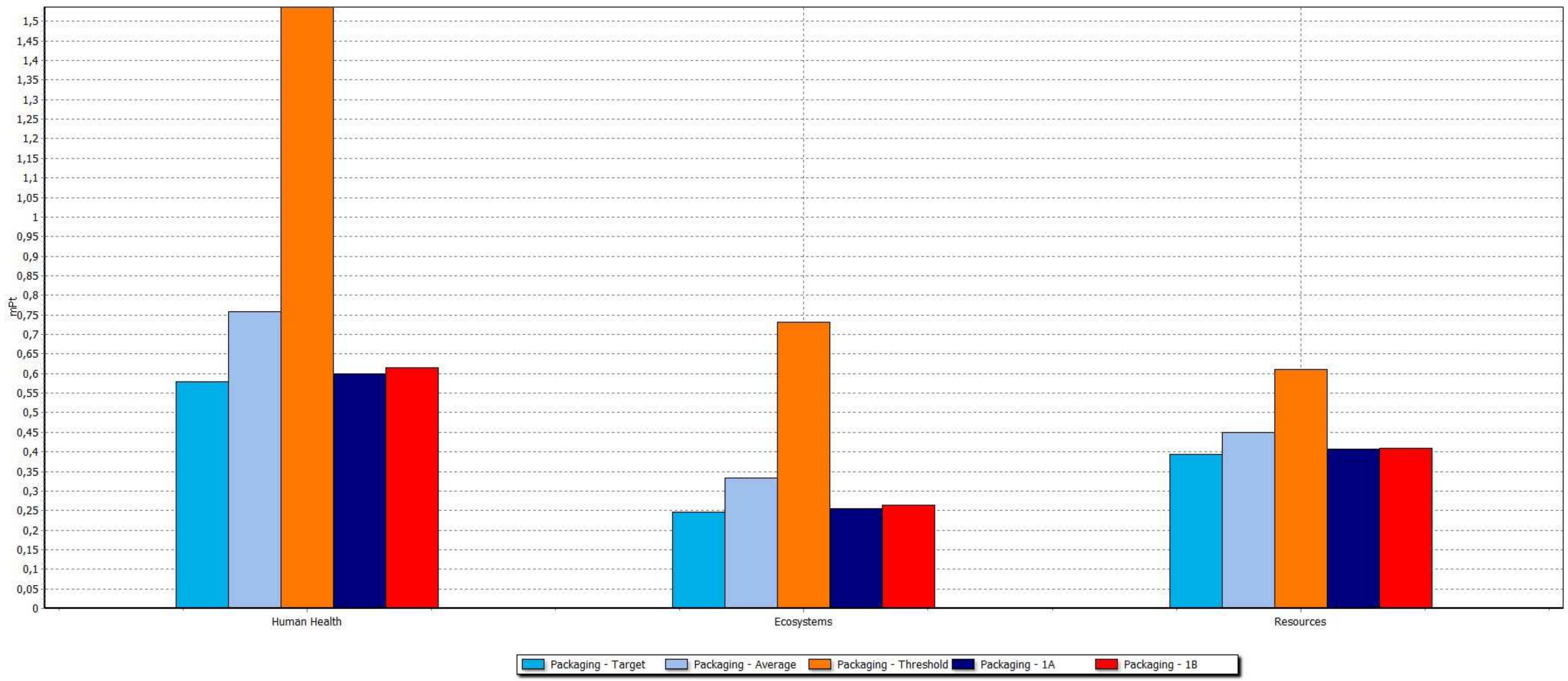


Figure 39. Damage assessment categories of recycling process of packaging 1A (dark blue) and 1B (red). Figure also presents the theoretical cases of target and threshold results of recycling parameters that can be obtained in the EcoPaperLoop recyclability score for corrugated boxes. As can be seen, the recyclability of packaging 1A and 1B is slightly above the target value, and much below the average value from the recyclability benchmark database. Human health has the relative highest impact from all damage categories.

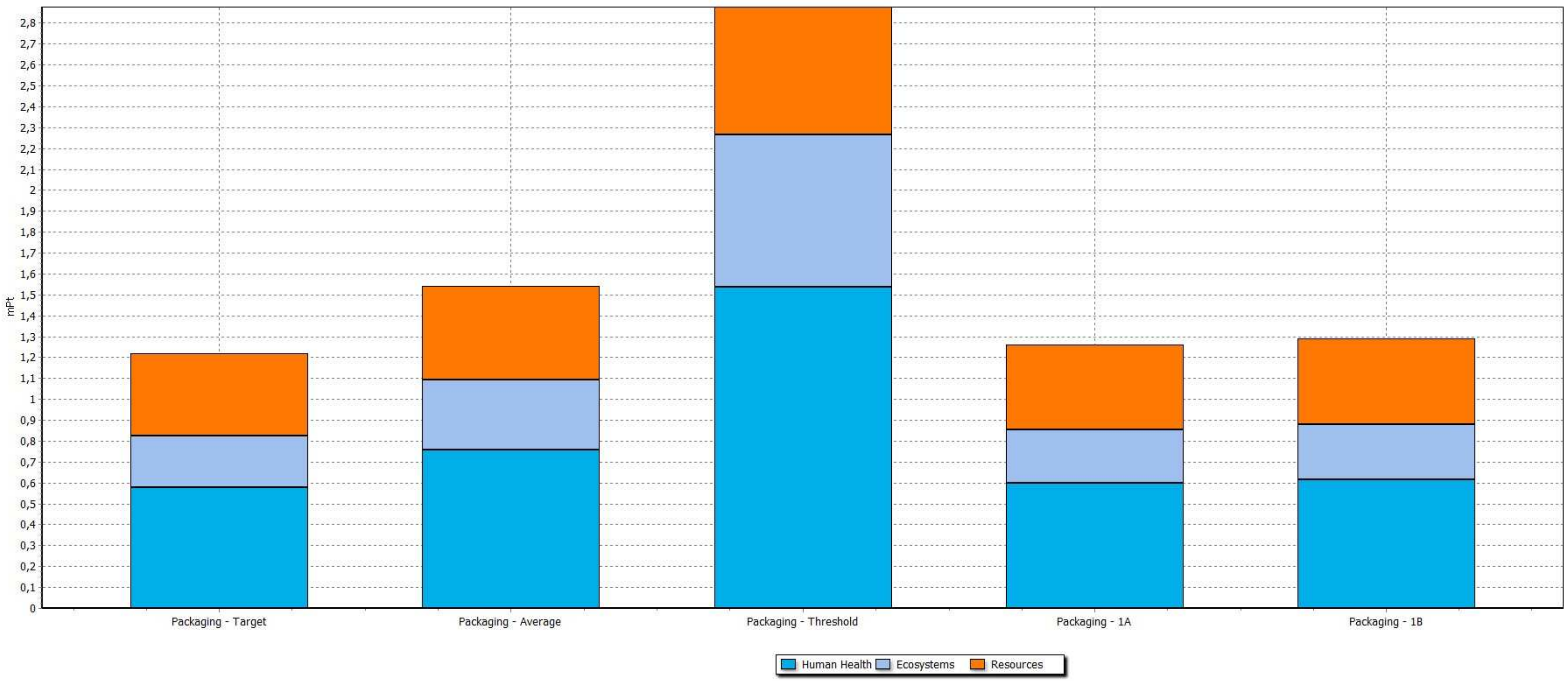


Figure 40. Damage assessment categories of recycling process of packaging 1A and 1B expressed as a single score. Figure also presents the theoretical cases of target and threshold results of recycling parameters that can be obtained in the EcoPaperLoop recyclability score for corrugated boxes. As can be seen, the recyclability of packaging 1A and 1B is slightly above the target value, and much below the average value from the recyclability benchmark database. This figure shows that the difference between impacts of target and threshold values of recyclability parameters results in more than twice the amount, which in turn shows that eco-design phase of packaging is important when considering recyclability environmental impact.

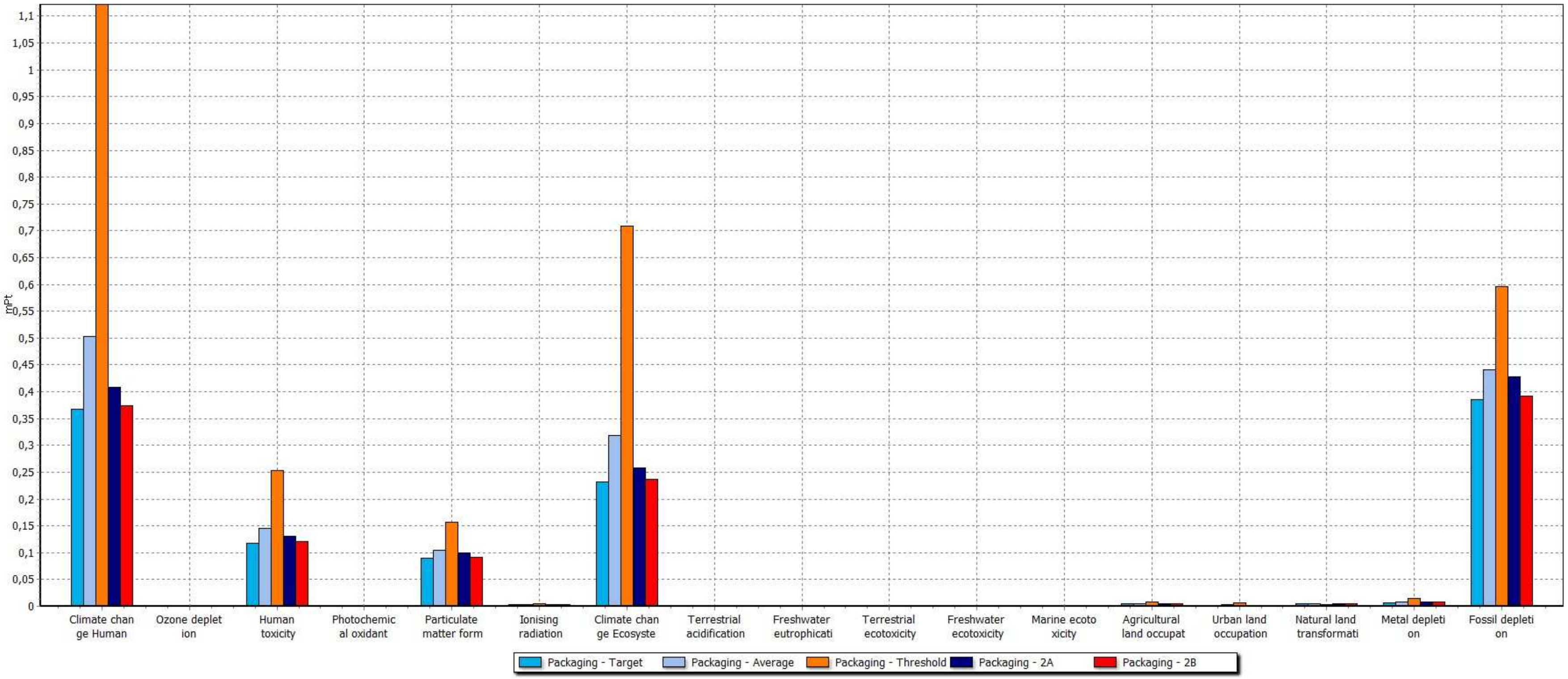


Figure 41. Impact assessment categories of recycling process of packaging 2A (dark blue) and 2B (red). Figure also presents the theoretical cases of target and threshold results of recycling parameters that can be obtained in the EcoPaperLoop recyclability score for corrugated boxes. As can be seen, the recyclability of packaging 2A and 2B is above the target value, and slightly below the average value from the recyclability benchmark database. Environmental impact categories that are relevant in packaging recycling are: climate change from human health and ecosystem perspective, human toxicity, particulate matter formation and fossil depletion. Those categories are related to amount of waste and electricity generated in recycling process based on the recyclability scores of EcoPaperLoop method.

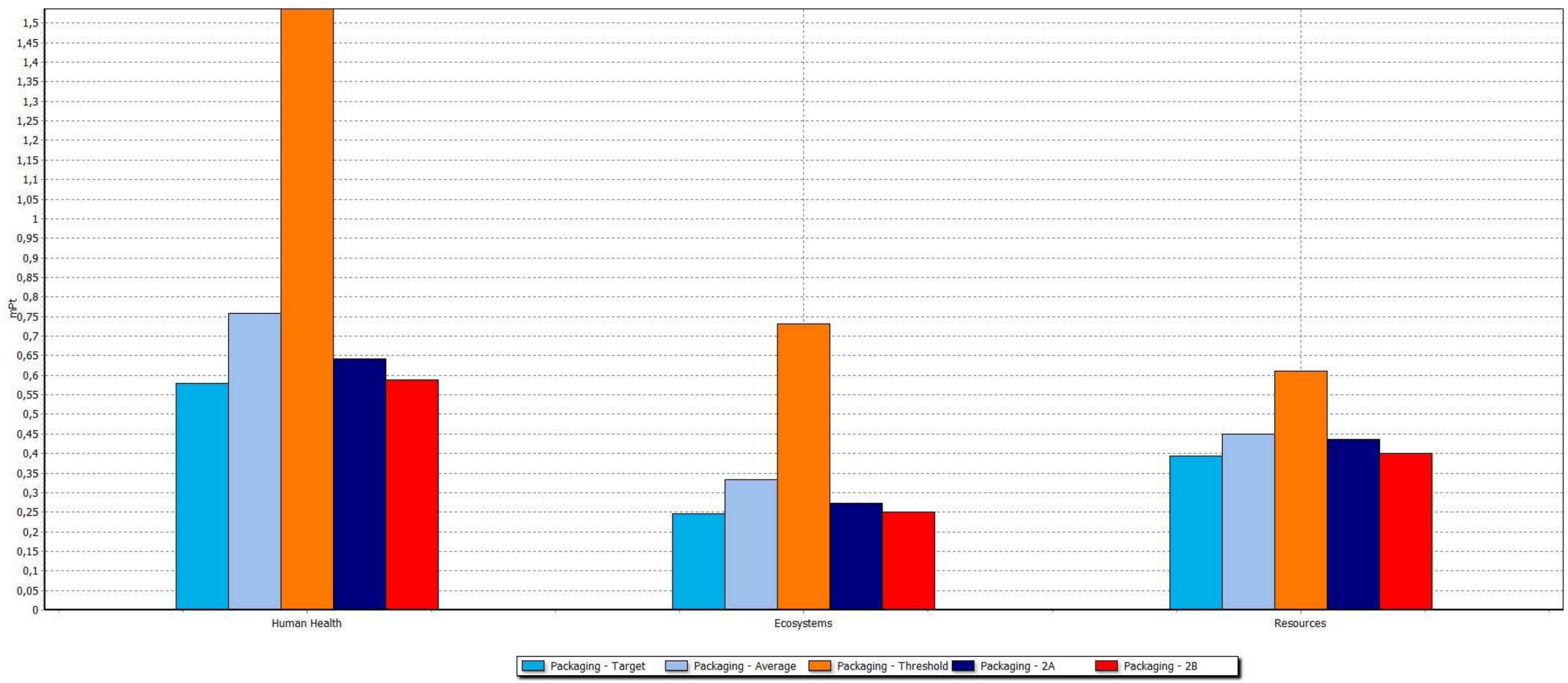


Figure 42. Damage assessment categories of recycling process of packaging 2A (dark blue) and 2B (red). Figure also presents the theoretical cases of target and threshold results of recycling parameters that can be obtained in the EcoPaperLoop recyclability score for corrugated boxes. As can be seen, the recyclability of packaging 2A and 2B is above the target value, and below the average value from the recyclability benchmark database. Human health has the relative highest impact from all damage categories.

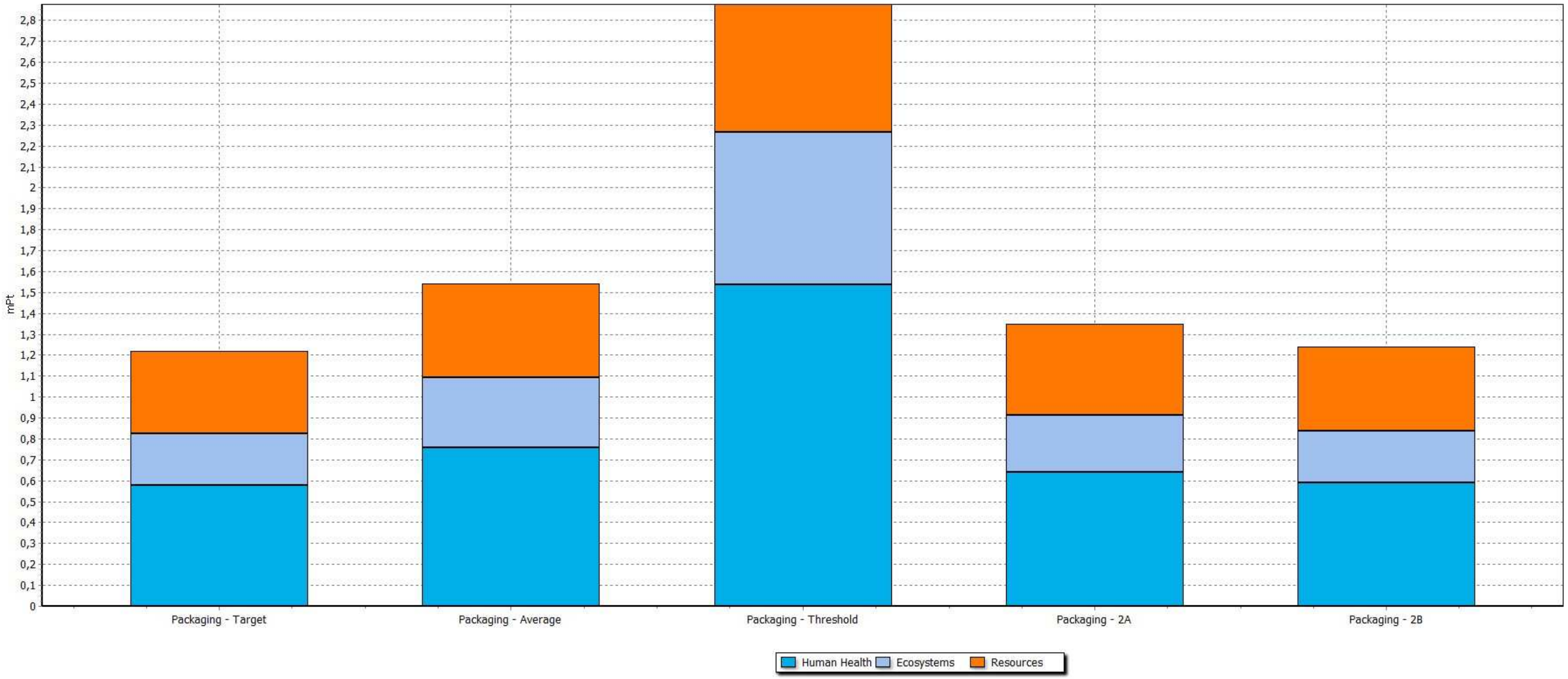


Figure 43. Damage assessment categories of recycling process of packaging 2A and 2B expressed as a single score. Figure also presents the theoretical cases of target and threshold results of recycling parameters that can be obtained in the EcoPaperLoop recyclability score for corrugated boxes. As can be seen, the recyclability of packaging 2A and 2B is slightly above the target value, and much the average value from the recyclability benchmark database. This figure shows that the difference between impacts of target and threshold values of recyclability parameters results in more than twice the amount, which in turn shows that eco-design phase of packaging is important when considering recyclability environmental impact.

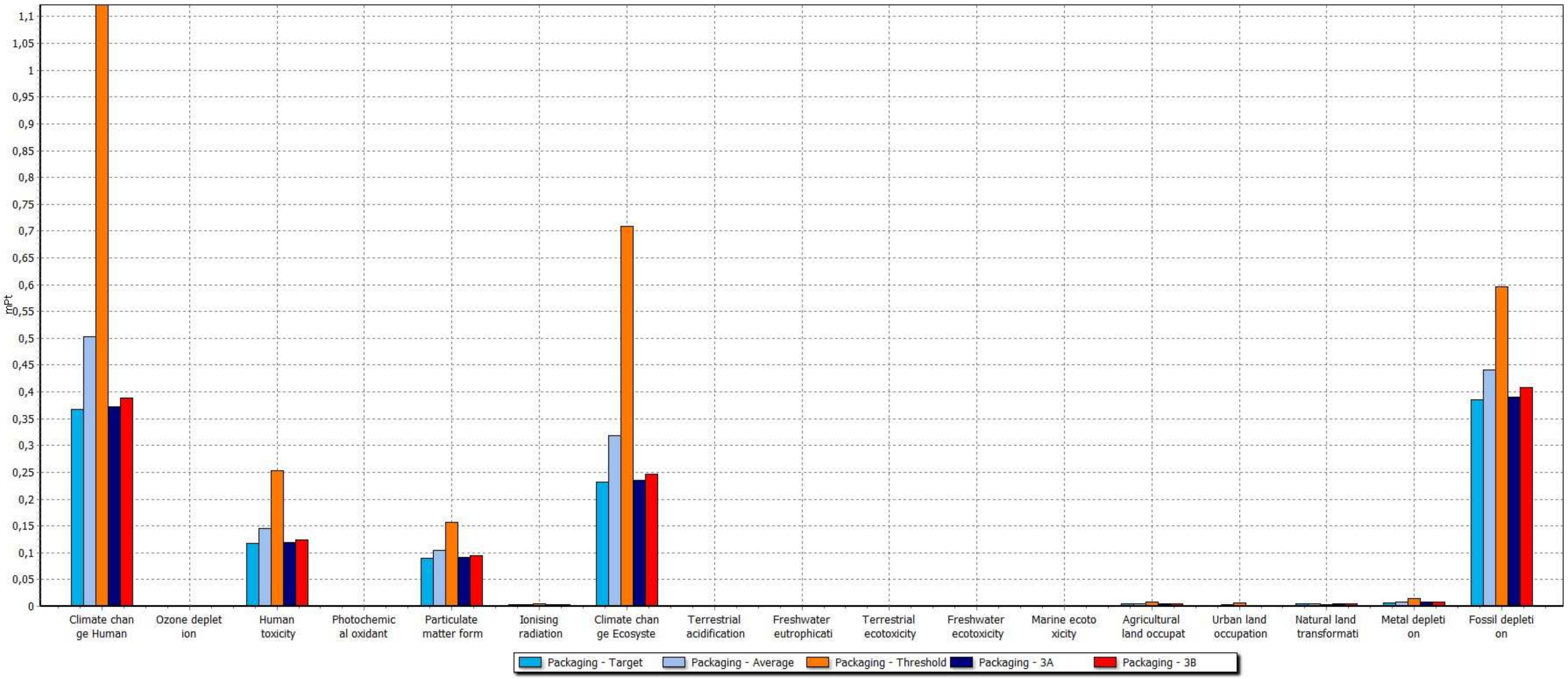


Figure 44. Impact assessment categories of recycling process of packaging 3A (dark blue) and 3B (red). Figure also presents the theoretical cases of target and threshold results of recycling parameters that can be obtained in the EcoPaperLoop recyclability score for corrugated boxes. As can be seen, the recyclability of packaging 3A is almost on the target value and 3B slightly above target value of the recyclability benchmark database. Environmental impact categories that are relevant in packaging recycling are: climate change from human health and ecosystem perspective, human toxicity, particulate matter formation and fossil depletion. Those categories are related to amount of waste and electricity generated in recycling process based on the recyclability scores of EcoPaperLoop method.

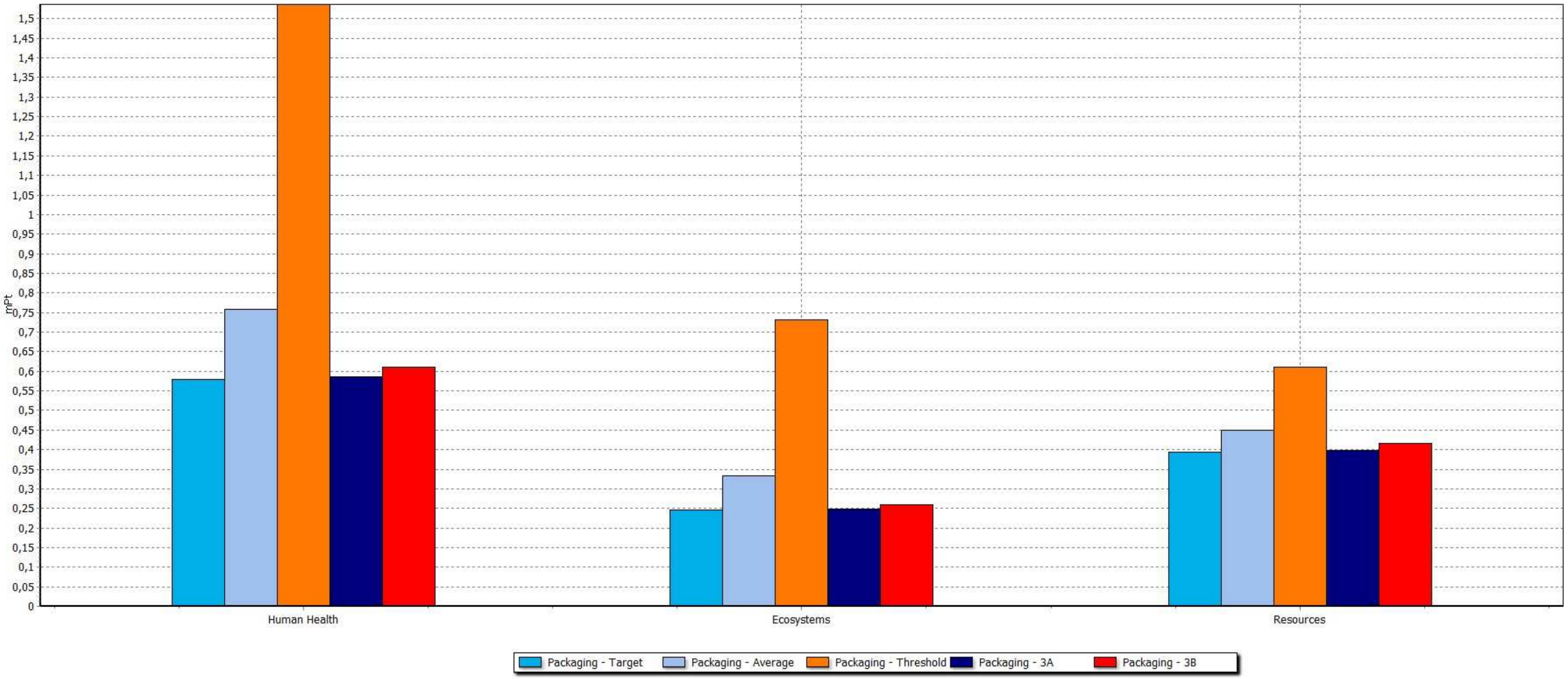


Figure 45. Damage assessment categories of recycling process of packaging 3A (dark blue) and 3B (red). Figure also presents the theoretical cases of target and threshold results of recycling parameters that can be obtained in the EcoPaperLoop recyclability score for corrugated boxes. As can be seen, the recyclability of packaging 3A is almost on the target value and 3B slightly above target value of the recyclability benchmark database. Human health has the relative highest impact from all damage categories.

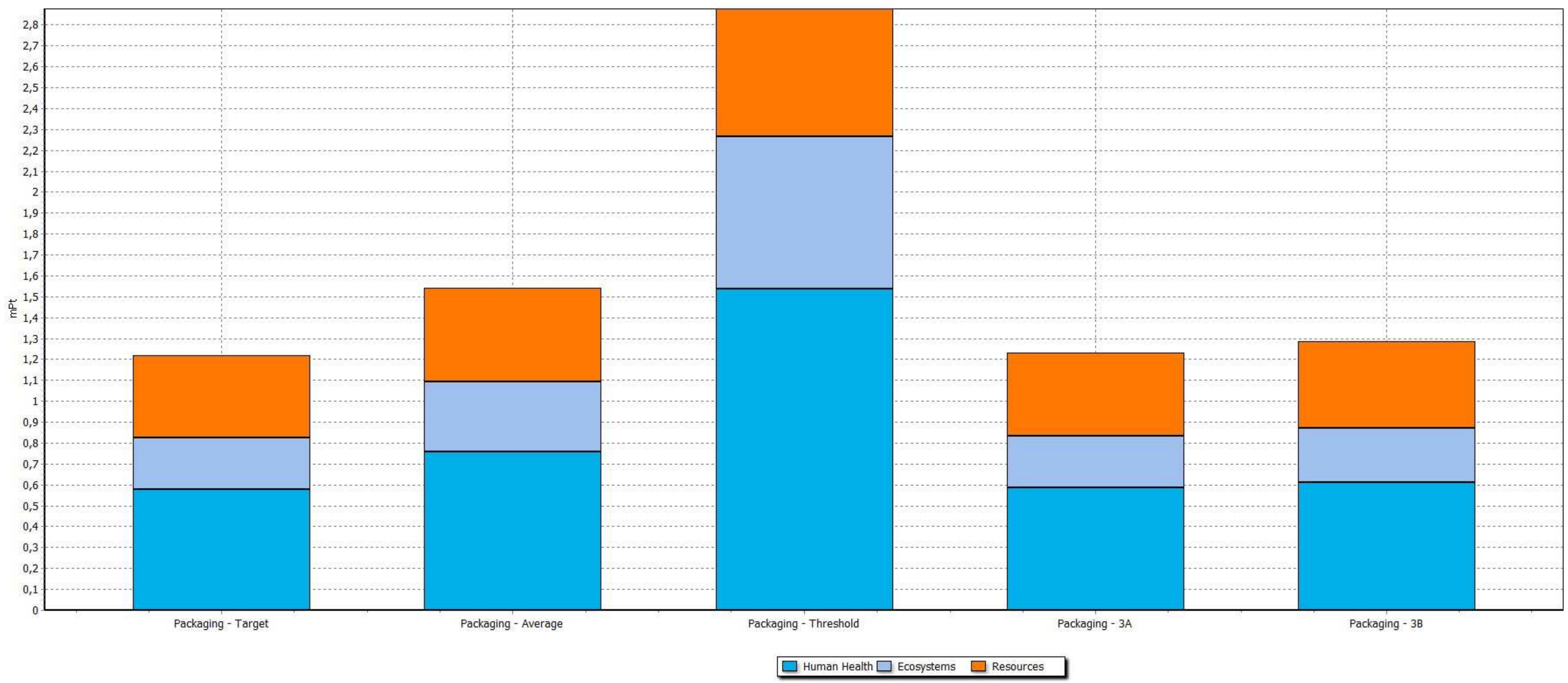


Figure 46. Damage assessment categories of recycling process of packaging 3A and 3B expressed as a single score. Figure also presents the theoretical cases of target and threshold results of recycling parameters that can be obtained in the EcoPaperLoop recyclability score for corrugated boxes. As can be seen, the recyclability of packaging 3A and 3B is just slightly above the target value. This figure shows that the difference between impacts of target and threshold values of recyclability parameters results in more than twice the amount, which in turn shows that eco-design phase of packaging is important when considering recyclability environmental impact.

Conclusion:

The quantitative relation were developed and validated successfully and they represent a new instrument for a deeper characterization of the recycling process in the disposal scenario of LCA.

Similarly to graphic paper LCA, the differences in terms of full life cycle and disposal scenario of the selected packaging are quite limited, because tested samples are all well recyclable. The differences among tests results are quite small. However the possible differences can be more important when products with bigger differences in the recycling behaviour are compared. This was demonstrated by the hypothetical scenarios with different paper grade that can be used, and by showing the minimum, average and maximum value of the recyclability parameters.

Key conclusions of the packaging LCA:

- Packaging provided for the study have all very good recyclability
- The majority of environmental impacts of tested corrugated board boxes stem from the production of corrugated board. Other packaging production processes (such as printing, cutting, construction etc), contribute to only about 8-9% of all impacts.
- When considering the packaging LCA in closed loop system, environmental benefits of recycling are on average 25%. That is – environmental impacts avoided due to recycling constitute of 25% of all impact.
- Packaging provided for the study by the company are produced from testliner grade of corrugated board. According to the quality factor assumptions of the study this board has more sustainable recycling than theoretical variants of the same packaging but from kraftliner grade and from the average corrugated board grade provided by the Ecoinvent v3 database. The quality factor is due to the fact that production of krafliner paper cannot be directly avoided when closing the recycling loop – i.e. Kraftliner paper cannot be produced from recycled paper – virgin krafliner is needed to ensure the same quality of cardboard box.
- Combining methodology of packaging recyclability benchmark (output of EcoPaperLoop WP3) and LCA, allows for a precise and innovative comparison of paper and board packaging eco-design from the point of view of their future recycling and their environmental impact.
- Packaging samples provided for the LCA study have very good recyclability according to the established recyclability benchmark tests. That is why direct comparison of recycling impacts of tested packaging solutions does not show significant difference. That is why the viability of the methodology was presented by contrasting the actual results with the best possible scenarios and worst possible scenarios from the point of view of Coarse Reject and Macrostickies content benchmark values. Those results show that environmental impacts of recycling can be a significant factor based on the eco-design of the packaging itself.

References:

[1] EcoPaperLoop Method 1. Recyclability Test for Packaging Products. November 2014.

[2] EcoPaperLoop project, WP5 Deliverable List of relevant parameters affecting the recyclability performance and sustainability of selected products for LCA.

[3] Schabel S., Holik H. , in *Recycled fibers and Deinking*, Papermaking Science and Technology, Vol.7, 2010.

[4] Holik H. , in *Handbook of Paper and Board*, ed. H. Holik, Chapter 7, 2013.

[5] FEFCO International fibreboard case code - http://www.fefco.org/sites/default/files/files/FEFCO_ESBO_codes_of_designs.pdf